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HYDROGEN PEROXIDE HANDBOOK

By

Chemical and Material Sciences Department Research Division Rocketdyne, a Division of North American Aviation, Inc. Canoga Park, California

Technical Report AFRPL-TR-67-144

July 1967

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> Air Force Rocket Propulsion Laboratory Research and Technology Division Edwards Air Force Base, California Air Force Systems Command United States Air Force



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> Air Force Rocket Propulsion Laboratory Research and Technology Division Edwards Air Force Ease, California Air Force Systems Command United States Air Force

FOREWORD

This handbook is submitted as the final report under Rocketdyne G.O. 7108 in compliance with Contract AF04(611)-11397, Part I, Para. B.1, and line items 2 and 3 of DD 1423. The effort under this contract was sponsored by the Air Force Rocket Propulsion Laboratory, Research and Technology Division, Air Force Systems Command, USAF, Edwards, California, with 1/Lt. Ralph Fargnoli acting as the Air Force Project Officer.

This program was conducted by the Propellant Technology function of the Rocketdyne Research Division, with Dr. E. F. C. Cain serving as Program Manager and Mr. M. T. Constantine serving as Responsible Project Scientist. Technical personnel who contributed to the compilation and analysis of the data and information in this handbook include M. M. Williams and K. J. Youel.

This handbook has been assigned the Rocketdyne identification number R-6931.

This report has been reviewed a.d is approved.

W. H. EBELKE, Colonel, USAF Chief, Propellant Division

ABSTRACT

1.2.5

This handbook is a compilation of the engineering properties and handling characteristics of propellantgrade hydrogen peroxide. The handbook includes data and information on hydrogen peroxide physicochemical properties, production, storability, materials compatibility, materials treatment and passivation, facilities and equiptent, disposal, transportation, safety, and decomposition.

ACKNOWLEDGMENT

This handbook includes data and information generated through experimental and analytical studies conducted at many different organizations. Although every effort has been made to reference these studies, a great number of individuals responsible for these data have been neglected. These individual contributions as well as the contributions of the industry and government organizations are gratefully acknowledged.

Appreciation is also gratefully extended to the various organizations who responded to a request for data and information during an industry survey. These organizations (with the responding individual noted) are as follows:

Aerojet-General Corporation, Azusa, California (S. D. Rosenberg) Aerojet-General Corporation, Sacramento, California (Robert J. Kuntz) Air Reduction Company, Inc., Murray Hill, New Jersey (Walter B. Moen) Explosives Research and Development Establishment,

Waltham Abbey, England (A. L. Lovecy) General Electric Company, Philadelphia, Pennsylvania (Arnold D. Cohen) Hughes Aircraft Company, El Segundo, California (M. E. Ellion) Jet Propulsion Laboratory, Pasadena, California (D. D. Evans) Walter Kidde and Co., Inc., Belleville, New Jersey (John C. Scheider) Laporte Chemicals, Ltd., Luton, England (H. L. Hulland) The Marquardt Corporation, Van Nuys, California (R. Carl Stechman) Pennsalt Chemicals Corporation, Los Angeles, California (J. C. Neighbors) Pesco Products, Bedford, Ohio (F. G. Johnston) Pratt and Whitney Aircraft, West Palm Beach, Florida (Mark H. Young) Bocket Propulsion Establishment, Westcott, England (J. D. Lewis) Southwest Research Institute, San Antonio, Texas (Herbert I. Hoffman) TRW Incorporated, Redondo Beach, California (Glen W. Howell) U.S. Army Missile Command, Redstone Arsenal, Alabama (Walter W. Wharton) In addition, a special acknowledgement is due the following organizations (and the noted personnel) for providing technical consultation during the industry survey:

Bell Acrosystems

H. Huebusch, A. Bottara, J. L. Laspisa, S. Long, W. Reinhart, R. Sperlazza

E. I. duPont de Nemours & Co.

J. M. Snyder, V. J. Reilly, T. D. Canby, F. H. Lindberg, J. C. Schwenberger, A. D. Stafford, J. E. Williams

F.M.C. Corporation

J. McCormick, C. Rawleigh, L. Darbee, L. Dierdorff

LTV Astronautics Division

U. M. Robinson, A. B. Featherston

Picatinny Argenal

W. Buckley

Shell Chemical Company

G. J. Moore, R. R. Renshaw, W. H. Wulf

Shell Development Company

II. J. Baumgartner, G. C. Hood, J. M. Monger, J. Toombs

Thiokol Chemical Corporation - Reaction Motors Division

H. A. Kock, F. Hoffman, C. Dimmick, W. Fishgrund, P. Gwordy, A. Lum

U.S. Javal Ordnance Test Station

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SECTION 1: INTRODUCTION

1.1 GENERAL

The discovery of hydrogen peroxide was reported to the Paris Academy of Sciences in July 1818 by Louis-Jacques Thenard and was initially described as oxidized water. The discovery was a result of government-subsidized vesearch on the preparation of voltaic cells. Thenard, in working with alkaline earth oxides. discovered that the reaction of barium peroxide with cold nitric acid resulted in the formation of "oxygenated water." Thenard then conducted a fairly extensive study of hydrogen peroxide. which included catalytic decomposition studies, density determinations, measurements of the volume of oxygen released, etc. He noted extensive supercooling and the inability to achieve appreciable concentration increases with crystallization techniques. Thenard also reported that vacuum distillation could continue to complete dryness in the reservoir without appreciable decomposition, although the determination of normal boiling points was impossible because of decomposition of the hydrogen peroxide. His work led to the publication of several papers, which are extensively summarized in Ref. 1.1.

In his work, Thenard cites reactions with some 130 clements, oxides, salts, acids, and bases with frequent notations of decomposition of the hydrogen peroxide. These decomposition reactions were sometimes accompanied with the note that "in these decompositions, chemical action is evidently missing; it is necessary then, to attribute these actions to a physical cause; but the actions are dependent on neither heat nor light, whence it follows that they are probably due to electricity" (Ref. 1.1). These "unexplained" reactions were later recognized by Bergelius (Ref. 1.2) in 1936 in the first notation of catalysts and catalytic activity.

Although Thenard's only noted uses for hydrogen peroxide were in removing sulfide deposits on oil paintings and as a skin irritant for medicinal purposes, hydrogen peroxide and its aqueous solutions have found a number of commercial applications since its discovery. The primary bulk of this commercial use is limited to hydrogen peroxide grades of less than 52 percent $H_2 O_2$ by weight; these "industrial grades" have been used for many years in textile and pulp bleaching, synthesis of chemical derivatives, the menufacture of foam rubber, the oxidation of dyes, the purification of metal salt solutions, the treatment of metal surfaces, etc. The requirement for higher concentrations and their subsequent commercial development was based primarily on the establishment of hydrogen peroxide as a source of energy.

Hydrogen peroxide (in a 60 w/o aqueous solution) was first utilized as an energy source for underwater propulsion in Germany in 1934; this work led to its subsequent application (in higher concentrations) during World War II for auxiliary propulsion and gas generation concepts in aircraft and rockets. Its use in these areas reculted from its thermally or catalytically initiated exothermic decomposition (with substantial heat release) to yield a gaseous mixture of oxygen and superheated steam. Although its advantages as a monopropellant include a 47 w/o available oxygen content, high density, high beiling point, unlimited availability, and nontoxic exhaust gases, the initial areas of application for hydrogen peroxide were limited because of its questionable storage stability.

The use of hydrogen peroxide has been expanded with improvements in its stability, through stabilization additives and increased purification. Currently, hydrogen peroxide is the primary monopropellant used for underwater propulsion, aerospace propulsion, and auxiliary power concepts. Hydrogen peroxide/water solutions can now be stored for extended periods without significant decomposition (i.e., decomposition rates of ≤ 0.1 percent/year

are readily attainable). Reaction control systems using hydrogen peroxide have already demonstrated space storability in excess of 2 years (with an estimated storability of 5 years).

The use of hydrogen peroxide as a monopropellant in the aerospace industry has been widespread in the areas of station maintenance, space maneuvering, thrust vector control, power generation, etc. Some examples of systems which have used or are presently utilizing hydrogen peroxide include the V-2 (gas generator), Redstone (gas generator). Mercury Spacecraft (reaction control system). Scout (reaction control system--2nd and 3rd stages), Little Joe II (reaction control system), Burner II (reaction control system). SATAR (reaction control system), ASSET (reaction control system), 122Y (attitude control system), Lunar Landing Simulator (main propulsion and attitude control systems), Astronaut Maneuvering Unit (main propulsion), SYNCOM (reaction control system), COMSAT (reaction control system), HS-303A "Blue Bird" (reaction control system), ATS (reaction control system), Personnel Rocket Belt. and X-15 (gas generator, reaction control, and auxiliary power systems). Although the use of hydrogen peroxide in operational bipropellant systems has been limited thus far to extremely highperformance aircraft rockets, hydrogen peroxide is potentially applicable to a variety of liquid bipropellant and hybrid propellant systems.

This widespread application potential of hydrogen peroxide has led to the requirement for a comprehensive and definitive compilation of physical, chemical, and handling properties of this important oxidizer. As a result of this interest, this handbook represents a current summary of the engineering properties of propellant-grade hydrogen peroxide. Propellant-grade hydrogen peroxide is defined in this report as high-purity hydrogen peroxide/water solutions in which the hydrogen peroxide concentration is \geq 70 percent by weight. Within this concentration

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range of interest, solutions containing 70, 75, 90, 95, 98, and 100 percent by weight hydrogen peroxide have been designated as concontrations of special interest.

1.2 HANDBOOK FORMAT

The material contained in this handbook has been organized inte sections. These are:

Section 1: Introduction Section 2: Physico-Chemical Properties Section 3: Production Section 4: Storage and Handling Section 5: Transportation Section 6: Safety Section 7: Decomposition, Stabilization, and Catalysts Section 8: Bibliography

Each section is subdivided further to permit the user of this handbook to obtain specific information expeditiously. The material is arranged in such a manner as to permit convenient updating of various sections as data are generated from additional studies in these areas.

The interest of each individual user may be limited to specific aspects of the subject material; however, it is recommended that personnel involved in H_2O_2 handling be thoroughly familiar with all of the engineering properties contained in this report. Although every effort has been made to provide presently availwhole information on H_2O_2 in sufficient detail for most of the additional users of the handbook, size limitations of the handbook obviously preclude inclusion of every conceivable detail.

Thus, for those users who desire additional details on specific items, consultation of the many referenced publications is recommended.

Wherever a series of reports or papers has been utilized to report the progress in a particular study, the data and information referenced are from final reports, whenever applicable. This was done to eliminate confusion in efforts where progress reports included incomplete experimentation and/or analysis of the data. In those efforts where a final report has not been issued or does not contain sufficient detail of the item, the data ware taken from the latest progress report sontaining the pertinent results.

The tables figures, and references noted in each section are contained in that section for convenience. Each table, figure, and reference number is preceded by the section number (i.e., Table 1.3 is the third table in Section 1, etc.).

Because the major portion of this handbook is related to areas of engineering interest, all of the data ar presented in angimeering terminology (i.e., English units). However, as a convenience to all of the users, data in certain sections (notably, the physical properties section) of the handbook are presented in both metric and English units. Where data are presented in both units, the attendant discussion indicates the units of the referenced work.

As a further convenience to the user, physical constants and conversion factors are presented in Tables 1.1 through 1.3 to enable the user to convert the values to his particular needs. Also, because these constants are presented to the known degree of significance, they can be rounded to fit particular needs.

REFERENCES 1.3

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- 1.1 Schumb, W. C., C. N. Setterfield, and R. L. Wentworth, Hydrogen Peroxide, A.C.S. Monograph 128, Reinhold Publishing Corporation, New York, New York, 1955.
- 1.2 Berzelius, J. J., Jahresber. Chem., 15, 237 (1836), as presented in Ref. 1.1.

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TABLE 1.1

PHYSICAL CONSTANTS

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Unit	Remarks	Value
E _c	Standard gravitational acceleration	32.1740 ft/aec ² 980.665 cm/aec
l atm	Standard atmosphere	1,013,250 dynes/sq cu
1 was Hg	Standard millimeter Hg	1333.2237 dynes/og cu
1 cal	Thermochemical calorie	4.1846 abs joules 41.2929 ±0.0020 cu cm-aim
1 cal (1. T.)	International Stream Tables calorie	1.000654 thermochem- ical calories
¶0 C	Ice Point,	491.6880 ±0.018 R 273.160 ±0.010 K
$(\mathbf{PV})_{0}^{\mathbf{P}=0} - (\mathbf{RT})_{0}$	Prer anno-Volume product for ideal gro at 0 C	22,414.6 ±0.4 cu cm- atm/g mole 2271.16 ±0.04 abs joules/g mole
₽ • • •	Nolar centant	8.31439 ±0.00034 abs joules/K-g mole 1.98719 ±0.00013 cal/ K-g mole 82.0567 ±0.0034 cu cm- atm/K-g mole 59.47 cu ft-atm/R-1b mole 10.73 cu ft-psia/R-1b mole
l Btu	• ·	1055.040 abs joules 252.161 thermochemical calories 251.996 I. T. calories
l in-	United States unit	2.54000508 cm
1 ft	United States unit	30.4800610 cm
1 1b	Avoirdupois	453.5924277 g
l gel	United States unit	0.133680555 cu It 3785.43449 cu cu

Note: Compiled by Bossini, F. D. <u>et al.</u>, <u>American Petroleum Institute</u> <u>Research Project 44</u>, U.S. Department of Commerce, Natl. Bur. Standards, Circular 461, U.S. Government Printing Office, Washington, D. C., 1947.

CONVERSION FACTORS

Temperature

C + 273.16 = K F + 459.69 = R $(C \ge 1.8) + 32 = F$ (F - 32)/1.8 = CK(1.8) = R

Pressure

atm x 14.69618 = psi mm Hg x 0.00131579 = atm mm Hg x 0.019337 = psi g/sq cm x 0.00096784 = atm g/sq cm x 0.0142234 = psi bars x 0.98692 = atm bars x 14.504 = psi megabaryes x 1 = bars

MASS

grams (mass) x 0.002204622 = pounds (mass)

Length

centimeters x 0.393700 = inches centimeters x 0.032808 = feet

Area

square centimeters x 0.15590 = square inches square centimeters x 0.0010764 = square feet square feet x 144 = square inches

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TABLE 1.2

(Concluded)

Viscosity

centipoises x 0.672 x $10^{-5} = 1b_f/ft-sec$ centistokes x 1.076 x $10^{-5} = sq ft/sec$ (kinematic viscosity) x (density) = (absolute) viscosity

Thermal Conductivity

(cal/cm-sec-C) x 241.8588 = Btu/ft-hr-F

Velocity of Sound

(m/sec) x 3.28083 = ft/sec

Compressibility

 $(sq cm/dyne) \times 1.01325 \times 10^6 = atm^{-1}$ $(sq cm/dyne) \times 6.8947 \times 10^4 = psi^{-1}$

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TABLE 1.2(Continued)

Volume

cubic centimeters x 0.061023 = cubic inches cubic centimeters x 3.531445 x 10^{-5} = cubic feet cubic inches (U.S.) x 5.78704 x 10^{-4} = cubic feet

Time

seconds/60 = minutes
seconds/3600 = hours
seconds/86,400 = days

<u>**Force**</u>

dynes x 0.00101972 = grams (force) grams (force) x 0.00220462 = pounds (force)

Density and Specific Volume

(g/cu cm) x 62.43 = lb/cu ft (cu cm/g) x 0.016018 = cu ft/lb

Surface Tension

 $(dynes/cm) = 6.8523 = 10^{-5} = 1b_{f}/ft$

Thermodynamic Properties

(cal/g mole) x 1.8 = Btu/lb mole (cal/g mole- K) x 1 = Btu/lb mole - R (Btu/lb mole)/mol. wt = Btu/lb (Btu/lb mole- R)/mol. wt = Btu/lb - R (Cal/g) x 1.8 = Btu/lb

TABLE 1.3

TFM PERATURE CONVERSION

		-479 to 0 0 to 30					30	International Bange						1000 to 1490 1500 to 9000							
	c	+	,	c				c + +				· •	c		7	c		,		-	,
		-1.90	† ———	-17.0	0	39.0	100		199.0		100	810						1039			
	-868	-450	{	-17.8	1	33.0	10.6	51	193.6	45	110	230	206	510	950	541	1010	1840	921 979	1510	8750
ļ	-869	-440		-16.7	2	33 6	11.1	52	125.6	19	127	248	871	520	958	149	1020	1868	827	1520	2768
1	-857	-430	}	-16.1	,	37.4	11.7	53	127.4	34	130	364	\$77	530	986	354	1030	1886	632	1530	2786
1	-451	-420		-15.6	•	39.8	18.8	*	129.2	60	140	284	982	540	1004	560	1040	1904	вун	1340	8601
	-849	-419	1	-15.0	3	41.0	18.8	55	131.0	65	150	302	286	550	1 022	966	1050	1992	863	1550	8623
	-840	-400		-16.6	0	42.8	13.3	95	132.8	71	160	320	293	560	1040	571	1060	1940	849	1360	2440
	-394	-390		-13.9		44.6	13.9	57	134.6	77	170	334	299	570	1058	577	1070	1958	854	1570	2858
		-370	1	-12.8		40.4	13.0	90	130.4	84	100	370	110	790	1070	202	1080	1001	800	1580	2870
	-818	-360	5 I	-12.2	10	50.0	15.6	60	160.0	93	200	392	116	600	1112	5:13	1100	2012	871	1600	2912
	-812	-350		-11.7	n	51.0	16.1	61	141.8	99	210	410	121	610	1130	799	1110	2030	877	1610	8930
	-207	-340		-0.1	12	53.6	16.7	62	113.6	100	212	614	327	620	1148	604	1120	8048	862	1620	2948
	-991	-330		-10.6	13	55.4	17.8	63	145.4	104	220	420	132	630	1166	610	1130	2066	866	1630	2966
	-196	-520		-10.0	-14	57.2	17.8	64	147.9	110	820	446	338	640	1184	616	1140	2084	893	1060	2984
1.0	-190	-310		- 9.44	15	59.0	18.3	65	14y.0	116	240	464	143	650	1202	621	1150	2102	(199	1650	3002
3.6	-164	-300		- 0.89	16	60.8	28.9	66	150.6	121	250	462	349	660	1220	627	1160	2120	904	1000	3020
7.0	-179	- 8941		- 8.33	17	02.0	19.4	67	152.6	197	260	500	334	670	1238	632	1170	2138	910	1670	3038
9.6	-169	-\$73	-439	- 7.99	10	66.9	20.6	60	196.9	114	270	510	300	690	1470	663	1100	81,70	910 910	1600	3076
18.6	-168	-870	-454	- 6.67	20	68.0	81.1	70	158.0	155	290	5.54	321	700	1992	649	1200	9192	927	1700	1092
16.2	-162	-260	-436	- 6.11	21	69.8	81.7	71	179.8	149	300	572	377	710	1310	654	1210	2210	932	1710	3110
10.0	-157	-850	-418	~ 5.56	922	71.6	82.2	78	161.6	154	310	590	382	720	1328	660	1220	2228	938	1720	3128
	-151	-840	-400	- 5.00	23	73.4	22.6	73	163.4	166	320	608	300	730	1346	606	1230	2246	913	1730	3146
	-146	-830	- 3 82	- 4.44	24	75.8	23.3	74	165.2	166	330	626	393	710	1364	671	1240	2264	949	1740	3154
	-140	-220	-364	- 3.09	85	77.0	83.9	75	167.0	171	340	666	399	750	1382	677	1250	8383	954	1750	3182
	-134	-210	-346	- 3.33	86	78.8	24.4	76	168.8	177	350	662	404	760	1400	682	1260	8300	960	1760	3200
	-129		-326	- 8.78	87	80.6	85.0	77	170%	182	360	660	410	770	1418	688	1270	2318	966	1770	3218
	-12)	-150	-910	- 1.67	29	84.2	26.1	79	174.9	193	3/0	716	491	710	1454	649	1290	2354	9.7	1790	3254
.	-118	-170	-874	- 1.11	30	86.0	86.7	80	176.0	199	390	754	427	800	1472	704	1300	8178	962	1800	3272
	-107	-160	-856	- 0.56	31	87.8	27.2	61	177.8	204	409	752	432	810	1490	710	1310	2390	986	1810	3290
	-101	-150	-4,20	•	32	89.6	27.0	28	179.6	816	410	770	458	820	1508	716	1320	2108	993	1820	3308
	- 95.	-140	~899	0.56	33	91,4	30. 3	85	181.4	816	420	784	443	830	2556	781	1330	24.26	399	1830	3324
	~ 90.	-130	-202	1.11	34	93.2	\$8.5	-	143.8	821	430	806	449	640	1544	787	1,40	2444	1004	1840	3344
	- 84.	-190	-184	1.67	35	95.0	89.4	85	185.0	897	440	824	454	850	1762	752	1350	2462	1010	1850	3362
	- 78.	-110	-196	1.12		70.0	90,9	80	100.0	232	479	942 860	460	860	1560	750	1360	2080	1016	1860	3380
	- 67.8		-130	3, 33	"	100.4	51.1		190.4	27 94 5	4.70	878	471	870	1570	749	13/4	2516	1021	1840	3416
	- 62.1	- 80	-118	3.45	39	106.8	31.7	89	192.2	34.9	480	896	477	890	1634	714	1390	85 14	1012	1890	34.34
1	- 56.	7 - 70	- 94	4.44	10	104.0	38,2	90	194.0	254	490	914	482	900	1652	760	1400	8552	1038	1900	5452
- 1	- 51.	- 69	- 76	5.00	41	105.8	32.6	91	193.6				488	910	1670	766	1410	\$570	1045	1910	3470
	- 45.	- 54	- 98	5.56	42	107.6	33.3	92	197.6				493	990	1686	771	1420	2586	1049	1920	3485
	- 40,	9 - 4Q	- 40	6.11	43	109.4	32.9	95	199.4				499	930	1704	\overline{m}	1430	96-06	2054	1930	. 506
	- 34.	- 30	- 22	6.67	44	111.2	34.4	94	201.2				504	940	1714	782	1440	3624	1060	1940	3524
	- 39.9	- 20		7.12	47	113.0	77.0 94.4	5	1003.0 904.0				510	970	1742	700	1450	9048 0640	1065	1950	3542
[- 17	- 10	19	1.78 A 33	17	116 6	99.0 94.3	970	305.6				514	970	1774	797	1400	1000	1071	1900	3700
			_	8,83	44	110.4	×.7	9	398.4				587	900	1796	804	1480	2696	1082	1980	3596
- 1				9.64	49	120.2	57.8	99	\$10.8				532	990	1014	110	1490	8714	1086	1990	3614
				10.00	50	122.0	37.0	160	\$12.0				538	1000	1852				1095	2000	5652
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Interpolation							
Factore							
0.56	1	1.6]					
1.11	2	3.6					
1.67	3	5.4					
8.22	- A -	7.2					
8.78	5	9.0					
3.33	6	10.8					
3.09	7	12.6					
4.14		14.4					
5.00	9	16.8					
3.50	10	18.0					

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SECTION 2: PHYSICO-CHEMICAL PROPERTIES

2,1 GENERAL DESCRIPTION

Hydrogen peroxide is a chemical compound with the empirical formula $H_2 0_2$. Because of the compound's complete miscibility with water above 32 F, hydrogen peroxide is commercially available in aqueous solutions at concentrations to ~98 percent by weight $H_2 0_2$. Propellant-grade hydrogen peroxide has generally been limited to aqueous solutions \geq 70 w/o $H_2 0_2$ with regulation of the concentrations and impurity levels of the more frequently applied propellant grades by government procurement specifications.

Hydrogen peroxide and its aqueous solutions are water-like in appearance in both the liquid and solid states. Although hydrogen peroxide is generally considered odorless, the odor of high vapor concentrations has been described as sweet and comparable to the odor of weak concentrations of ozone and the halogens. Aqueous hydrogen peroxide solutions are more dense, slightly more viscous, and have higher boiling and lower freezing points than water.

Although hydrogen peroxide solutions are normally insensitive to shock and impact and are nonflammable, they are active oxidizing materials and can decompose exothermally to yield water and oxygen. Because of their strong oxidizing nature and the liberation of oxygen and heat during their decomposition, propellant-grade solutions can initiate the vigorous combustion of many common organic materials such as clothing, wood, wastes, etc. In the absence of contamination, propellant-grade hydrogen peroxide solutions are relatively stable (nominal decomposition rates are 0.1 percent per year) over ambient temperature ranges. However, in the presence of higher temperatures and/or various contaminants (including many inorganic materials), the decomposition rate is drastically increased. Rapid decomposition can occur in situations where extreme temperature levels and/or mass contamination are present. As the decomposition rate increases, the attendant heat release causes additional decomposition; this bootstrap effect can lead to a runaway reaction.

Hydrogen peroxide is normally stored, shipped, and handled as a liquid under its own vapor pressure with provisions for relief of pressure buildup. When stored and/or transferred in clean, passivated, compatible systems by properly educated and trained personnel, hydrogen peroxide does not present a scrious storage or handling problem.

2.2 PHYSICAL PROPERTIES

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A majority of the physical properties of propellant-grade solutions of hydrogen peroxide have been experimentally characterized (or analytically extrapolated) with a reasonable degree of accuracy over ambient temperature ranges. However, because of the increasing decomposition rates of these propellant solutions with increase in temperature, very few measurements have been conducted above 200 F. In addition, the accuracy of data is questionable in temperature ranges where decomposition rates are relatively high. This is evident in the discontinuity of some of the data at the higher temperature ranges.

It should also be noted that the data reported for "pure" (or 100 w/o) H_2O_2 is questionable since there is some doubt as to the existence of H_2O_2 concentrations above 99.7 to 99.8 w/o. Some of the data reported for 100 w/o H_2O_2 were obtained by extrapolation of property data of H_2O_2 solutions of lower concentration, while other experimental measurements reported on "100 w/o" H_2O_2 indicated propellant assays of "99+ percent," "99 ±0.5 percent," etc. Even for most of those studies which report the H_2O_2 concentrations,

State in the methods of determining these concentrations are not reported or are based on an assumption of purity related to the purification technique.

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Although it is suspected (because of discontinuities in the data) that many of the measurements on the "100 w/o" $H_2 O_2$ represent, in reality, measurements on $H_2 O_2$ of lower concentrations, p operties are reported for 100 w/o $H_2 O_2$ wherever an extrapolation (from lower concentrations) scems reasonable. This characterization is of academic interest only because ~ 98 w/o $H_2 O_2$ is the highest concentration presently available commercially. Future aerospace industry utilization of higher concentrations appears unlikely because of practical and economical considerations.

Nominal values for physical property data that are recommended as the most representative of the existing data are summarized for the "100", 98, 95, 90, 75, and 70 w/o hydrogen peroxide grades in Table 2.1. All of the data presented are direct experimental determinations or are derived from curve-fits of the experimental data, except for those data referenced with an asterisk; the data referenced with an asterisk were a result of calculations made during the referenced work and based on standard analytical correlations and physical relationships. The absence of data on a particular property is denoted by blank spaces in the tables.

Properties for which property-temperature relationships have been established are noted in Table 2.1 with a figure or another table number; the corresponding property-temperature relationships are shown in Fig. 2.1 through 2.23 and Tables 2.2 through 2.17. The graphical illustrations represent either curve-fits of the best available experimental data or analytical estimations of the property; curve-fits of experimental data are noted with a solid line, while a dashed line designates calculated data. Equations

resulting from computer curve-fits of some of the data are presented in attendant discussions.

The origin of the selected data is referenced in each table and figure. A brief discussion of the available data for each property is presented in the following paragraphs.

2.2.1 <u>General Identification</u>

The physical classifications under general identification are those properties that are used to identify hydrogen peroxide and its physical state.

- 2.2.1.1 <u>Molecular Weight.</u> The molecular weight of hydrogen peroxide was experimentally determined by freezing point depression (Ref. 2.1 and 2.2) and vapor density (Ref. 2.3) measurements. The results of these studies are comparable to the value of 34.016 calculated from the International Atomic Weights. The mole percent and apparent molecular weight as a function of weight percent $H_2 0_2$ for various aqueous solutions of $H_2 0_2$, as shown in Fig. 2.1, were calculated from the molecular weights.
- 2.2.1.2 <u>Freezing Point</u>. The determination of freezing and melting points of $H_2 O_2 - H_2 O$ solutions is relatively difficult because of the large degree of supercooling possible with these solutions. In addition, phase equilibrium measurements (Ref. 2.2) have indicated that solid solutions are not formed in the solidification of concentrated (greater than 65 w/o $H_2 O_2$) aqueous solutions of $H_2 O_2$; instead, the solid consists of crystals of $H_2 O_2$ with occluded mother liquid. Thus, the range of temperatures over which the material melts or freezes is a function of the crystallization pattern of the $H_2 O_2$.

The freezing point of "100 percent" H₂0₂ has been reported as -0.-61 C (31.17 F), -0.43 C (31.23 F), and -0.41 C (31.26 F) in Ref. 2.2, 2.4, and 2.5, respectively. Based on a reported mample purity of 99.97 m/o H_0O_0 , the freezing point determination of Ref. 2.4 was selected as representative of 100 percent $H_2^{0}0_2$. Measurements of the freezing points of aqueous Bolutions of H_20_{Ω} (Ref. 2.2) indicate cutectics at 45.2 w/o H_20_2 and -52.4 C (-62.3 F), and at 61.2 w/o H_20_2 and -56.5 C (-69.7 F). The results of these measurements, which are graphically illustrated in Fig. 2.2 and 2.2a, represent the temperatures at which 20 to 30 percent of the liquid had solidified. Experimental melting point studies (Ref. 2.6), based on observation of the temperature at which melting was complete, resulted in slightly higher melting temperatures for concentrations above 60 w/o $H_0 0_0$.

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A variety of experimental studies have produced no significantly effective freezing point depressants for propellantgrade H₀0₀ solutions. These studies, described in detail in Ref. 2.3 and 2.6 through 2.9, have shown that many additives will form unstable or shock-sensitive mixtures with $H_0 0_0$.

Triple Point. The triple point of 99.97 m/o H₂O₂ was estimated 2,2.1.3 as 372.74 K (-0.42 C or 31.24 F) from experimental heat of fusion studies (Ref. 2.5). Although no vapor pressure measurements have been made on solid H₀0₀, the vapor pressure at the triple point has been calculated (Ref. 2.10) as 0.25 mm Hg (0.005 psia).

2.2.1.4 Normal Boiling Point. The normal boiling points of propellantgrade $H_2 \partial_2$ solutions have not been experimentally determined by conventional means since these points are in a temperature region where thermal decomposition of the H_00_0 is significant. The normal boiling points listed in Table 2.1 and Fig. 2.3



There has been no experimental deter-2.2.1.5 Critical Properties. minations of critical properties of H_20_2 wince the compound undergoes extensive decomposition before the critical temperature is achieved. However, because this property is of academic interest, the critical temperature has been estimated by ³⁸ assuming that the critical temperature/boiling point ratio of H₀0₀ is equal to that of water. Based on this technique, a critical temperature (T_c) of 458.8 C (857.8 F) has been reported for 100 w/o H_2^{0} (Ref. 2.11); another T_c value of 457 C (855 F) for 100 w/o H_00_p , which was alluded to in Ref. 2.12, was reported in Ref. 2.10. Using a vapor pressure equation established in Ref. 2.12, the critical pressure, P, was calculated (Ref. 2.10) as 214 atmospheres (3140 psia) at the latter T_.

> Using the estimated boiling point given in Table 2.1 and correlation technique described above, a T_c of 733 K (460 C, 860 F) is recommended for 100 w/o H_2O_2 . An estimation technique suggested in Ref. 2.12 (P_c/T_c is equivalent for both H_2O_2 and H_2O) resulted in a calculated and recommended P_c of 247 atmospheres (3630 psia) for 100 w/o H_2O_2 using the T_c value of 733 K. Pseudocritical constants were calculated for the propellant-grade $H_2O_2-H_2O$ solutions through the use of Kay's method (Ref. 2.13); the results of these calculations are shown in Table 2.1 and in Fig. 2.3.

2.2.2 Phase Properties

Those properties of hydrogen peroxide, which are associated with one particular phase (either solid, liquid, or gas) have been grouped as phase properties.

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<u>Density</u>. A density of 1.70 gm/cc (106.76 lb/cu It) was computed for solid 100-percent H_2O_2 from X-ray diffraction measurements (Ref. 2.14) at -20 C (-4 F). Density measurements on H_2O_2 -H_2O solutions during cooling and freezing (Ref. 2.15) indicated that true solid solutions of H_2O_2 and H_2O were not formed; this was later verified in Ref. 2.2. Since the occlusion of the mother liquor occurred in freezing, the measured densities were a function of the freezing technique. However, it was noted (Ref. 2.15) that solutions containing < 45 W/o H_2O_2 expand during freezing and solutions > 65 w/o H_2O_2 contract during freezing.

Experimental determinations of the liquid densities of various $H_2 O_2 - H_2 O$ solutions were reported as a function of composition in Ref. 2.6 (at 0 and 18 C), Ref. 2.15 (at 0 C), Ref. 2.16 (at 20 C), and Ref. 2.17 (at 0, 10, 25, 50, and 96 C). In addition, experimental studies have determined the density of 90 w/o $H_2 O_2$ from 76 to 193 C (Ref. 2.18), and the density of 98 w/o $H_2 O_2$ from 27 to 105 C (Ref. 2.19). The data from these six studies were simultaneously curve fitted by a least-squares computer program, and the following equation was found to adequately (actual deviation for each experimental point was < 0.002 gn/cc) describe the data from 0 to 193 C (32 to 379 F) over a concentration range of 60 to 100 w/o $H_2 O_2$.

$$P(cv/cc) = 1.0479 + 2.455 \times 10^{-3} \text{W} + 1.781 \times 10^{-5} \text{W}^2 - 6.76 \times 10^{-6} \text{T}(c)^{-2.4} \times 10^{-7} \text{T}(c)^{2} - 3.98 \times 10^{-6} \text{WT}(c)$$

where W is weight percent $H_2 O_2$.

Converting to English units, this equation becomes:

$$P(1b/cu ft) = 66.166 + 1.577 \times 10^{-1} W + 1.112 \times 10^{-3} W^2 - 2.31 \times 10^{-2} T_{(F)} - 4.7 \times 10^{-6} T_{(F)}^2 - 1.38 \times 10^{-5} W T_{(F)}$$

The curves described by these equations are graphically illustrated for propellant-grade H_2_0 solutions in Fig. 2.4 and 2.4a, respectively.

Experimental vapor density measurements (Ref. 2.3) at 92 C (165.6 F) show that H_2O_2 is not associated in the vapor state. If it is assumed that no decomposition occurs, the vapor density may be calculated through use of the perfect gas law.

2.2.2.2 <u>Coefficient of Thermal Expansion</u>. Using the curve fits of the density data, the coefficients (cubical) of thermal expansion were calculated for propellant-grade 1_20_2 -H₂9 solutions from 0 to 100 C (32 to 212 F) through the following relationship:

$$\boldsymbol{\alpha} = \frac{1}{\mathbf{V}} \begin{pmatrix} \frac{\partial \mathbf{V}}{\partial \mathbf{t}} \end{pmatrix}_{\mathbf{P}}$$

Curve fits of these calculations are presented in Fig. 2.5 and 2.5a.

Compressibility. The adiabatic compressibilities of $H_2 O_2$ solutions were calculated (Ref. 2.16) from experimental density and sonic velocity data covering a temperature range of 3.5 to 33.5 C (38.3 to 92.3 F) and a concentration range of 0 to 93.4 m/o (0 to 96.5 w/o). These data were used to plot the adiabatic compressibilities of propellant-grade $H_2 O_2$ solutions shown in Fig. 2.6 and 2.6a.

Although no experimental data have been reported on the isothermal compressibility of H_2O_2 , the adiabatic compressibility, density, and hert capacity data were used to calculate (Ref.2.16) an isothermal compressibility of 26.514 x 10^{-12} cm²/dyne (26.865 x 10^{-6} atm⁻¹, 18.281 x 10^{-5} psia⁻¹) for 100 w/o H_2O_2 at 20 C (68 F).

2.2.2.4 <u>Vapor Pressure</u>. The vapor pressure data resulting from four different experimental measurements (Ref. 2.11, 2.12, 2.20, and 2.21) on various aqueous solutions of H₂O₂ over temperature ranges of 0 to 90 C (32 to 194 F) have been correlated. Using a least squares curve-fit computer program, these data were curve-fitted with the following equations (in the metric system):

$$\frac{100 \text{ w/o H}_20}{(\text{mm Hg})^2} \frac{100 \text{ P}(\text{mm Hg})^2}{(\text{mm Hg})^2} \frac{8.92536 - 2482.60}{(\text{T}(\text{K}))} \frac{-24675}{(\text{K})}$$

 $\frac{98 \text{ w/o } \text{H}_2^0}{\text{T}_{(K)}} = \frac{108 \text{ P}(\text{mm Hg})}{\text{T}_{(K)}} = \frac{7.89728 - 1797.84}{\text{T}_{(K)}} - \frac{134089}{\text{T}_{(K)}^2}$
$$\frac{95 \text{ w/o H}_2 0_2}{90 \text{ w/o H}_2 0_2} \log P_{(nm Hg)} = 7.68235 - \frac{1647 \cdot 17}{T_{(K)}} - \frac{154665}{T_{(K)}^2}$$

$$\frac{90 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(nm Hg)}} = 7.67297 - \frac{1606 \cdot 47}{T_{(K)}} - \frac{157563}{T_{(K)}^2}$$

$$\frac{75 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(nm Hg)}} = 7.39108 - \frac{1351 \cdot 86}{T_{(K)}} - \frac{185963}{T_{(K)}^2}$$

$$\frac{70 \text{ w/o H}_2 0_2}{T_{(K)}^2} \log P_{(nm Hg)} = 7.42560 - \frac{1354 \cdot 10}{T_{(K)}} - \frac{181798}{T_{(K)}^2}$$
Converting these equations to English units resulted in the following:

$$\frac{100 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(psia)}} = 7.21175 - \frac{4468 \cdot 68}{T_{(R)}} - \frac{79947}{T_{(R)}^2}$$

$$\frac{98 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(psia)}} = 6.18367 - \frac{3236 \cdot 11}{T_{(R)}} - \frac{454448}{T_{(R)}^2}$$

$$\frac{95 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(psia)}} = 5.96874 - \frac{2964 \cdot 91}{T_{(R)}} - \frac{501115}{T_{(R)}^2}$$

$$\frac{90 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(psia)}} = 5.97936 - \frac{2891 \cdot 65}{T_{(R)}} - \frac{510504}{T_{(R)}^2}$$

$$\frac{75 \text{ w/o H}_2 0_2}{10 \text{ g} P_{(psia)}} = 5.67747 - \frac{2433 \cdot 35}{T_{(R)}} - \frac{602196}{T_{(R)}^2}$$

$$\frac{70 \text{ w/o H}_2 0_2}{T_{(R)}^2} \log P_{(psia)} = 5.71199 - \frac{2437 \cdot 38}{T_{(R)}} - \frac{589026}{T_{(R)}^2}$$

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The equations are illustrated graphically in Fig. 2.7 and 2.7a, where the data are extrapolated to temperatures above 90 C (194 F) by assuming a linear relationship between the temperatures for which H_2O_2 solutions and water have the same vapor pressures. These extrapolations were used to determine the pseudo-boiling points (the temperatures where the pressures are equivalent to 760 mm Hg) of the propellant-grade H_2O_2 mixtures.

2.2.2.5 <u>Vapor-Liquid Equilibrium</u>. Vapor-liquid equilibrium compositions of H₂0₂-H₂0 solutions were determined experimentally in two different studies (Ref. 2.12 and 2.21). Although comparable, there are slight differences in the data at some of the temperatures. The data of Ref. 2.12 were used in Ref. 2.22 to plot vapor composition and vapor-liquid equilibrium, and to calculate and plot activity coefficients for the system. These plots are shown in Fig. 2.8 through 2.10.

Calculations (Ref. 2.23) of saturation pressure, activity coefficients, and vapor compositions have been made for three different $H_2^{0}_2$ - H_2^{0} solutions (90, 81.5, and 65.4 w/o) at high temperatures and pressures. The computation of these data, which are shown in Table 2.2, are described in detail in Ref. 2.23. Although these computations were based on assumptions of $H_2^{0}_2$ critical constants that are different (critical temperature = 457 C, critical pressure = 215 atmospheres)from the values recommended in this handbook, corrections to Table 2.2 are slight.

2.2.2.6 <u>Surface Tension</u>. The surface tensions of $H_2 O_2 - H_2 O$ solutions have been experimentally determined (Ref. 2.24) as a function of composition at O C (32 F) and 20 C (68 F). Graphical representations of the data are shown in Fig. 2.11 and 2.11a.

Thermodynamic Properties

The H_2O_2 properties which define energy changes in the physical transitions through the various solid, liquid, and gas states, as well as in chemical changes, have been listed under thermo-dynamic properties.

2.2.3.1

<u>Heat of Formation</u>. The heats of formation (ΔH_F) of propellantgrade $H_2 0_2$ solutions were calculated in this study from heat of dissociation data given in Ref. 2.25. Heat of fusion, heat of vaporization, heat of mixing, and heat capacity data used to characterize the heat of formation over a range of temperatures, phases, and concentrations are given in subsequent sections. Data for the aqueous solutions are presented as heats of formation of the solution (which includes the heat of formation contributions of both $H_2 0$ and $H_2 0_2$, and the heat of mixing).

The ΔH_F data for the liquid and solid phases of propellantgrade $H_2^{0}{}_2$ solutions are given in Tables 2.3 through 2.8 and Fig. 2.12 and 2.12a. Figures 2.13 and 2.13a illustrate the ΔH_F of the liquid at 25 C (77 F) as a function of composition. The heats of formation of the vapor of propellant-grade $H_2^{0}{}_2$ - H_2^{0} solutions are given in Tables 2.9 through 2.14.

- 2.2.3.2 <u>Heat of Fusion</u>. The heats of fusion of propellant-grade H₂O₂ solutions were taken from the experimental studies of Ref. 2.2; these data are shown in Tables 2.3 through 2.8 as the change in enthalpy at the freezing point.
- 2.2.3.3 <u>Heat of Veporization</u>. The experimental data of Ref. 2.26 were used to plot the heats of vaporization of $H_2 0_2 - H_2 0$ solutions as a function of temperature; curve-fits of the data at 0, 25, 45, and 60 C (32, 77, 113, and 140 F) are shown in Fig. 2.14

and 2.14a. Heats of vaporization of propellant-grade H_2O_2 solutions at other temperatures can be obtained by computing the difference in the heats of formation of the liquid (Tables 2.3 through 2.8) and vapor (Tables 2.9 through 2.14) phases of the $H_2O_2-H_2O$ solutions at the corresponding temperatures and H_2O_2 concentrations.

- 2.2.3.4. <u>Heat of Sublimation</u>. The heat of sublimation of 100 w/o $H_2^0_2$ has been calculated (Ref. 2.10) from the heats of fusion and vaporization as 457.8 cal/gm (824 Btu/lb).
- 2.2.3.5 <u>Heat of Mixing</u>. Graphical representations of the heats of mixing of propellant-grade $H_2^{0}{}_2$ - H_2^{0} solutions, shown in Fig. 2.15 and 2.15a, were plotted from smoothed data given in Ref. 2.26. These data represent experimental data of the referenced work, previous experimental studies (Ref. 2.25), and their extrapolation to higher temperatures for comparison with the experimental data of Ref. 2.12. Excellent agreement is noted between the data of Ref. 2.26 and Ref. 2.12 except in the 20 to 30 w/o $H_2^{0}_2$ concentration range.
- 2.2.3.6 <u>Heat of Decomposition</u>. The heats of decomposition, graphically represented in Fig. 2.16 and 2.16a, were converted from smoothed data from the experimental studies of Ref. 2.25. The figures illustrate the heats of decomposition of propellant-grade $H_2^0 - H_2^0$ solutions with decomposition to either liquid water or water vapor.
- 2.2.3.7 <u>Heat Capacity</u>. The heat capacities of solid and liquid propellantgrade H₂O₂-H₂O solutions are shown in Tables 2.8 through 2.13 and in Fig. 2.17 and 2.17s from 0 to 400 K (0 to 720 R). The

heat capacities of solid $H_2^{0}_2$ were taken from the data of Ref. 2.5. Since solid solutions of $H_2^{0}_2$ and H_2^{0} are not formed in the concentration region of interest, the heat capacities of the solid phases of propellant-grade $H_2^{0}_2$ - H_2^{0} solutions were assumed to be the sum of the individual heat capacity contributions of solid H_0^{0} and solid $H_0^{0}_2$.

The liquid heat capacities were curve-fitted from the experimental data of Ref. 2.25 and 2.26; these studies indicated that the change in heat capacity of an $H_2 O_2 - H_2 O$ solution of constant composition over the indicated temperature range was of the order of the accuracy of the experimental data. Experimental measurements of liquid heat capacity were not conducted below 0 C (32 F); therefore, the heat capacity was estimated in this region using the heat capacity of supercooled $H_2 O$ and the extrapolated heat capacity contribution of the $H_2 O_2$.

During experimental heat transfer studies at relatively high temperatures (Ref. 2.18), the heat capacities of 90 w/o $H_2 O_2$ were indirectly determined from heat transfer data over a temperature range of 240 to 380 F. An equation was developed for the data which indicated an increasing deviation of the experimental data from the curve fit of the data with increasing temperature. The differences in these data from extrapolations of the data presented in Fig. 2.17 and 2.17a, which are ≤ 0.01 Btu/lb-F (cal/gm-C), are assumed to be the result of $H_2 O_2$ decomposition in the experimental study.

The heat capacities of the vapor phase of propellant-grade $H_2^{0}_2$ solutions are given in Tables 2.9 through 2.14. The origin of these data is discussed in Section 2.2.3.9.

Enthropy and Enthalpy. The entropy and enthalpy of the solid and liquid phases of propellant-grade H_20_2 solutions were calculated from the other thermodynamic functions given in Tables 2.3

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2.2.3.8

through 2.8. The basis for the vapor-phase entropy and enthalpy data on propellant-grade H_2O_2 solutions, given in Tables 2.9 through 2.14 is discussed in Section 2.2.3.9.

2.2.3.9 <u>Vapor-Phase Thermodynamic Properties</u>. The thermodynamic properties of hydrogen peroxide vapor were calculated (Ref. 2.27) from structural data. These data, which replaced earlier reported data (Ref. 2.28), were based on new spectroscopic measurements (Ref. 2.29) and new calorimetric data (Ref. 2.5 and 2.25). The primary difference in the presently accepted values and those reported earlier are in the internal rotation values.

The structural values used by Ref. 2.27 in the computation of the vapor-phase thermodynamic properties, given in Tables 2.9 through 2.14, are:

r 0-H	■ 0.965 Å	$v_1 = 3610 \text{ cm}^{-1}$
r 0-0	- 1.49 Å	$v_2 = 1350 \text{ cm}^{-1}$
α 00H	- 100 degrees	$v_3 = 880 \text{ cm}^{-1}$
φ	≈ 95 degrees	$v_4 = 520 \text{ cm}^{-1}$
IA	= 2.785 x 10 ⁻⁴⁰ gm-cm ²	$v_5 = 3610 \text{ cm}^{-1}$
I _B	$= 34.0 \times 10^{-40} \text{ gm} - \text{cm}^2$	$v_6 = 1266 \text{ cm}^{-1}$
ı _c	- 33.8 x 10 ⁻⁴ 9 gm-cm ²	σ ≈ 2
I _{Red}	= 0.696 x 10 ⁻⁴⁰ gm -cm ²	

2.2.4 Transport Properties

All properties of propellant-grade solutions of H_2O_2 that involve the transfer of mass or energy at the molecular level are presented in the following paragraph:,

2.2.4.1 <u>Viscosity</u>. Experimental determinations of the viscosity of liquid $H_2O_2-H_2O$ solutions ranging in composition from 0 to 100 w/o H_2O_2 , have been reported in Ref. 2.6 (0 and 18 C), Ref. 2.24 (0 and 20 C), and Ref. 2.22 (0, 25, and 50 C). Curvefits of these data at 0, 20, 25, and 50 C (32, 68, 77, and 122 F) are graphically illustrated as a function of w/o H_2O_2 (from 50 to 100 w/o) in Fig. 2.18 and 2.18a. In addition, viscosity measurements have been conducted on 98 w/o H_2O_2 (Ref. 2.19) from 20 to 85 C (68 to 185 F) and on 90 w/o H_2O_2 (Ref. 2.18) from 77 to 325 F (25 to 162.8 C). The data for 98 and 70 w/o H_2O_2 from the various sources has been plotted as a function of temperature and compared to the viscosity of water in Fig. 2.19 and 2.19a.

The viscosity of the vapor phase of $H_2O_2-H_2O$ solutions at 1 atmosphere has been calculated (from experimentally determined data) as reported in Ref. 2.30. An equation (Ref. 2.30) representing these data from 100 to 300 C (212 to 540 F) with an estimated precision of ±2 percent is given as:

 μ (micropoises) = 134 + 0.35 [T_(C) - 100] -14 Y

where

 $Y = mole fraction H_0 O_0$ in vapor

This equation, comparing the vapor viscosity of water with 100 w/v H₀O₀, is graphically represented in Fig. 2.20.

2.2.4.2 <u>Thermal Conductivity</u>. Experimental measurements of the thermal conductivity of $H_2^{0}_2-H_2^{0}$ solutions have been limited to determinations (Ref. 2.22) on 98.2 w/o $H_2^{0}_2$ at 0 C (32 F) and 25 C (77 F) and on 50 w/o $H_2^{0}_2$ at 25 C; resulting thermal conductivities were 0.321, 0.339, and 0.347 Btu/hr-ft-F, respectively.

Using the two experimental data points, the thermal conductivity of 98.2 w/o H_2O_2 was extrapolated to the critical point (Ref. 2.31). This extrapolation, shown in Fig. 2.21, used H_2O as a reference substance and assumed no decomposition and a thermal conductivity of 0.100 Btu/hr-ft-F at the critical point.

Experimental heat transfer studies (Ref. 2.19) indicated that the estimated thermal conductivities reported in Ref. 2.31 agree reasonably well with those calculated from the experimental heat transfer data.

2.2.4.3 <u>Coefficient of Diffusion</u>. The experimental determination of the diffusion coefficient of liquid $H_2 0_2$ into water has been reported (Ref. 2.32) for 0.17 w/o $H_2 0_2$ from 0 to 40 C (32 to 104 F) and for 0.019, 1.44, and 7.92 w/o $H_2 0_2$ at 20 C (68 F). At 20 C (68 F), the diffusion coefficients were <1.2 cm²/day for the concentrations studied.

The diffusion coefficient of H_2O_2 vapor into air was experimentally determined (Ref. 2.33) in a vertical tube as 0.188 cm²/sec at 60 C (140 F) and 1-atmosphere pressure. This can be compared to a diffusion coefficient of 0.320 cm²/sec reported (Ref. 2.34) for water vapor under identical conditions.

2.2.4.4 Sonic Velocity. The velocity of sound was experimentally measured (Ref. 2.16) in H₂O₂-H₂O solutions from 3.5 to 33.5 C (38.3 to 92.3 F). These data are plotted for propellant-grade H₂O₂ solutions in Fig. 2.22 and 2.22a.

2.2.5 Electromagnetic Properties

The electrical, magnetic, and electromagnetic (optical) properties of $H_0 O_0$ have been grouped as electromagnetic properties. These properties generally are related to the electronic structure of the atoms in contrast to the transport properties which involve only molecular movement.

- 2.2.5.1 <u>Index of Refraction</u>. The refractive indexes of H₂O₂-H₂O solutions were experimentally determined (Ref. 2.15) using the sodium D line. The data for propellant-grade H₂O₂-H₂O solutions are presented in Table 2.15 at 25 C (77 F) with a temperature correction guide.
- 2.2.5.2 <u>Dipole Moment</u>. Calculated dipole moments of H_2O_2 were reported as 2.22 Debye (or 2.22 x 10^{-18} esu-cm) and 2.05 Debye in Ref. 2.35 and 2.36, respectively. In addition, a value of 2.26 Debye was estimated (Ref. 2.37) from the Stark effect, and a value of 2.13 Debye was determined (Ref. 2.38) for H_2O_2 in dioxane. The latter value was selected as the representative dipole moment for H_2O_2 .
- 2.2.5.3 <u>Dielectric Constant</u>. Figures 2.23 and 2.23a show the dielectric constants of propellant-grade $H_2 O_2 - H_2 O$ solutions as a function of temperature. These data were interpolated from the experimental studies reported in Ref. 2.39, in which the dielectric constants were determined as a function of composition at constant temperatures from -40 to 30 C (-40 to 86 F). Because of the supercooling of the $H_2 O_2 - H_2 O$ solutions, measurements were obtained on the liquid below the freezing point. The data from the measurements on 100 w/o $H_2 O_2$ were curve-fitted from -60 to 30 C (-76 to 86 F) to the following equation (Ref. 2.40):

 $\epsilon = 84.2 - 0.02 T_{(C)} + 0.0032 T_{(C)}^2$

- 2.2.5.4 <u>Electrical Conductivity</u>. The conductivity of "pure" H₂O₂ has been reported by several investigators with values ranging from 2 to 0.39 micromhos (microohms⁻¹). Experimental studies (Ref. 2.41) of the conductivity of unstabilized H₂O₂ were conducted as a possible means of determining its purity. The results of this study are summarized as follows:
 - 1. Fractional crystallization reduced the conductivity of commercial 90 w/o $H_2 O_2$ (11.5 microohms⁻¹ at 25 C) to approximately one-half (5.0 microohms⁻¹ at 25 C) of its initial value, while increasing its concentration to 98+ w/o $H_2 O_2$.
 - Distillation of the crystallized H₂O₂ reduced its specific conductance to ~2 micromhos. This value compared with that reported in earlier studies (Ref. 2.42).
 - A second distillation of the crystallized and oncedistilled H₂O₂ reduced its specific conductance to 1.2 micromhos; this value was still greater than that reported in Ref. 2.43 and 2.44.
 - 4. The specific conductance of both 98 w/o H₂O₂ and deionized water increased on storage in contact with Pyrex glass. A conclusion of these studies indicated that only a rough correlation between low electrical conductivity and high stability was found (or that electrical conductivity per se is not a reliable indicator of stability).
 - The electrical conductivity of both water and hydrogen peroxide is increased by the addition of one to the other.
- 2.2.5.5 <u>Magnetic-Optic Rotation (Verdet Constant)</u>. Although not optically active, $H_2 O_2$, when placed in a magnetic field, will

rotate the place of polarized light. This is expressed as:

α – k_uth

where

a - degree of rotation

L = path length

H = field strength

k, - Verdet constant

The Verdet constant, k_v , as reported in Ref. 2.45 at 10 C (50 F), is shown for various $H_2 O_2 - H_2 O$ solutions in Table 2.16.

2.2.5.6 <u>Magnetic Susceptibility</u>. Hydrogen peroxide is diamagnetic. The magnetic susceptibility of liquid H₂⁰ has been summarized in Ref. 2.10.

> Values of -9.73×10^{-6} cgs-emu/cc at 10 C, -0.50×10^{-6} cgs-emu/g, -17 x 10^{-6} cgs-emu/g mol, and 0.9999908 are reported for the volume susceptibility (K), mass susceptibility (X_g), molar susceptibility (Xm), and permeability (P), respectively. In addition, an equation expressing the mass susceptibility of $H_2 0_2 - H_2 0_3$ solutions at 10 C (50 F) is given as:

$$X_g \times 10^6 = -0.720 + 0.218 w$$

where

 $w = weight fraction H_00_9$

The susceptibility of the solid becomes more positive upon freezing, while the susceptibility of the vapor is assumed to be the same as the liquid.

2.2.5.7 Other Molecular and Electromagnetic Properties. A number of miscellaneous molecular and electromagnetic properties have been summarized for H_2^{0} in Table 2.17. The origin of these data is referenced in the table.

2.2.6 Structure and Spectra

The equilibrium geometry of hydrogen peroxide was established by an electron diffraction study (Ref. 2.48). This was supported by an X-ray study (Ref. 2.14) with limited least-squares data reduction, an infrared study (Ref. 2.49 and 2.50), and a microwave study (Ref. 2.37 and 2.51). The results of these studies are summarized in Table 2.18. The infrared study may be regarded as definitive, although the structure of the solid, as determined by X-ray, may be appreciably different from the gas phase. The X-ray study may be questioned, however, because the data analysis used visual intensity estimation and primitive numerical machines. The rotational constants measured in the infrared are A' = 10.356 cm⁻¹, B' = 0.8656 cm⁻¹, C' = 0.8270 cm⁻¹, $D_{J=4.5 \times 10^{-6} \text{ cm}^{-1}$, $D_{K} = 7.5 \times 10^{-4} \text{ cm}^{-1}$, and $D_{JK} = -2 \times 10^{-5}$ cmⁿ. Dipole moments of 3.15 ±0.05 D and 3.24 ±0.05 D were measured (Ref. 2.51) for each of the two potential minima. A far infrared study (Ref. 2.50) showed the angle 7 has two equilibrium values (with the lowest at 111.5 degrees ±0.5) and determined an accurate hindered-rotation potential function. The best geometric parameters are those underlined in Table 2.18.

Hydrogen peroxide forms tetragonal crystals, space group $D_4^4 - P_{12}^4$, upon freezing (Ref. 2.14). There are four molecules in the unit cell of dimensions a = 4.06Å and c = 8.00Å. The crystal structure has been completely determined, and the volume of the unit cell is 131.9Å³(Ref. 2.14). This gives a crystal density of 1.70 gm/cc.

Hydrogen peroxide is the simplest molecule having an internal rotation motion, and, therefore, has had fairly extensive study with respect to absorption spectra. Hindered internal rotation effects are observed in all regions of the spectrum. Extensive studies have been conducted on the vapor, the crystalline solid, and dilute solutions. Less work has been spent on the concentrated liquid solutions, because of decomposition effects and the difficulty in finding suitable window materials. Since the spectrum as a whole is very complicated, it is considered beyond the scope of this handbook; thus, references to H_2O_2 spectrum characterization are provided as a guide for interested individuals.

The infrared absorption by H_2O_2 is not very useful for chemical analysis because the spectrum is quite similar to that of water and since suitable window materials are not widely available. Ultraviolet absorption by H_2O_2 is quite strong, and (although Beer's law does not hold strictly) if the solution is clear and transparent to ultraviolet, direct spectrophotometry measurements are suitable for analysis of dilute solutions. The ultraviolet spectrum of concentrated hydrogen peroxide has been reported for 50 and 90 w/o solutions in Ref. 2.39, and for 55 and 99 w/o hydrogen peroxide solutions in Ref. 2.24. The infrared absorption spectrum of H_2O_2 has been reported in Ref. 2.50, 2.52, and 2.53. The Raman spectrum of concentrated hydrogen peroxide (99+ percent) is probably covered best in Ref. 2.39.

CHEMICAL PROPERTIES

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Hydrogen peroxide is a strong oxidizing agent in either acid or alkaline solutions; however, with a very strong oxidizing agent such as MnO_L^{-} , it will also behave as a reducing agent.

Hydrogen ion concentration (pH), the presence and nature of catalysts, and temperature are important controlling parameters in hydrogen peroxide reactions. By proper choice of reaction conditions, it is possible to modify the oxidizing action of concentrated hydrogen peroxide solutions. As an oxidizing agent, hydrogen peroxide has the distinct advantage of producing only water as a by-product. Hydrogen peroxide also forms simple addition complexes, forming compounds similar to hydrates. These compounds are normally called hydroperoxidates. These are generally accepted as hydrogen-bonded compounds, which are analogous to anion water compounds. Hydroperoxidates are readily formed with highly electronegative atoms such as nitrogen, oxygen, and fluorine. Amino groups form stronger bonds with peroxide than carboxyl or hydroxyl groups.

Compilations of typical hydrogen peroxide reactions have been reported in Ref. 2.10 and 2.55. These compilations were combined and are presented in Table 2.19 along with references to the original work.

2.4 SOLUBILITY AND MISCIBILITY

Because of hydrogen peroxide's chemical and thermodynamic activity (as noted in Section 2.3), precautions should be observed when considering solutions of $H_2 O_2$ with various organic and inorganic compounds. Although violent reactions upon mixing are the exception, such reactions have been observed. Many $H_2 O_2$ solutions may be fairly stable when undisturbed but are subject to violent detonation under certain conditions. The addition of any material which may be oxidized or reduced should be suspect, particularly as the relative concentrations approach stoichiometric proportions. For these reasons, it is suggested that appropriate references be consulted in detail to define the

chemical nature of the proposed solution as well as the solubility of the solute before solutions of H_2O_2 with other materials are attempted.

The solubility and miscibility of hydrogen peroxide and its aqueous solutions with a number of organic and inorganic compounds are referenced in detail in Ref. 2.10. In general, concentrated H_2O_2 solutions are completely miscible with most organic liquids (including ethanol, isopropanol, acetone, ethyl cellosolve, pyridine, etc.) that are miscible with water in all proportions. In addition, hydrogen peroxide is more miscible than water in a number of organic materials, such as methyl methacrylate, dimethyl and diethyl phthalate, ethyl acetate, and aniline. Compounds with which hydrogen peroxide is nearly immiscible include petroleum ether, toluene, styrene, carbon tetrachloride, chloroform, kerosene, fuel oil, and gasoline.

Hydrogen peroxide and its aqueous solutions also possess, in general, solvent or solute relationships that are similar to water. The results of several experiments show that sodium fluoride, potassium nitrate, various potassium or sodium phasphates, potassium chloride, and sodium or potassium sulfate are more soluble in H_2O_2 than in water. Sodium nitrate, sodium chloride, silver nitrate, lead nitrate, and lithium nitrate and sulfate are less soluble in H_2O_2 than in water. Chlorine and iodine are only slightly soluble in anhydrous H_2O_2 .

In consideration of the materials compatibilities of various lubricants with H_20_2 , the solubilities of several organic compounds in propellant-grade H_20_2 are discussed in Table 4.14a, Section 4.

2.5 GELATION

Results of gel studies on hydrogen peroxide are given in detail in Ref. 2.99 and 2.100.

2.6 HEAT TRANSFER PROPERTIES

Since heat transfer involves a combination of phase, thermodynamic, and transport properties, as well as some consideration of chemical kinetics, this section on heat transfer properties has been included as part of the physico-chemical properties. This section is designed as a reference guide and summary of the various experimental heat transfer studies that have been conducted on propellant-grade hydrogen peroxide solutions.

Experimental heat transfer studies on 90 w/o H_2O_2 solutions (reported in Ref. 2.101) indicated that a high flux heat transfer, usually associated with boiling, was obtained from a 347 stainlesssteel surface to liquid 90 w/o H_2O_2 as a result of the H_2O_2 decomposition mechanism. This decomposition, which simulates boiling by the liberation of gas bubbles at the heat transfer surface, is accelerated with temperature increase of the surface. Figure 2.24 illustrates the magnitude of this effect, as well as the lesser effect of pressure and liquid temperature, in terms of heat flux. Because of these effects, the study showed that the temperature difference between the surface and liquid was not significant.

An extension of these studies to high fluid velocities and moderately high temperature differences was reported in Ref. 2.102. At high flowrates and high Reynolds numbers (where decomposition is limited by the short liquid residence time), the resultant heat transfer data agreed with that expected for

forced convective heat transfer. It was found that heat fluxes as high as 11.75 Btu/sq in.-sec (at liquid velocities of ~ 80 ft/sec) could be obtained with 90 w/o H_2O_2 without complication by decomposition of the hydrogen peroxide. A least-squares fit of the heat transfer data obtained on 90 w/o H_2O_2 resulted in the following expression:

$$(N_{Nu})_{f} = 0.0287 (N_{Re})_{f}^{0.6} (N_{Pr})_{f}^{1/3}$$

The standard deviation of the experimental data from this equation was 10.2 percent.

Heat transfer studies in the forced convective region of both 90 w/o and 98 w/o H_2O_2 were reported in Ref. 2.103. Peak heat flures of 7.80 Btu/sq in.-sec were measured for 90 w/o H_2O_2 at fluid velocities of 41.3 ft/sec. The results obtained for peak heat flux of 98 w/o H_2O_2 at the conditions investigated are shown in Fig. 2.25. The correlation of the data on 98 w/o H_2O_2 with the Dittus-Boelter, Colburn, and Sieder-Tate equations (Fig. 2.26 through 2.28, respectively) indicated better agreement of the data with the Dittus-Bcelter relationship. It has been suggested, however, that some of the apparently low heat transfer coefficients, indicated by the correlations of Fig. 2.26 through 2.28, may be due to slight scaling (oxidation) of heat transfer surfaces.

A current study on the use of 98 w/ hydrogen peroxide for regeneratively cooled rocket engi as has reported (Ref. 2.104) that during 18 experimental tests (with fluid velocities from 25 to 198 ft/sec, pressures from 2000 to 4700 psia, and feed temperatures from 60 to 240 F), heat fluxes up to 48.2 Btu/sq in.-sec were achieved. It was found that the heat flux at burnout (under the conditions tested) was directly proportional

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to the fluid velocity by the relationship: heat $flux_{BO} = 0.21 \text{ x}$ velocity. These results indicated good correlation of heat flux and fluid velocity with the studies of Ref. 2.102 and 2.103. During these tests, no appreciable difference in heat transfer could be associated with feed temperature, and no detectable decomposition was evident. Four similar tests with 90 w/o hydrogen peroxide indicated no discernible differences from the results of the 98 w/o hydrogen peroxide tests. As in the studies of Ref. 2.103, the Dittus-Boelter correlation was found to represent the data more closely than either the Colburn or Sieder-Tate relationships.

The results of all of these studies have shown that hydrogen peroxide has coolant properties comparable to those of water. Of course, the difficulty in its use as a regenerative coolant lies in the limited stability of the H_00_0 at higher temperatures. As a result, various bulk liquid temperature limits have been suggested and established in the use of H_{000} as a regenerative coolant. These limits range from established (Ref. 2.105) maximum allowable temperatures of 225 F (with a 105 F rise over inlet temperature) to suggested operating limits (Ref. 2.106) of 250 F (with red line conditions at 275 F). More detailed analysis of minimum safe design criteria of $H_0 0_0$ regenerativecooling systems, based on the available data from various sources, is presented in terms of ultimate heat flux and fluid velocity in Ref. 2.107. Additional analysis of transient heat transfer for an $H_0 O_0$ regeneratively cooled engine model are given in Ref. 2.108.

2.7 IGNITION CHARACTERISTICS

Although ignition characteristics are system-related parameters, they are also a direct indication of chemical reactivity and/or stability. As such, these characteristics have been included as a part of the Physico-Chemical Properties Section of this

handbook. However, because a detailed characterization of these parameters would involve a discussion of system design variables (such as configuration, intended use environment, operating sequence, etc.) that are beyond the intended scope of this handbook, this review of hydrogen peroxide ignition characteristics is limited to a general and brief summary and reference guide to various ignition studies previously conducted. In addition, this summary is limited further by the security classification of many of these studies as opposed to the unclassified nature of this handbook. For the purpose of clarity, the characterization of hydrogen peroxide ignition is presented in terms of its two primary application areas: monopropellant systems and bipropellant systems.

2.7.1 <u>Monopropellant Systems</u>

Studies of the controlled decomposition process, that characterize hydrogen peroxide's use as a monopropellant, are given in Section 7.2. As a result of these studies, which are detailed and referenced in Section 7.2, the initiation period for hydrogen peroxide decomposition in a monopropellant chamber are fairly well-defined for all propellant-grade concentrations. As expected, all the studies demonstrate the effect of many variables, such as the initiating source and type (catalyst or thermal bed), injection technique, chamber configuration, hydrogen peroxide concentration, hydrogen peroxide inlet temperature, initial chamber temperature, exit pressure, etc., on the start transient. (The start transient is defined in these efforts as the time period from injection of hydrogen peroxide into the decomposition chamber to the achievement of 90-percent of the operating chamber pressure.)

In general, the start transient for a hydrogen peroxide catalytic monopropellant decomposition chamber normally ranges from 50 to 150 ms. This start transient is typical of all of the

catalysts used in the decomposition of hydrogen peroxide concentrations ranging from 76 w/o (Ref. 2.109) to 98 w/o (Ref. 2.18, 2.110 and 2.111).

The greatest effect on this typical start transient is caused by variation in the hydrogen perovide and/or catalyst bed temperature. Laboratory studies (Ref. 2.41) have demonstrated the lack of reaction between solid or super-cooled hydrogen peroxide and a typical catalytic material, while studies with actual engine catalyst beds (Ref. 2.110) have shown limited initiation of decomposition and excessive start transient periods when the temperature approaches the propellant's freezing point. However, the low temperature start characteristics of various catalyst beds have been improved through special design of the catalyst chuber and special treatment of the catalyst bed (Ref. 2.18, 2.110, and 2.111). Conversely, an increase in propellant or catalyst bed temperature (such as experienced in pulsing or other heat feedback operations) has resulted in start transients as low as 10 ms (Ref. 2.18, 2.104, 2.109, 2.110, and 2.111).

Although exit pressure has a slight effect on the start transient, this effect is usually within the ranges noted above and controlled by the temperature effects. Of course the start transients are affected by the catalyst life and generally are the . best indication of the decline in catalytic effectiveness.

The start transients in a hydrogen peroxide thermal decomposition chamber are entirely related to the technique and configuration employed. Since this concept depends on the initial heating of a thermal pack (see Section 7.2.2) prior to injection of the hydrogen peroxide, the start transient of the main hydrogen peroxide stream should approach the hot bed start transients (~ 10 ms) noted above. However, studies with both 90 w/o (Kef. 2.18) and 98 w/o (Ref. 2.113) have indicated that adequate heating of the thermal pack may require periods ranging

500 ms to several minutes depending on the technique employed. Hypergolic slugs of hydrazine containing mixed cyanide sults (Ref. 2.18) have produced initial start transients (i.e., the period measured from injection of the hypergol) of 10 to 20 ms, but this technique required 300 ms hydrogen peroxide leads and 500 ms hypergol injection periods.

2.7.2 <u>Bipropellant Systems</u>

Although some studies have indicated that 90 w/o and 98 w/o hydrogen peroxide solutions are hypergolic (i.e., ignites without producing damaging overpressures to the system) with the hydrazine and 50 w/o N_2H_4 -50 w/o (CH₅) $_2N_2H_2$ fuels (Ref. 2.111), other studies (Ref. 2.18) have indicated that the hypergolicity of 90 w/o hydrogen perioxide with both hydrazine and $(CH_{x})_{O}N_{O}H_{O}$ is questionable. Ignition delays (e.g., the time period from injection of the second propellant into the combustion chamber to 90 percent of the designed chamber pressure) of \sim 5 to 25 ms were reported for $H_0 0_0 / N_0 H_1$ systems in Ref. 2.111; however, large overpressures (e.g., the peak pressure to chamber pressure ratio) and crratic chamber pressure fluctuations were demonstrated in these systems. In the studies reported in Ref. 2.18, which demonstrated ignition delays for this system of 10 to 109 ms (with average delays of 35 to 52 ms recorded for various mixture ratios), it was concluded that hypergolicity was marginal and unreliable.

As a result of these and similar studies of other hydrogen peroxide bipropellant systems, including the $H_2 O_2 / CH_3 N_2 H_3$ (Ref. 2.111) and $H_2 O_2 / B_5 H_9$ (Ref. 2.113) systems, it is concluded that the hypergolicity of hydrogen peroxide with various fuels is, at best, marginal. For this reason many hydrogen peroxide bipropellant systems utilize hydrogen peroxide decomposition gases (resulting from injection of the hydrogen

peroxide in a catalyst chamber upstream of the main combustion chamber) as the ignition source. Through the use of this concept, successful system ignition has been demonstrated with various liquid (including those noted above, as well as with JP-5 in the AR-2 system), solid (Ref. 2.114) and heterogeneous (Ref. 2.104) fuels. Ignition delays between the hot decomposition gases and the fuels are minimal (5 to 10 ms), although the system design controls the overall start transient period (i.c., from injection of the hydrogen peroxide into the catalyst chamber to the achievement of main chamber combu tion). Many system designs employ only a small "pilot light" catalyst chamber with subsequent main stream liquid injection (which bypasses the catalyst chamber), while other systems utilize prior decomposition of all of the hydrogen peroxide throughout the operation of the bipropellant system.

The use of hypergols in the ignition of hydrogen peroxideoxidized bipropellant systems has been studied (Ref. 2.18) with the hydrazine, $(CH_3)_2N_2H_2$ (UDMH), and JP-5 fuels. In these studies, which were designed to demonstrate the feasibility of direct liquid injection of 90-percent hydrogen peroxide into bipropellant chambers, relatively smooth and rapid ignivion was achieved with all three fuels using nitrogen tetroxide as the hypergol for the first two tuels and aluminum triethyl with the latter fuel. In addition, the use of mixed cyanide salts as an ignition aid to the H_2O_2/N_2H_4 system is noted in Ref. 2.18.

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TABLE 2.1

PHYSICAL PROPERTIES OF HYDROGEN PEROXIDE AT \$

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	L u	ni te	100 Per	oent Heug	98 Pers	ant Rgog	95 Per	ant Hg0g	1
Property	Notric	miglieb	Hetric	English	Natrie	Muglish	Netrie	Inglish	t
General Identification						· · · · · · · · · · · · · · · · · · ·	······		1-
Identification			Hydrogen	Feroaide	Hydrogen	Perezide	Hydrogen	Peranide	
Nolocular Formula			tio tio	U _u	(H,0) 0.9684	(H_0) 0.0372	(H_0_) 0.9090	(H.O) 0.0904	
Heleeula: Weight	g-mole	1b-mula	34.016	34.016	33.484	33.494	39.971	38.971	
Freening Point	c	F	-0.3	31.1	-0,1	28.2	-5.1	29.8	
Triple Foint	C	P.	-0.62	31.84				1	1
Normal Boiling Point	C	Y	150.0	302.0	148.7	899.0	140.0	894.3	
Gritical Properties					l				
Temperature	C	r	460	860	450.5	854	434	840	
Pressure	atm	paia	947	3030	840	3015	244.5	גערל	
Depaity	E oc								
Phase Properties									
Density									
Bolid	L oc	1b/cu ft	1.71 at -R0 C	105.76					
Liquid	A oc	1b/cu ft	1.444	90	1.434	MG A	1.415		1,
						0,10			ľ
Gas	£, or	1b/cu ft	, Ber Beat	105 2.2.2.1	Ner M	etion M.C.M.L	See Beatie	1 2 2 2 1	
Thormal Kapanayon Commence the State Control] c ^{−1}	7 -1	7.502 = 10	4.105 x 10 **	7.508 × 10-4	4.105 x 10-4	7.908 # 10-4	4.168 # 10-4	i
Adiabatio	11	-1	a		-3		1		k
Instherm	• • •	pain -1	8.431 x 10 -	1.640 x 10	2.445 ± 10-7	1.605 + 10	2.496 ± 10"	1.699 a 10-9	1
Nevue Breekun		10 IO	Reolis IO - At MU C	3.840 x 10 at of F					
APPAS STADARYA		Lerv	¥.048	0.075	2.30	0.045	2.13	0.033	
Surface Tension	dyn#/am	16/ft	80.15 at 80 C	5-490 at 48 F	79.95 at go c	5.477 at 68 2	79.64 at 20 C	5.450 AL 68 F	1
									1

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TABLE 2.1

	Un	its	100 Percent B202		98 Percent H202		95 Percent H202	
Property	Hetric	English	Ketric	English	Hetric	English	Netric	English
Thermodynamic Properties								
Heats of								
Formation	cal/g	Btu/1b	-1320	-2376	-1369	-2464	-1447	-2601
Tusion	cal/g	Btu/1b	86	155	87	157	85	153
Vaporisation	cal/g	Dtu/1b	364	654.5	368	661.5	376	677
Bublimtion	cal/r	Btu/1b	457.8	824				
Miving	cal/g (solution)	Btu/1b (colution)	0	0	1.0	1.8	2.4	4.2
Decomposition	cal/g (bolucio_/	8tu/1b					See Fi	g. 2.16 and
Heat Capacity	~/ B					1	1	
Solid	cal/g_C	Btu/1b-F	0.461 at melting point	0.461 at melting point	C.461 at melting point	0.401 at melting point	0.414 at melting point	0.414 at melting pol
Liquid	cal/g-C	Btu/1b-F	0.625	0.626	0.633	0.633	0.645	0.645
Gas								
C_	cal/g-C	Btu/1b-F	0.303	0.303	0.306	0.300	0.310	0.310
C_	cal/g-C	Btu/1b-F						
Entropy	ca1/g-0	Btu/16-F		,	•	,) 5 e	Bection 2.5
Enthalpy	cal/g	Btu/1b		1	1	4	Be	Bection 2.
Transport Properties								
Viscosity				-3				N
Liquid	Contipoises	lb/ft-sec	1.153	0.770 x 10 '	1.158	0.772 x 10	1.160	0.775 x 10
Gas	Centipoises	1b/ft-eec	1.91 x 10 ⁻²	1.283×10^{-5}				
Thermal Conductivity								, ,
Liquid	cal/cm-sec-C	Btu/ft-hr-F	l		1.40×10^{-7}	0.34		
Gas	cal/cm-eec-C	Btu/ft-hr-F						1
Coefficient of Diffusion	cm ² /sec	in. ² /sec						
Sonic Velocity								
Liquid	w/se c	ft/eec	1781.0	5843	1774.6	5821	1767.0	5794
Gas	m/sec	ft/sec						

TABLE	2.	1
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(Continued)

⁰ 2	95 Percent Hg02		02 90 Percent H202		75 Percent NgOg		70 Ferceat H ₂ 0g		Timur oui	
ri ek	Netric	English	Netric	English	Metric	English	Netric	English	Table Number	Number
		e (a)								
	-1997	-4001	-1571	-2828	-1946	-3503	-3070	-3720	T2.3-2.14, F2.12-2.13a	2.25, 2.54
	63	153	62	148	77	138	72	129	12.3-2.8	2.2
	376	677	389	700	427	768	438	789	T2.3-2.14 F2.14, F2.14a	2.26
	<u>.</u>							·		2.10
'	2.4 Rec Fi	••* • • • • • • • • • • •	4.3	7.6	8.15	14.65	9.0	16.05	F2.15, F2.15a	2.26
	699 F3	1. 1. 2. 10 mma 4.1	1			,			F2.16, F2.16a	2.25
l at ang point	0.414 at melting point	0.414 at melting point	0.417 at melting point	0.417 at melting point	0.577 at melting point	0.377 at melting point	0.415 at molting point	0.415 at melting point	T2.3-2.8 F2.17, F2.17a	2.5
ſ	0.04)	0.045	0.663	0.663	0.720	0.720	0.738	0.736	T2.3-2.8 F2.17, F2.17a	2.18, 2.25, 2.26
	0.310	0.310	0.317	0.317	0.338	0.338	0.346	0.346	12.9-12.14	2.27
	5.] • Section 2.2.3.	ļ .6	!]	ļ	1	T2.3 -T2.14	2.54
	. Be	e Section 2.2.3.	.8						T2.5 -T2.14	2.54
_										
2 x 10 ⁻³	1.160	0.775×10^{-3}	1.150	0.777 x 10 ⁻⁵	1.136	0.769×10^{-3}	1.123	0.758 x 10 ⁻⁵	F2.18, F2.18a F2.19, F2.19a	2.5, 8.22, 2.24
									F2.20	2.30
					•				F2.21	2.31
				1		1				
	1767.0	5794	1752.5	5745	1706.9	5598	1690.3	5543	F2.22, F2.22a	2.16

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TABLE 2.1(Cor.cluded)

	Uni	te	100 Perce	at Mg ⁰ g	96 Per	cont $N_2^{0}_2$	95 Percent Ng0g	
Treperty	Netzie	Maglish	Netrio	English	Notrie	English	Netric	Englis
Electromgnetic Properties						1		1
Index of Refraction	(Sedium	D-Line)						
\$ +lid						1		
Liquid			1.4067		1.4049		1,4083	
Gas								
Dipole Homeni	Debye	Unite	8.13			1		
Dielectric Comstant			70.5		71.6		75.0	
Liquid								
Gas					I	1		ł
Electrical Conductivity	miere-(ohan ⁻¹					Be	re Soction (
Veršej Complexi								See Table ;
Magnetic Dusceptibility			-0.50 x 10-6 at	1 - Contraction of the contracti	1	1	1	1
1	a Ba _ ann A B		10 C (50 F)					
ABLE 2.1

oncluded)

95 Perc	ent N ₂ 0 ₂	90 Perc	eat H202	75 Perc	ent H202	70 Perce	ent N ₂ 0		
Netzi	English	Netric	English	Netric	English	Netric	English	Table Number	Reference Number
1.6025		1.5860		1.5854		1.3814		¥2.15	2.15
73.0		75.0		78.5		79.5		F2. 8 3	2.34 2.39
¥.	 = Section 2.2.5 	1	1		1			T2.1¢	2.41, 2.42, 2.4) 2.44 2.45
									2.10

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CALCULATED SATURATION PRESSURE, ACTIVITY COFFICIENTS, AND VAPOR COMPOSITIONS FOR HYDROGEN PEROXIDE-WATER SOLUTIONS AT HIGH TEMPERATURES AND PRESSURES

		Þ	ž -	1. Les	Activity	Activity			Hole Praction	Mole Praction	Partial	Ĩ
		Ĩ	a e		Confrictent, 12,02	Coefficient, E20	. 202	• ^H	202 is Vaper	R20 IB Vaper		20, Mie
R	Ř	R-	<u>ر</u> ،		0.5 0 35 -	0.5782	0.996	1.00.1	0.6706	1201.0	2.1	្រំព
							0.9502	1.0125	0.2290	0.1112	8 9 8 8	111
						>	0.69%	0.642	0.000	1610.0	22.2	5.5.2
13					0.470	0.6526	1606.0	1.011	0.4592	0.52.06	5.82	21.2
							0.9785	1.0316	0.1670	0.7766	20.8	4. 12 6. 12
							0.6975	158.0	0.0700	0.0%)		27.2 29.8
						-	0.2075	0.6641	0.0451	0.0774	1-4	36.0 61.2
					0.8402	0.7790	0.9%	1.0726	0.207	102.0	13.1	9.94 9.94
							0.9452	1.00%	c.1190 0.0503	1664.0	15.8	49.6 54.2
				>			0.6946 0.4646 0.2075	0.6417 0.6638 0.4122	0.9360 9.0273 0.0309	0.1157 0.0744 0.0604	18.5 27.5 60.00	5. 6. 6. 7. 1. 9 1. 9. 1. 9. 1. 9 9 1. 9 1. 9 9 1. 9 9 1. 9 1. 9 1. 9 9 1. 9 1. 9 9 1. 9 1
	Ř-	8-		ă	0.947	0.5922	5.9.9	1.0624	0.6928 0.1297	0.7072	5.5 5	21.4 21.8
				<u> </u>			0.8724 0.7712 0.5512 0.2955	0.9735 0.9055 0.7470 0.5064	0.1207 0.1207 0.0942 0.0990	0.0712 7.0409 0.0701 0.0224	*3 • •	22225 23252
					1056-0	0.6674	0.9715	1.0570	0.4672 6.5519	0.5128	1.01	8.14 5.3
							0.8713	0,00		0.1110		45.5 48.8 1
+	+	-		+	+	•	0.2955	0.5064	0.0659	0.0474	a A	87.1

"Baturated wher pressure at the temperature and liquid composition indicated. "Black's importection term (<u>AICAE Journal</u>, <u>5</u>, 249, 1999) TABLE 2.2 (Concluded)

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	System	Practica # 0 to		4		ž e	Activity	Activity			Truction	Traction	Prtial	i i
Concentration, v/e		Lightle	c I		2,2, 1, ,	2 . eie	K202	R 2 ⁰	E 2 ⁰ 2	3°	2-2 Ve~er	2 Veper		
65.4	109.3*	0.5000	200 39	2	8.9 2	¥.	0.8482	9497.0	5.20	2.5	0.2760	0.766	17. 17.	5
	211.7							·	1000		1160.0	2005		
	1014.7		=	<u></u>						0.9035	0.0651	0.16.)	5.5 8 1	
-	2.4102	*	-			 *	•	•	0.2954	. 5062	0.0100	0.0035	€. €	<u>1</u>
8	*	0.174	84 862	11 17	<u>~</u>	2.	0.9 0 67	0.6170		1.1038	101	1.98.0	2	
	211.7									2010	0.3145	0.1118	23	р
	1014.7								0.727.0	12.8	0.1949	0.0645 0.0126	55	
61.5		0.7000					0.9562	0.6423	60. G	1.0355	0.5405	0.455	1.021	1.8
	314.7								0.9516		146.0	0.5399	R.	Ň
-	514.7								1.1	1.01	1923.0	0.2141	53	21
	1014.7						-	-	201 - O		0.1278		2 2	ើរ
64.1	ĩ	0.1000					0.2621		1. X. X	920	9.241A		n R	1.96
	311.7	-							6.9	0666	0.2346	5000	8	1
	211.7								1.52.0	1.0157	0.167	9.4165	8	112
-	2011.7	->									161.0	0.1985	<u> </u>	
8	461.04	0.174	22	<u>د</u> ۲	21			0.672	1066.0	1.1515	2.9.	0.2727	ĸ	107
	514.2								8.4.0		5.69.0	0.2112	5	88
-	2011.7	•						+	0.6295	Ĩ	0.2.6	0.170	1% 2	
81.5	1.81	0.3000					0.961	0.690	o. 97ar	1.1406	. Y	0.1102	£	1.10
_	1014.7								5	1.0337	1:2.0	0.22%	Ø.	×
	2.4102	•					•	•	0.0200	- 60/03 ·	1013-0	0.1398	¢.	E.
69.4	1.	0.9000					0.671	0.803	0.90	1.1138	1625.0	0.670	197.2	61.6
-	1014.7	>					,			1060.1	0.2140			
-				_			-							
1					1									

"Saturated vapor pressure at the temperature and liquid composition indicated. **Black's imperfection term (<u>AICME Journal</u>, <u>5</u>, 249, 1959) SOLID- AND LIQUID-PHASE THERMODYNAMIC FROMERTIES OF 100 v/o ${\rm H_20_2^*}$

		:	1	Eath	alpy			
Tempel	mture	Heat Capacity, cal/g-K	Entropy, cal/g-K	(B, -	H ₂₉₈)	Heat of	Formation	
K	ж	(Btu/Ib-R)	(Btu/Ib-R)	cal/g	Btu/lb	cal/g	Btu/lb	Phase
•	0	0	C	-160.2	-288.4	-1359	-2446	Solid
8	8	0.000	0.00	-160.2	-288.4	-1368	-2462	
•0	R	0.05	0,02	-159.7	-287.5	-1374	-2473	
60	106	0.100	0.050	-158.2	-284.8	-1383	-2489	
80	144	0.144	0.085	-155.7	-280.3	-1389	-2500	
100	180	0.181	0, 121	-152.5	-274.5	-1395	-2511	
120	216	0.210	0.157	-148.6	-267.5	-1798	-2516	
140	252	0.236	0. 192	-144.1	-239.4	1041-	-2522	
160	228	0.259	0.225	-139.5	-251.1	-1404	-2527	
180	32 4	0.281	0.257	-134.7	-242.5	-1407	-2533	
200	360	0.302	0.:287	-128.9	-232.0	6041-	-2536	
220	396	0.325	0.311	-122.6	-220.7	1141-	-2540	
240	4 32	0.319	0.346	-115.9	-208.6	-1412	-2542	
260	468	0. 382	0.376	-108.6	-195.5	-1413	-2543	
272.7	490.8	0.461	0.794	-103.2	-185.8	-1412	-25.2	+

#Refer to Section 2.2.3

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TABLE 2.3 (Concluded)

				Entha	lpy			
Temer	ature	Heat Capacity, cal/g-K	Entropy, cal/e-K	(R _T - H	298 ⁾	Heat of]	Formation	
K	R	(Btu/lb-R)	(Btu/ib-R)	cal/g	Btu/lb	cal/g	Btu/Ib	Phase
272.7	490.8	0.520	0.716	-17.4	-31.3	-1326	-2387	Liquid
280	504	0.626	0.734	-11.4	-20.5	-1324	-2383	
298.1	5.36.7	0.626	0.774	0.0	0.0	-1320	-2376	
300	540	0.626	0.777	1.11	2.0	-1319	-2374	
310	558	0.626	0.798	7.40	13.32	-1317	-2371	
320	576	0.626	0.819	13.68	24.62	-1314	-2365	
330	594	0.627	0.838	19.96	35.93	-1312	-2362	
340	612	0.627	0.857	26.23	47.21	-1310	-2358	
350	630	0.627	0.876	32.51	58.52	-1308	-2354	
360	648	0.627	168.0	38.73	69.71	-1306	-2351	
370	666	0.628	0.911	45.07	81.13	-1304	-2347	
380	684	0.628	0.928	51.34	92.41	-1301	-2342	
390	202	0.628	0.945	57.68	103.72	-1299	-2338	
400	720	0.628	0.961	63.94	115.02	-1298	-2336	-

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SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES

OF 98 w/o H,02 SOLUTIONS*

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				Enth	alpy			
Tempel	rature	Heat Capacity,	Catropy,	(B _T -	R ₂₉₆)	Heat of	Formation	
¥	æ	(Btu/lb-R)	(Btu/lb-R)	cal/g	Btu/Ib	cal/g	Btu/lb	Phase
0	0	0	0	-160.44	-288.79	-1402	-2524	Solid
ଷ	×	0.00	0.017	-160.40	-288.72	-1406	-2534	
10	8	0.05	0.031	-159.92	-287.86	-1425	-2565	
69	108	0.100	0.072	-158.82	-295.87	-1430	-2574	
80	144	0.144	0.108	-156.38	-281.45	-1430	-2590	
100	180	0.181	0.138	-153.14	-275.65	-1445	-2601	
120	216	0.210	0.168	-143.72	-258, 70	-1443	-2597	
140	252	0.236	0.197	-144.74	-260.53	-1452	-2614	
160	288	0.260	0.225	-179.78	-251.60	-1454	-2617	
180	324	0.282	0.253	-134.63	-242.33	-1456	-2621	
200	360	0.303	0.281	-128.50	-231.30	-1458	2624	
220	365	0.326	0.310	-122.20	-219.96	-1460	-2628	
240	4.32	0.351	0.338	-115.42	-207.76	-1461	-2630	
260	468	0. 384	0.366	-108.08	-194.54	-1463	-2633	
271.1	4 88	0.461	0.957	-107.51	-186.32	-1462	-2632	-

#Refer to Section 2.2.3

TABLE 2.4 (Concluded)

			i					
Tempet	rature	Heat Capacity,	Entropy,	$(H_T - I)$	¹ pir 1298	Heat of Fo	rum tion	
X	æ	(Btu, ib-R)	(Btu Ib-R)	cal g	Btu Ib	cal /g	Btu lb	Phase
271.1	4,8%	0.633	0.682	-17.14	-30.85	-1375	-2475	Liguid
280	50 4	0.633	0.690	-11.49	-20.68	-1374	-2473	
062	522	0.633	0,720	-5.16	9.20	-1771-	-2468	
298.1	5.36.7	0.633	0.7.9	0.0	0.0	-1369	-2464	
300	540	0.633	0.743	1.17	2.11	-1369	-2464	
310	558	0.633	0.764	7.50	13.50	-1367	-2461	
320	576	0.633	0.78h	13.83	24.89	-1365	-2457	
330	594	0.633	0.803	20.16	36.29	-1362	-2452	
340	612	0.634	0.820	26.49	47.68	-1360	-2448	
350	630	0.634	0.836	32.83	60.65	-1378	2444	
360	648	0.635	0.854	79.17	16.07	-1357	-2443	
370	666	0.635	0.872	45.51	81.52	-1354	-2437	
380	684	0.635	0.889	51.86	93.35	-1352	-2434	
065	702	0.636	0.907	5 8.22	104.80	-1350	-2430	
900¥	220	0.636	0.925	64.58	116.24	-1 <u>5</u> 47	-2425	

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BOLTD- AND LITUID-PHASE THERMODYNAMIC PROPERTIES

OF 95 w/o H202 SOLUTIONS*

Tempe	rature	Heat Capacity, cal/K	Entropy, cal/=_K	Entin (H _T -)	1 pv 1298)	Heat of	Formation	
24	æ	(Btu/lb-R)	(Btu/lt-R)	cal/g	Btu/lb	cal/g	Btu/lb	Phase
0	0	0	0	-160.19	-288.34	-1483	-2669	Solid
ଷ	R	n.001	0.017	-160.15	-288.27	-1492	-2665	£
4	R	0.051	0.037	-159.65	-287.37	-1500	-2700	
60	108	0.101	0.072	-158.13	-284.63	-1508	-2714	
60	144	0.145	0.108	-155.67	-280.21	-1513	-2723	
100	180	0.182	0.138	-132.35	-27A.23	-1519	-2734	
120	216	0.211	0.16g	-148.49	-267.28	-1523	-2741	
140	252	0.238	0.197	-143.99	-259.18	-1526	-2747	
160	288	0.261	0.225	-139.01	-250.22	-1529	-2752	
180	324	0.284	0.253	-133.555	-240.39	-1531	-2756	
200	360	0.305	0.281	-127.67	-229.81	-1533	-2759	
ହୁଁ	396	0.329	9.310	-121.33	-218.39	-1535	-2763	
240	432	0.354	0.338	-114.49	-206.08	-1536	-2765	
260	468	9.387	0.366	-107.02	-192.64	-1536	-2765	
268.1	482.6	0.414	0.368	-103.85	-186.93	-1537	-2767	-
#Refe	r to Bei	ction 2.2.3						

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	¢ • .		(Cond	c luded)				
Tempe	rature	Heat Capacity,	Entropy,	Entha (H _T - H	11py [298)	. Heat of]	Formation	
К	R	(3tu/lb-R)	(Btu/lb-R)	cal/g	Btu/lb	cal/g	Btu/lb	Phase
268.1	482.6	0.645	0.683	-19.38		-1452	-2614	Liquid
280	504	9.645	0.702	-11.71	-21.08	-1450	-2610	
290	522	0.645	0.723	-5.30	-9.54	-1448	-2606	
293.1	536.7	0.645	0.742	-0.0	0.0	-1445	-2601	
300	540	0.645	0.746	1.19	2.14	-1445	-2601	
310	558	0.645	0.767	7.63	13.73	-1443	-2597	- <u>_</u>
320	576	0.645	0.787	14.07	25.33	-1441	-2594	
330	594	0.645	0.809	20.51	36.92	-1439	-2590	
340	612	0.645	0.826	26.95	48.51	-1436	-2585	
350	630	0.645	0.845	33.40	60.12	-1434	-2581	
360	648	0.645	0.863	39.85	71.73	-1432	-2578	
370	666	0.646	0.880	46.30	83.34	-1430	-2574	
380	684	0.646	0.897	52.76	94.97	-1427	-2569	
390	702	0.647	0.914	59.22	106.60	-1425	-2565	
400	720	0.648	0.930	65.69	118.24	-1423	-2561	->

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SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES

OF 90 w/o H202 SOLUTIONS*

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Temperatu	Ire	Heat Capacity,	Entropy, cal/c_K	Enth (E _T -	ы ру Н ₂₉₈)	Form	t of ation	
K	Я	(Btu/1b-R)	(Btu/lb-R)	cal/g	Btu/lb	cal/g	Btu/1b	Phase
0	0	0	0	-160.62	-289.12	-1606	-2891	Solid
8	36	0.003	0.004	-160.58	-289.04	-1615	-2907	
40	72	0.053	0.023	-160.08	-288.14	-1624	-2923	
60 10	38	0.103	0.054	-158.52	-285.34	-1631	-2936	
80 14	54	0.147	0.090	-156.02	-280.84	-1638	-2948	
100 15	80	0.184	0.127	-152.72	-274.90	-1644	-2959	
120 21	16	0.213	0.163	-148.74	-267.73	-1647	-2965	
140 25	52	0.240	. 0.193	-144.20	-259.56	-1651	-2972	
160 25	38	0.264	0.223	-139.16	-250.49	-1654	-2977	
180 32	24	0.287	0.252	-133.66	-240.59	-1656	-2981	
200 36	3	0.309	0.281	-127.70	-229.86	-1658	-2984	
220 35	8	0.333	0.309	-121.28	-218.30	-1660	-2988	
240 43	32	0.358	0.338	-114.38	-205.88	-1662	-2992	
260 46	89	0.392	0.366	-106. °2	-192.46	-1663	-2993	
263.3 47	73.9	0.417	0.368	-105.59	-190.06	-1662	-2992	٨

*Refer to Section 2.2.3

TABLE 2.6 (Concluded)

	Phase	Liquid														>
t of lation	Btu/1b	-2844	-2835	-2831	-2828	-2828	-2822	-2819	-2815	-2810	-2806	-2803	-2799	-2794	-2790	-2786
Hea Form	cal/g	-1580	-1575	-1573	-1571	-1571	-1568	-1566	-1564	-1561	-1559	-1557	-1555	-1552	-1550	-1548
alpy H ₂₉₈)	Btu/1b	41.59	-21.65	-9.72	0	2.20	14.15	26.06	38.00	49.93	61.88	73.84	85.79	92.76	109.73	121.72
Enth. (H _T -	cal/g	-23.11	-12.03	-5.40	0.0	1.22	7.86	14.48	21.11	27.74	34.38	41.02	47.66	54.31	60.96	67.62
Entropy, cal/r-K	(Btu/lb-R)	0.680	0.714	0.735	0.755	0.759	0.781	0.802	0.822	0.842	0.861	0.880	0.898	0.916	0.933	0.950
Heat Capacity, cal/ <u>r-K</u>	(Btu/lb-R)	0.664	0.664	0.663	0.663	0.663	0.663	0.563	0.663	0.664	0.664	0.664	0.664	0.663	0.666	0.667
ature	R	473.9	504	522	536.7	540	558	576	594	612	630	648	666	684	702	720
Temper	K	263.3	280	290	238.1	300	310	320	330	340	350	360	370	380	390	400

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SOLID- AND LIQUID-PHASE THERMODYNAMIC PROPERTIES

of 75 w/o B202 SOLUTIONS *

	Phase	Solid													
t of tion	B ⁺ a/1b	-3555	-3577	-3593	-3607	-3618	-3631	-3638	-3645	-3650	-3654	-3659	-3663	-3667	-3668
Hea. Forme	cal/g	-1975	-1987	-1996	-2004	-2010	-2017	-2021	-2025	-2028	-2030	-2033	-2035	-2037	-2038
hal py H ₂₉₈)	Btu/1b	-296.89	-296.84	-295.68	-292.73	-288.13	-282.01	-2-4.70	-266.38	-257.09	-246.87	-235.82	-273.83	-210.94	-210.20
Eat (H _T -	cel/g	-164.94	-164.91	-164.27	-162.63	-160.07	-156.67	-152.61	-147.99	-142.83	-137.15	-131.01	-124.35	-117.19	-116.78
Entropy, cal/r_K	(Btu/lb-R)	0	0.010	0.032	0.065	0.192	0.140	0.171	0.202	0.232	0.262	0.292	0.321	0.350	0.355
Heat Capacity, cal/a-K	(Btu/lb-R)	0	0.007	0.057	0.107	0.152	0.188	0.218	0.245	0.271	0.296	0.319	0.345	0.372	0.377
ature	R	Q	36	72	108	144	180	216	252	268	324	360	396	432	444
Temper	K	0	80	9 4	8	8	100	120	140	160	180	200	550	240	241.1

#Refer to Section 2.2.3

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TADR.E 2.7 (Conclud 3)

remperature K Rtu Ib-ri R (Rtu Ib-ri) (Rtu Ib-ri) (Rtu Ib-ri) (Rtu Ib-ri) (Rtu Ib-ri) (Rtu Ib-ri) Env/Ib Env/Ib Phase 241.1 444 0.736 0.662 -41.54 -74.77 -1956 -5790 Liquid 260 468 0.7736 0.717 -27.65 -49.73 -1956 -5790 Liquid 290 522 0.720 0.717 -15.07 -23.553 -19946 -5790 Liquid 290 536.7 0.720 0.717 -15.07 -23.553 -1946 -5700 -5706 290.1 536.7 0.720 0.816 0.0<0 -1946 -5705 -5901 710 558 0.720 0.8044 8.52 15.34 -1946 -7497 710 558 0.720 0.8044 8.52 15.34 -1946 -7497 750 576 0.720 0.8066 15.71 $28.28.28$ -1946 -7483	E		lleat Capacity.	Entropy.	Ent (H _T -	halpy Il ₂₉₈)	Heat Formu	t of ation	
241.1 444 0.736 0.662 -i1.54 -74.77 -1951 -5320 Liquid 260 468 0.776 0.717 -27.65 -49.75 -1956 -5510 Liquid 280 504 0.776 0.771 -17.07 -23.55 -1956 -5510 -5510 290 524 0.720 0.794 -6.71 -11.5 -1946 -5505 -5506 298.1 576.7 0.720 0.816 0.0 0 -1946 -5505 -5505 310 556 0.720 0.816 0.0 0 -1945 -5905 -5407 310 576 0.720 0.816 0.0 0 0 -1945 -5905 320 576 0.720 0.866 15.71 28.28 -1946 -5405 320 612 0.720 0.910 79.26 -5485 -5465 560 648 0.720 0.910 79.25	K	R	cel_g-K (Btu lb-R)	cal/g-K (Btu 1b-R)	cal/g	Bta/1b	cel/g	Btu/lb	Pase
260 468 0.776 0.717 -27.63 -49.73 -1976 -5721 280 504 0.726 0.771 -15.07 -23.53 -1976 -5710 290.1 576.7 0.720 0.704 -6.71 -11.3 -1948 -5905 290.1 576.7 0.720 0.816 0.0 0 -1946 -5705 200 540 0.720 0.820 1.37 2.79 -1946 -5903 510 576 0.720 0.820 1.73 2.79 -1946 -7901 570 594 0.720 0.820 1.73 2.79 -1946 -797 570 594 0.720 0.844 8.52 15.74 -1943 -7497 570 594 0.720 0.889 22.90 41.22 -1943 -7497 570 650 0.720 0.910 70.09 54.16 -1973 -7483 570 650 0.720 0.910 70.09 54.16 -1972 -7483 570 666 0.720 0.910 77.28 67.10 -1972 -7483 570 666 0.720 0.910 77.28 67.10 -1972 -7465 570 666 0.720 0.972 51.691 106.04 -1927 -7465 570 702 0.720 0.972 51.09 -1922 -7466 570 722 0.922 70.99	241.1	444	0.736	0.662	46.14-	-74.77	-1961	-3530	Liquid
280 504 0.726 0.771 -15.07 -23.55 -1950 -5510 290 522 0.720 0.794 -6.71 -11.3 -1948 -5505 298.1 576.7 0.720 0.816 0.0 0 -1946 -5505 300 540 0.720 0.816 0.0 0 -1945 -5701 310 558 0.720 0.820 1.53 2.39 -1945 -5701 370 576 0.720 0.866 15.71 28.28 -1940 -5497 370 594 0.720 0.866 15.71 28.28 -1940 -5497 370 594 0.720 0.866 15.71 28.28 -1949 -5495 370 648 0.720 0.910 70.09 54.16 -1935 -3495 370 648 0.720 0.910 70.09 54.16 -1935 -3469 370 648 <td< th=""><th>260</th><td>468</td><td>0.736</td><td>0.717</td><td>-27.63</td><td>-49.73</td><td>-1956</td><td>-3521</td><td></td></td<>	260	468	0.736	0.717	-27.63	-49.73	-1956	-3521	
290 522 0.720 0.720 0.720 0.720 0.720 0.720 0.816 -10.4 -1946 -5505 790 540 0.720 0.816 0.0 0 -1946 -5505 710 558 0.720 0.814 8.52 15.34 -1945 -5501 710 558 0.720 0.844 8.52 15.34 -1945 -5407 730 594 0.720 0.889 22.90 41.22 -1943 -7497 730 594 0.720 0.889 22.90 41.22 -1935 -7483 740 612 0.720 0.910 70.09 54.16 -1935 -7483 750 648 0.720 0.910 70.09 54.16 -1935 -7478 750 648 0.721 0.910 79.09 54.16 -1937 -7478 750 648 0.722 0.912 97.04 -1927 -74.69	280	504	0.726	177.0	-15.07	-23.53	-1950	-3510	
298.1 575.7 0.720 0.816 0.0 0 -1946 -5505 700 540 0.720 0.820 1.33 2.39 -1945 -5501 710 558 0.720 0.820 1.33 2.39 -1945 -5407 720 576 0.720 0.866 15.71 28.28 -1940 -3497 730 594 0.720 0.889 22.90 41.22 -1976 -7485 740 612 0.720 0.910 7009 54.16 -1976 -7485 740 612 0.720 0.910 70.09 54.16 -1976 -7485 750 648 0.720 0.910 70.28 67.10 -1975 -7485 750 648 0.721 0.972 77.28 67.10 -1972 -7485 750 648 0.722 0.972 44.48 80.06 -1972 -7469 770 666 0.722 0.972 51.69 97.04 -1972 -7465 790	290	522	0.720	0.794	-6.31	-11.3	-1948	-3506	
300 540 0.720 0.820 1.33 2.39 -1945 -3501 310 556 0.720 0.844 8.52 15.34 -1943 -3497 320 576 0.720 0.866 15.71 28.28 -1940 -3497 370 594 0.720 0.866 15.71 28.28 -1940 -3492 370 594 0.720 0.889 22.90 41.22 -1936 -3483 340 612 0.720 0.910 30.09 54.16 -1935 -3483 350 630 0.721 0.910 30.09 54.16 -1935 -3478 360 648 0.721 0.910 37.28 67.10 -1932 -3478 370 6648 0.721 0.992 54.16 -1932 -3469 370 6648 0.722 0.992 54.04 -1927 -3469 370 702 0.722 0.992	298.1	536.7	0.720	0.816	0.0	0	-1946	-3503	
J10 558 0.720 0.844 8.52 15.34 -1943 -3497 720 576 0.720 0.866 15.71 28.28 -1940 -3492 730 594 0.720 0.889 22.90 41.22 -1936 -3483 740 612 0.720 0.910 70.09 54.16 -1978 -3483 750 650 0.720 0.910 70.09 54.16 -1973 -3483 750 650 0.720 0.971 77.28 67.10 -1972 -3478 750 648 0.721 0.972 51.69 97.04 -1972 -3478 750 648 0.722 0.972 51.69 97.04 -1972 -3465 760 684 0.722 0.992 51.69 97.04 -1927 -3465 790 702 0.722 0.992 58.91 106.04 -1927 -3465 700 702	300	540	0.720	0.820	1.33	2.39	-1945	-3501	
720 576 0.720 0.866 15.71 28.28 -1940 -7492 730 594 0.720 0.889 22.90 41.22 -1936 -3488 740 612 0.720 0.910 70.09 54.16 -1935 -3483 750 650 0.720 0.910 70.09 54.16 -1935 -3483 750 650 0.720 0.931 77.28 67.10 -1932 -3478 750 648 0.721 0.952 44.48 80.06 -1930 -7478 770 666 0.721 0.972 51.69 97.04 -1927 -3469 770 6684 0.722 0.972 51.69 97.04 -1927 -3469 770 702 0.722 0.992 58.91 106.04 -1927 -3465 700 720 0.720 1.011 66.16 1'9.092 -3465 700 720 0.725 1.011 66.16 1'9.09 -1922 -3465 700 <td< th=""><th>310</th><td>558</td><td>0.720</td><td>0.844</td><td>8.52</td><td>15.34</td><td>-1943</td><td>-3497</td><td></td></td<>	310	558	0.720	0.844	8.52	15.34	-1943	-3497	
730 594 0.720 0.889 22.90 41.22 -1978 -3488 740 612 0.720 0.910 70.09 54.16 -1975 -3483 750 630 0.720 0.910 70.09 54.16 -1975 -3483 750 648 0.721 0.952 44.48 80.06 -1972 -3478 770 666 0.721 0.972 51.69 97.04 -1972 -3478 770 666 0.721 0.972 51.69 97.04 -1927 -3469 770 666 0.722 0.972 51.69 97.04 -1927 -3465 790 702 0.722 0.972 51.69 97.04 -1927 -3465 700 702 0.722 0.992 58.01 106.04 -1922 -3465 700 77.43 179.09 -1922 -3465 -3465 -3465 700 720 0.725 1.011 66.16 119.0.99 -1922 -3466 700 <	320	576	0.720	0.866	15.71	28.28	-1940	-3492	
740 612 0.720 0.910 70.09 54.16 -1975 -7483 750 630 0.720 0.931 77.28 67.10 -1972 -7483 760 648 0.721 0.952 44.48 80.06 -1972 -3478 770 666 0.721 0.972 51.69 97.04 -1927 -3476 780 684 0.721 0.972 51.69 97.04 -1927 -3469 780 684 0.722 0.992 58.91 106.04 -1927 -3469 790 702 0.723 1.011 66.16 1'9.09 -1925 -3469 700 720 0.723 1.011 66.16 1'9.09 -1922 -3469 700 720 0.726 1.011 66.16 1'9.09 -1922 -3469 700 720 0.726 1.011 66.16 1'9.09 -1922 -3469 700 720 0.726 1.011 66.16 1'9.09 -1922 -3460 <th>330</th> <td>594</td> <td>0.720</td> <td>0.389</td> <td>22.90</td> <td>41.22</td> <td>-1938</td> <td>-3488</td> <td></td>	330	5 94	0.720	0.389	22.90	41.22	-1938	-3488	
750 67.10 -1972 -7478 -7469 -7478 -7469 -7478 -7469 -7478 -7469 -	340	612	0.720	0.910	30.09	54.16	-1935	-3483	
360 648 0.721 0.952 44.48 80.06 -1970 -3474 370 666 0.721 0.972 51.69 93.04 -1927 -3469 380 684 0.722 0.992 58.91 106.04 -1925 -3465 390 702 0.723 0.992 58.91 106.04 -1925 -3465 400 702 0.723 1.011 66.16 119.039 -1922 -3465 400 720 0.725 1.011 66.16 119.039 -1922 -3465	350	630	0.720	0.931	37.28	67.10	-1932	-3478	
770 666 0.721 0.972 51.69 93.04 -1927 -3469 780 684 0.722 0.992 58.91 106.04 -1925 -3465 790 702 0.723 0.992 58.91 106.04 -1925 -3465 790 702 0.723 1.011 66.16 119.09 -1922 -3465 400 720 0.726 1.011 65.16 119.09 -1922 -3460	360	648	0.721	0.952	44.48	80.06	-1930	-3474	
780 684 0.722 0.992 58.91 106.04 -1925 -7465 790 702 0.723 1.011 66.16 119.09 -1922 -7465 400 720 0.726 1.030 73.43 132.17 -1919 -5454	370	666	0.721	0.972	51.69	93.04	-1927	-3469	
390 702 0.723 1.011 66.16 119.09 -1922 -3460 400 720 0.726 1.030 73.43 132.17 -1919 -3454	380	684	0.722	0.992	58.91	106.04	-1925	-3465	
400 720 0.726 1.030 73.43 132.17 -1919 -3454	390	702	0.723	1.011	66.16	119.09	-1922	-3460	
	00	720	0.726	1.030	73.43	132.17	-1919	-3454	>

SOLID- AND LIQUID-PRASE THERMODYNAMIC PROPERTIES OF 70 ×/0 H20, SOLUTIONS*

Temperature Heat Capacity, Entropy, Cal/g-X $(H_T - H_2)g_B$ Formation 0 0 0 0 0 -7796 Solid 20 76 0 0 -174.66 -314.39 -2109 -5796 Solid 20 76 0.009 0.013 -174.58 -314.29 -2119 -3614 40 72 0.009 0.013 -174.58 -314.29 -3194 5014 40 72 0.059 0.015 -173.94 -313.09 -3675 5014 40 72 0.059 0.076 -173.94 -313.09 -3675 5014 80 114 0.157 0.107 -169.60 2019 -3677 -3677 120 216 0.5991 0.145 -166.10 -291.76 -3677 120 216 0.209 0.145 -162.10 -291.76 -3677 120 286 0.2040 0.145 -162.10 -291.76					Enth	alpy	dea	of	
KR(Btu/1b-R) $ca1/g$ Btu/1bPhate0000 -174.66 -314.39 -2109 -3796 Solid20360.0090.013 -174.66 -314.39 -2109 -3796 Solid20360.0090.013 -174.66 -314.39 -2109 -3796 Solid40720.0090.0056 -173.94 -313.09 -2129 -3879 Solid601060.1090.070 -172.22 -310.00 -2129 -5845 Solid601080.107 -169.60 -305.28 -2143 -3877 -3877 1001800.1890.107 -166.18 -299.12 -2150 -5877 11001800.2200.145 -166.18 -299.12 -2157 -3897 11002520.2460.277 -167.10 -2157 -3897 11002520.273 0.267 -157.42 -287.56 -3169 1202560.299 0.267 -157.42 -287.56 -3169 180324 0.299 0.297 -152.22 -2164 -3895 180324 0.329 0.345 -140.27 -2166 -3899 200360 0.396 0.345 -140.26 -295.47 -2166 -3899 201326 -140.26 -3897 -140.26 -3895 -31992 201396 0	Temer	uture.	Heat Capacity,	Entropy,	(B, -	^H 298)	Forme	tion	
0 0 0 0 0 0 0 0 0 55 14.35 514.39 5103 5796 5614 40 72 0.009 0.013 -174.58 -314.24 -2119 -5814 5 40 72 0.009 0.013 -173.94 -315.09 -2129 -5845 5 60 106 0.107 -173.22 -310.00 -2136 -3845 5 - 80 1144 0.157 0.070 -172.22 -310.00 -2136 -3845 - - - -3845 5 - - - - - - - - - -3845 -5845 -	М	В	(Btu/1b-R)	(Btu/1b-R)	cal/g	Btu/lb	cal/2	Btu/1b	Phase
20 36 0.009 0.013 -174.58 -314.24 -2119 -3814 40 72 0.059 0.035 -173.94 -313.09 -2129 -3832 60 106 0.107 -169.60 -305.28 -2143 -3857 80 114 0.157 0.107 -169.60 -305.28 -2143 -3857 80 114 0.157 0.107 -169.60 -305.28 -2150 -3877 100 180 0.189 0.176 -166.18 -299.12 -2154 -3877 1120 216 0.220 0.176 -165.10 -291.76 -3777 -3877 1140 252 0.248 0.277 -152.22 -374.06 -367 -3877 1160 286 0.299 0.277 -152.22 -274.06 -367 -3877 1160 296 0.294 0.277 -152.22 -274.06 -3697 180 324 0.	0	•	0	0	-174.66	-314.39	-2109	-3796	Solid
40 72 0.059 0.056 -173.94 -313.09 -2129 -3872 60 106 0.107 0.070 -172.22 -310.00 -2156 -3857 80 114 0.157 0.107 -169.60 -305.28 -2150 -3857 100 180 0.189 0.107 -166.18 -299.12 -2154 -3877 1100 180 252 0.248 0.176 -166.18 -299.12 -2154 -3877 1100 180 252 0.248 0.207 -157.42 -283.36 -2157 -3893 1160 252 0.249 0.207 -157.42 -283.36 -2157 -3893 1180 324 0.299 0.207 -157.42 -283.36 -2161 -3893 1200 286 0.273 0.207 -146.50 -265.770 -2164 -3893 200 324 0.277 -146.50 -265.477 -2893 -3893 200 356 0.349 0.2902 0.2903 -146.50 <td< th=""><th>20</th><th>8</th><th>0.09</th><th>0.013</th><th>-174.58</th><th>-314.24</th><th>-2119</th><th>-3814</th><th></th></td<>	20	8	0.09	0.013	-174.58	-314.24	-2119	-3814	
60 106 0.109 0.070 -172.22 -510.00 -2136 -5845 80 1144 0.153 0.107 -169.60 -305.28 -2143 -3857 100 180 0.189 0.145 -166.18 -299.12 -2150 -3877 120 216 0.220 0.145 -166.18 -299.12 -2157 -3877 120 216 0.220 0.176 -162.10 -291.72 -3877 180 252 0.248 0.207 -157.42 -283.36 -3877 160 286 0.248 0.207 -152.22 -274.06 -3161 -5893 160 324 0.277 -152.22 -274.06 -2164 -5895 180 324 0.297 -140.26 -252.47 -5895 -5895 200 360 0.325 0.297 -140.26 -256.47 -5895 200 396 0.3140.26 -3140.27 -2166	04	72	0.059	0.036	-173.94	-313.09	-2129	-3832	
80 1¼ 0.153 0.107 -169.60 -305.28 -2143 -3857 100 180 0.189 0.145 -166.18 -299.12 -2150 -3870 120 216 0.220 0.176 -166.18 -299.12 -2154 -3877 120 216 0.220 0.176 -162.10 -291.72 -3877 -3877 140 252 0.248 0.207 -157.42 -283.36 -2157 -3893 160 286 0.273 0.207 -157.42 -283.36 -2161 -3893 160 286 0.273 0.207 -157.42 -283.36 -2161 -3893 180 324 0.297 -166.50 -265.70 -2164 -5893 200 360 0.323 0.297 -146.50 -2657.47 -2164 -5895 200 396 0.349 0.326 -146.50 -2164 -3895 201 419.6 <t< th=""><th>60</th><th>106</th><th>0.109</th><th>0.070</th><th>-172.22</th><th>-310.00</th><th>-2136</th><th>-3845</th><th></th></t<>	60	106	0.109	0.070	-172.22	-310.00	-2136	-3845	
100 180 0.189 0.145 -166.18 -299.12 -2150 -3870 120 216 0.220 0.176 -162.10 -291.72 -2154 -3877 140 252 0.248 0.176 -162.10 -291.72 -2154 -3877 160 286 0.273 0.207 -157.42 -283.36 -2161 -5893 160 286 0.273 0.207 -152.22 -274.00 -2161 -5890 180 324 0.299 0.267 -146.50 -263.70 -2164 -3893 200 360 0.323 0.297 -140.26 -252.47 -3895 200 366 0.323 0.297 -140.26 -252.47 -3895 210.3 419.6 0.349 0.326 -133.54 -2164 -3895 233.1 419.6 0.415 0.345 -128.55 -2164 -3895	80	14	0.153	0.107	-169.60	-305.28	-2143	-3857	
120 216 0.220 0.176 -162.10 -291.76 -3877 140 252 0.248 0.207 -157.42 -283.36 -2157 -3883 160 286 0.273 0.207 -152.22 -274.00 -2161 -5890 160 286 0.299 0.267 -152.22 -274.00 -2161 -5890 180 324 0.299 0.267 -146.50 -265.70 -2164 -5895 200 360 0.323 0.297 -140.26 -252.47 -2164 -3899 200 396 0.323 0.297 -140.26 -252.47 -2166 -3899 220 396 0.349 0.326 -140.25 -291.39 -2166 -3999 235.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	100	180	0.189	0.145	-166.18	-299.12	-2150	-3870	
140 252 0.248 0.207 -157.42 -283.36 -2157 -3883 160 288 0.273 0.237 -152.22 -274.00 -2161 -5890 180 324 0.299 0.267 -146.50 -265.70 -2164 -5895 200 360 0.323 0.297 -146.50 -265.70 -2164 -3895 200 396 0.323 0.297 -140.26 -252.47 -2166 -3899 200 396 0.349 0.326 -140.26 -252.47 -2166 -3899 210.1 419.6 0.415 0.345 -128.55 -211.39 -2164 -3895	120	216	0.220	0.176	-162.10	-291.78	-2154	-3877	
160 288 0.273 0.237 -152.22 -274.06 -2161 -5890 180 324 0.299 0.267 -146.50 -265.70 -2164 -5895 200 360 0.323 0.297 -146.50 -265.70 -2164 -5895 200 360 0.323 0.297 -140.26 -252.47 -2166 -3899 220 396 0.349 0.326 -133.54 -240.37 -2168 -3902 237.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	140	252	0.248	0.207	-157.42	-283.36	-2157	-3883	
180 324 0.299 0.267 -146.50 -265.70 -2164 -5895 200 360 0.323 0.297 -140.26 -252.47 -2166 -3899 200 396 0.349 0.297 -140.25 -252.47 -2166 -3899 220 396 0.349 0.326 -133.54 -240.37 -2168 -3902 233.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	160	286	0.273	0.237	-152.22	-274.00	-2161	-3890	
200 360 0.323 0.297 -140.26 -252.47 -2166 -3899 220 396 0.349 0.326 -133.54 -240.37 -2168 -3902 233.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	180	324	0.299	0.267	-146.50	-263.70	-2164	-3895	
220 396 0.349 0.326 -133.54 -240.37 -2168 -3902 233.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	200	360	0.323	0.297	-140.26	-252.47	-2166	-3899	
233.1 419.6 0.415 0.345 -128.55 -231.39 -2164 -3895	220	396	0.349	0.326	-133.54	-240.37	-2168	-3902	
	233.1	419.6	0.415	0.345	-128.55	-231.39	-2164	-3895	-

*Refer to Section 2.2.3

TABLE 2.8	Concluded)
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Liquid Plane Btu/1b -3766 -3710 -3695 -3692 -3685 -3676 -3681 -3746 -3726 -3715 -3706 -3757 -3735 -731 -3724 -3721 -3701 Formation . Heat of cal/g -2092 -2045 -2042 -2056 -2047 -2075 -2070 -2069 -2059 -2053 -2087 -2067 -2064 -2081 -2073 -2051 -2061 -24.10 42.30 55.62 82.15 95.45 -77.85 135.58 2.45 15.73 29.02 -100.46 -50.81 68.87 108.77 122.13 -10.80 Btu/1b 0 (R₁ - R₂₉₈) Enthalpy cal/g -28.23 -6.8 30.90 67.85 75.32 -13.39 23.50 60.43 1.36 8.74 38.26 45.64 53.05 -55.81 -43.25 16.12 0.0 Entropy, cal/gm-K (Btu/1b-R) 0.649 0.670 1.010 1.048 0....0 0.785 0.810 0.836 0.860 0.928 0.949 0.970 1.030 0.906 0.831 0.983 0.991 Heut Capacity, cal/gm-K (Btu/lb-R) 0.740 0.738 0.738 0.742 0.746 0.749 0.746 0.738 0.738 0.738 0.739 0.739 0.745 0.739 0.739 0.758 0.757 5.96.2 419.6 540 558 576 648 666 468 504 522 294 612 630 664 702 720 **4**32 Temerature ei, 233.1 298. 240 280 290 30 310 320 330 340 350 360 370 380 390 **4**0 260 2

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VAPOR-PHASE THERMODYNAMIC PROPERTIES OF

100 w/o H202*

Tempe	erature	Heat Capacity, cal/gm-K	Entropy, cal/gm-K	Enth (H _T -	alpy H ₂₉₈)	Heat Forme	of tion
K	R	(Btu/lb-R)	(Btu/lb-R)	cal/gm	Btu/lb	cal/gm	Btu/1b
0	0	0	0	-76.26	-137.27	-912.08	-1641.74
100	180	0.235	1.310	-52.86	-95.15	-931.45	-1676.61
200	360	0.259	1.479	-25.78	-46.40	-942.56	-1696.61
298	536.4	0.303	1.636	0.0	0	-956.38	-1721.48
300	540	0.304	1.638	0.56	1.01	-956.86	-1722.35
400	720	0.340	1.743	32.81	59.06	-965.61	-1738.10
500	900	0.369	1.810	68.35	123.03	-972.11	-1749.80
600	1080	0.391	1.879	106.46	191.63	-976.81	1758.26
700	1260	0.407	1.941	146.41	263.54	-980.34	-1764.61
800	1440	0.420	1,996	187.83	338.09	-983.13	-1769.63
900	1620	0.432	2.046	230.47	414.85	-985.37	-1773.67
1000	1800	0.441	2.092	270.15	486.27	-987.13	-1776.83
1100	1980	0.451	2.135	318.78	573.80	-988.48	-1779.26
1200	2160	0.459	2.175	364.27	655.69	-989.54	-1781.17
1300	2340	0.466	2.211	410.42	738.76	-990.31	-1782.56
1400	2520	0.474	2.246	457.55	823.59	-990.87	-1783.57
1500	2700	0.480	2.279	505.18	9 09 .3 2	-991.31	-1784.36

#Refer to Section 2.2.3

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VAPOR-PHASE THEEMODYNAMIC PROPERTIES OF

98 w/o H_2^0 50LUTIONS *

				Enth	alpy	·····	
Tempe	rature	Heat Capacity	Entropy cal/s-K	(H _T -	^{II} 298)	Beat of	Formation
K	R	(Btu/lb-R)	(Btu/lb-R)	cal/gm	Biu/1b	cal/gm	Btu/1b
0	0	0	0	-77.36	-139.25	-95 7.2	-1723.0
100	180	0.239	1.32	-53.55	-96.39	-976.6	-1757.9
200	360	0.262	1.49	-26.13	-47.03	-987.6	-1777.7
29 8	536.4	0.3 00	1.65	0.0	0	-1001.4	-1802.5
300	540	0.307	1.65	0.56	1.01	-1001.9	-1803.4
460	720	0.342	1.74	33.07	59.53	-1010.7	-1819.3
500	900	0.3 70	1.83	68.82	123.88	-1017.3	-1831.1
600	1080	0.393	1.90	107.11	192.80	-1022.2	-1840.0
700	1260	0.409	1.96	147.25	265.05	-1025.9	
800	1440	0.422	2.01	188.84	339.91	-1028.8	-1851.8
900	1620	0.434	2.06	231.67	417.01	-1031.2	-1856.2
1000	1800	0.443	2.11	271.64	488,95	-1033.2	-1859.8
1100	1980	0.453	2.15	320.41	576.74	-1034.6	-1862.3
1200	2160	0.461	2.19	366.13	659.03	-1035.8	-1864.4
1300	2340	0.469	2.23	412.53	742.55	-1036.7	-1866.1
1400	2520	0.477	2.25	449.55	809.19	-1037.4	-1867.3

*Refer to Section 2.2.3

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		Host Cannoity	Butropy	Enth (u	alpy N)		
Tempe	rature	cal/g-K	cel/g-K	<u>'''</u>	¹¹ 298 ⁷	Heat of 1	Formation
x	R	(Btu/1b-R)	(Btu/lb-R)	cal/gm	Btu/1b	cal/gm	Btu/1b
0	0	0	0	-79.0	-142.2	-1024.9	-1854.8
100	180	0.245	1.345	-95.1	-99.2	-1044.2	-1879.6
20 0	3 60	0.268	1.52	-26.7	-48.1	-1055.2	-1899.4
29 8	536.4	0.310	1.68	0.0	0	-1068.9	-1924.0
300	540	0.311	1.68	0.6	1.1	-1069.4	-1924.9
400	720	0.346	1.75	3 3.5	60.3	-1078.4	-1941.1
500	900	0.374	1.80	69.5	125.1	-1085.2	-1953.4
600	1080	0.395	1.86	108.1	194.6	-1090.3	-1962.5
700	1250	0.411	1.92	148.5	267.3	-1^94.2	-1969.6
800	1440	0.425	2.05	190.4	342.7	-1097.4	-1975.3
90 0	1620	0.437	2.09	233.5	420.3	-1100.0	-19 80.0
1000	1900	0.446	2.14	273.9	493.0	-1102.2	-19 8 4.0
1100	1980	0.457	2.18	322.8	5 81.0	-1103.9	-1987.0
1200	2160	0.465	2.22	36 8.9	664.0	-1105.2	-1989.4
1300	2340	0.472	2.26	415.6	748.1	-1106.3	-1991.3
1400	2520	0.481	2.32	463.5	834.3	-1107.0	-1992.6

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF 95 w/o H_2^{0} SOLUTIONS*

*Refer to Section 2.2.3

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF

90 w/o H202 BOLUTIONS*

Тетре	rature	Heat Capacity, cal/gm-K	Entropy, cal/sm-K	Ent (H _T -	halpy H ₂₉₈)	Hoat Form	t of stigg
K	R	(Btu/1b-R)	(Btu/16-R)	cal/gm	Btu/1b	cal/gm	Btu/1b
0	O	O	0.0	-81.76	-147.17	-1137.8	-2048.0
100	180	0.256	1.38	-56.34	-101.41	-1157.0	-2082.6
200	360	0.277	1.56	-27.55	- 49.59	-1167.9	-2102.2
29 8	536.4	0.317	1.72	0.0	0	-1181.5	-2126.7
300	540	0.318	1.72	0.58	1.04	-1182.0	-2127.6
400	720	0 .3 51	1.81	34.11	61.40	-1191.2	-2144.2
500	900	0.379	1.90	70.69	127.24	-1198.3	-2156.9
600	1080	0.400	1.96	109.73	197.51	-1203.8	-2166.8
700	1260	0.416	2.03	151.53	272.75	-1208.1	-2174.6
800	1440	0.429	2.09	192.91	347.24	-1211.7	-2181.1
900	1620	0.442	2.15	236.50	425.70	-1214.7	-2186.5
1000	1800	0.452	2.19	277.59	499.66	-1217.2	-2191.0
1100	1980	0.462	2.23	3 26.92	588.46	-1219.2	-2194.6
1200	2160	0.471	2.27	3 73.57	672.43	-1220.9	-2197.6
1300 .	2340	0.479	2.31	420.97	757.75	-1222.2	-2200.0
1400	2520 `	0.488	2.39	469.42	844.96	-1223.3	-2201.9

WRefer to Section 2.2.3

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF

75 w/o H202 BOLUTIONS*

Tempe	rature	Heat Capacity,	Entropy,	Ent (H _T -	halpy H ₂₉₈)	Hoat Formu	of tion
K	R	(Btu/lb-R)	(Btu/1b-R)	cul/gm	Btu/1b	cal/gm	Btu/lb
. 0	0	0	0	-90.02	-162.04	-1476.4	2657.5
100	180	0.287	0.98	61.57	-110.83	-1495.5	-2691.9
200	360	0.305	1.64	-30.21	-54.38	-1505.8	-2710.4
298	536.4	0.338	1.80	0.0	0	-1519.2	-2734.6
300	540	0.339	1.80	0.62	1.12	-1519.6	-2735.3
400	720	0.368	1.90	36.06	64.91	-1529.5	-2753.1
500	900	0.393	1.99	74.21	133.58	-1537.7	-2767.9
600	1080	0.413	2.06	114.64	206.35	-1544.2	-2779.6
700	1260	0.429	2.13	156.83	282.29	-1549.8	-2789.6
800	1440	0.443	2.19	200., 52	360.94	-1554.6	-2798.3
900	1620	0.456	2.24	245.55	441.99	-1558.8	-2805.8
1000	1800	0.467	2.29	288.76	519.77	-1562.4	-2812.3
1100	1980	0.479	2.33	339.13	610.43	-1505.4	-2817.7
1200	2160	0.489	2.37	387.53	697.55	-1568.0	-2822.4
1300	2340	0.498	2.41	436.81	786.26	-1570.2	-2826.4
1400	2520	0.508	2.58	487.24	877.03	-1572.0	-2829.6
1500	2700						

"Refer to Section 2.2.3

VAPOR-PHASE THERMODYNAMIC PROPERTIES OF 70 w/o $H_2^{0}_2$ SOLUTIONS*

Tempo	erature	Heat Capacity, cal/gm-K	Entropy, cal/gm-K	Ent (H _T -	halpy H ₂₉₈)	Heat Forma	of tion
K	R	(Btu/Ib-R)	(Btu/1b-R)	cal/gm	Btu/1b	cal/gm	Btu/1b
0	0	0	0	-92.8	-167.0	-1589.2	-2860.6
100	180	0.297	1.52	-63.3	-113.9	-1608.3	-2894.9
200	360	0.314	1.75	-31.1	56.0	-1618.5	-2913.3
298	536.4	0.346	1.89	0.0	0	-1631-8	-2937.2
300	540	0.346	1.90	0.63	1.13	-1632.2	-2938.0
400	720	0.374	1.99	36.7	66.1	-1642.3	-2956.1
500	900	0.398	2.09	75.4	135.7	1650.8	-2971.4
600	1080	0.418	2,16	116.2	209.2	-1657.8	-2984.0
700	1260	0.434	2.23	158.9	286.0	-1663.8	-2994.8
800	1440	0.448	2.28	203.1	365.6	-1668.9	-3004.0
900	1620	0,461	2.34	248.6	447.5	-1673.4	-3012.1
1000	1800	0.473	2.39	292.5	526.5	-1677.4	-3019.3
1100	1980	0.485	2.40	343.2	617.8	-1680.8	-3025.4
1200	2160	0.495	2.50	392.2	706.0	-1683.7	-3030.7
1300	2340	0.505	2.52	442.1	795.8	-1686.1	-3035.0
1400	2520	0.515	2.71	493.2	887.6	-1688.2	- 3 038.8

*Refer to Section 2.2.3

10.00

H_02, w/o	0.3, percent	0.2, percent	0.4, percent	0.6, percent	0.8, percent
66	1.3782	1.3784	1.3785	1.3787	1.3788
67	790	752	793	796	796
68	798	800	801	803	804
69	806	808	809	811	812
70	1.3814	1.3816	1.3817	1.3819	1.3820
71	822	824	825	827	828
72	830	832	833	835	836
73	83 8	840	841	843	844
74	846	848	849	851	852
75	854	856	857	859	860
76	862	864	865	867	868
77	870	872	873	875	876
78	878	880	881	883	884
79	886	888	889	891	892
80	1.3894	1.3896	1.3897	1.3899	1.3901
81	9 03	904	906	908	909
82	911	913	915	916	918
83	920	921	923	925	927
84	9 28	930	932	933	935
85	937	939	940	942	944
86	945	947	949	950	952 .
87	954	956	957	959	961
88	962	964	966	968	9 69
89	971	973	974	976	978

REFRACTIVE INDEX (SODIUM D-LINE) OF PROPELLANT-GRADE H202-H20 SOLUTIONS AT 25 C*

*Refer to Section 2.2.5.1

NOTE: Temperature correction is $-0.34 \times 10^{-5}/C$ from 15 to 25 C.

TABLE 2.15(Concluded)

H ₂ 0 ₂ , w/o	0.3, percent	0.2, percent	0.4, percent	0.6, percent	0.8, percent
90	1.3880	1.3981	1.3983	1.3985	1.3986
91	988	99 0	992	993	995
92	997	9 99	1.4000	1.4002	1.4004
93	1.4006	1.4097	009	011	313
94	014	016	018	020	021
95	023	025	027	028	030
96	032	034	035	037	039
97	041	042	044	046	048
98	049	051	053	055	056
99	058	060	062	063	065
100	1.4067				

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VERDET CONSTANT OF HYDROGEN PEROXIDE-WATER SOLUTIONS AT 10 C*

H_0	-k _v , min/gauss-cm x 10 ³			
v/o	5893 Å	5780 Å	5461 Å	4358 Å
100	11.48	11.90	13.52	22.65
9 6	11.60	12.03	13.64	22.70
78.5	11.98	12.45	14.07	23.45
62.0	12.30	12.80	14.43	24.11
50.9	12.53	12.98	14.60	24.22
38.1	12.69	13.15	14.86	24.47
18.1	12.91	13.38	15.13	25.00
0	13.09	13.64	15.40	25.21
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*Refer to Section 2.2.5.5

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MISCELLANEOUS MOLECULAR AND ELECTROMAGNETIC PROPERTIES OF HYDROGEN PEROXIDE

Property	Value	T en perature	Reference
Specific Refraction	0.1705 cm ³ /gm	25 C	2.15
Molar Refraction	5.801 cm ³ /mole	25 C	2.15
Polarizability	2.30 x 10 ⁻²⁴ cm ³ /mele	25 C	2.15
Molar Dispersion	1.3576 cm ³ /mole		2.45
Dispersion Constant	8.479 x 10^{30} sec ⁻²		2.45
Characteristic Frequency	$2.979 \times 10^{15} \text{ sec}^{-1}$		2.45
Molecular Radius	1.32 Å		2.45
Molecular Susceptibility	-21.0 ±4	25 C	2.46
Molecular Diamagnetism	16.73 ±0.20	25 C	2.47

STRUCTURE AND STRUCTURAL PARAMETERS OF HYDROGEN PEROXIDE

Structure



Structural Parameters

	$\mathbf{R}(0,0),\mathbf{\dot{A}}$	<u>R(0-H), Å</u>	0(00H), degrees	τ (H00H), <u>degrees</u>
Electron Diffraction	1.47			
Crystal Piffraction	1.49		97	94
Far Infrared	1.475 ±0.004	0.950 ±0.005	<u>94.8 ±2</u>	(119.8 ±3)
Nicrovave				111.5

REACTIONS OF HYDROGEN PERMIDE

Reference

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INORGANIC COMPOUNDS

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Ag +
$$H_2 0_2$$
 \longrightarrow dissolves (Ag⁺) 2.56

$$A1 + H_2 0_2 \longrightarrow A1(0H)_3$$
 2.10

$$A = + H_2 0_2 - H_3 A = 0_4$$
 2.10

$$A = 0_3^{-3} + H_2^{0}_2 \longrightarrow A = 0_4^{-3}$$
 2.57

$$A_{s(0^{\mu})_{3}} + H_{2}^{0}_{2} \longrightarrow H_{3}^{A_{s0}}_{4}$$
 2.10

Au +
$$H_2 0_2$$
 HCl dissolves 2.58

$$0xid$$
, $f gold + H_2 0_2$ alkaline reduction 2.58

B (colloidal) +
$$H_2^{0_2} \longrightarrow H_3^{B0_3}$$
 2.59

$$Ba(OH)_2 + H_2 O_2 \longrightarrow BaO_2 + H_2 O_2$$
 2.10

$$Bi_2^0_3 + H_2^0_2 \longrightarrow Bi_2^0_4$$
 2.60

$$Bi(NO_{3})_{3} + H_{2}O_{2} \xrightarrow{alkaline} Bi(OH)_{3}$$
 2.61

$$Br0_{3}^{-1} + H_{2}0_{2} \longrightarrow Br^{-1} + Br_{2}$$
 2.10

$$CN^{-1} + H_2 0_2 - CO_3^{-2} + CN 0^{-1}$$
 2.62

$$CNS^{-1} + H_2 O_2 \longrightarrow NH_3 \longrightarrow NO_5^{-1}$$
 2.63

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TABLE 2.19 (Continued)

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Roference

INORGANIC COMPOUNDS (cont.)

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$$C1_{2} + H_{2}0_{2} \longrightarrow C1^{-1}$$
 2.64

$$Clo_3^{-1} + H_2O_2 \xrightarrow{\text{alkaline or}} \text{no reaction}$$
 2.65

$$C10_{5}^{-1} + H_{2}0_{2} \xrightarrow{acid} C1_{2} + C10_{2}$$
 2.65

$$HC10_4 + H_20_2$$
 — no reaction 2.10

$$HOC1 + H_2^{0} - C1^{-1}$$
 2.64

$$C_0 + H_2 0_2 \xrightarrow{alkaline} C_0(H0)_3$$
 2.10

$$Cr + K_2 0_2 \longrightarrow slow solution$$
 2.10

$$Cr0_3 + H_20_2 - Cr^{+3}$$
 2.67

$$Cu + H_2 O_2 \xrightarrow{\text{acid}} \text{dissolves}$$
 2.68

$$Cu0 + H_2 0_2 - Cu0_2 + H_2 0$$
 2.69

$$Cu_{2} + H_{2}_{2} - Cu_{0} + H_{2}_{0} + 0_{2}$$
 2.69

$$Fe + H_2 0_2 \longrightarrow Fe^{+2} \longrightarrow Fe^{+3}$$
 2.10

$$F_{e}(CN)_{6}^{-1_{4}} + H_{2}O_{2} \xrightarrow{\text{acid}} F_{e}(CN)_{6}^{-3}$$
 2.70

TABLE 2.19 (Continued)

Reference

INORGANIC COMPOUNDS (cont.)

.

$$Fe(CN)_{6}^{-3} + H_{2}0_{2} \xrightarrow{alkaline} Fe(CN)_{6}^{-4}$$
 2.70

$$Hg + H_2 0_2 \longrightarrow dissolves$$
 (2.10)

Hg +
$$H_2 0_2$$
 Alkaline oxides of mercury 2.10

$$I_2 + H_2 0_2 \longrightarrow I^{-1} \longrightarrow I 0_3^{-1}$$
 2.71

$$HI + H_2 0_2 \longrightarrow I_2 + H_2 0$$
 2.10

$$Li^{+1} + H_2 0_2 \longrightarrow Li_2 0_2$$
 2.10

$$Mg + H_2 U_2 \longrightarrow Mg(0H)_2$$
 2.10

$$Mn0_4^{-1} + H_2^{0} - \frac{acid}{2} - Mn^{+2} + H_2^{0} + 0_2$$
 2.10

$$Mn0_4^{-1} + H_20_2 \xrightarrow{alkaline} Mn0_2 \qquad 2.10$$

$$MoS_2 + H_2 O_2 - SO_4^{-2}$$
 2.10

Ni +
$$H_2 O_2 = \frac{HC1 \text{ or}}{H_2 SO_4}$$
 dissolves 2.10

NiSO₄ +
$$H_2O_2 \xrightarrow{H^+}$$
 no reaction 2.72

$$N_2H_4 + H_2O_2$$
 \rightarrow various products depending upon conditions 2.73

$$HONH_2 + H_2 O_2 \longrightarrow NO_3^{-1}$$
 2.74

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TABLE 2.19 (Continued)

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INOBEGANIC COMPOUNDS (cont.)

$$NO_2^{-1} + H_2O_2 - \cdots + NO_5^{-1}$$
 $NO_3^{-1} + H_2O_2 - \cdots + NO_5^{-1}$
 $O_3 + H_2O_2 - \cdots + H_2O + O_2$
 $P + H_2O_2 - \cdots + PH_3 + H_3PO_4$
 $P_2O_5 + H_2O_2 + H_2O - \cdots + H_3PO_5$
 $PO_4^{-3} + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5^{-3} + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5^{-3} + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5^{-3} + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5 + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5 - 1 + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5 - 1 + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5 - 1 + H_2O_2 - \cdots + PO_4^{-3}$
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 $PO_5 - 1 + H_2O_2 - \cdots + PO_4^{-3}$
 $PO_5 - 1 + H_2O_2 - \cdots + PO_4^{-3}$

TABLE 2.19 (Continued

Reference

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INORGANIC COMPREMOS (cont.)	
$s_{0_{3}}^{-2} + H_{2}^{0} + S_{2}^{0} +$	2.85
$Sb + H_2^0_2$ — no reaction	2.10
$Sb_2S_3 + H_2O_2$ antimoniate	2 .86
Se02	2.87
Se + $H_2 O_2$ $H_2 SeO_4$	2.10
$H_2Se + H_2O_2$	2.10
$\operatorname{Se0}_{3}^{-2} + \operatorname{H}_{2}^{0}_{2} \xrightarrow{-2} \operatorname{Se0}_{4}^{-2}$	2.88
$\operatorname{Sn}^{+2} + \operatorname{H}_2 \operatorname{O}_2 \longrightarrow \operatorname{Sn}^{+4}$	2.89
$SnO_2 + H_2O_2$	2.10
$Te + H_2 O_2 \longrightarrow H_6 TeO_6$	2.90
$Ti^{+3} + H_20_2 - Ti0_3$	2.91
$Ti0_2^{+2} + H_2 0_2 - Ti(0_2)_4^{-4}$	2 .92
$T1 + H_2 O_2 \longrightarrow T10H$	2.10
$T10_2 + H_20_2 \longrightarrow T1_20_3$	2.10
$W + H_2 O_2 - H_2 WO_4$	2.10

TABLE 2.19 (Continued)

Reference

INGRGANIC COMPOUNDS (cont.)

$$\mathbf{Ln} + \mathbf{H}_2 \mathbf{0}_2 \quad \mathbf{Ln0} \quad 2.10 \\
 \mathbf{Ln} + \mathbf{H}_2 \mathbf{0}_2 \quad \mathbf{alkalinc} \\
 \mathbf{alcoholic} \quad \mathbf{2.93} \\
 \mathbf{Lr} + \mathbf{H}_2 \mathbf{0}_2 \quad \mathbf{no} \text{ reaction} \quad 2.94$$

$$\operatorname{Er}(\operatorname{SO}_4)_2 + \operatorname{H}_2 O_2$$
 \longrightarrow no reaction 2.94

ORGANIC COMPOUNDS

Alkanes:

Saturated paraffins +
$$H_{20}^{0}$$
 with and without no reaction 2.55

Grignard reagent (ENgX) + $H_2 0_2$ ------alcohol 2.95

Alkones:

$$\mathbf{BCH} = \mathbf{CHR}' + \mathbf{H}_{2}\mathbf{0}_{2} \xrightarrow{\mathbf{BCOOOH}} \mathbf{BCH} - \mathbf{CHR}' \xrightarrow{\mathbf{CHR}'} \mathbf{BHC} - \mathbf{CHR}' \qquad 2.10,$$

$$\mathbf{OH} \quad \mathbf{OH} \quad \mathbf{OH} \qquad 2.55$$

$$\mathbf{epoxy} \qquad \mathbf{glycol}$$

(Continued)

Reference

ORGANIC COMPOUNDS (cont.) Alcohols:

$$ROH + H_2 O_2 \frac{cold}{no \ catalyst} no \ reaction \qquad 2.55$$

$$RCH_2OH + H_2O_2 \xrightarrow{Fe^{+3}} RCOOH \longrightarrow CO_2$$
 2.55

Carboxylic Acids:

$$\frac{1\% H_2 S_4}{Peroxy \ acid} = \frac{1\% H_2 S_4}{RC000H + H_2 0} = \frac{2.55}{2.55}$$

Aldehydes:

$$R-CHO + H_2O_2 \xrightarrow{80 C} RCOOH$$
 2.55

Aromatics:

Benzene or toluene +
$$H_2 0_2$$

no reaction 2.10

Benzene +
$$H_2 O_2 = \frac{Fe^{++} \text{ catalyst}}{A1 \text{ strips}}$$
 phenol 2.55

$$\beta$$
-naphthol + H_2O_2 RC000H \Rightarrow o-carboxycinnamic acid 2.96,
(in acetic acid) 2.98

Hydrazobenzene +
$$H_2 O_2 \xrightarrow{22-23C} azobenzene$$
 2.55
Azobenzene + $H_2 O_4 \xrightarrow{1\%} H_2 SO_4$

Azobenzene +
$$H_2 0_2 \xrightarrow{2} RC000H$$
 azoxybenzene 2.55
(in acetic
acid)

TABLE 2.19 (Concluded)

ORGANIC COMPOUNDS (cont.)

Aromatics:

Aniline +
$$H_2 C_2 \xrightarrow{22-23C}$$
 aniline black products 2.55

Benzaldehyde +
$$H_2O_2$$
 $\xrightarrow{22-23C}$ benzoic acid 2.97
(in acetic acid) RC000H

Anthracene +
$$H_2 0_2 \xrightarrow{\text{RC000H}}$$
 anthraquinone 2.96
(in acetic acid)

Primary Amines:

Secondary Amines:

$$(R)_{2} NH + H_{2} 0_{2} \longrightarrow (R)_{2} NOH$$

hydroxylamine 2.55

Tertiary Amines:

$$(R)_{3}N + H_{2}O_{2} \longrightarrow R_{3}NO$$
 2.55

amineoxide



Figure 2.1. Concentration and Apparent Molecular Weight of Aqueous Hydrogen Peroxide Solutions












Figure 2.3. Critical Temperature, Critical Pressure, and Boiling Point of Propellant-Grade Hydrogen Peroxide-Water Solutions



DENSITY, gm/cc

Figure 2.4. Density of Propellant-Grade Hydrogen Peroxide-Water Solutions







Figure 2.5. Coefficients (Cubical) of Thermal Expansion for Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.5a. Coefficients (Cubical) of Thermal Expansion for Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.6. Adjubatic Compressibility of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.6a.

Adiabatic Compressibility of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.7. Vapcr Pressure of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.7a. Vapor Pressure of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.8. Vapor Composition Over Hydrogen Peroxide-Water Solutions (Ref. 2.22)



Figure 2.9. Vapor-Liquid Equilibrium for the Hydrogen Peroxide-Water System (Ref. 2.22)



Figure 2.10. Activity Coefficients for Hydrogen Peroxide-Water Solutions (Ref. 2.22)











Figure 2.12. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.12a. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.13. Heats of Formation of Propellant-Grade Hydrogen Peroxide-Water Solutions at 25 C





Figure 2.14. Heats of Vaporization of Hydrogen Peroxide-Water Solutions





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Figure 2.15. Heats of Mixing of Hydrogen Peroxide-Water Solutions







Figure 2.16. Heats of Decomposition of Propellant-Grade Hydrogen Peroxide-Water Solutions at 25 C







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Figure 2.18a. Viscosity of Liquid Hydrogen Peroxide-Water Solutions



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Figure 2.19a. Viscosities of 98 w/o Hydrogen Peroxide, 70 w/o Hydrogen Peroxide, and Water







Figure 2.21. Thermal Conductivity of 98.2 w/o Hydrogen Peroxide (Ref. 2.31)



Figure 2.22. Velocity of Sound in Propellant-Grade Hydrogen Peroxide-Water Solutions










Figure 2.23a. Dielectric Constant of Propellant-Grade Hydrogen Peroxide-Water Solutions



Figure 2.24. Heat Flux From a 347 Stainless-Steel Surface to 90 w/o Hydrogen Peroxide as a Function of Surface Temperature







Figure 2.26. Correlation of Heat Transfer Coefficients of 98 w/o Hydregen Peroxide With Dittus-Boelter Equation (Convective Region)

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Figure 2.27. Correlation of Heat Transfer Coefficients of 98 w/o Hydrogen Peroxide With Colburn Equation (Convective Region)





3.1 MANUFACTURING TECHNIQUES

3.1.1 . Preparation

The early laboratory preparation of hydrogen peroxide was based on the technique that Thenard used during the initial preparation of hydrogen peroxide. In this technique, barium nitrate, purified by recrystallization, was decomposed by heating in air in a porcelain retort. The resulting oxide was further oxidized by heating in a stream of oxygen to a dull red heat. The barium peroxide which formed was then dampened, ground, and dissolved in hydrochloric acid (nitric acid was used in Thenard's initial experiments). A slight excess of sulfuric acid was then added to precipitate barium sulfate and regenerate hydrochloric acid. The procedure of barium peroxide solution and sulfate precipitation was repeated several times in the same solution to increase the peroxide concentration (concentrations of up to 33 percent by weight hydrogen peroxide could be achieved in this manner).

The concentrated solution containing water, hydrogen peroxide, and hydrochloric acid, along with accumulated impurities, was cooled with ice and saturated with barium peroxide; iron and manganese impurities in the solution were then precipitated out as phosphates. The hydrochloric acid was removed by the addition of silver sulfate and the sulfate ion was removed by the subsequent addition of barium oxide. Further concentration was accomplished by vacuum distillation until "no further density increase occurs." Thenard reported that 100 w/o hydrogen peroxide (on the basis of density data and the measurement of the volume of oxygen released) could be obtained by this technique.

The first record of commercial production of hydrogen peroxide appeared in the 1865 to 1875 period. The first commercial production in the United States was by the Oakland Chemical Company, Brooklyn, New York, in 1881. Laporte Chemicals Ltd. established a factory in Yorkshire, England, in 1888. With the exception of substitution of fluorosilicic acid for the hydrochloric acid, Thenard's process was used essentially unchanged for the manufacture of hydrogen peroxide until nearly 1900. The formation of hydrogen peroxide in the electrolysis of sulfuric acid was first reported in 1853; later developments made the manufacture of hydrogen peroxide by an electrolytic process possible in 1908. By 1939, only 10 percent of the world's production was by the barium peroxide process.

Currently, hydrogen peroxide is commercially manufactured either by an electrolytic (inorganic) method or one of two organic processes. The electrolytic process (Ref. 3.1) involves the electrochemical formation of either peroxydisulfuric acid or peroxydisulfates (from an ammonium bisulfate solution), their subsequent hydrolysis, and separation of hydrogen peroxide by distillation. The basic equations for these reactions may be summarized as follows:

$$2NH_4HS0_4 \xrightarrow{\text{electrolysis}} (NH_4)_2S_20_8 + H_2$$
$$(NH_4)_2S_20_8 \xrightarrow{\text{hydrolysis}} 2NH_4HS0_4 + H_20_2$$

Although sulfuric acid may be used as the starting material, the ammonium bisulfate process is cheaper and has a higher cell efficiency.

The electrolysis is carried out in stoneware tanks with platinum electrodes; conversion of bisulfate to the persulfate takes place at the anode. After hydrolysis of the persulfate (with steam) in an evaporator, the resulting dilute aqueous solution of $H_2^{0}_2$ is separated from the bisulfate and further distilled in a stoneware distillation column. The resulting solution is approximately 30 w/o H_20_2 . Both the cathode liquor (after purification) and the bisulfate from the evaporator (and separator) are recycled back to the cells.

One of the organic processes used commercially for the manufacture of hydrogen perexide involves the catalytic reduction of a substituted anthraquinone and subsequent oxidation back to the quinone structure with the production of $H_2 O_2$ (Ref. 3.2). Although the process may vary slightly among the several commercial manufacturers who use it, the basic reactions can be summarized as follows:



where R may be ethyl, t-butyl, etc.

The reduction of the substituted anthraquinone with hydrogen is accomplished from room temperature to 40 C or more and at 1 to 3 atmospheres of pressure in the presence of a Raney nickel, nickel, palladium, or platinum catalyst. The catalyst is separated from the hydroquinone solution and recycled to the hydrogenator. After oxidation of the hydroquinone by either air or oxygen, the resulting quinone solution containing 0.5 to 1 w/o H_20_2 is extracted with water at 25 to 40 C. The aqueous solution of hydrogen peroxide (~ 15 to 35 w/o H_20_2) is cleaned of organic contamination and vacuum distilled to ~ 70 w/o H_20_2 . The organic phase from the extractor is evaporated from entrained water, partially dried, cleaned of H_20_2 (by a decomposition catalyst), and recycled as the work solution to the hydrogenator. The second organic process used in the present commercial manufacture of hydrogen peroxide is based on the oxidation of propane or a propane derivative (such as isopropyl alcohol). Although the actual details of hydrogen peroxide manufacture by these processes are not defined, the basic reactions of the propane oxidation are postulated as follows (Ref. 3.3):

$$C_{3}H_{8} - O_{2} - C_{3}H_{7} \cdot C_{3}H_{6} + HO_{2} \cdot C_{3}H_{7} \cdot C_{3}H_{6} + HO_{2} \cdot C_{3}H_{7} \cdot C_{3}H_{6} + C_{4}H_{4} + CH_{4} + CH_{4$$

As noted, the side products in this reaction series are a variety of oxygenated organic species, propylene, methane, and ethylene.

The oxidation of isopropyl alcohol may occur as follows (Ref. 3.3):

$$(CH_3)_2 CHOH + 0_2 - (CH_3)_2 CO + H_2 0_2$$

It is reported that the latter reaction can be conducted in either the liquid or vapor phases. Hydrogen peroxide concentrations of 15 to 17 w/o $H_2 0_2$ and 25 to 30 w/o $H_2 0_2$ are obtained from the propane and isopropyl alcohol oxidations, respectively.

3.1.2 Concentration

In most applications outside the propulsion field, only dilute solutions of hydrogen peroxide are required and the product grades normally obtained from the conventional commercial processes are adequate. To meet the demands of propellant-grade hydrogen peroxide, additional concentration is required. Although hydrogen

peroxide is normally concentrated commercially by fractional distillation to concentrations $\leq 90 \text{ w/o H}_20_2$, other concentration procedures, such as fractional crystallisation combined with vacuum distillation, have been frequently used for small-scale purification. The concentration of the 96 w/o H_20_2 solutions to ~ 98 w/o H_20_2 is presently being accomplished commercially (Ref. 3.4) by fractional crystallisation. This crystallization process also removes most of the impurities.

The high volatility of water with respect to hydrogen peroxide makes it relatively easy to concentrate peroxide by simple distillation procedures; however, there are several disadvantages to this technique. Concentration of the nonvolatile impurities, which occurs in the hydrogen peroxide during distillation, decreases the stability of the product. In addition, the rate of decomposition increases with temperature rise (2.3 times for each 10 C rise in temperature). Finally, hydrogen peroxide vapors which are in excess of 26 m/o $H_0 O_0$ are explosive.

3.1.3 **Purification**

For some purposes, a relatively high impurity and stabilizer content may be innocuous and a lower stability acceptable; however, for most propellant applications it is essential that the impurities be removed or kept to a minimum. This is particularly true when concentrations of 80 w/o or more are desired. High purities in the propellant-grade solutions are obtained by a multiple-stage distillation process in which the hydrogen peroxide is completely vaporized in the first stage, leaving only the nonvolatile impurities. A vacuum distillation is usually performed (Ref. 3.3) to keep the temperature (and subsequently, the decomposition) to a minimum. This technique also decreases the potential explosion hasard.

Theoretically, the removal of impurition by distillation or fractional crystallization should be complete scept for impurity pickup from the apparatus itself in either the final process condenser or receiver. How er, because of the catalytic impurities acquired during the handling and storage operations, a stannate stabilizer is usually employed in small concentrations to buffer the effects of these impurities. However, the gradual dropout of this stabilizer during storage results in additional emphasis on the importance of impurity removal from hydrogen peroxide solutions.

Although ionic impurities may be removed by applying an electric potential, the use of ion-exchange resins may prove to be a more practical means of purification because this method could be applied easily at the point of final use to remove contamination acquired during transfer operations as well as residual manufacturing impurities. Extensive experimental studies in this area (Ref. 3.5) have indicated that stannic acid seems the most likely choice for an ion-exchange media.

3.2 CURRENT PRODUCTION

3.2.1 Availability

The principal European manufacturer of hydrogen peroxide is Laporte Chemicals, Ltd. of Luton, Bedfordshire, England. Principal U.S.A. manufacturers are Allied Chemical & Dye, Columbia Southern Chemical Corporation, E. I. duPont de Nemours and Company, Inc., Food Machinery and Chemical Corporation (FMC), and Shell Chemical Company. Of these U.S.A. manufacturers, duPont (anthraquinone process), FMC (electrolytic and anthraquinone processes), and Shell (oxidation of isopropyl alcohol) are the major producers of propellant-grade ($\geq 70 \text{ w/o H}_20_2$) hydrogen peroxide. Allied Chemical, which presently produces H_20_2 grades to 70 w/o, has indicated a potential interest in production of higher grades. Presently, FMC is the only commercial manufacturer of $\geq 90 \text{ w/o H}_20_2$ grades. Although hydrogen peroxide concentrations of 99.7 to 99.8 w/o H_20_2 have been produced commercially (Ref. 3.4 and 3.6), the economic- and application-feasibility tradeoff will probably limit commercial manufacture to maximum concentrations of 98 to 99 w/o H_2O_2 .

The production of hydrogen peroxide was estimated (Ref. 3.7) to be 55,000 short tons (as 100 w/o $H_2 \theta_2$) for the year 1966. This quantity, which includes all grades of hydrogen peroxide, represents an increase over the productions of 52,567, 45,519, and 39,085 short tons which were quoted for the previous 3 years. The present production capacities of the duPont (Memphis, Tenn.), FMC (Buffalo, N.Y., Charleston, W. Va., and Vancouver, B.C.), and Shell (Norco, La.) hydrogen peroxide plants have been quoted as 2.5×10^6 , 3×10^6 , and $> 5 \times 10^6$ pounds hydrogen peroxide (as 100 w/o $H_2 \theta_2$) per year, respectively.

Hydrogen peroxide is available in various quantities up to tank car sizes (4000-, 6000-, or 8000-gallon capacity). The use of 500- and 1300-gallon capacity portable hydrogen peroxide tanks that can be filled at the plant and used as storage vessels at the user's site offers many advantages, particularly for remote, overseas, or temporary sites. Tank trucks with capacities up to 4000 gallons are presently in service or available. Small quantities are normally purchased in 30-gallon drums.

3.2.2 Cost

Because hydrogen peroxide sales are of a highly competitive nature, the cost of propellant-grade hydrogen peroxide is flexible. The grade (including concentration, purification, stabilization, etc.), quantity, and present competition are all prime factors in the determination of hydrogen peroxide cost. Thus, all individual manufacturers should be contacted at the time of procurement to determine the exact cost.

For the purpose of estimation, the current price list (Ref. 3.6) of FMC includes the following prices for three different grades of hydrogen peroxide in tank car quantities:

The quoted list prices of the other manufacturers are similar for the 90 and 70 w/o $H_2^{0}_2$ grades. However, the last Air Force procurement (FY 1967) of 90 w/o $H_2^{0}_2$ was based on a cost of 0.23+ (tank car lots) to 0.30/1b (drum lots).

In the procurement of low concentrations of hydrogen peroxide for initial system passivation, pond decontamination, or other applications requiring limited stability, it has been recommended by various manufacturers that higher concentrations be purchased and diluted on site; this technique effects some cost savings in transportation (cost per pound of solution shipped as $H_2 O_2$). However, for the high-purity grades or grades requiring special degrees of stabilization, product treatment should be limited to that performed at the manufacturing site.

3.3 PROPELLANT SPECIFICATION

Currently, there are two government specifications for the procurement of hydrogen peroxide. These are:

- MIL-P-16005D, "Propellant, Hydrogen Peroxide," (18 March 1965).
- MIL-H-22868 (Wep)—"Hydrogen Peroxide Stabilized, 70% and 90% (for Torpedo Use)," (21 March 1961).

In addition, during the development and utilization of the Bedstone Nussile System, there was a "purchase description" document, ABNA-PD-H-763, dated 14 August 1958, which was issued by the Army Ballistic Missile Agency for the purpose of procurement of $H_2 O_2$ used in this system. Although no longer applicable, this document controlled the previous procurement of 76 v/o $H_2 O_2$.

A comparison of the limits and analytical techniques used in these specifications, which have been used in the procurement of 90 w/o propellant-grade, 70 and 90 w/o torpedo-grade, and 76 w/o propellantgrade hydrogen peroxide, respectively, is presented in Table 3.1. It should be noted that many of the users of propellant-grade hydrogen peroxide have company-procurement and use specifications for hydrogen peroxide; however, because of the many variations, these specifications are not discussed in this handbook.

The impurity limits established for torpedo-grade hydrogen peroxide are based on stabilization requirements for maximum storability with respect to to pedo use; thus, the high concentrations of the phosphates, tin, and nitrate ions are required. In the establishment of limits for propellant-grade hydrogen peroxide, minimum stabilization requirements had to be met, but impurities that cause 1,0, catalyst poisoning were strictly controlled. These impurities were identified during an experimental study reported in Ref. 3.8. Phosphate, which acts as a stabilizer by complexing the heavy metal ions which promote H_2O_2 decomposition, is a severe catalyst poison; thus, its content in propellantgrade H_2O_2 is limited. Tin (as stannous chloride) is added to the peroxide as a stabilizer to offset the effects of residual phosphate; therefore, a minimum limit was established for tin. (The tin content in H₀O₀ will gradually decline during storage due to drop-out from the solution). The chloride and sulfate ions are limited because they cause container corresion (through solution of aluminum). Nitrate has been found to inhibit the effects of chloride and sulfate, and a lower level has been established for this ion to inhibit container corrosion. Although certain carbonaceous materials are known to be catalyst poisons, the effect of carbon is not entirely defined. This effect is discussed further in Section 7.2.1.3.1.

All manufacturers of propellant-grade 90 w/o hydrogen peroxide can presently meet the limits established in NIL-P-16005D. This is illustrated in Table 3.2 with typical analyses of products from three different manufacturers, duPont, FNC, and Shell, compared to the procurement specification requirements.

> NOTE: Although there are some differences in impurity types and levels in the hydrogen peroxide produced by the various manufacturers, the limits criteria established by MIL-P-16005D are adequate to govern the procurement and operational quality of propulsion-grade 90 w/o hydrogen peroxide. Further discussion of this analysis is presented in Section 7.2.1.3.

Currently, there is no government procurement specification for 98 w/o hydrogen peroxide. However, the Air Force Rocket Propulsion Laboratory, which has been assigned primary responsibility for DOD and NASA propellant specification coordination, has indicated (Ref. 3.9) that a procurement specification for 98 w/o H_20_2 will be released in 1967. Present plans are to revise MIL-P-16005D to include the limitations for higher concentrations of H_20_2 . The tentative limits on the H_20_2 assay of the higher concentration, the revision will include some changes in the analytical techniques recommended in the present specification. An indication of these changes is given in the following discussion under Chemical Analysis.

3.4 CHEMICAL ANALYSIS

The currently recommended procedures and techniques for the complete analysis of propellant-grade hydrogen peroxide are presented in the appropriate procurement specifications. The chemical analysis of other propellant grades, not included in the present procurement specifications, can be conducted with similar techniques. Chemical analysis techniques for hydrogen peroxide also are available from the hydrogen peroxide manufacturers upon request.

Because w? the space limitations of this handbook and the ready availability of the analytical procedures, they are not reproduced in this handbook. However, in summation of the analytical techniques recommended by MIL-P-16005D, H₀O₀ assay is determined by standard titration with ceric sulfate to a ferroin end point. The Al. Cl. NHL, NOg, POL, and SO, ions are all determined spectrophotometrically, and tin is determined polarographically. Carbon content is determined by combusting the sample in a furmace to change the carbon materials to CO_0 ; this is subsequently determined by titration (Ref. 3.9). There are some differences in the analytical techniques recommended by MIL-P-16005D and those recommended by the various manufacturers and used in the industry. The differences in these procedures, which are for the most part minor, are summarized in the following paragraphs. The Air Force Rocket Propulsion Laboratory has recognized these differences and has indicated probable changes in the presently recommended analytical inchniques during the next revision of the procurement specification.

3.4.1 H₂0₂ Assay

Although NIL-P-16005D recommends determination of $H_2^{0}O_2$ assay by ceric sulfate titration, a survey of the industry has indicated that most laboratories prefer $H_2^{0}O_2$ assay determination by a permanganate titration because of the ease in identification of the end point. However, all laboratories can perform the ceric sulfate titration with equivalent accuracies.

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3.4.2 Aluminum

In the spectrophotometric procedure specified in MIL-P-16005D for determination of the aluminum ion, an aluminon-gelatic buffer solution is used for color formation. The duPont (Ref. 310) and Shell (Ref: 3.11) procedures suggest the use of 8-hydroxyguinoline and extraction with chloroform for

color formation. The FMC (Ref. 3.6a) procedure suggests that the sample size be increased from 10 to 25 milliliters and that the buffer solution, prepared by the specification method, may be slightly less stable than the buffer solution preparation detailed in the FMC procedure.

3.4.3 Chloride

Shell (Ref. 3.12) suggests determination of the chloride ion by measurement of turbidity with a colorimeter instead of the spectrophotometer specified in MIL-P-16005D. The FMC procedure (Ref. 3.6b) is a colorimetric method using mercuric thiocyanate and ferric ammonium sulfate.

3.4.4 <u>Ammonium</u>

In determination of the ammonium ion by spectrophotometry, duPont (Ref. 3.10) separates the ammonia from the other contaminants by distillation before color formation. The FMC (Ref. 3.6) and Shell (Ref. 3.13) procedures essentially agree with MIL-P-16005D except FMC suggests that greater accuracy may be achieved by increasing the sample size from 10 to 50 milliliters.

3.4.5 Nitrate

FMC (Ref. 3.6) recommends that the heating step with the phenoldisulfonic acid reagent, employed in the determination of the nitrate ion, be increased to 15 minutes (from 5 minutes) to ensure complete contact and nitration of the sample residue. The Shell procedure (Ref. 3.14) utilizes & larger sample size and increases the heating time to 10 minutes.

3.4.6 Phosphate

The duPont procedure for the determination of the phosphate ion is escentially identical to MIL-P-16005D except that the ether extraction is omitted (Ref. 3.10). The Shell (Ref. 3.15) procedure also omits the ether extraction and uses hydrazine instead of stannous chloride to develop the molybdenum blue color. The FMC (Ref. 3.6c) procedure is somewhat different. FMC (Ref. 3.6) reports that attempts to use this procedure (MIL-P-16005D) failed to give valid or comparative results. Although only preliminary investigations have been conducted, studies indicate an error in pH adjustment of the sample solution before extraction with ether. It also appears that the stannous chloride reagent is too acid, as the blue molybdate color is removed by this reagent. Three reagents added to the sample solution (HBr, HCl, and HNO_{π}), are not added in the calibration curve procedure. Thus, the PO_{L} content of the sample could be enhanced by any PO, contained in these reagents.

3.4.7 Sulfate

For the determination of sulfate, duPont (Ref. 3.10) recommends the use of a preliminary perchloric acid oxidation to measure total sulfur, instead of only sulfate sulfur. Shell (Ref. 3.16) recommends precipitation with barium chloride, stabilization of the suspension by the addition of alcohol and glycerine, and turbidity measurements with a photoelectric colorimeter. FMC (Ref. 3.6d) also suggests the use of a turbidimeter (rather than the spectrophotometer), and a method which converts SO_4 to H_2S instead of a caustic addition with BaSO_h precipitation.

Both duPont (Ref. 3.10) and FNC (Ref. 3.6e) suggest the use of a polarographic method for determining tin in contrast to the spectrophotometric technique recommended in MIL-P-16005D. Shell (Ref. 3.17) uses a spectrophotometric technique which is different from that in the MIL-P-16005D; the stannic tin is extracted into an 8-hydroxyquipoline-chloroform solution at a pH of 0.85, and the tin is determined spectrophotometrically in the chloroform extract.

3.4.9 Carbon

DuPont (Ref. 3.10) suggests that measurement of change in conductivity of the barium hydroxide scrubbing solution is a more accurate technique for carbon determination than the titration recommended in MIL-P-16005D. FMC (Ref. 3.6) suggests that the MIL-P-16005D procedure is (1) "time consuming and hence expensive to run, and (2) it requires rather elaborate combustion equipment." Instead, FMC suggests the use of a procedure (Ref. 3.6f) where the sample is decomposed by addition of silver nitrate solution and the noncondensable vapors, from boiling of the resulting solution, are passed through a combustion tube packed with copper oxide at 750 C; the resulting gas is passed through a solution of barium hydroxide and potassium persulfate, which is then titrated with standard HCl solution to determine carbon. Shell (Ref. 3.18) uses a combustion technique to convert the carbon to CO_o, which is determined in a gas chromatographic column.

3.4.10 Residue

DuPont (Ref. 3.10) obtains residue by atmospheric pressure concentration rather than in a vacuum oven.

5.4.11 Particulate

The stringency of the particulate limit, 1 mg/liter, established by MIL-P-16005D has been noted (Ref. 3.6) in comparison to that established (10 mg/liter) for other propellants. In addition, duPont (Ref. 3.10) prefers the use of a Teflon polytetrafluorethylene filter instead of a polyethylene filter for reasons of safety.

3.4.12 Stability

Host laboratories prefer gas collection techniques for determining stability in contrast to the weight loss technique recommended in MIL-P-16005D.

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- 3.2 F.M.C. Corporation, New York, New York, "Hydrogen Peroxide," <u>Hydrocarbon Processing</u>, <u>44</u>, 225, (1965).
- 3.3 Schumb, W. C., C. N. Satterfield, and R. L. Wentworth, <u>Hydrogen Peroxide</u>, A.C.S. Monograph 128, Reinhold Publishing Corporation, New York, New York, 1955.
- 3.4 Bloom, Ralph, Jr., and Norris J. Brunsvold, "Anhydrous Hydrogen Peroxide as a Propellant," <u>Chem. Eng. Prog.</u>, <u>53</u>, (11), 541-7 (1957).
- 3.5 Shell Development Company, Emeryville, California, <u>Storable</u> <u>Concentrated Hydrogen Peroxide</u>, Report No. AFRPL-TR-66-262, Report period: June - August 1966, Contract AF04(611)-11416.
- 3.6 Private communication, J. C. McCormick, F.M.C. Corporation, Buffalo, New York, to M. T. Constantine, Rocketdyne, Canoga Park, California, December 1966.
- 3.6a Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-11 (Rev. 0).
- 3.6b Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-18 (Rev. 0).
- 3.6c Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-21.
- 3.6d Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-22B.
- 3.6e Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-12.
- 3.6f Ref. 3.6, based on F.M.C. Analytical Procedure SC-55-5 (Rev. 0).
- 3.7 _____, Chemical and Engineering News, 5 September 1966.

- 3.8 Naval Research Laboratory, Washington, D.C., <u>The Role of</u> <u>Inorganic Contaminants in the Catalytic Decomposition of</u> <u>Hydrogen Peroxide</u>, Report No. 5117, 15 April 1958.
- 3.9 Forbes, F. S., "Propellant Specification, Quality Control Analysis," Presented at the Sixty-first National Meeting, A.I.Ch.E., Houston, Texas, 19-23 February 1967.
- 3.10 Private communication, J.C. Snyder, duPont, Memphis, Tennessee, to M. T. Constantine, Rocketdyne, Canoga Park, California, 22 November 1966.
- 3.11 Shell Development Company, Emeryville, California, <u>Shell</u> <u>Analytical Methods for Hydrogen Peroxide</u>, SMS 714/59, 1959.
- 3.12 Ref. 3.11, SMS 722/59, 1959.
- 3.13 Ref. 3.11, SMS 708/59, 1959.
- 3.14 Ref. 3.11, SMS 720/62, 1962.
- 3.15 Ref. 3.11, SMS 712/59, 1959.
- 3.16 Ref. 3.11, SMS 725/59, 1959.
- 3.17 Ref. 3.11, NP-99/63, 1962.
- 3.18 Ref. 3.11, SMS 749/59 (Rev. 11/13/64), 1959.

TABLE 3.1

SUMMARY OF MILITARY SPECIFICATIONS (D) IN The PROCUREMENT OF HYDROGEN PPROXIDE

		NTL-P-1	Q. Cool		MTL-8-22668			M-PD-E -763
	Li	ite	Amintical	iei.l	te	Amintical	Limite	Assirtical
Property	Minimum	Maximum	Technique	Minimu	Nar i ma	Technique	Marx imm	Technique
Velght Percent E202	90.0	91.0	CeSO4 Titration	69.5 to 71.0	89.5 to 91.0	Din0, Titration	76 ±0.5	Dia04 Titration
Aluations, mg/liter		5.0	Spectrophotometric				0.6	Speetrephetametric
Chloride, mg/liter		1.0	Spectrephotometric (tarbidimetric)		1.0	Turbidiz-tric	0.5	Fur bidiætric
Amonim, mc/liter		0 5	Spectrophotometric				3.5	Colorimetric
Fitrate, mg/liter	3.0	50	Spectrophotometric	66	130	Colerimetric	5.0	Colorimetric
Phosphate, mc/liter		0.2	Spectrophotometric	ĸ	33	Colorimetric	0.5	Celerimetric
Bulfate, mg/liter		3.0	Spectrophotometric (turbidimetric)		10.0	Turbidizetric	3.25	T urbidimetrie
Tim, mg/liter	1.0	\$.0	Spectrophotometric	8	8	Polaregraphic	2.40	Polarographic
Carbon, mg/liter		200.0	Combustion	Į	1		ł	
<u>ال</u>	ł	ł		1.2 te 1.6	0.0 to 0.4	pil Neter	1	
Barface Tenation, <u>Arnes</u>	I	I		2	74 at 20 C	Capillary Rise	ł	
Braperative Residue, mg/liter		20.0			325		10	
Stability, percent		5	(Lose in wight after 24 hours at 100 C)		Q	(Less in weight after 24 heurs at 100 C)	I	
Co lor		Clear, ce	lorless)	. 9	llear, celerle	()	(C1•	ar, celerless)
Centaimer Comdition) Aie	defecta, ma of deci	leaks or Meposition)	(No defecte	l, leaks er de	cemposities)		

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TABLE 3.2

COMPARISON OF TYPICAL ANALYSES FOR PROPELLANT-GRADE 90 v/o HYDROGEN PEROXIDE FROM THREE DIFFERENT COMMERCIAL MANUFACTURERS

	Military			
	Specification	DuPont	Sbell	FMC
Percent H ₂ 0 ₂	90.0 to 91.0	90.7	90.7	90.8
Percent AOL	5.0 maximum	0.9	0.3	1.1
Carbon, mg/liter	200 maximum	11	150	BDL*
Residue, mg/liter	20 maximum	15	15	15
cl ⁻¹ , mg/liter	1.0 maximum	0.2	< 0,1	0.2
PO ₄ ⁻³ , mg/liter	0.2 maximum	0.1	0.04	0.07
NO ₃ ⁻¹ , mg/liter	3.0 to 5.0	3	3.6	3.5
S0 ₄ ⁻² , mg/liter	3.0 maximum	0.3	< 3.0	0.02
Sn, mg/liter	1.4 to 4.0	1.8	1.8	1.9
NH ₃ , mg/liter	3.0 maximum	0.3	< 3.0	0.03
Al, mg/liter	0.5 maximum	0.2	0.2	0.07
Insolubles, mg/liter	1.0 maximum	<1.0	<1.0	<1.0

*Below Detectable Limits

SECTION 4: STORAGE AND HANDLING

4.1 STORABILITY

4.1.1 General

The storability (or storage stability) of hydrogen peroxide is usually described in terms of decomposition rate and/or concentration change of the $H_2 O_2$ over a period of time. Because storability is directly related to decomposition, it becomes a function of the considerations involved in the decomposition mechanisms. In a simplification of these mechanisms, which are described in detail in Section 7, the basic factors controlling decomposition rate in a storage system are $H_2 O_2$ concentration; temperature; impurity types and concentrations in the $H_2 O_2$; and the composition, area, and condition of the surface in contact with the $H_2 O_2$. Although many of these factors are discussed in other sections of this handbook as a result of studies of materials compatibility, passivation techniques, decomposition mechanisms, etc., they are interrelated and presented in this section in terms of storability.

Until the early 1960's, the generally accepted decomposition rate AOL* of commercial, unstabilized, propellant-grade hydrogen peroxide under normal storage conditions (e.g., in a 30-gallon storage drum at an S/V of 0.38 in.⁻¹) was ~1 percent/year at ambient temperatures of 77 to 86 F (Ref. 4.1). This rate is theoretically equivalent to a propellant-grade hydrogen peroxide concentration loss of ~ 0.5 w/o $H_2 O_2$ /year. Some examples of decomposition rates actually experienced during drum storage (under field handling conditions) of various types of hydrogen peroxide between 1945 and 1963 are shown in Table 4.1 in terms of concentration changes and actual oxygen loss. These results, which are essentially representative of propellant manufactured before 1960 and of storage at the S/V (0.38 in.⁻¹) typically found in 30-gallon storage drums, were reported in Ref. 4.2.

*AOL (active oxygen loss) is defined in Section 4.2.1.1.4.

There are some discrepancies noted in Table 4.1 between the reported oxygen losses and the H_2O_2 concentration changes. It would appear that if the magnitudes of the reported H_2O_2 concentration changes were entirely attributable to H_2O_2 decomposition, the oxygen losses would be much higher. Although it is possible that some of the H_2O_2 concentration change during the storage period was due to moisture absorption from the air (during drum "breathing"), the discrepancies do cause some doubt in the validity of the oxygen losses reported. Because the technique for determination of oxygen loss is not reported, and it is assumed that such a measurement would be difficult under the uncontrolled conditions of drum storage, the concentration change appears to be the most indicative factor of decomposition rate during these tests.

From the $H_2^{0}_2$ concentration changes reported in Table 4.1, the decomposition rate of the unstabilized 90 w/o $H_2^{0}_2$ can be estimated as approximately 1-percent AOL/year which corresponds to that rate generally accepted by the industry during this period. The data presented in the table also indicate smaller decomposition rates for both the 98 w/o $H_2^{0}_2$ propulsion grade and the stabilized torpedo grades (90 and 70 w/o $H_2^{0}_2$) under essentially the same storage conditions. These effects are discussed further in Sections 4.1.3.2 and 4.1.3.5.

Recently, improvements have been reported in the storage stability of hydrogen peroxide, particularly, in the 90 w/o grade. The gross result of this improvement is illustrated in Table 4.2 with data from studies conducted in 1947 (Ref. 4.3) and in 1965 (Ref. 4.1 and 4.4) on 90 w/o H_20_2 and studies on 99+ w/o H_20_2 in 1953 (Ref. 4.5). In this table the rate of decomposition of the hydrogen peroxide has been reported as a function of temperature and as a function of contamination for the three different time periods. Although the reasons for the improvement in hydrogen peroxide stability are not defined in Table 4.2, the data are indicative of the progress that has been made in the storability of hydrogen peroxide.

4.1.2 Storability Improvement Studies

This resent increase in the storage stability of hydrogen peroxide is a result of a combination of factors including (1) increased purity of the hydrogen perioxide, (2) better selection of the container materials, (3) improved surface treatment and passivation of the container, and (4) development of more effective stabilization techniques. A recent characterization of these factors resulted from three primary studies directed at the improvement of hydrogen peroxide storability. These studies, which were conducted by duPont (Ref. 4.6), FMC (Ref. 4.7), and Shell (Ref. 4.1, 4.8 and 4.9), are summarized in the following paragraphs.

DuPont (Ref. 4.6) conducted studies on (1) the stability of solid and low-temperature (32 F) liquid hydrogen peroxide (90 to 100 w/o H_20_2) in Pyrex; (2) the effect of aluminum, Pyrex, polyethylmne, and fluorocarbon polymers on the stability of H_20_2 in the 122 to 158 temperature range; and (3) the reaction mechanisms of hydrogen peroxide decomposition. As a result of this study, the decomposition rate of high-purity or commercially stabilized hydrogen peroxide at -76 to 32 F was found to be less than 0.04 percent per year in Pyrex. In addition, the decomposition rate of 90 w/o H_20_2 in contact with a Teflon FEP fluorocarbon film that had been mildly irradiated in air was less than one-third of the rate involved in contact of the 90 w/o H_20_2 with a passivated aluminum surface and less than one-half the rate with Pyrex.

Sealed storage studies of the commercial and propulsion grades of 90 and 98 w/o $H_2^{0}_2$ in TFE Teflon bladders (contained in mild steel tanks) were conducted at 70 to 72 F (5 months), 120 F (7 days), and 165 F (72 hours) by FMC (Ref. 4.7). Although bleaching and cracking of the bladders were experienced, the tests demonstrated a reduction in H_2^{0} decomposition rates through

improved surface pretreatment and passivation techniques and use of stabilizers. Extrapolations of the data indicated the oxygen losses of 98 w/o H_2O_2 were less than 0.4 percent/year at 70 F in the bladders. Compatibility screening studies indicated that other bladder materials such as NAA Vicone 185, duPont Viton B (805), and 3M Fluorel 2141 were superior to the TFE Teflon material.

In the study conducted by Shell (Ref. 4.1), experimental investigations were directed into three major areas: (1) improvement of $H_0 \rho_0$ purity, (2) development of an improved liquid decomposition inhibition system, and (3) assessment of container materials of construction for long-term storage. Storage decorposition rates for 90 w/o $H_2^{0}0_{2}$ were reduced to 0.04 percent/year at ambient temperature as a result of H_00_0 stabilization and careful selection and preparation of the storage container material (Pyrex). It was also indicated that the use of other materials such as ACLAR-33C and Kel-F plastics, 1260 aluminum, and electrolytic tin plate (special preparation) in large storage tanks [minimum surface-to-volume ratio (S/V) could reduce overall decomposition rates under normal storage conditions to 0.1 percent/year. Various means of purification such as distillation, recrystallization, and ion exchange on insoluble inorganic exchangers have also been effective in reducing the decomposition rate; it was also indicated that decomposition rates of 99 w/o H_00_0 were slightly lower than those of 90 w/o H_2^{0} under the same environmental conditions (including the degree of contamination).

Shell has continued the investigation of hydrogen peroxide purification and stabilization techniques and the passivation of container materials to determine the feasibility of sealed hydrogen peroxide storage for periods of 5 years (Ref. 4.8 and 4.9). In this study, which was scheduled to be concluded in January 1968, β -stannic acid was determined to be the most effective ionexchange purification medium for increasing the stability of hydrogen peroxide in storage; decomposition rates of 90 w/o H_2O_2 treated with this technique were approximately one-third the

rates of untreated 90 w/o $H_{2}O_{2}$ after storage in aluminum for periods of 1 year. It was also determined that the minimum decomposition rate of hydrogen peroxide in contact with aluminum surfaces was achieved when the aluminum was subjected to a caustic-nitric acidhot (212 F) 90 w/o $H_{2}O_{2}$ pretreatment sequence prior to testing; however, only minor changes in stability resulted from various types of chemical pretreatment of stainless-steel surfaces (Tables 4.31 and 4.31a and Section 4.2.2.12). The decomposition rate of 90 w/o $H_{2}O_{2}$ in contact with tin-plated (electroplated) aluminum was greater than that observed with either the best tin surface or the best passivated aluminum surface.

4.1.3 Factors Affecting Storability

As noted throughout the various studies of storability, decomposition, passivation, materials compatibility, propellant purification, etc., reported in various sections of this handbook, storage stability of hydrogen peroxide is dependent on a variety of factors. Because it is difficult, however, to separate the influence of each contributing factor under actual storage conditions, many of these studies have been conducted under ideal or isolated environments. Although, for this reason, the translation of the data from these tests into gross storability in terms of particular rates are difficult, the general degree of influence can be fairly accurately predicted and established. Thus. the general effect of factors such as concentration, purity, temperature, container material, container surface pretreatment, and passivation, S/V container ratio, and propellant stabilization system on storability are discussed briefly in the following paragraphs.

4.1.3.1 <u>Concentration</u>. Under equivalent storage conditions, it has been determined that the storage stability of hydrogen peroxide is increased with its concentration (Ref. 4.1 and 4.2). This is

generally attributed to the decrease in impurities and ionization with the loss in water content, and to the decrease in container contact area with decrease in surface tension. This effect is illustrated as a function of concentration from 90 to 98 w/o in Fig. 4.1; comparisons of other decomposition rates between 90 and 98 w/o H_2O_2 are shown at two other conditions in Fig. 4.2 and 4.3.

- 4.1.3.2 <u>Purification</u>. As the various inorganic and organic contaminants are removed from hydrogen peroxide-water solutions, storage stability will approach that of high concentration (98 w/o) hydrogen peroxide; however, because of the various effects (described in Section 4.1.3.1) resulting from water elimination, the storability of the more aqueous solutions will never equal the stability of 98 w/o H_2^{0} assuming the same degree of impurities (Ref. 4.1). Current studies (Ref. 4.8 and 4.9) have demonstrated that various types of purification techniques will produce hydrogen peroxide with homogeneous decomposition rates on the order of 0.03 to 0.07 percent AOL/year at 77 F.
- 4.1.3.3 <u>Temperature</u>. In general, the decomposition rate of hydrogen peroxide has been found to increase 2.3 times for each 10 C (18 F) rise in temperature; this effect is illustrated in Fig. 4.4 which was reprinted from Ref. 4.1. Other data on this effect have been reported in Ref. 4.5.
- 4.1.3.4 <u>Container Surfaces</u>. The effect of the storage container on the storability of hydrogen peroxide is essentially a function of the type of material, the surface treatment and passivation, and the S/V of the material in contact with the liquid volume.

- 4.1.3.4.1 <u>Container Material</u>. The effect of various materials in contact with the hydrogen perexide is described and compared in the Materials Compatibility Section (Section 4.2.2). However, for comparison purposes, decomposition rates resulting from the effect of selected materials in combination with other effects are shown in Fig. 4.4 (Ref. 4.1) and 4.5 (Ref. 4.1 and 4.10) for 90 w/o H_0O_0 .
- 4.1.3.4.2 <u>Surface Treatment and Passivation</u>. Several studies (i.e., Ref. 4.1, 4.7 to 4.9, and 4.11 to 4.18) have established the importance and effect of surface pretreatment and passivation on the decomposition rate and the stability of hydrogen peroxide. Detailed data in this area are presented in Section 4.2.2.12 and Tables 4.21 through 4.31a as part of the Materials Compatibility Section. An example of the effect of surface pretreatment in terms of storability of hydrogen peroxide is shown in Fig. 4.6.
- 4.1.3.4.3 <u>Surface to Volume Ratio</u>. The effect of the storage container surface on the decomposition rate of the hydrogen peroxide is usually illustrated in terms of S/V. This ratio is generally defined as the immersed surface area (that area in contact with the liquid hydrogen peroxide)/liquid volume of the hydrogen peroxide. The relationship between these two factors has been found to be an effective means of expressing the contribution of the heterogeneous decomposition rate of the liquid to the overall decomposition rate of the hydrogen peroxide.

In determination and comparison of the compatibility of various materials, the S/V is usually kept constant. For most of the studies illustrated in Section 4.2.2, a sample size of 1-1/2 by 1/2 by 1/16 inch has been immersed in 75 milliliters of hydrogen periode, thus establishing a S/V value of 0.38 in.²/in.³ (0.38 in.⁻¹). This number generally corresponds to the

conditions found in the storage of hydrogen peroxide in a standard 30-gallon storage drum.

It is obvious that as the surface in contact with the liquid is reduced $(S/V \rightarrow 0)$, the heterogeneous decomposition rate is reduced. Thus hydrogen peroxide stored in large storage tanks should have a minimum decomposition rate, assuming the equivalency of the other factors. This is illustrated in Fig. 4.5a in which experimental studies (Ref. 4.1) were used to predict the decomposition rates shown in the figure; as S/V is reduced, the overall decomposition rate of the hydrogen peroxide approaches that of the homogeneous decomposition rate. Further, it was indicated in this study that "decomposition rates of the order 0.1 percent AOL/year at ambient temperature appear to be readily attainable by use of highest quality (90 w/o H_2O_2) stabilized with sodium stannate and stored in vessels of low surface activity and low S/V ratio.

Other experimental studies (Ref. 4.5 and 4.10) of the effect of S/V on hydrogen peroxide storability are illustrated in Fig. 4.5b, 4.5c, and 4.7. Figure 4.5a, 4.5b, and 4.5c also indicate the effect of S/V as a function of different materials. Figure 4.7 represents work (Ref. 4.5) that attempted to limit the homogeneous decomposition rate through the use of high purity (99+ w/o) hydrogen peroxide and limit the catalytic effect of the container surface by using carefully pretreated glass. It was concluded from the latter study that "the whole inside surface of the container plays a part in the decomposition, but per unit area the immersed surface is more effective than the nonimmersed surface."

4.1.3.5

Stabilization. The use of stabilizers to improve hydrogen peroxide storage stability is essentially based on the premise that they will inhibit decomposition by contamination incurred during storage and handling operations. If the hydrogen

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peroxide could be protected against contact with soluble and insoluble contaminants, stabilization would not be required. In addition to the contamination of the hydrogen peroxide by the system febrication materials, H₀0₀ contamination may result from improper storage and/or handling system cleaning and passivation techniques. The incomplete removal of organic solvents, acids, detergents, chromic acid cleaning solutions, etc., by inadequate rinsing or the use of rinse waters which contain various impurities can readily cause contamination of hydrogen peroxide by the storage or handling system. For the preceding reasons, and because the normally manufactured hydrogen peroxide does contain traces of impurities that will cause $H_0 O_0$ decomposition, some degree of stabilization has been effected in most of the commercially manufactured hydrogen peroxide. The degree and type of stabilization has depended on the planned use of the $H_0 0_0$.

There is no single stabilizing agent which may be designated as the most effective or the most desirable. The selection of a stabilizer must be made with regard to the conditions under which the hydrogen peroxide ultimately is to be used, to the type of contamination likely to be encountered, and to such considerations as the required storage period and the probable prevailing temperature during that storage period. If the storage period is to be relatively brief, an organic stabilizer may be satisfactory; however, over a long period of time, slow oxidation may destroy the effectiveness of an organic component. However, limitations may be placed upon the choice of an inorganic stabilizer because of the quantity of undesirable residues which may remain after a large quantity of hydrogen peroxide has been decomposed. It is also apparent that a large proportion of stabilizer is unsatisfactory.

An extensive number of stabilizers, both inorganic and organic have been tested (i.e., Ref. 4.1, 4.5, 4.8, and 4.9) with both dilute and concentrated hydrogen peroxide solutions. Among

these substances, the most notable success was obtained, especially in the case of the highly concentrated hydrogen peroxide solutions (Ref. 4.5), with sodium stannate or 8hydroxyquinoline ("oxine") in the presence of a soluble pyrophosphate, or a phosphate-pyrophosphate mixture. A detailed discussion of hydrogen peroxide stabilizers is presented in Ref. 4.19 and 4.20.

Recently, the effect of the contaminants most commonly encountered in propellant-grade hydrogen peroxide on the stability of hydrogen peroxide was characterized (Ref. 4.21). Separate 90 w/o hydrogen peroxide solutions were contaminated with various concentrations of selected ions (Cr^{+3} , Fe^{+3} , Cu^{+2} , Ni^{+2} , PO_4^{-3} , SO_4^{-2} , NO_3^{-1} , Cl^{-1}) to determine their influence upon the stability of the hydrogen peroxide. Copper was found to exhibit the greatest effect (toward decreasing the stability) followed by iron, nickel, and chromium (Table 4.2). The anions exhibited no detectable influence in the concentration ranges studied when stability was measured by standard weight loss technique.

4.1.3.5.1

The total effectiveness of hydro-Stabilization Effects. gen peroxide stabilization depends largely on the type and quantity of stabilizer used, the initial H_{20} concentration and purity, and the container material type and surface pretreatment. Recent studies by Shell (Ref. 4.5) on storage in 5-gallon drums has demonstrated that commercially available 90 w/o hydrogen peroxide can be stabilized and stored in properly prepared vessels with a decomposition rate as low as 0.04 percent/year at ambient temperatures. The evolved gas at such rates can be contained in the vessel with relatively low ullage and at reasonable pressures for several years. The decomposition rate depends to an appreciable extent upon the container material and the surface finish. Pyrex effects the lowest decomposition rate. However, with the proper passivation and surface treatment, containers of ACLAR, Kel-F, 1260 aluminum
and electrolytic tin having low S/V demonstrated decomposition rates as low as 0.1 percent/year. The rates predicted for these materials as a function of S/V are shown in Fig. 4.5a.

Other examples of the end results of stabilization are illustrated in Fig. 4.1, 4.8, and 4.9. Figure 4.1 (Ref. 4.2) compares oxygen loss over a 24-hour period between commercially stabilized and unstabilized hydrogen peroxide as a function of concentration at 212 F. Figure 4.8 (Ref. 4.7) illustrates the reduction in AOL by commercial stabilization of 98 w/o hydrogen peroxide as a function of temperature. The effect of stabilizer quantity is illustrated in Fig. 4.9 (Ref. 4.8); the stabilizer used in this illustration was sodium stannate, which was added in varying amounts to hydrogen peroxide obtained from three different manufacturers.

4.1.3.5.2

Stabilization Requirements. The requirement for hydrogen peroxide stabilization is based on the end use to which the hydrogen peroxide will be applied. Generally, stabilizers are added to extend the storage life of the propellant, and as such, would appear to be desirable for all situations. However, when the end use of the propellant depends on its decomposition in a fixed catalyst bed chamber, the use of stabilization is severely limited by the poisoning effect of the stabilizer on the catalyst (Section 7). This is reflected in the two primary propellant specifications presently in use. The torpedograde propellant specification, MIL-H-22868, which requires long-term sealed storage propellant not subject to decomposition in a fixed-bed catalyst, specifies a large amount of stabilizers. MIL-P-16005D, which is the procurement specification for propulsion-grade hydrogen perolide, limits the total stabilizer content to a few mg/liter because of the usual application of this hydrogen peroxide grade in fixed catalyst beds. Hydrogen peroxide used in the che: ical pretreatment and passivation of hydrogen peroxide systems is sometimes

(Ref. 4.2) heavily stabilized to provide enough ions to complex all of the potential catalytic sites. Therefore, the quantity and type of hydrogen peroxide stabilization is dictated by the end use of the material.

Stabilization is usually effected by the hydrogen peroxide manufacturer as a condition of the procurement. The individual requirements should be discussed with the manufacturer and his assistance sought in determining the need for and type and amount of stabilization required. All hydrogen peroxide manufacturers indicate that conventional stabilization should be accomplished at the manufacturing site.

Emergency Stabilization. Stabilization of hydrogen per-4.1.3.5.3 oxide at storage sites has been utilized under "emergency conditions." The conditions, which necessitate this corrective action, are usually associated with self-heating of hydrogen peroxide storage systems due to excessive decomposition caused by unanticipated contamination of the system. One source (Ref. 4.22) has recommended such corrective action when the temperature of the hydrogen peroxide (without external heating) rises to a level 20 F greater than that of the surroundings. The rate of temperature rise also determines the urgency of the corrective measures. Another source (Ref. 4.3) considers it desirable to maintain time-temperature records of all storage units and recommends taking corrective action when the bulk temperature achieves a 2 to 3 F increase in temperature over the maximum ambient temperature. Corrective action is also recommended if the rate of temperature increase is greater than 0.5 F/hour. The more conservative methods limitations of Ret. 4.3 should result in fewer "incidents" and provide additional time to consider appropriate action.

> In estimating the necessity of corrective action based on AOL, Ref. 4.23 states that for a 30-gallon drum, a rate of more than 2 percent AOL/year (or 0.0054 percent AOL/day) is abnormal;

for a 500-gallon tank, a rate greater than 1 percent AOL/year or 0.0027 percent AOL/day is excessive and for flow systems a decomposition rate of 0.05 percent AOL/hour is the maximum permissible rate concurrent with a temperature rise of approximately 5 F above ambient conditions.

In the early stages of storage system self-heating, temperature rises may be counteracted by the use of water spray on the storage container. If adequate pure water is available, if container free space is available, and if moderate dilution is not critical to the end use, the most rapid cooling may be achieved by the addition of water directly to the hydrogen peroxide in the storage container. This cooling period allows greater flexibility and additional time for analysis, procurement, or preparation of stabilizer, but does not eliminate the need for further action.

When attempting to control a self-heating tank, a careful record of the temperature vs time should be maintained to help evaluate the effectiveness of the control technique. In projecting a time-temperature curve from previous experience, several assumptions must be made. Most of the approximations will overestimate the hazard and underestimate the time before eruption from the storage container. There are two major factors which may result in decomposition rate accelerations with time: (1) excessive temperature rise may result from the decomposition of the stabilizer, and (2) decomposition at the container walls may result in the formation of a gas blanket which prevents adequate heat transfer through the container wall causing additional temperature increase of the solution and increased decomposition. In the latter case, a temperature-indicating device on the outside wall of the tank will not indicate the temperature increase in the liquid but will indicate a lower temperature. Because heat transfer under these conditions may be somewhat erratic, this temperature is a poor indication of true liquid conditions.

The hydrogen perceide bulk temperature will lag changes in air temperature depending on the container size. A large tank which has been warmed during the day will require some time to cool because of the volume of solution. For a tank to be warmer than air temperature at night is normal and no cause for alarm. For the tank temperature to be gradually increasing toward an increased air temperature is normal. For the temperature of a tank not exposed to direct rays of the sun to be increasing in temperature when the air temperature is decreasing is abnormal. For the tank temperature to be consistently higher than ambient air temperature is normal.

In making a decision to stabilize a "hot system," the advice of the hydrogen peroxide manufacturer should be sought if at all possible. If the conditions are so critical that this contact cannot be accomplished, the guide of Paragraph 1.6.6 in "The Handling and Storage of Liquid Propellants - Hydrogen Peroxide" (Ref. 4.24) can be used:

1.6.6 Emergency Stabilization: The decomposition of hydrogen peroxide at an accelerating rate, as evidenced by increasing gas evolution and temperature may be brought under control by the following emergency stabilization procedure: add 1 pound of 85 percent phosphoric acid solution (in water) for each 100 gallons of hydrogen peroxide solution. Mixing is not necessary because the turbulence will disperse the stabilizer. After being thus stabilized and if the decomposition subsides, hydrogen peroxide may be stored in aluminum containers until consumed or otherwise disposed of. This solution must not be used in applications involving catalytic decomposition chambers, because the stabilizer will poison the catalyst.

4.1.3.5.4 <u>Effective Life of Stabilizers</u>. Storage in metal containers slowly destroys the stabilizing effect of stannate by precipatation out of the solution. This normally takes approximately 4 months for aluminum containers; in Pyrex containers the stabilizer is approximately 45 percent depleted in 4 months; however, in polyethylene, no loss of stabilizer was detectable (Ref. 4.20). The analysis of hydrogen peroxide solutions for

tin will also reveal varying concentrations depending upon the age of the solution when tested. Comparison of analytical reports from separate laboratories on the same solution must allow for this variation.

Hydrogen peroxide used by the Germans during World War II was usually 85 percent by weight $H_2 O_2$ and was stabilized with 8hydroxyquinoline in the form of the pyrophosphate or mixed with sodium pyrophosphate. This stabilizer slowly oxidized and in approximately 6 months had effectively disappeared. This organic stabilizer is normally considered superior to stannate in protection against iron.

4.2 MATERIALS OF CONSTRUCTION

Initial selection of materials for application in hydrogen peroxide storage and handling systems is based on a series of materials compatibility tests. These tests may range from an evaluation of a material sample under a set of general test conditions to the definition of the specific limitations of various pieces of hardware fabricated from a number of different materials. Although the compatibility of materials with a propellant is usually based primarily on the ability of the material to withstand chemical attack by the propellant (as expressed by corrosion rate), the emphasis in the evaluation of materials compatibility with hydrogen peroxide is placed on the effect of the material on hydrogen peroxide stability (as expressed by decomposition rate). Because hydrogen peroxide decomposition is a function of several variables, including material type, surface area, contamination, temperature, etc., it is essential that the selection of a material represent an evaluation of all of these potential effects.

The available technology on materials compatibility testing with hydrogen peroxide is summarized in this section. A description of the compatibility studies that have been conducted

and the criterin established by these results are used to provide a basis for the selection of materials of construction for hydrogen peroxide service. The final evaluation of a material and its suitability for an application involving contact with H_2^{0} is based on experience resulting from that application. In general, the recommendations of materials classification for H_2^{0} service contained herein are based on both the results of laboratory tests and on practical experience. In a few instances, practical experience has revealed results different from those of laboratory tests. Whenever this is the case, the greater consideration has been given to practical experience and conclusions are drawn accordingly. Criteria established for laboratory tests are based as far as possible on correlations with experience resulting from placing the materials in service.

> NOTE: The user of this handbook should be cautioned that the materials compatibility data presented herein should only serve as a basis for selection of materials for hydrogen peroxide service. Careful consideration should be given to the conditions of testing; the use of the material under a different set of conditions may have an entirely different effect. Meterials which are not suitable for use at high temperatures may be acceptable for uses at lower temperatures. Different fabrication procedures and passivation techniques may result in variation in compatibility classificattion. Even different lots of the same parts fabricated from "compatible" materials by the same manufacturer using the same manufacturing techniques have revealed variations in compatibility. Thus, it must be emphasized that any material used in hydrogen peroxide service be thoroughly tested and qualified under the conditions of its intended use before it is placed in service.

4.2.1 Compatibility Studies

Compatibility studies that have been conducted with hydrogen peroxide are described in terms of standard test procedures,

standard compatibility classification definitions, and standard rating criteria. Although the illustrated procedures and classifications do not necessarily reflect the most desirable methods for all purposes, they do represent the most typical (as noted in Ref. 4.25) of the general tests, classifications, and rating criteria presently employed.

- 4.2.1.1 <u>Compatibility Test Procedure</u>. The compatibility test procedure normally consists of three basic tests. An initial screening test is performed to eliminate all materials that cause gross decomposition of the hydrogen peroxide. The compatibility of the preselected materials with hydrogen peroxide is then determined by measuring a rate of H_2O_2 decomposition (as percent AOL) during an immersion of the materials in hydrogen peroxide (of a selected composition) for a stated temperature and time interval. The final evaluation in the compatibility test procedure is the determination of the stability of the hydrogen peroxide after contact with the material.
- 4.2.1.1.1 <u>Screening</u>. Prior to quantitative testing, a new or untried material should be immersed (after chemical pretreatment) in 75 milliliters of hydrogen peroxide in a passivated container at room temperature for 24 hours. Special attention should be directed to possible violent decomposition, combustion, solution, dimensional distortion, etc. If no unusual action occurs, the sample should be subjected to a further screening at 150 F for 24 hours. If no gross reaction occurs under these preliminary conditions, the material is further tested using the following technique.
- 4.2.1.1.2 <u>Sample Size</u>. In determinations of the compatibility of solid materials, a sample strip, 3 by 1/2 by 1/16 inches, is normally used for evaluation of both the liquid and vapor phases. For those materials that will be used in a continuously

wetted condition, a sample strip, 1-1/2 by 1/2 by 1/16 inches, is usually immersed in 75 milliliters of the hydrogen peroxide solution. This test condition simulates an apparent sample surface area of 1 sq in. per 42.8 milliliters of hydrogen peroxide (which approximates the 0.33 in. $^2/in.^3$ S/V of the wetted surface of a standard drum containing 250 pounds of $H_0 0_0$). If it is necessary to test a differently sized sample, retention of this apparent S/V will aid in comparison of the results with those of previous studies. In evaluating materials for specific applications, the S/V of the application should be duplicated if possible. In testing the compatibility of liquids with $H_0 O_0$, a 5-milliliter sample size is normally used; evaluations of greases are usually conducted with samples of 5-milliliter size which have been smeared on the inside of the test flask. It is important to record and report surface area of the test sample and the liquid volume of the H_0O_0 used. Vapor space or ullage should be minimized or held constant in comparison of different materials.

4.2.1.1.3

Cleaning and Passivation of the Test Container and

<u>Specimens</u>. Prior to use, all glassware (the test container) should be immersed in a 10-percent sodium hydroxide solution for 1 hour at room temperature, rinsed with water, immersed in a 10-percent HNO₃ solution (3-hour minimum), and finally rinsed with distilled water. The use of chromic acid cleaning solutions should be avoided, and passivation with hot concentrated (70+ percent) hydrogen peroxide is recommended.

Aluminum samples should be scrubbed with a warm detergent solution, immersed in 0.26 w/o (N/15) sodium hydroxide at room temperature for 15 to 20 minutes, washed, immersed in 45-percent nitric acid for 45 minutes to 1 hour at room temperature, and finally washed with distilled water. The samples should then be pretreated with 35 w/o H_0O_0 at 68 to 72 F for 8 to 24 hours.

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Stainless-steel samples should be degreased by scrubbing with trichloroethylene, rinsed with water, allowed to drip dry, and immersed in 70-percent nitric acid for 4 to 5 hours at room temperature. Then, the samples should be washed with clean water, washed with distilled water, and finally pre-treated with 35 w/o $H_2 O_2$. In instances where the stainless-steel specimens do not respond well to the preceding passivation technique (as noted by decomposition activity in the 35 w/o $H_2 O_2$), stainless-steel specimens may be passivated by the following alternate procedure which has been utilized successfully in the past:

- 1. Degrease by scrubbing with trichloroethylene and allow to drip dry.
- 2. Immerse the specimen in 2-percent $Na_2Cr_2O_7$ solution, wash twice with H_2O , and immerse in a 20-percent HNO_3 solution for 1/2 hour at 120 to 130 F. (This procedure has been questioned because contamination with chromate ions is possible.)
- 3. Flush with potable water.

4. Flush with distilled water and pretreat with 35 w/o H_2O_2 .

In the case of rusted stainless-steel surfaces and stainlesssteel welds, an acid pickling is required before satisfactory passivation can be achieved. The procedure for this treatment is as follows:

- Immerse in a 3-percent hydrofluoric acid-10-percent nitric acid solution for 30 minutes at 100 k, or 2 to 3 hours at 65 to 70 F.
- 2. Flush with rotable water and scrub with a stiff brush to remove welding scale and rust.

3. Passivate by immersion in 70-percent nitric acid for 4 to 5 hours at room temperature, rinse with clean potable water, and finally rinse with distilled water. Expose the specimen to 35 w/o H₂0₂ at 68 to 72 F for 8 to 24 hours.

Plastics and elastomer samples should be thoroughly acrubbed in an 0.5-percent solution of a synthetic detergent, rinsed with distilled water, and immersed in a 10-percent HNO_3 -water solution at 68 to 72 F for 1 hour. The samples should then be pretreated with 35 w/o H_2O_2 .

During the final rinsing of all passivated specimens, the samples should not be touched with bare fingers; at this point only gloves or tongs should be used in sample handling. It is usually convenient to wash sample strips on a Pyrex funnel (as a handling medium), taking care to wash all areas. The strip should be dried between two sheets of filter paper at room temperature or in a 122 F oven and then placed in a test flask which is immediately capped with aluminum foil to eliminate possible contamination by dust, dirt, etc.

4.2.1.1.4

<u>AOL Determination by Weight Loss</u>. The specimen, prepared as described in the preceding paragraph, is placed in a passivated 100-milliliter Kjeldahl flask that has been rinsed with a small volume of hydrogen peroxide of the required strength. The flask is weighed to 0.01 gram and the desired quantity (usually 75 milliliters) of hydrogen peroxide of the desired strength is added to the flank. The flask is reweighed and the initial weight of hydrogen peroxide solution is recorded as the difference between these weights. At conclusion of the desired test, the flask and its contents are remeyed from the constant-temperature bath, cooled to room temperature and weighed. As a minimum requirement, these tests should be conducted in duplicate.

The percent of active oxygen lost is calculated as follows:

Percent Active Oxygen Loss =
$$\frac{W_1 - W_2}{CW_1 \times 0.470} \times 100$$

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The results of some compatibility tests (Ref. 4.10 through 4.16 and 4.18) have been based on H_20_2 concentration determinations before and after the tests. During these tests the active oxygen loss is determined by the expression

Percent AOL =
$$\frac{(W_1C_1 - W_2C_2)}{W_1C_1} \times 100$$

where

 W_1 , W_2 , and C_1 are as defined previously and C_2 is the final concentration of hydrogen peroxide.

NOTE: The term 0.47 in the first equation represents the weight fraction of available oxygen in 100 w/o $H_0 O_0$.

Qualitative observations are also recorded on such effects as discoloration of the hydrogen peroxide and apparent changes in the physical properties of the test material. The latter includes: (1) for metals--corrosion, staining, and any surface change during or after testing; (2) for plastics and elastomers-blistering, swelling, distortion, changes in flexibility, color, transparency, tensile strength, and tear resistance; and (3) for fabrics—changes in color, tensile strength, burning, and tear resistance.

4.2.1.1.5 AOL Determination by Gas Evolution. During compatibility tests where the AOL is small, probably the most accurate method of measurement is by gas evolution. This technique, which is described in detail in Ref. 4.26, involves the collection of the gas evolved during the test period in a small gas measuring buret. The long neck on the special test flask acts as an aircooled condenser to reduce loss of the hydrogen peroxide vapor. The peck is connected by means of small bore tubing to nozzles submerged under a few centimeters of water in a trough. Burets arc inverted over the nozzles to collect the gas. A multiple arrangement of differently sized burets with appropriate valving is used to permit selection of the proper size and additional volume without loss of any gas. The volume of gas collected is converted to weight of oxygen evolved by use of the relationships expressed in the perfect gas laws. The percent AOL is then computed from the following expression:

Percent AOL = 100 x weight of oxygen evolved/0.47 x $C_1 \times W_1$

where C_1 and W_1 refer to the original concentration of hydrogen peroxide in the test sample expressed as weight fraction and W_1 is the original weight of the test sample.

4.2.1.1.6 <u>Stability Determination</u>. The recommended procedure for stability determinations on the resultant hydrogen peroxide is the same as presented in the MIL-P-16005D procurement specification (Ref. 4.27). The stability of the H_2O_2 , which is obtained from the compatibility test flasks, is measured by determining the active oxygen loss (by either weight loss or gas evolution techniques) over a 24-hour period at 212 F.

In MIL-P-16005D the stability is expressed in percent AOL, although most procedures essentially express stability as (100-AOL) percent.

4.2.1.1.7

<u>Special Compatibility Test Methods</u>. A suggested procedure (Ref. 4.25) for determining the compatibility of protective clothing is performed on 4 by 4 inch clean test samples of "as received" material. The H_2O_2 is permitted to drop on the cloth sample at a rate of 4 milliliters per minute for ~ 1 hour. Results are evaluated by visual observation of any changes in the material during this period. To simulate soiled cloth," a swatch of the material is soaked in a 0.005 N KMnO₄ solution for 30 seconds and dried at 230 F for 1 hour. The test is then performed with the procedure used with the "as received"

Sealing compounds are tested (Ref. 4.25) initially for impact sensitivity while immersed in H_20_2 . Qualified (nonimpact sensitive) materials are then applied to the male threads of a plug and a nipple, which are assembled into a coupling and tightened with a torque wrench (using a 1200 in. 1b torque on stainless-steel assemblies and a 600 in. 1b torque on aluminum assemblies). After drying at room temperature for 24 hours to set the scaling compound, the assemblies are tested for leakage by charging them with nitrogen and immersing them in water. A maximum of 1200-psig nitrogen pressure is applied to a stainless-steel assembly and 500-psig pressure is applied to an aluminum assembly. The pressure at which leakage, if any, occurs is noted. The torque required for disassembly should be noted. The sealing compound may also be tested by coating 1-1/2 by 1/2 by 1/16 inch, clean, passivated metal strips of 1060 aluminum and 316 stainless steel on one side. After drying at room temperature for 24 hours, the strips are subjected to the normal strip compatibility test described in Section 4.2.1.1

Protective coating materials are usually evaluated in accordance with standard compatibility procedures. The coating is applied according to the manufacturers' specifications to standard test strips and is tested as generally described in Section 4.2.1.1. (It is important to differentiate between compatitiblity of the coating material and the effectiveness or covering ability of the coating on the base metal.) The percent AOL is determined, and visual observations of any physical changes in the coating are noted. Other variations of this coating test involve filling a coated steel cup with $H_0 0_0$, inverting a second coated cup on top of the cup containing the liquid, and maintaining two such sets at 86 and 150 F for 1 year and 1 week, respectively. A final laboratory test involves the half-filling of a coated 5-gallon container with II_{00} and allowing the test container to stand at room temperature in the laboratory or in a controlled temperature room. Containers with a 12-inch ID and 12 inches high with a 2-inch vented opening in the top are recommended for a 12-month test duration. Hydrogen peroxide concentration is determined initially and bimonthly thereafter for both the cup tests and the container test. Prior inspection of the coating for blisters or pinholes should be made before the tests are initiated.

A method for determining the compatibility of bladder materials has been suggested in Ref. 4.28. In this procedure, the bladder is immersed in concentrated HNO_3 for 10 days at the maximum potential application temperature (110 F, Ref. 4.28). At the conclusion of the immersion test, the bladder is removed and the $IINO_3$ is evaporated to dryness. The "residue" is treated with the test H_2O_2 at 140 F; acceptance of the bladder material depends on the resultant nonreaction between the "residues" and the test H_2O_2 .

4.2.1.2 <u>Hydrogen Peroxide Materials Compatibility Classifications</u>. The results of the various laboratory materials compatibility evaluations and of application experience have shown that materials can be classified into various categories based on their contemplated types of use in hydrogen peroxide service. All materials need not be suitable for indefinite storage because in applications requiring only short-time contact with H_2O_2 , materials of a lesser degree of compatibility can be employed. To facilitate selection on this basis, materials have been generally classified according to the types of applications for which they are suited.

A system of four classes has generally been adopted (Ref. 4.25, 4.29, and 4.30) for materials for hydrogen peroxide service. These classes are arbitrary but they do provide a standard for rating materials compatibility with H_2O_2 . These classes are:

- <u>Class 1</u>: Materials Satisfactory for Unrestricted Use with H_2O_2 . Such service includes long-time contact with the H_2O_2 . Typical use is for storage containers.
- <u>Class 2</u>: <u>Materials Satisfactory for Repeated Short-Time Contact</u> with $H_2_0_2$. Such materials are used for transient contact with the $H_2_0_2$ prior to storage of the $H_2_0_2$, or limited contact with the $H_2_0_2$ prior to use. Such contact is not to exceed 4 hours at 72 C (160 F) or 1 week at 22 C (70 F). Typical uses are for valves and pumps in $H_2_0_2$ transfer lines and feed tanks.
- <u>Class 3</u>: <u>Materials Which Should be Used Only for Short-Time Contact</u> with H₂O₂. These materials should be used only where neither a Class 1 nor Class 2 material would suffice. These materials can be used for repeated contact, but a single use period should not exceed 1 minute at

160 F or 1 hour at 70 F. An example of a Class 3 application is materials for use in a flow system. The hydrogen peroxide should be consumed in the application or disposed of after the test because contamination of hydrogen peroxide solutions with Class 3 material is usually sufficient to render it unsuitable for storage. Many Class 3 materials indicate satisfactory room temperature service; however, the material should be checked prior to use.

- <u>Class 4</u>: Materials not Recommended for Use with $H_2 0_2$. These materials (1) cause excessive decomposition of $H_2 0_2$ even on short-time contact, (2) are attacked or deteriorate on contact, (3) yield corrosion or deterioriation products which cause excessive decomposition of $H_2 0_2$ on subsequent contact, or (4) form impactsensitive mixtures with concentrated $H_2 0_2$.
- <u>Other Classifications</u>: Clothing materials are classified as "suitable" or "unsuitable". Within the classification of "suitable," choices are made on the basis of resistance of the material to deterioration in contact with the $H_2 O_2$.
- 4.2.1.3 <u>Test Evaluation Criteria</u>. An explanation of typical (Ref. 4.25) criteria used to evaluate the materials compatibility tests described in Section 4.2.1.1 (as well as results from application experience), and to rate the results in the appropriate classifications per Section 4.2.1.2 is illustrated in Table 4.3. Because the illustrated classification system is general for all types of materials of construction that may be used in hydrogen peroxide storage and handling systems, and the classification limits were selected arbitrarily, more precise limits should be established for specific applications. The application of the criteria of Table 4.3 to results from

compatibility tests are usually subjected to the following modifying considerations (Ref. 4.25):

- If there is any doubt as to whether a material should be in a given category, e.g., Class 1 or 2, the material is placed in the lower category, e.g., No. 2.
- 2. If the results of practical experience are at variance with the results of laboratory tests, then the greater weight is given to the practical experience in selecting the classification.
- 3. The main distinction between Class 2 and 3 is the possible effect on the stability of the H_2O_2 . If there is any doubt as to whether the stability might be affected, the material is placed in Class 3. Slight deterioration of the materials causing foreign matter to enter the H_2O_2 might cause decreased stability of the H_2O_2 .
- 4. Numerical limits for the various classes are approximate. Class 1 materials would fall within rather narrow limits, while Class 2 materials have much broader limits. In general, the higher the active oxygen loss for a particular material, the less reproducible are the results.

The AOL reported during H_2O_2 materials compatibility tests has numerous meanings in the study of hydrogen peroxide solutions. This report uses the expression "Active Oxygen Loss" (AOL) or percent AOL as defined in the government procurement specifications for hydrogen peroxide; this definition may be simply explained by the following mathematical expression:

Percent AOL = 100 $(H_2 O_2 \text{ weight loss during testing})/$ initial $H_2 O_2$ weight 1 0.470

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The weight loss is measured over a specific period of time at a controlled (and known) temperature. The generally accepted criteria for AOL vs compatibility rating are presented in Table 4.3.

Hydrogen peroxide stability, which is usually reported as percent stability, is the test used to determine the relative homogeneous decomposition reaction rate of hydrogen peroxide solutions. As applied in the materials compatibility tests, it is essentially a measure of the degree of contamination of the solution by the test material. This is determined by essentially measuring the AOL of the H_2O_2 during a 212 F exposure for 24 hours. The stability is then expressed as (100-AOL) percent.

Another rating criteria for $H_0 O_0$ materials compatibility is that of impact sensitivity. Liquid and powdered materials, including solids which might yield finely divided particles in service such as a carbon bearing ring, must be evaluated for possible sensitivity to impact when in intimate contact with hydrogen peroxide solutions. This impact sensitivity is determined by subjecting varying proportions of the material and H_00_0 to the impact of a weight dropped from a specified height. Illustrations of some impact sensitivity results are presented in Table 4.14; however, no weight-distance data were reported for many of the positive results. Because there are appreciable variations in impact results with various machines, operators, and facilities, these data are not quanitative, but simply indicate that under some conditions sensitive situations are possible with the noted materials. In some impact test procedures, a small amount of wetting agent is added to the H₀0₂ to simulate the intimate contact which might be created by mechanical load (such as might be found in pump packings or bearings). This practice, however, is not employed consistently. Any material which is impact sensitive when in contact with $H_2 O_2$ in any proportion is

considered a Class 4 material. The criteria of impact sensitivity of a material in contact with the H_2O_2 is the incidence of any positive detonation on the basis of a minimum of 10 trials. A mixture which gives negative results during the initial 10 valid tests is tentatively considered to be nonimpact sensitive unless later tests produce a positive result.

During tests of protective coating materials, special care is necessary (and perhaps additional criteria are necessary) if the test is to determine the compatibility of the coating material and not its efficiency or covering power. Ideally, coating materials should first be tested alone or as coatings on known Class 1 base metals; after these tests are completed, the materials should be tested as coatings on the particular base metal contemplated for end use in the composite assembly. Criteria (Ref. 4.25, 4.29 used in expressing the results of coating tests will depend on the type of service contemplated; the coating must yield the class of compatibility required for the application and must continue to tightly adhere to the metal during the standard compatibility tests. Exact criteria for these coating tests have not been established; but it is believed that the coating should show no blisters or deterioration in contact with either the liquid phase or vapor phase for a period of 1 year at 86 F or 1 week at 150 F (or at the desired service temperature). Splash resistance coatings to be used as protection for surfaces in $H_0 0_0$ installations should not react violently with the H₂O₂ and should not blister during a period of 24 hours at room temperature.

Clothing materials are normally classified (Ref. 4.25) according to recommendations for their use. Criteria for such classification are as follows:

First Choice: The material does not burn on immersion or during drip tests in the "as received" or "soiled" condition; the material fibers are not appreciably weakened after immersion for 1 month in $H_2^{0}_2$.

- <u>Second Choice</u>: The material does not burn on immersion or during drop tests in the "as received" stage; however, the material may show some tendency toward burning in the "soiled" state and its fibers may be significantly weakened.
- <u>Not Suitable</u>: The material either causes excessive decomposition of the H₂O₂, burns, dissolves, and/or disintegrates in either the "as received" or "soiled" state.

Selection of materials for use as joint scaling compounds with $H_2^{0}_2$ is based primarily on the impact sensitivity of the compound with the appropriate concentration of hydrogen peroxide. The impact tests should show no positive results with a 3 kg-meter impact at room temperature. Decomposition of the $H_2^{0}_2$ in contact with the compound is of secondary importance; however, the compound must not act as a strong $H_2^{0}_2$ decomposition catalyst and the compound should not be a Class 4 material. These compounds should also show zero leakage during the tests described in Section 4.2.1.1.7.

4.2.2 <u>Materials Compatibility</u>

A large number of laboratory hydrogen peroxide materials compatibility tests and the experience provided by a number of years of H_2^{0} usage have resulted in a comprehensive knowledge of the effects of certain materials on hydrogen peroxide. These materials compatibility data are summarized in Tables 4.4 through 4.31a. Although the most extensive compilation of materials compatibility data was taken from Ref. 4.25, the most recent data are those of Ref. 4.10 through 4.18.

In general, the compatibility data reported in these tables are tests for usage with 90 w/o H_2O_2 ; but it has been found that materials suitable for ≥ 90 w/o H_2O_2 service are usually suitable for use with lower concentrations. In a few instances, materials that are unsuitable for ≥ 90 w/o H_2O_2 service have been found suitable for service at lower concentrations. However, it is uncertain as to whether materials suitable for 90 w/o H_2O_2 service will be suitable for use in higher concentrations. Therefore, some compatibility data have been generated (Ref. 4.9, 4.25, 4.29) on a selected number of materials with 98 w/o H_2O_2 and are presented in Tables 4.4, 4.5, 4.8, 4.19, and 4.31.

The results presented in these tables indicate that, in general, the materials suitable for 90 w/o $H_0 O_0$ service are suitable for 98 w/o $H_2 \theta_2$ service. Some plastics are attacked more severely by the more concentrated $H_0 O_0$ solutions. With metals, 98 w/o H_{00} generally showed less active oxygen loss than did 90 w/o H₂O₂. This apparent greater stability of 98 w/o hydrogen peroxide in the presence of metals was found to result in in-creased storage stability in the pure aluminum shipping drums which are used for all hydrogen peroxide shipments. The data in Tables 4.4 through 4.18 are presented and classified according to the criteria of Section 4.2.1.2. Materials compatibility presented in Tables 14a. and 4.19 through 4.31a are results of studies conducted under special and specific conditions. These results are presented only in terms of measured values and no attempt has been made to classify the results to meet a specific set of standards.

The results presented herein are based on the conditions noted. Different conditions (i.e., temperatures, passivations, fabrication techniques, etc.) can result in significantly different results. The data should be used as a basis for materials selection; however, all systems after construction or fabrication should be tested for compatibility prior to actual use.

The materials compatibility data presented in Tables 4.4 through 4.31a are summarized with respect to various types of materials in Sections 4.2.2.1 through 4.2.2.10, and various controlling effects in Sections 4.2.2.11 through 4.2.2.14.

4.2.2.1 <u>Aluminum and Aluminum Alloys</u>. The results of a large number of compatibility tests of aluminum alloys with 90 and 98 w/o are summarized in Tables 4.4, 4.20, 4.21, and 4.31. These results indicate that several aluminum alloys meet the stringent requirements of Class 1 materials. Of these, aluminum alloys with low copper content such as 1060, 1160, 1260, 5254, and 5652 have shown excellent service. Minimum corrosion has been experienced with 1060 alloy, and this alloy is the one most frequently used in storage containers. The higher strength 5254 and 5652 aluminum alloys have shown excellent service in shipping drums, tank trucks, and tank car fabrication materials. The 5254 alloy, in various grades of temper, has been used successfully in several missile applications.

> Aluminum 1000 has been used extensively for standard piping despite its low tensile strength and ultimate yield. Where pressures may be involved which are too great for standard pipe, the use of schedule 90 pipe of 1060 aluminum is recommended. Alternate choices of piping material are 5254 and 5652 aluminum.

Other aluminum alloys with low copper content, such as 6061 and 6063, have shown Class 2 compatibility. The high strength structural alloys such as 2014, 2017, and 2024 are unsuitable for service with H_2^{0} because of corrosion and a high rate of decomposition of the H_2^{0} in contact with them.

Aluminum casting alloys 43 and 356 have been employed successfully for pump and valve bodies for many years although some corrosion generally does occur. The low copper casting alloy

B-356 has indicated Class 1 compatibility during laboratory tests with H_20_2 , and satisfactory service experience has resulted with various H_20_2 concentrations.

Some testing has been conducted on hard-coat aluminum. The laboratory results from tests of 10-, 20-, and 30-minute penetration on aluminum alloy 6061 indicated Class 3 compatibility with H_20_2 . Use experience is very limited, but it may be desirable to apply hard-coat aluminum in place of 300 series stainless steel in equipment that is fabricated predominantly of aluminum. Experience is needed to determine the resistance of hard-coat aluminum to corrosion in service with intermittent wetting.

Most cases of aluminum corrosion in H_2O_2 systems result in localized pitting (cell effect) because of the presence of foreign materials, and hydrated aluminum oxide formed during wetting and drying cycles. The presence of chloride ion in hydrogen peroxide results in aluminum pitting; however, if a 7:1 ratio of nitrate ion to chloride ion is present, almost complete elimination of corrosive action is obtained (Ref. 4.25). Therefore, the nitrate ion is added to H_2O_2 to counteract the possibility of chloride damage to aluminum.

4.2.2.2 <u>Stainless-Steel Alloys</u>. The compatibility of stainless-steel alloys with 90 and 98 w/o H_2C_2 is presented in Tables 4.5, 4.19, 4.22, 4.23, 4.24, 4.25, 4.31 and 4.31a. Although there are no Class 1 stainless steels, several Class 2 stainlesssteel alloys are known. In general, the wrought or forged AISI 300 series stainless-steel alloys with proper passivation are suitable for Class 2 service with hydrogen peroxide. Cast stainless steel is generally unsatisfactory for H_2O_2 service unless special casting techniques are followed. It has been reported that some formular of the type 303 free machining alloy are not suitable for use with $H_{20}O_2$. Therefore, prior to use of this alloy, it is suggested that a sample of the lot to be used be evaluated for compatibility with the pertinent $H_{0}O_p$ grade.

Cryogenically prestrained 301 stainless steel offers high yield (200,000 psi) strength and a 280,000 tensile strength. The test data in Table 4.5 reveal that this treatment results in a material that has a borderline Class 1/Class 2 compatibility with 90 or 98 w/o H_0O_0 .

Experience with use of the wrought 300 series stainless steel for scamless tubing, scamless pipe, fabricated equipment for piping systems, and welded tanks has been satisfactory. The use of 300 series stainless steel is recommended for highpressure flow systems and applications where the presence of aluminum oxide, which is difficult to avoid in P_2O_2 handled in aluminum, cannot be tolerated.

Usually hydrogen peroxide test tanks have been fabricated of 347 stainless steel which contains miobium (columbium) as a welding stabilizer. More than 15 years of satisfactory service have been achieved at FMC with these tanks in the handling of 90 and 98 w/o H_2O_2 . Although 321 stainless steel has been used in some systems, the titanium welding stabilizers have a slight catalytic effect upon the H_2O_2 . The extra-low carbon 304 stainless steel has been shown to be an excellent H_2O_2 tank material. This material demonstrates good compatibility with H_2O_2 at room and elevated temperatures.

An extensive amount of testing has been conducted on precipitation-hardening stainless-steel älloys such as AM-350 and 17-7 PH alloys. The AM-350 material has given excellent

service in flight vehicles; however, the material hardness must be less than 42 Rc (Rockwell Hardness Scale C), or there is an increase in H_2O_2 decomposition and development of metal rusting. The '~ 7 PH material has proved very successful with 70 w/o H_2O_2 and moderately successful with 90 w/o H_2O_2 ; however, a special presivation treatment (Ref. 4.31) is required to achieve a Class 2 rating for this material. Surface finishing of the sample with 120-grit abcasive compound was found to be effective in improving the compatibility of this alloy.

The AISI 400 series stainless steels, whether anrealed or in the heat-treated form, 40 to 58 Rc, will rust if the surface finish is greater than 10 rms. This type of corrosion phenomenon indicates that it is necessary to examine samples from compatibility tests after the actual test has been completed. It is suggested that this examination should be made at 24-hour and 1-week intervals of exposure to air after the sample is dried. It has been found that immersion of a sample in distilled water for 24 hours following the compatibility test will tend to induce this type of stainless-steel corrosion.

In general, stainless steels suitable for $H_2^{0}_2$ service, i.e., AISI 300 series and precipitation-hardening alloys, are nonmagnetic or only weakly magnetic. Therefore, any metals that are magnetic should be suspected of incompatibility with $H_2^{0}_2$. For example, iron, mild steel, and AISI 400 series stainless steels are magnetic and are not suitable for $H_2^{0}_2$ service. Any unknown material that is magnetic is of questionable compatibility with $H_2^{0}_2$ until completely tested.

It has been determined experimentally that, in general, the smoother the material finish of H_2O_2 system components, the better the compatibility. Finishes should not exceed 32 rms,

and should be smoother if possible. This is especially important in stainless-steel storage and handling systems; a rough spot in a tank, for example, will cause $H_2 \theta_2$ decomposition. This condition can be avoided with proper design and system fabrication. In addition, it has been noted (Ref. 4.32) that stainless-steel alloys require cleaning and repassivation after extended service in $H_2 \theta_2$ to limit the gradual buildup of decomposition activity.

4.2.2.3 <u>Pure Metals and Other Metal Alloys</u>. The compatibility of pure metals and various other metal alloys with 90 w/o hydrogen peroxide is presented in Tables 4.6 and 4.7, respectively. Many metals other than the aluminum and stainless-steel alloys have been evaluated, but few have been found suitable for H_2O_2 service. Silicon, tantalum, tin, and zirconium are exceptions. Of these, tin has been utilized to the greatest extent, i.e., for gaskets and as a solder for stainless steel.

> Most other metallic elements exhibit catalytic action in contact with H_2O_2 . This is especially true of silver, lead, cobalt, and platinum. Iron oxide causes rapid catalytic decomposition of H_2O_2 . Titanium and zinc are severely attacked by the H_2O_2 .

A few alloys have shown suitability for Class 3 service end might, with other passivation techniques, be made suitable for Class 2 service; however, additional research would be required in this area. Unfortunately, none of the extreme hardness metals tested have shown suitability for even Class 3 service, except the 10 rms finish 440C stainless steel (50 to 58 Rc) and hard-bearing chrome plating (58 to 70 Rc).

4.2.2.4 Plagtics and Rubber Compounds. An excellent summary of the results of compatibility tests with various plastic and rubber compounds, presented in Tables 4.8 through 4.12 and 4.26 through 4.30, was presented in Ref. 4.25. Because plastics and rubber compounds are organic in nature, the compatibility with hydrogen peroxide varies considerably. Even those materials which have shown excellent compatibility with 90 w_i o $\Pi_0 \theta_0$, both in the laboratory and in use, may be suspect when new conditions are met which have not been encountered or simulated previously. Conditions which may lead to reaction between a plastic material and $W_{\rm p} \theta_{\rm p}$ are extremely varied and difficult to predict or to evaluate in the laboratory. However, the following one generalization must always be considered: the combination of high-strength hydrogen peroxide, organic materials, and heat from either an external source or from $H_0 \theta_0$ decomposition may lead to an explosive reaction.

> The compatibility of plastics often is not determined by the chemical nature or composition of the polymer itself but is determined by the impurities present in it Contamination of molding materials during handling and storage with dirt, dust, and other organic materials as well as inclusion of metal chips or granules can cause noticeable decomposition reactions. A surface speck of foreign material originating in the mold may initiate a reaction with hydrogen peroxide with sufficient heat release to initiate reactions with the polymer. Laminated plastics or compression molded materials which contain minute pores or air pockets may be incompatible because of the accumulation of organic material in these voids. This is usually the result of some cleaning or rinsing process involving organic materials.

For these reasons, there may be differences in the compatibility of plastics from different manufacturers and even lot-to-lot variations in a given polymer material from the same manufacturer. Lot-to-lot variations are usually much less noticeable than

differences caused by various processing and handling techniques. Compatibility of plastic and other polymeric or composite materials are therefore usually associated with a manufacturer's name.

Clean polyethylene has been safely utilized during laboratory work, and polyethylene has proved to be a satisfactory material for use with 27.5 through 50 w/o $H_2 O_2$. However, polyethylene at its melting temperature has ignited on contact with concentrated hydrogen peroxide and is therefore not recommended for concentrations in excess of 70 w/o $H_2 O_2$. Although no information has been obtained, this possibility should also be considered in the use of other combustible polymers for service at temperatures approaching their melting point or thermal decomposition temperature.

High-temperature service materials such as Kel-F and Teflon have not demonstrated any indication of reaction with hydrogen peroxide over the entire concentration range at ambient temperature conditions. These materials were also found to be compatible with 90 w/o H_00_2 up to 270 F. There is no known reason to avoid using those materials in any ${\rm H_{0}0_{\odot}}$ service where the $\Pi_{\underline{0}} \theta_{\underline{0}}$ will remain below its normal atmospheric boiling point. However, mixtures of these materials with other materials must always be evaluated because reactions are varied and the compatibility of any added ingredient must always be considered. Glass-filled Teflon is acceptable, carbon-filled Teflon may be acceptable, and asbestos-filled-Teflon is not acceptable. Kel-F, Aclar, and "virgin" Teflon are the most compatible plastic material, at high operating temperatures and should be utilized wherever the physical properties are suitable. It is especially reconnended that these materials, which have exceptionally low coefficients of friction, be applied in $il_{0}0_{0}$ service as dynamic bearings

and seals without lubricants wherever possible because of the limitations of the available lubricants. Special high-pressure, 2-hour compatibility tests at 132 C (270 F) and 1000 psig with 90 w/o H_2O_2 demonstrated that Teflon and Kel-F are not adversely affected. The AOL for these 2-hour periods is comparable to the percent AOL experienced at 66 C (151 F) in 7 days. Filled plastics such as Kel-F elastomers, 9711 Silicone, and Vitons show swelling at the high test temperatures.

Kel-F elastomeric compounds are generally inferior to Kel-F itself in compatibility with H₂0₂, and most of these materials tested have met the Class 2 criteria.

Aclar, Mylar, and Dacron plastics have demonstrated excellent compatibility with H_20_2 in the laboratory. Dacron has been used fairly extensively as cloth for protective clothing and reinforcement of other plastics which contact H_20_2 . Mylar film has been used very little because it does not heat seal, and a compatible adhesive has not been found. Aclar is heat sealable and is being used in some applications. Use of these materials, particularly Aclar 33C film, as bag liners for storage containers is currently under study (Ref. 4.9).

There are many plastic materials that break down upon extended exposure (> 7 days) to 90 and 98 w/o H_20_2 at elevated temperatures (151 to 165 F) but exhibit no effect upon 24-hour exposure. The majority of Viton A, Viton B, Fluorel 2141, and Fluorel 4121 compounds show this effect. However, most service applications are at ambient temperature conditions 10 to 50 C (50 to 120 F) and these same plastics and rubbers demonstrate excellent service at these temperatures.

Viton A and Fluorel materials demonstrate Class 1 ratings in 10 to 49 C (50 to 120 F) service. Viton A 271-7, produced by Parker Hannefin Corporation, has demonstrated excellent service as 0-rings in 90 and 98 w/o H_20_2 solenoid values and for component seals. Seals Eestern Corporation's Fluorel 2141 and Fluorel 4121 0-rings, seals, and bladders have proved satisfactory in the moderate temperature range. David Clark Company's Omni (Viton A) has proved useful as 0-rings and when used to impregnate glass or Teflon cloth, produces a material which is satisfactory for use as an H_20_2 splash cloth or curtain (Table 4.8).

Polyvinylchlcride-based materials vary in their reaction with H_2O_2 because of the plasticizer content and because other additives such as fillers and pigments are used. It is generally true that such additives reduce the compatibility of the compound with H_2O_2 . Koroseal 700 (molded) has been extensively used as a gasketing material in low-pressure service. The formula for this material was developed specifically for H_2O_2 service. Koroseal 116 and 117 (molded) are both inferior to Koroseal 700 (molded) for H_2O_2 penetrates into the sheet and develops gas pockets which separate the layers of material. Calendered materials which do not exhibit this condition can only be fabricated of materials which are absolutely impermeable to H_2O_2 .

Polyvinylchloride plastics are generally permeated by 90 w/o H_2O_2 . This has been determined for both molded and plastisol types of polyvinylchloride. The absorption of H_2O_2 is indicated by the fact that the materials which are generally clear or translucent turn an opaque white after a period of contact with the H_2O_2 . The polyvinylchloride material containing

absorbed H_2O_2 may be shock sensitive although no adverse experience of this nature has ever been encountered. Polyvinylchloride plastics will also leach chloride ion into the H_2O_2 which will cause corrosion of aluminum even when present in minute quantities.

Silicone rubber elastomers also vary considerably in compatibility with hydrogen peroxide because of the use of pigments and fillers in some compounds. However, there are a number of these compounds, mostly unpigmented, which indicated Class 2 compatibility with H_2O_2 . Of these, Silastic 9711 has demonstrated the most satisfactory compatibility with 90 w/o H_2O_2 . Silascic 9711 is used in various applications as an O-ring, gasket, hose, and bladder material. Although silicone rubbers are not subject to heat sealing, welding techniques have been developed and Silastic 9711 welded with Silastic 2200 indicated satisfactory compatibility with H_2O_2 .

The compatibility of several possible bladder materials is reported in Tables 4.26 through 4.28. Compatibility tests of 90 w/o $H_2^{0}0_2$ at 110 F for 10 days with Silastic 9711 (surgical grade), Fluorel 2141, and Aclar 22C (Ref. 4.17) revealed Aclar to be the most compatible material. A similar study involved the use of Vicone 185, alone and as part of a composite structure with aluminum in addition to the preceding materials. Vicone 185 was not quite as satisfactory as Aclar in the pure state. In the composite structures, Vicone 185 with aluminum exhibited the highest decomposition rate while Fluorel with aluminum exhibited the most stable combination. Following compatibility tests conducted at 160 F, both Silastic and Fluorel were badly blistered (Ref. 4.12 and 4.15 through 4.17). These results are in slight conflict with Ref. 4.25 which reported the most compatible bladder material readily available for 90 w/o H_00_0 is North

American Aviation's Vicone 185 (Table 4.26). Other satisfactory bladders are the B. F. Goodrich Company's 9711 high purity silicone material, and duPont's thin film FEP Teflon (heat sealed). There are other materials that show promise as bladder materials, such as Viton A and B.

Some adhesive agents for bonding silicone rubber Silastic 9711 to aluminum 6061 were evaluated in the form of finished washers. Chemloc 607 appeared to be most suitable and DCA 4094 is only slightly inferior to it. With the adhesive present, compatibility results were reported to be poorer than would be expected for the silicone rubber and aluminum alone; however, a control test was not run for comparison.

Silicone rubbers that indicate Class 2 results for H_2O_2 service are considered to be superior to polyvinylchloride materials because the possibility of chloride leaching is eliminated and, in general, the flexibility of silicone rubbers varies much less over a wide temperature range. Permeability studies of silicone rubber to H_2O_2 indicate slow seepage and layer separation because of oxygen evolution in the pores. Because of the permeability of silicone rubber to hydrogen peroxide, prolonged contact even at atmospheric pressure may make the silicone rubber susceptible to rapid oxidation should a flame be encountered.

Most of the plastic materials discussed can be utilized as gaskets in the proper type of flanges. However, there are two reinforced Teflon gasketing materials which have exhibited satisfactory compatibility, and should find application. Korda-flex, a Teflon-coated glass fabric, has indicated Class 1 results and Duroid 5600 yielded Class 2 results. Actual use experience has not yet been gained with either of these materials.

Several tests have been made of built-up diaphragms, usually a plastic and cloth sandwich type construction using Dacron or glass fabric. The compatibility of these diaphragms with 90 w/o $H_2 0_2$ has been satisfactory when using Omni (Viton A) impregnated glass, Teflon, or Dacron cloth. Polyethylene and Kel-F sheet diaphragms have been utilized successfully in pressure transducers with water on the pressure gage side. Stainless-steel diaphragms have also been utilized satisfactorily. In designing equipment for $H_2 0_2$ service, it is best to avoid diaphragms if possible. If a diaphragm must be used, there should be adequate testing of diaphragm materials with $H_2 0_2$ before the materials for its construction are chosen.

4.2.2.5 Porous Materials. The results of compatibility tests of 90 w/o hydrogen peroxide with porous materials, presented in Table 4,13, are summarized in Ref. 4.25. In this summary, it was indicated that porous materials are generally of interest for use in the filtration of hydrogen peroxide to collect any solid foreign material which accidentally enters into the H₂O₂. Whereas a minor amount of catalytic dirt might be tolerated in a large tank of H_00_{2} , collection of this dirt on a filter in a relatively small quantity of ${\rm H_00}_{
m o}$ could cause considerable decomposition. Therefore, care must be exercised to keep the use of filters to a minimum and to select filtering media that will not readily react with decomposing $H_0 O_0$. Therefore, for concentrations of H_{00} above 50 w/o, low melting materials such as Dacron are not recommended for filter elements (Ref. 4.25).

Some porous porcelain bacteriological filters have exhibited good serive in H_2O_2 power system refueling operations. Tests indicate that porous Teflon and Kel-F may be suitable for use as filter media.

Stainless-steel filters fabricated of wire, either wrapped or woven, yield Class 2 or 3 results. When using these materials for filter elements, welding should be kept to a minimum. Filters made of 316 stainless steel have been used successfully in various H_2O_2 operations, such as fueling operations involving flight vehicles. Porous stainless-steel elements formed by sintering powdered metal have not proved satisfactory for H_2O_2 service.

Filtros C has been used extensively for filtering all concentrations of $H_2 O_2$ and for filters on storage and shipping tank vents, but it is fragile and difficult to back-wash. Replacement of this material for both uses is being investigated. It is not recommended for power-system use.

When using filters for H_2^{0} service, it is important to keep them clean and to examine them frequently. When dirt on a filter is allowed to dry, oxidation may occur which may cause increased catalytic action. Therefore, it is a good policy to flush a filter before use, and to back-wash an H_2^{0} filter immediately after use with distilled or clean water.

4.2.2.6 <u>Lubricants</u>. The compatibility of various lubricants (Ref. 4.25 and 4.33) with 90 w/o H_2O_2 is presented in Tables 4.14 and 4.14a. The test results indicate that only the fluorinated hydrocarbous are sufficiently compatible with 90 w/o H_2O_2 to be considered. Even these materials can probably react with the 90 w/o H_2O_2 if there is sufficient force or heat applied to the mixture. However, the use of fluorinated hydrocarbons has been satisfactory in transfer pump packing glands in use with 300 series stainless-steel shafts.

The prisent fluorinated hydrocarboxs do not possess good lubricating qualities, and their viscosities vary widely with temperature. Some lubricity additives were evaluated several years ago, but none was completely satisfactory because of the difficulty of attaining stable emulsions. In addition, use of fluorinated hydrocarbons as lubricants for aluminum threads or in conjunction with aluminum with a high surface area in applications where that may be created (which is a natural condition in all applications requiring lubricants) may lead to detonating reactions without any $H_2^{0}0_2$ present. Two instances of such an occurrence, one during a thread cutting on aluminum pipe using Fluorolube as a cutting lubricant and the other when fluorinated hydrocarbon was used as a thread compound on the aluminum head bolts of a decomposition chamber, have been reported. This reaction was reproduced in the laboratory by dropping a fluorinated hydrocarbon on heated aluminum in powder form.

There also is some indication that presence of a fluorinited hydrocarbon in intimate contact with an organic material and 90 w/o H_20_2 may cause increased sensitivity. Although this phenomenon has not been adequately evaluated, it appears that the use of fluorinated hydrocarbons in conjunction with organic materials in concentrated H_20_2 service should be avoided unless the specific system to be used has been adequately tested. The best practice if possible, is to eliminate the need for lubricants.

In evaluating lubricants for H_2O_2 service, the results of the impact test are of greatest significance. However, there is no standard impact tester, and the reproducibility of most testers is marginal. The modified Bureau of Mines Impact Tester used for the results reported in Table 4.14 is simple to use and has been proved to be generally reliable; but it is subject to variations in results with different operators, and the condition of the anvil plunger or weight is another variable. Despite the practice of regular calibration of the tester with a "known" mixture of ethyl alcohol and 90 w/o H_2O_2 in equal-volume propertions, poor reproducibility has been experienced. Because of this situation, it is thought that any positive detonation should be sufficient to place a lubricant in Class 4 for H_2O_2 service. Thus, even though a lubricant or grease may pass all tests with negative results and then give a positive result during a later check test, it will be classed as unsuitable for H_2O_2 service.

Pump packing lubrication is one problem which can be overcome by the use of mechanical seals which require no lubrication. Seals fabricated of 300 series stainless steel with ceramic and glass-filled Teflon mating surfaces and cooled with the liquid H_2^{0} being pumped have been successfully applied to centrifugal transfer pumps for several years.

Ceramic and Refractory Materials. A summation of the re-4.2.2.7 sults of compatibility tests of 90 w/o hydrogen peroxide with ceramic and refractory materials, which are presented in Table 4.16, has been taken from Ref. 4.25. Testing of materials in this category has been limited because applications are often limited by fragileness where shock impact may be experienced. Most of these materials have been considered for applications where hardness is important or as filter elements contained in a stainless-steel housing. Coors Ceramic AB-2 has been utilized successfully in conjunction with glass-filled Teflon for mechanical seals on H_2O_2 transfer pumps, which use H_2O_2 as a coolant for the seal. Coors Ceramic AB-2 and AI-200 have been utilized for plunger pump parts, but no experience has been obtained with Н₂0₂.
Selas porous porcelain microbiological filters have shown satisfactory service with 90 w/o and 98 w/o H_2^{0} and may be used to filter high-strength H_0^{0} .

Aluminum oxide coating materials were evaluated and found to be unsatisfactory. The poor results may be due to the method of coating, added agents, or the roughness of the coating.

Laboratory glassware is used extensively for carrying out compatibility and stability tests as well as general laboratory handling. Pyrex glass is superior to soft glass and is used extensively as piping in the $H_2 \vartheta_2$ manufacturing facilities. Glass linings have been evaluated to a limited extent; the more common glass used for lining contains cobalt, which demonstrates poor compatibility with $H_2 \vartheta_2$. Some glass formulas do, however, show excellent compatibility with $H_2 \vartheta_2$, but there is no use experience available with these linings.

Synthetic sapphire has not been applied extensively despite its excellent compatibility with H_2O_2 . Rotameter floats are probably the only present application.

4.2.2.8 <u>Protective Coating Materials</u>. The compatibility of protective coatings (Ref. 2.25 and 4.29) with 90 w/o H_2O_2 is presented in Table 4.17. Protective coatings are not recommended for H_2O_2 storage tank service, but may be of value for special purpose tanks and to protect incompatible materials from H_2O_2 splash. Of the protective coatings evaluated for service with 90 w/o H_2O_2 , only Teflon, Kel-F, and hot air-sprayed polyethylene have indicated suitability for more than splash contact at temperatures to 71 C (160 F) for Teflon and Kel-F, and temperatures of 49 C (120 F) for polyehtylene; however, there has been no experience with such coatings in actual service. The application of such coatings

or paints is recommended for surfaces of materials subject to corrosion. Prevention of rust in $H_2^{0}{}_2$ handling and storage areas is a safety measure because the possibility of contaminating the $H_0^{0}{}_0$ is reduced.

Kanegin-coated (electroless nickel) mild steel has shown good compatibility with 90 w/o $H_2^{0}O_2$. Tin-plating, followed by a heat treatment at 215 C (420 F) to seal the pores, has proved to be an effective coating for $H_2^{0}O_2$ service.

It is believed that protective liners may be used to advantage in $H_2^{0}_2$ service for prevention of corrosion of aluminum surfaces and for special cases of high-pressure feed tanks to allow fabrication from metals which possess high strength-to-weight ratios but are not sufficiently compatible with the $H_2^{0}_2$ to allow a practical holding time.

In general, platings, such as timplate, strip off when exposed to $10 \text{ w/o} \text{ H}_2 \text{ 0}_2$ unless special precautions are taken to prevent this. Apparently, the $\text{H}_2 \text{ 0}_2$ seeps through pinholes in the plate or under the edge and then decomposes when it contacts the undersurface, liberating oxygen gas. The gas then forms a blister which eventually breaks and allows more $\text{H}_0 \text{ 0}_0$ to contact the undersurface.

4.2.2.9 <u>Protective Clothing Materials.</u> The results of compatibility tests of protective clothing materials with 90 w/o hydrogen peroxide, summarized in Tables 4.18 and 418a, are discussed in Ref. 4.25. The study of materials for protective clothing was directed primarily at finding materials which would not ignite if 90 w/o H_2O_2 was spilled on them when they were soiled with catalytic dirt. The chief hazard encountered when concentrated hydrogen peroxide is accidentally splashed

on a work/r is the possibility that the worker's clothing will ignite. The materials were also evaluated for resistance to deterioration by the action of concentrated hydrogen peroxide.

As a result of this study, it was found that in both the clean and soiled condition, "virgin" Dacron in all forms, Saran-monofilament, and 55 percent Decron-45 percent woul cloth resisted ignition. Dynel and Saran stable fiber resisted ignition in the clean condition and ignited only with difficulty when soiled. Daeron was unaffected by 90 w/o H_2O_2 , and Dacron-wool and Dynel were only slight detiorated. It must be noted that some treated and dyed Dacrons in the "soiled" condition will ignite with 90 w/o H_2O_2 , and all samples must be tested before use.

Based on this study, sources were developed for permeable and impermeable clothing; a recommended protective clothing and necessary accessories list for $H_2 O_2$ handling is presented in Section 5.4. This list includes safety clothing and equipment such as goggles, gloves, aprons, and shoe coverings which are made from plastics or rubbers acceptable for the purpose. Dacron and Dynel work clothing have been utilized to a considerable extent with satisfactory service.

It must be pointed out that even protective clothing MUST BE KEPT CLEAN and particularly free of ordinary greases and catalysts such as potassium permanganate. Grease-soiled samples of Dacron, Dynel, and 55 percent Dacron-45 percent wool fabrics have been found to ignite and burn vigorously when wetted with 90 w/o $H_2^{0}_2$. When laundering or cleaning Dynel fabrics, special techniques must be employed because of Dynel's low softening and embrittling points. Dacron may be laundered without special precautions. Thus, Dacron is preferred for this reason in addition to its better resistance to the $H_0^{0}_0$. 4.2.2.10 Joint Sealing Compounds. The results of physical and chemical tests of joint scaling compounds with 90 w/o hydrogen peroxide are summarized in Ref. 4.25 and Table 4.15. Most commerical pipe joint sealing compounds vere found to be unsuitable for high-strength hydrogen peroxide service. In systems for concentrations of less than 52 w/o ${
m H_{9}O_{9}}$, Aviation Grade Permatex No. 3 and equivalent have been used satisfactorily. There are two thread compounds that have shown good service in 52 through 98 w/o $H_{0}O_{0}$ systems. These are T Film, a Teflon water-dispersion paste for small pipe threads and Teflon tape for 1/4- through 4-inch-size pipe thread. Fluorinated hydrocarbon-based materials react violently with hot powdered aluminum. Therefore, these compounds must not be used on hot aluminum threads and must never be used as a thread cutting lubricant.

> Applications of even the approved joint sealing compounds to threads for an H_2^{0} flow system must be made so that no compound will enter the system. The compound should be used sparingly, only on the male part and not on the first two threads. Thus, the surplus amount will press out of the threads, not into the system. Pipe threads should be avoided in H_2^{0} systems; flanges and 37-degree flare connections are recommended.

4.2.2.11 <u>Temperature Lifects</u>. The effect of high temperatures, in the 212 to 270 F region, on materials compatibility with 98 w/o $H_2^{0}_2$ is shown in Table 4.19. This effect is of particular interest in selection of materials for use in $H_2^{0}_2$ regeneratively cooled thrust chambers (Ref. 4.29).

The effect of high-temperature storage conditions (151 F) on materials compatibilities with $H_2^{0}{}_2$ is shown in Tables 4.21, 4.22, and 4.24 through 4.30. The appropriate references to this work are given in each of the corresponding tables.

4.2.2.12 Evaluation of Passivation or Surface Preparation Techniques. Laboratory tests (Ref. 4.13) have been conducted to: (1) determine the effectiveness of selected passivation methods upon 321 stainless steel, 6061-T6 aluminum (bare and anodized), and Silastic 9711, (2) determine the influence of cyclic exposure of passivated surfaces to hydrogen peroxide; and (3) investigate the effects of various storage conditions upon passivity of materials used in hydrogen peroxide service. The passivation methods employed in these studies are given in the following references:

> CVA-10-62a (Ref. 4.34) NAA LA 0110-003 (Ref. 4.35) Walter Kidde 520007 (Ref. 4.36) FMC Bulletin 104 (Ref. 4.25) McDonnell A/C 13002 (Ref. 4.37) LTV 308 - 20-3 (Ref. 4.38) CVA 10-64a (Ref. 4.39)

The results of these tests are given in Tables 4.21, 4.24, and 4.27.

The preferred passivation method for 321 stainless steel was found to be CVA 10-02a with posttreatment with 35 w/o commercial hydrogen peroxide. For 6061-T6 aluminum (bare and anodized), the best passivation technique was according to North American Aviation Specification LA-0110-003. All passivation methods investigated were found to give about the same results with Silastic 9711. The ease in passivation of all materials was found to improve with each exposure to concentrated hydrogen perocide. Environmental exposure tests revealed that 321 stainless steel can be stored best in clean air with relative humidities up to 100 percent; anodized 6061-T6 aluminum remains more passive in a dry nitrogen atmosphere. Silastic 9711 appears to retain its passivation best in a relative humidity of 100 percent.

The loss of oxygen in 90 w/o H_20_2 solutions in contact with 316L and 321 annealed stainless-steel tubing for 3, 5, 7, and 10 days at a constant temperature of 110 F was determined as a function of two different passivation techniques. One-half of the tubing specimens was passivated by CVA Specification 10-62a with a posttreatment of 35 w/o hydrogen peroxide inhibited with a 0.03-percent H_3PO_4 solution; the other half was passivated by Walter Kidde Co. Specification No: 520007. The stability of the $H_{0}0_{0}$ solution was also determined after each test. In general, 321 stainless steel produced less hydrogen peroxide decomposition than the 316L material. The best passivation method, as indicated by the AOL results for both the 316L and the 321 stainless, was found to be CVA Specification 10-62a plus posttreatment (Ref. 4.18). These data are summarized in Tables 4.23 and 4.24.

In another study (Ref. 4.9), the effect of surface treatment on the compatibility of various materials was determined and expressed in heterogeneous reaction rates (k_2) , as shown in Tables 4.31 and 4.31a.

4.2.2.13 Effect of Surface Finish. The effect of surface finish on materials compatibility with H₂O₂, summarized in Ref. 4.14, is shown in Tables 4.21 through 4.25. Five different surface finishes applied to 304 stainless steel and aluminum alloy 6061-T6 (both bare and anodized) were evaluated in contact with 90 w/o hydrogen peroxide to determine the influence of surface finish on the stability of the peroxide. The stainless-steel specimens were passivated according to CVA Specification 10-62a with posttreatment in 35 w/o inhibited (0.03 percent H₂PO₄) hydrogen peroxide. The aluminum specimens were passivated according to North American Specification LA 0110-003. Although inconsistent correlations were obtained between the surface finish and AOL with the 304 stainless steel and the bare 6061-T6 aluminum specimens,

the active oxygen loss resulting from the anodized aluminum in contact with the hydrogen peroxide indicated an increase in AOL values with surface roughness. (Surface roughness may simply be considered as a surface area factor; the rougher the surface the higher the actual surface area compared to the apparent surface obtained through measurements of the linear dimensions of the sample.)

This investigation has strongly indicated (Ref. 4.14) that the Industry Standard AOL test is not an adequate tool for highly selective screening of materials for hydrogen peroxide service. The AOL test is considered insufficiently sensitive to the detection (with any degree of accuracy) of the catalytic decomposition influence exhibited by small variations in surface roughness or materials in contact with concentrated hydrogen peroxide.

4.2.2.14

Effects of Dissimilar Metals. The results of an experimental investigation of dissimilar metal couples compatibility in H_2O_2 (Ref. 4.11) are shown in Table 4.30. In this study, the decomposition rate of 90 w/o hydrogen peroxide was measured with the following couples: 1060 Al + 6061-T6 Al; 6061-T6 Al + 321 stainless steel; 6061-T6 Al + 316L stainless steel; 321 stainless steel + 316L stainless steel. The AOL and H_2O_2 stability was determined during an exposure of 10 days at 110 F and 7 days at 15? F. The tests at 110 F revealed no significant influence of the dissimilar metal upon the hydrogen peroxide; however, the 151 F test revealed that the catalytic decomposition of the hydrogen peroxide was greater for the dissimilar metal couples than for either of the single-metal alloys.

4.3 MATERIALS TREATMENT AND PASSIVATION

4.3.1 General

All material surfaces that come in contact with propellantgrad > hydrogen peroxide must be specially cleaned and treated prior to their use to minimize hydrogen peroxide decomposition and material corrosion. The general terminology applied to this process, which is designed to provide an inactive surface and eliminate potential contamination sites, is passivation. This section provides a detailed outline of the passivation procedures normally used for materials in hydrogen peroxide service.

The passivation procedure essentially consists of three primary steps prior to the material contact with propellantgrade hydrogen peroxide. The initial step is a chemical and physical cleaning procedure designed to remove oxides, scale, dirt, weld (and heat treat) slag, oil, grease, and other foreign material from the base material. The second step is usually the treatment ("basic passivation") of the material with an alkaline or acid solution to form a film (probably a complex oxide) on the surface to minimize chemical or catalytic activity between the surface and propellant. Finally, the material is subjected to propellant conditioning to check the completeness of the chemical treatment and to eliminate, through further oxidation and chemical complexing, all remaining active sites. Normally, propellant conditioning is conducted in 35 w/o H_00_0 , although many organizations prefer additional propellant conditioning of materials at the conditions (H_{00} , concentration and temperature) that will be experienced in final application of the material.

The material surfaces should be subjected to passivation after part fabrication and before component or system assembly.

Basically, items such as valves, pumps, actuators, system piping, etc., cannot be cleaned properly in the assembled atate, because the solvent, cleaning solution, residual contamination, etc., may be trapped in inaccessible areas. The cleaning should be conducted immediately before component or system assembly, unless provisions are made for packaging the passivated part to protect against re-contamination until ready for assembly. After assembly, components, such as valves, should be packaged until they are utilized in the final system assembly. It is also standard procedure to check all passivated items with propulsion-grade hydrogen peroxide prior to assembly in the system.

All cleaning, passivating, and rinse solutions should be applied by immersing, spraying, wiping, circulating, or other manner so that all surfaces to be cleaned will be <u>completely</u> <u>wetted and flushed with the solutions</u>. Any section of the item to be cleaned that can trap or retain any liquid should be drained or emplied between the applications of each different solution or chemical mixture. The item should be rinsed until it is chemically neutral between each operation. Surfaces should not be allowed to dry off between the cleaning and the "basic passivation" steps. The water grade used, depending upon the passivation stage, should be distilled, deionized, or potable tap water (which has been filtered through a 40-micron nominal filter). Unless otherwise specified, all chemicals should be C.P. (chemically pure) grade or better.

4.3.2 <u>Passivation Facilities</u>

The passivation of meterials for hydrogen peroxide service should be conducted in an area designed only for that purpose. The area must be kept clean and free of combustible

material. Equipment to be used in the passivation procedures should be large enough to accommodate all items to be placed in the intended system and provide a method of complete wetting (with all solutions) of the surfaces requiring passivation.

Procedures for handling hydrogen peroxide and the various passivation solutions should be well established and observed. Some of the more important requirements are discussed in the following paragraphs.

- 4.3.2.1 <u>Personnel Education</u>. All personnel operating in the area should be well informed of all operating procedures, potential hazards, safety precautions, proceaures, etc. (see Section 6.0).
- 4.3.2.2 <u>Area Cleanliness</u>. The area must be protected from dust and dirt to prevent contamination of the cleaned parts. Although a clean room atmosphere is not essential, it is recommended, particularly, for passivation of flight hardware.
- 4.3.2.3 <u>Drainage</u>. An adequate water supply and drain must be available for flushing away spilled acid and hydrogen peroxide. All spillage or dump of chemicals must be heavily diluted before passage into a drainage system; protected open trough drainage is recommended.
- 4.3.2.4 <u>Safety Showers</u>. An adequate number of deluge safety showers must be provided for area personnel. The locations of these showers should be such that they can be reached within a few steps from any location.

- 4.3.2.5 Eye Wash Fountains. An adequate number of eye wash fountains should be provided in easily accessible locations.
- 4.3.2.6 <u>Ventilation</u>. Adequate ventilation must be provided to maintain a minimum concentration of solvent and acid fumes. Hoods with suction fans should be installed and used wherever possible.
- 4.3.2.7 <u>Warning Signs</u>. Safety and warning signs should be placed where they can be seen and should be appropriate to the hazards created by the cleaning, passivating, and hydrogen peroxide solutions.
- 4.3.2.8 <u>Personnel Protection</u>. Personnel, when handling the various passivating solutions, should be dressed in suitable protective clothing. The minimum garb should consist of a face shield or goggles, rubber (acid-resistant) gloves, rubbers, and an apron. (For additional information, see Section 6.0).
- 4.3.2.9 <u>Minor Equipment</u>. Various-sized polyethylene beakers should be provided for the treatment of small parts. These beakers are resistant to all reagents normally recommended and used in the passivation procedures. Although glass beakers can be substituted for the polyethylene beakers in the use of all but hydrofluoric-nitric acid solution, their easy breakage can result in a greater hazard. The polyethylene beakers should not be used for conditioning or surveillance tests with H_2O_2 .

4.3.3 Cleaning and Passivation Solutions

Generally, the chemical solutions required in the passivation procedure may be prepared as described in the following paragraphs.

- 4.3.3.1 <u>Detergent Solutions</u>. A 1 w/o solution of a powlered commerical detergent such as Dreft, Naconal, Tide, Ali, Swerl, etc., in potable water is normally used for cleaning materials and glassware. Liquid detergent (of the same approximate concentration) or a mild solution (5 to 7 ounces/gal) of a commercial alkaline cleaner such as Turco No. 4090 (or its equivalent) may also be used; however, it should be noted that a strongly alkaline cleaning solution must be avoided. The container for the detergent solution should be rust-resistant and covered to minimize dirt pickup. Since most procedures recommend the use of <u>hot</u> detergent solution, provisions should be made for heating the detergent container to 140 to 160 F.
- 4.3.3.2 Degreasing Solvents. Commercial-grade trichloroethylenc, perchloroethylene, or a commercial solvent such as Varsol or Sunoco cleaner are used for degreasing metals which are heavily soiled or very greasy. Alternate degreasing may be performed in a vapor degreaser using trichloroethylene (which meets the Mil-T-7003 specification) or an equivalent grade of one of the above solvents; however, it should be noted that the working temperature of the vapor degreaser must be higher than the boiling point of the selected solvent. The solvent should be stored in a covered galvanized iron, black iron, steel, or other suitable container. Care should be taken to prevent entry of water into the chlorinated solvents contained in the mild steel containers because the resulting conversion to acids will cause corrosion of the metal and subsequent contamination of the material during passivation.
- 4.3.3.3 Sodium Hydroxide (NaOH) Solution, Approximately 1/15 N. A mild (0.25 w/o) NaOH solution can be used as an alternate method for cleaning heavily soiled aluminum equipment. A supply of this solution, which should be available at all times, can be stored in a stainless-steel drum or polyethylene

container which has been previously washed with a detergent solution and rinsed with clean potable water.

- 4.3.3.4 <u>Sodium Hydroxide (NaOH) Solution, 10 w/o</u>. A 10 w/o solution of NaOH solution is used for cleaning glassware which is heavily soiled or has contained an unknown solution.
- 4.3.3.5 Sulfuric Acid (H_2SO_4) Solution, 35 w/o. A solution of H_2SO_4 is used primarily for passivating glassware. The solution can be stored in a polyethylene-lined container or the glass carboys in which it is received. A lid must be provided if stored outdoors. Heated storage may be necessary depending upon the concentration of the acid and the winter temperature of the locality where stored.
- 4.3.3.6 Nitric Acid (HNO₃), 42 degrees Baume'. A nitric acid of 42 degrees Baume' (~70 w/o HNO₃) is recommended by FMC (Ref.
 4.25) for passivating stainless-steel equipment. It should always be readily available and stored in the containers in which it is received.
- 4.3.3.7 Nitric Acid (HNO₃), 45 w/o. A 45 w/o HNO₃ solution is preferred by most organizations for the "basic passivation" step for aluminum and stainless-steel parts. The acid is normally stored in a polyethylene-lined or AISI 300 series stainless-steel container. A lid must be provided to keep out dirt and confine the acid fumes.
- 4.3.3.8 Nitric Acid (HNO_3) 35 w/o. A dilute HNO_3 solution of 35 w/o is recommended by FMC (Ref. 4.25) for passivating aluminum equipment. This acid is stored as above (Section 4.3.3.7).

4.3.3.9 Hydrofluoric Acid (HF)-Nitric Acid (HNO₃) Mixture, 3 w/o-<u>10 w/o</u>. A 3 w/o HF-10 w/o HNO₃ solution is used for pickling and cleaning stainless steel when rust or other surface contamination exists which cannot be removed by the nitric acid solution. A polyethylene-lined container, with a lid to keep out dirt and confine the acid fumes, should be used for storage.

- 4.3.3.10 Hydrofluoric Acid (HF)-Nitric Acid (HNO₃) Mixture, 1 w/o-<u>10 w/o</u>. Unanodized sluminum and aluminum alloy components that are excessively dirty or contain oxide film from welding, heat treating, etc., may be treated with a 1 w/o HF-10 w/o HNO₃ solution. This solution should be stored in the same manner as the solution discussed in Section 4.3.3.9.
- 4.3.3.11 <u>Clean Potable Water</u>. Drinking water, after filtration through a 40-micron nominal filter, is used for rinsing parts during the initial stages of passivation.
- Fresh Distilled or Deionized Water. Distilled or deionized 4.3.3.12 water, which is used for rinsing parts after passivation, should have a maximum specific conductivity of 10^{-6} mhos/cm. This water should not be stored in aluminum for periods longer than 1 week prior to or during use. Storage of distilled or deionized water in an aluminum H_2^{0} storage tank for any length of time results in slime formation which may render the tank unsuitable for $H_2 O_2$. In the storage and handling of potable water, distilled water, or deionized water, the potential contamination by tanks, valves, lines, etc., should be considered (i.e., the use of copper in the system should be avoided). Storage time of deionized or distilled water should be minimized, preferably less than 1 week. Distilled water should be used for the preparation of defonized water.

Hydrogen Peroxide Solution, 35 v/o. Although a stabilized 4.3.3.13 35 w/o hydrogen peroxide solution is available (from various commercial manufacturers) for the initial propellant-conditioning atep, many users utilize 35 w/o H,0, solutions obtained by dilution of higher concentrations. However, various hydrogen peroxide manufacturers recommend that if the 35 w/o H₀O₀ is obtained by dilution of propellant-grade H,O, (with no or minimum stabilization), a stabilizer should be added to the dilute H₀O₀, and the pH of the solution adjusted so that residual active metal sites can be deactivated by complexing with the stabilizer (recommendations of the hydrogen peroxide manufacturers are encouraged in this area). Regardless of the user's preference in the use of stahilizers, any dilution of $H_2 O_2$ must be conducted with distilled or deionized water of suitable quality. The 35 w/o solution should be stored in an aluminum 1060, 5652, or 5254 container. The storage container must be vented at all times, and the vent line should be provided with a suitable filter to keep out dust or dirt. A hydrogen peroxide shipping drum is a convenient container; however, once removed, the hydrogen peroxide must not be returned to the original drum or container. Hydrogen peroxide from a satisfactory activity test may be reused, if economics dictate.

4.3.4 Typical Passivation Technique

Specific passivation procedures that are being or have been previously used by various organizations involved in hydrogen peroxide usage are contained in the following documents:

Chance-Vought Aircraft*	Specification CVA 10-62a
Chance-Vought Aircraft*	Specification CVA 10-64a
FNC	Bulletin 104 (Ref. 4.25)
LTV Astronautics	Specification LTV 308-20-3
McDonuell Aircraft	Specification 13002

*NOTE: CVA specifications were obtained from LTV Astronautics (Bef. 4.34 and 4.39).

North American Aviation, Inc.	Specification NAA LA (0130-20)
Reaction Notors Division	Specification BM1 7000
Walter Kidde Company	Specification 520007

There are numerous differences in the exact techniques and procedures used by various organizations for the passivation of materials, parts, systems, etc., for hydrogen peroxide mervice. However, for the most part, these differences are insignificant and the general techniques used are very similar. Although various storability and compatibility studies (see Section 4.1 and 4.2) have indicated the greater effectiveness of some techniques over others, it is believed that no one technique has consistently demonstrated a repeated superiority.

Thus, in developing a procedure to be used by any facility, the general or typical technique described below can be used as a starting point. More specific (in detail) procedures or modifications of these typical procedures may be developed and preferred with the acquisition of "passivation experience"; however, the typical procedures described will passivate most compatible materials. The solutions called out in the procedure are those designated in Section 4.3.3.

4.3.4.1 <u>Degreasing and Cleaning</u>. Excessively greasy metal parts should be initially degreased either by cold flushing with a solvent for 30 minutes (repeat with clean solvent if necessary), or through the use of a solvent vapor degreaser for at least 10 minutes. All metal parts should then be cleaned with a hot (140 to 160 F) commercial detergent solution or a mild alkaline commercial cleaner. (A 1/15 N NaOH solution has been used for monanodized aluminum.) Cleaning can be accomplished by agitation of the part in the cleaning solution, scrubbing with a stiff nylon brush, and/or pumping the solution through the part (as in the case of tubing and

piping). The metal parts should then be rinsed <u>thoroughly</u> in warm potable water to remove all traces of the cleaning compound.

Nonmetallic and bonded nonmetallic parts such as gaskets, 0rings, chevron rings, hoses, etc., should be degreased by immersion or scrubbing at 140 to 160 F, with a commercial detergent or a mild alkaline cleaner, followed by a <u>thorough</u> rinsing with warm distilled or deionized water. Teflon, polyethylene, Kei-F, or Viton, except when bonded to metal, may be cleaned with a solvent, but immersion time should be limited to a short period (~5 seconds). Items which have solvent or water remaining on their surface and are not to be chemically cleaned further, will be dried immediately with clean dry nitrogen gas or air.

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NOTE: Following the degreasing and cleaning step, the cleaned surfaces of the parts should be handled with clean gloves or tongs only. Any possible means of recontamination of the part should be avoided from this point.

4.3.4.2 <u>Descaling</u>. Newly fabricated or reworked metal parts, which have scale from welding, or heat treatment, or impurities from casting or forging, should be descaled ("pickled"). Descaling solutions should not be used after finish-machining of precision surfaces without protection, or on parts that do not have heavy oxide or foreign material buildups in the form of rust or scale. The contact time of the descaling solution with the item to be cleaned should be the minimum time necessary to clean the part or the maximum allowable time per this section, whichever is shorter. Only plasticcoated or nonmetallic gaskets should be used with nitrichydrofluoric descaling baths to prevent excessive metal loss caused by electrolytic corrosion.

4.3.4.2.1

<u>Stainless Steel</u>. Stainless-steel parts should be etched for a minimum period, and not longer than 60 minutes, at room temperature (60 to 80 F) with a mixture of 3 w/o technical-grade hydrofluoric acid, 10 w/o technical-grade nitric acid, and the remainder water.

CAUTION: A close visual check should be maintained during descaling operations with the HF-INO3 mixture to prevent material pitting or excessive etching. After descaling, the part should be thoroughly rinsed with potable water to remove all traces of descaling solutions. Loosely adhering smut or flux may be removed by spraying with water or scrubbing with a stainless steel or hemp brush. If the parts are to be passivated immediately after acid cleaning, they need not be dried. The parts may be dried completely by purging with dry, hydrocarbon-free nitrogen or air, or in an oven at 140 to 150 F. The AISI 400 series, 303S, 303SE, and AM 355 stainless steels will be descaled by mechanical methods such as machining, abrasive tumbling, or grit blasting.

4.3.4.2.2

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<u>Aluminum and Aluminum Alloys</u>. Nonanodized aluminum and aluminum alloy parts may be descaled by immersion in a 1 w/oHF-10 w/o INO₃ solution for 30 seconds to 5 minutes at 115 F maximum.

CAUTION: A close visual check should be maintained during descaling operations with the HF-HNO3 mixture to prevent material pitting or excessive etching. After descaling, the part should be <u>thoroughly</u> rinsed with potable water to remove all traces of the acid solution. It should be noted that a 35 w/o H_2SO_4 solution at ~115 F can also be used as an alternate "pickling" solution for aluminum and aluminum alloys.

4.3.4.3 "Basic Passivation." Immediately following the cleaning (or descaling) operation, the metal parts should be subjected to the "basic passivation" step. Although this step is slways accomplished with HNO₃ solutions, the concentrations used by different organizations vary. The following procedures are those preferred by the m.jority. It should by noted that plastic and synthetic rubbers <u>should not</u> be subjected to this step in the passivation procedure. 4.3.4.3.1 <u>Stainless Steel</u>. Stainless-steel parts should be immersed in a solution of 45 w/o HNO₃ at 60 to 80 F, for a minimum period of 30 minutes. FMC (Ref. 4.25) recommends the use of 70 w/o HNO₃ for a period of 4 to 5 hours as the stainless-steel passivation step. The parts should then be rinsed and flushed <u>thoroughly</u> with deionized or distilled water to remove all traces of the passivating solution. Unless the part is immediately placed in the propellant-conditioning solution, it should be drained and dried by purging with dry, filtered, hydrocarbon-free nitrogen or air, or dried in a dust-free oven at 140 to 150 F; the part should then be protected from recontamination by sealing in a sealed clean plastic bag.

The nitric acid passivation solution should be used for the AISI 300 and 400 series stainless steel. The protective film resulting from this passivation process will not normally be visible, but surfaces will be uniform in appearance, free from scale, corrosion, pitting, and contaminants. Normal discoloration from welding will be permitted, provided no scale or rust is associated with the discoloration.

Some organizations recommend electropolishing of stainlesssteel parts (except for AM 355) by the best available commercial practice as an alternate method for stainless-steel

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passivation. Following electropolishing, the material should be cleaned with detergent (Section 4.3.4.1) rinsed <u>thoroughly</u> with deionized or distilled water, and dried in an oven.

4.3.4.3.2

Aluminum and Aluminum Alloys. Aluminum and aluminum alloy materials are usually passivated with a solution of 45 w/o HNO_m at room temperature for a period of 1 hour; however, FMC (Ref. 4.25) recommends the use of 35 w/o HNO_3 as the passivation acid. The materials should be rinsed and flushed with water to remove all traces of nitric acid, and unless immediately conditioned with the propellant, the materials should be drained and dried by purging with dry, filtered, hydrocarbon-free nitrogen or air, or dried in a clean oven at 140 to 150 F. Machined aluminum barstock parts do not normally require descaling or passivating processes and can be prepared for service by degreasing and thoroughly rinsing. Welded, cast, or corroded parts will require descaling, cleaning, and passivating. Anodized aluminum parts will not be descaled or passivated and should be prepared for service by degreasing and thorough rinsing.

4.3.4.4

<u>Propellant Conditioning</u>. Following cleaning and acid treatment steps, metallic materials should be propellant conditioned to check passivation ("activity testing") and passivate further potentially active sites in the materials. The nonmetallic materials are propellant conditioned following the cleaning step. Normally, most procedures recommend initial propellant conditioning with 30 to 35 w/o H_2O_2 (see Section 4.3.3.13). Following this conditioning, most procedures call for conditioning with hydrogen peroxide of the grade with which the material will eventually be applied. Propellant conditioning, which should be conducted for a minimum period of 3 to 6 hours, is conducted on both the unassembled parts and components and the assembled systems.

4.3.4.4.1

<u>Materials, Parts, and Components</u>. Before the initial activity tests are conducted, components such as valves, pumps, etc., should be assembled (care must be taken to avoid contamination during assembly). The passivated surfaces should be exposed to the selected $H_2 O_2$ solutions by either immersion of the part or by filling the composite assemblies (components) with the $H_2 O_2$. Low openings in the composite assembly may be closed with passivated plugs of the same material or polyethylene-covered rubber stoppers; however, there must be a vent to allow escape of gases from the assemblies. During the tests of the composite assemblies, all sliding surfaces must be completely wetted (through valve actuation, etc.) by the $H_2 O_2$.

Acceptance of passivation is contingent upon no reaction of the material with the hydrogen perioxide (as evidenced by the lack of gas bubbles evolving from the H_00_0). If, at the end of the exposure period, the gas bubble rate is very minimal. the unexposed surfaces of the materials are cool to the touch, and the gas bubbles are not confined to a particular location, the material or part is considered acceptable. If rapid bubbling, clouding of solution, or a local hot spot is observed during the test, the solution should be discarded and the active part repassivated in accordance with Sections 4.3.4.1 and 4.3.4.3. If it is practical, the active area should be marked for future observation. A component or part should be rejected if it fails three consecutive passivation tests. If a part shows only marginal unacceptable reaction, it should be removed from the $H_0 0_0$ solution, rinsed several times with distilled or deionized water, and reconditioned with fresh $H_2^{0}0_2$ solution; the part should then be repassivated if it continues to demonstrate marginal unacceptability. Parts which cause discoloration of the H_00_9 solution will be reimmersed in fresh H_20_2 solutions; if discoloration continues, the part should be rejected and the discolored $H_0 O_0$ solution disposed of immediately.

Any part which shows blackening, rust streaks, or signs of excessive corrosion should be rejected.

After the materials, parts, and/or assemblies have passed all activity checks in the selected $H_2 O_2$ solutions, they should be rinsed <u>thoroughly</u> in distilled or deionized water and dried with clean dry air or nitrogen. Heat may be used to dry if the plastic materials are maintained below 120 F and the metals below 150 F. All parts must be handled with clean tongs and/or clean neoprene-gloved hands to prevent recontamination. After drying, the materials should be assembled in the final system or packaged according to Section 4.3.7.

4.3.4.4.2

System Assembly. After complete assembly of a handling installation, storage facility, or any other hydrogen peroxide system from compatible and passivated materials (that have undergone preliminary activity checks), the system should be conditioned as a whole. The entire system assembly should be filled with 30 to 35 w/o H_00_2 (see Section 4.3.3.13) and activity checks conducted. Again, it is noted that the system should be vented and all valves and sliding surfaces should be operated to wet all surfaces with H_00_0 . The test should be conducted for a period of 4 hours unless a local heated area or excessive gas evolution indicates the test should be terminated. The observations and conclusions in the assembled system tests are identical to those of the materials, parts, and components conditioning (Section 4.3.4.4.1) with one exception; most organizations advocate an activity check of the system using a laboratory-type "wet test meter" to measure the actual gas rate.

After successful preliminary testing of the system with 30 to 35 w/o H_2O_2 solution, the system should be conditioned with H_2O_2 solutions of the grade it will eventually

utilize. Following this passivation, the system is considered ready for hydrogen perioxide service. All such passivated systems should be protected against further contamination with dust caps. In addition, the system should be continuously surveyed during use for evidence of excessive $H_2 O_2$ decomposition.

4.3.5 <u>Glassware Passivation</u>

Because glassware passivation is slightly different from that associated with the materials commonly used in hydrogen perioxide system fabrication and more often involves a laboratory-type operation, the technique used has been seperated from the typical passivation section. The procedure for the passivation of glassware, which includes thermometers and hydrometers, is contained in the following paragraphs.

Glassware that is heavily soiled should be immersed in a 10 w/o NaOH solution for 1 hour at room temperature. If the glassware is relatively clean, a commercial detergent should be used instead. Following this cleaning, the glassware should be rinsed thoroughly in clean potable water.

Chemical passivation is accomplished by immersion in 35 w/o H_2SO_4 for at least 1 hour at room temperature. After the glass is <u>thoroughly</u> rinsed in distilled or deionized water, it should be dried with clean air or nitrogen, or in an oven at 230 F.

The passivated glassware can be stored in a "ready-for-use" condition by packaging in accordance with Section 4.3.7. Bottles, flasks, or other containers can be stored by covering the opening tightly with aluminum foil.

4.3.6 Passivation Aids

So that materials passivation be accomplished with minimum difficulty, several general rules should always be observed. The primary rule is, of course, strict adherence to cleanliness thoughout the procedure. Other considerations, primarily associated with the materials treatment prior to initiation of passivation procedures, are noted below.

- 4.3.6.1 <u>Metal Machining</u>. In addition to the selection of compatible metals, the effectiveness of future passivation of these metals for hydrogen peroxide service depends upon eliminating contamination of the materials with incompatible materials during machining. Thus, the use of zinc, copper, copper alloys (i.e., bronze or brass), tin, iron (low carbon, nonstainless types), silver, lead, cadmium, carbide, sand, etc., should be avoided in tooling and machining operations.
- 4.3.6.2 <u>Surface Finish</u>. All surfaces which contact hydrogen peroxide should be as smooth as possible, with manufacturing marks, identification symbols, and irregularities reduced to a minimum. All surfaces contacting hydrogen peroxide should be free of cracks, pits, inclusions, and foreign material. Whenever practical, sharp corners should be broken and a surface finish of 40 rms (root mean square) or finer achieved.
- 4.3.6.3 <u>Abrasives</u>. Abrasive cleaning methods should not be used if
 a suitable chemical method is available. When abrasives are
 necessary, only glass beads, aluminum oxide abrasives, or
 stainless-steel wire brushes should be used. AX 355 should
 be cleaned only by mechanical methods. Acid descaling should
 be avoided if possible.

4.3.6.4 <u>Anodized Aluminum</u>. Aluminum surfaces which contact hydrogen peroxide should be anodized. Exceptions are surfaces whose shape makes anodizing impracticable (i.e., the interior of long tubes). Sulfuric acid anodizing is preferred and should be used where that process is available. Sealing of sulfuric acid-anodized surfaces should be done in hot water (195 1 10 F for 30 minutes). Deionized water is preferred for seal-ing although tap water may be used.

- 4.3.6.5 <u>Rework</u>. All fabrication and fitting of detail parts and components should be completed prior to passivation treatment. Any rework on passivated areas makes repassivation mandatory.
- 4.3.6.6 <u>Welded Assemblies</u>. For welded assemblies, each part should be cleaned prior to welding. Completed weld assemblies must be passivated prior to further assembly.
- 4.3.6.7 <u>Pressure Testing</u>. Pressure testing of a system using various test fluids or replacement of a component in any assembly will automatically make it mandatory to repeat the activity testing procedure for that assembly.

4.3.7 Handling of Passivated Materials

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Items that have been cleaned and passivated should be handled, stored, or packaged in a manner to prevent recontamination. Immediately following cleaning and passivation, large valves, piping sections, vessels, flex joints, subassemblies, and other prefabricated items should be dried and have ends and openings capped, plugged, or flanged and sealed with clean compatible sealing material. Small valves and components should be purged with clean, dry gaseous nitrogen and wrapped and sealed in clean plastic or metal foil bags. These components should be kept sealed until installation.

4.3.7.1 <u>Acceptable Materials</u>. Small items should be sealed in clean preformed envelopes, rolls, or sheets of: (1) polyethylene film, polyethylene-backed paper, polyethylene-backed cloth, or polyethylene-backed aluminum foil, (2) vinyl (Vinylite), (3) Koroseal, (4) Saran, or (5) Mylar. Materials for short-term storage of passivated items can also include aluminum foil (or aluminum-backed cloth or paper) and cellophane.

- 4.3.7.2 <u>Indefinite Storage</u>. In the packaging of small passivated items for long-term storage, the items should be dried and packaged as soon as practicable after passivation and activity testing. Any openings of the items should be sealed with clean new polyethylene or aluminum caps (used closures will be discarded to prevent reuse). The materials should be enclosed in a clean envelope and sealed to stop free passage of air. This envelope should then be wrapped in heavy paper or placed in a protective container.
- 4.3.7.3 <u>Identification</u>. The passivated parts should be identified with standard markings such as date, part number, part name, etc., but in addition, a tag should be attached which notes the equivalent of the following:

PASSIVATED PART

This part passivated for use with w/o hydrogen peroxide. Activity Test OK

(Date)

(Inspector)

NOTE: If a part is contaminated before packaging or if a package containing a passivated part is torn, the part should be returned to proper area for passivation or activity test as needed.

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4.4 FACILITIES AND EQUIPMENT

4.4.1 Storage and Handling Facilities

A facility for the storage and handling of hydrogen peroxide may exist in the form of: (1) a singular storage facility for hydrogen peroxide only, (2) a special handling area for hydrogen perioxide, such as an equipment passivation area, (3) a storage complex for oxidizers including hydrogen peroxide, (4) an area storage complex for fuels and oxidizers, or (5) a handling complex for various propellants. Although it is desirable that any such facility be located in an isolated area, out of necessity, it may be located in the proximity of a test or launch facility.

The specific design criteria for each type of hydrogen peroxidecontaining facility must be considered independently although most considerations apply to all facilities. This is necessary because any other propellants stored or handled at the facility also require special considerations. In addition, a facility located in the proximity of a launch or test installation, for example, is exposed to vibrational, thermal, and possibly shrapnel effects, all of which require special considerations.

The design principles presented in this handbook apply to those criteria associated with storage and handling facilities for only hydrogen peroxide. Thus, in the use of these criteria in areas where other propellants are stored and/or handled, the facility designer must consider the integration of various other requirements in his design of the hydrogen peroxide facility.

4.4.1.1 <u>Facility Layout and Orientation</u>. Hydrogen peroxide storage and handling areas should be situated in such a manner as to provide the least hazard to surrounding facilities and

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personnel under any given condition. Since the layout of test areas is dependent upon particular requirements and considerations, in which many attendant hazards must be accepted, the inyout considered here is related primarily to storage or handling areas which can be mituated as desired. All such facilities should have adequate drainage and be situated so that they are exposed to the minimal climate changes for the particular area. Some air flow should normally be available.

4.4.1.1.1 <u>Meteorological Considerations</u>. Hydrogen peroxide does not present a serious toxicology threat to personnel through vapor inhalation because of its low vapor pressure and comparatively high threshold limit value. Thus, very little consideration is usually given to the potential release of hydrogen peroxide vapor into the atmosphere, either through venting or gross spillage. Normally, such situations do not pose a chreat to personnel outside of the immediate area, particularly if spillage is immediately diluted with large quantities of water. However, site orientation should be such that a vent or spill of any conceivable magnitude will be reduced to relatively harmless concentrations by the time it reaches downwind population.

4.4.1.1.2

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<u>Quantity-Distance Considerations</u>. All hydrogen peroxide solutions above 52 w/o H_2O_2 are classified as Hazard Group II propellants by the criteria established for the Department of Defense (Ref. 4.52). As such, these solutions are grouped with other strong oxidizers as a fire hazard. The DOD criteria (Ref. 4.52) also indicate that solutions above 96 w/o H_2O_2 can detonate and appropriate precautions should be taken (Ref. 4.53). Based on the Hazard Group II designation, the following criteria have been recommended in Ref. 4.52 for the location of hydrogen peroxide sites in relation to surround habitations and public transportation.

Propellant Quantity, pounds		Distance in Feet to		
		Inhabited Buildings, Bailroads Highways and	Intragroup and Compatible Group II	
Over	Not Over	Incompatible Group II Storage	Storage	
	100*	60	30	
100	500*	100	50	
5 00	1,000	120	60	
1,000	10,000	180	90	
10,000	50,000	240	120	
50,000	100,000	270	135	
100,006	300,000	330	165	
300,000	500,000	369	180	
500,000	1,000,000	410	205	

*NOTE: These criteria do not apply to a single standard minimum size shipping container (such as one 55-gallon drum); these should be stored and handled as prescribed by the controlling authority.

4.4.1.2

Storage Containers. The storage capacity of each facility is dependent upon the particular requirements of that facility. A user may require one large bulk storage facility with severa! ready storage facilities, each to supply a particular test site. Large storage facilities for propellantgrade hydrogen peroxide may contain one or more bulk storage tauks with capacities ranging from 5000 to 25,000 gallons. In addition, the various facilities may require areas for drum storage.

The propellant-grade hydrogen peroxide tanks and containers should be stored in an area by themselves and not integrated with other oxidizer storage (Ref. 4.24). The area layout should allow for easy access and egress for loading and unloading vehicles and adequate separation of the bulk storage tanks from each other, and from the drum storage area. All storage tanks and associated valves and piping should be

located aboveground to facilitate the detection of leaks. All main tank connections should be made through the top portion of the tanks to reduce the possibilities of propellant spill.

4.4.1.3 Buildings. Hydrogen peroxide bulk storage tanks do not require surrounding buildings; however, they should, if possible, be shielded from direct sun radiation. Drums are usually stored on a raised pad under an open-wall roof. The structural framework for either protective covering should consist of either steel or masonry. Wooden supports should not be used. Any siding should be brick, tile, or other masonry units; corrugated sheet asbestos; aluminum; or steel with an approved protective coating. Slate shingles, corrugated sheet asbestos, aluminum, or coated steel can be used for roofing; but the use of petroleum-based roofing materials is prohibited. A vinyl-base, high-temperature aluminum paint can be used as weather protection for the applicable structural materials. Floors should be smooth, finished concrete with a built-in slope for drainage.

4.4.1.4 <u>Diking and Retainment</u>. Each hydrogen peroxide bulk storage tank should be installed within a separate dike, revetment, or walled area to retain spilled propellant. This containment should have a smooth, impervicus, and acid-resistant cement lining. The dike or retainment should be capable of retaining 1.5 to 2 times the tank capacity. The diking system should be designed so that it will gravity drain into a collection basin via open-trough, concrete-lined drainage canals.

4.4.1.5

Safety and Fire Protection. Good system design, development and observation of good operating procedures, and <u>,</u> 1

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good housekeeping are the best safety precautions in hydrogen peroxide storage and handling areas. These areas must be kept neat, clean, and absolutely free of any type of combustible material. All leaks and spills should be flushed immediately with large amounts of water. Frequent inspection of the areas to ensure compliance with these regulations should be meintained.

<u>Personnel Education</u>. Standard operating procedures should be established for all operations and potential situations that might occur in hydrogen peroxide storage and handling areas. Thorough education of all operating personnel with respect to these procedures is mandatory. In addition, these areas should be restricted to a minimum number of previously authorized personnel required for operation and safety.

4.4.1.5.2 <u>Personnel Protection</u>. Proper protective clothing, an adequate number of deluge safety showers and eye baths, and easy egress from the area should be provided for the protection of operating personnel. This equipment should be clearly located and marked.

4.4.1.5.3 <u>Facility Protection</u>. An adequate water supply mist be available for fire fighting, flushing and decontamination, tank cooling, tank dilution, and personnel safety equipment. In storage areas where the tank temperature may be over 100 F for extended durations, a tank sprinkling system should be provided to cool the tanks. The locations for floor flushing, drainage flooding, and fire protection valves (either for hoses or fixed nozzles) should be clearly marked by signs and red lights. In the absence of a fixed tank dilution installation, an adequate hose length should be available to reach the dome of any storage tank for dilution in an emergency situation.

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4.4.1.6

Electrical Concepts. All electrical installations throughout the hydrogen peroxide storage and handling areas should conform to the national, state, and local codes for the type of area and service involved. The areas should be floodlighted in accordance with good industrial and safety practices for the type of operation involved. Electrical power distribution within the areas should be through rigid aluminum or steel conduits, which are preferably located underground. Spark-proof or explosion-proof fixtures are not required, but vapor-proof fixtures are recommended. Adequate electrical receptacies should be strategically located for maintenance purposes.

All vent stacks, storage tanks, and steel structures should have integrally mounted lightning protection systems in accordance with Section 8 of Ref. 4.54. All storage tanks, pumps, loading points, electrical equipment, and propellant transfer lines should be grounded and bonded electrically, in accordance with national, state, and local codes.

4.4.1.7

<u>Access Roads</u>. At least two access roads to transfer and storage sites should be provided with adequate space at each site for turning. The use of asphalt-paved access roads in close proximity to storage and handling facilities should be prohibited.

4.4.1.8

<u>Fencing</u>. Storage and handling areas, drainage ditches, and catch ponds should be fenced and equipped with warning signs, safety placards, and other equipment and techniques typical of good industrial practice.

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Equipment Design Criteria

In the design of an item of equipment for hydrogen peroxide service, the same basic principles of design apply as for any other fluid-handling system. For hydrogen peroxide service, simplicity in design is essential. Since the decomposition rate of hydrogen peroxide is a direct function of the surface area contacted, the material surface area relative to the hydrogen peroxide volume should always be minimized. The number of parts in a system or component assembly should be kept to a minimum that is consistent with the mechanical and structural requirements of the equipment, and the equipment must be designed so that all units can be easily disassembled into component parts for ease in passivation and inspection.

Throughout the design and layout of a hydrogen peroxide system, the potential integrity of the system with respect to cleanliness and compatibility with the hydrogen peroxide must be constantly reviewed. The use of each material and its potential contact with the propellant must be consistent with the material compatibility data, as illustrated in Section 4.2.2. Because of the possibility of unforeseen hydrogen peroxide contamination (with resulting decomposition and gas release), all systems must be designed so that they can be completely vented and pressure relieved. Whenever possible, the system should be designed to "fail open."

Typical equipment design and selection considerations are given in the following paragraphs. Although these considerations will aid the hydrogen peroxide user in the design of hydrogen peroxide storage and handling systems, they are not intended as a substitute for good engineering practices nor do they exclude other competent and knowledgeable considerations. It is also noted that the following criteria are primarily for semipermanent or permanent facilities

and do not apply to flight hardware although many of the considerations may be applicable.

4.4.2.1

Storage Vessels. All pressure vessels for hydrogen peroxide storage and feed should be constructed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, latest edition (Ref. 4.55). Also, all pressure vessel design and construction should satisfy applicable local and state codes for such vessels. All other storage vessels for hydrogen peroxide service should be designed and fabricated in accordance with good engineering practice for the pressure and service in which they are to be used. A minimum safety factor of 4 for vessel and vessel support material strength should be maintained in all designs with adequate allowances for local seismic and atmospheric disturbances, temperature conditions, and external and/or internal corrosion.

Hydrogen peroxide storage tanks are normally fabricated of Class 1 materials. The majority of the tanks used for bulk storage are fabricated from aluminum 1060, which is 99.6 w/o aluminum. When greater strength is required, aluminum alloys 5254 and 5652 are normally used for bulk storage. In consideration of requirements for high-pressure lightweight tankage, AM 350 stainless steel has been used successfully. The 17-7 precipitation hardening stainless steel has been used successfully in 76 and 90 w/o H_2O_2 systems; however, this material is generally more difficult to passivate than the AM 350 material, particularly when used in 90 and 93 w/o H_2O_2 systems. Both steels offer yield strengths of 160,000 psi.

The hydrogen peroxide tankage used in rocket test facilities and various other feed and ready storage applications (which required only short periods of hydrogen peroxide storage)

are usually fabricated from 347 stainless steel. Other materials successfully utilized in tankage for these types of applications are the low-carbon 304, 316, and 321 stainless steels.

The cryogenic prestrained 301 stainless steel has demonstrated excellent compatibility with 90 and 98 w/o $H_2^{0}0_2$, and the high strength of this material (260,000 psi yield) favors its use for hydrogen peroxide tankage in flight vehicles and for high-pressure applications.

4.4.2.1.1

<u>General Considerations</u>. The particular requirements of the storage and handling facility will determine the size and number of storage and feed tanks. If hydrogen peroxide shipments are received in tank trucks or tonk cars, storage tanks with capacities greater than 8000 gallons should be available, and more than one bulk storage tank is recommended at each particular installation. Bulk shipments should preferably be maintained in containers of similar size instead of being transferred to a number of smaller containers. In addition, the number of hydrogen peroxide transfers from the initial storage to final use should be minimized. Observation of these rules will limit the chance of contamination and the number of hazards involved.

Although atmospheric-pressure, horizontal tanks have usually been preferred to vertical tanks for the bulk storage of hydrogen peroxide, any well-engineered tank is suitable. High-pressure feed or ready storage tanks are usually vertical so they can be fully drained. It should be noted that the optimum stress-to-weight ratio is contained in a spherical tank, and this type of tank provides a minimum surface-to-volume ratio. A 2-to-1 length-to-diameter ratio tank is also advantageous with reference to strength-toweight and surface-to-volume ratios. Regardless of the shape, the tank should be designed with sufficient volume

capacity to limit the liquid level from rising above the head attachment weld.

Normally, all hydrogen peroxide tankage should be provided with openings for filling, draining, venting, special instrumentation (temperature, pressure, and liquid level indication), and pressure relief (usually a large burst disk). Large storage tanks should be provided with a top opening manway of at least 18 inches diameter for cleaning and inspection. All bulk storage tanks should have at least a G-inch-diameter opening for use during cleaning and passivation. Many organizations fit the large openings on atmospheric-pressure bulk storage tanks with a floating cover, which is designed to exclude dirt but free to relieve pressure buildup in the tank. A cover of this type is especially effective in providing a large emergency vent to prevent pressure rupture of the tank in case of massive contamination of the contained hydrogen peroxide.

Top inlet and outlet connections are usually recommended for large bulk storage tanks; however, a bottom outlet is generally required for propellant feed and ready-storage tanks to provide complete drainage. Flanged connections should be used for all openings whenever possible. Storage tanks must have a filtered (to protect against inflow of dirt) vent of at least 2 inches, which cannot be inadvertently closed. Pressure vessels should be designed with fail-open vents. In addition, many storage tank designs incorporate a temperature alarm, in which a thermocouple is installed in a protective aluminum tube inside the tank or fastened to the outside wall of the tank below the liquid level (with external glass wool insulation). Mercury thermometers and liquid-type manometer gages should not be used in direct contact with the liquid.
4.4.2.1.2

Pressure or Volume Changes. Throughout the design, fabrication, and application of hydrogen peroxide storage vessels, the pressure and volume changes resulting from hydrogen peroxide decomposition must always be considered. A liberation of oxygen from decomposition results in a subsequent change in gas volume and/or pressure of a sealed container. To illustrate this point, Fig. 4.10 shows the volume of oxygen liberated per unit volume of hydrogen peroxide as a function of hydrogen peroxide concentration and temperature, assuming a decomposition rate of 0.1 percent AOL per year and a constant pressure of 14.7 psia. Figure 4.11 demonatrates the pressure increase resulting from this decomposition in an unvented system with an initial ullage volume of 10 percent. Pressure increases observed under actual storage conditions are illustrated in Fig. 4.3 and 4.6.

For these reasons, venting of systems for normal long-term hydrogen peroxide storage is necessary. This venting may be either continuous or of the intermittent variety. The latter is used when the rate of pressure increase is used as a measure of stability. Commercial shipping containers are normally of the continuous-venting type. A somewhat labyrinthine path is made with holes drilled through the cover material. The geometry is such that the possibility of contaminants entering through the holes is neglible, and the possibility of trapping and subsequent blowing overboard of liquid hydrogen peroxide is insignificant. For most aerospace applications, nonvented systems are employed and allowances for pressure increase during the storage period must be made in the design.

4.4.2.1.3 <u>Self-Heating</u>. Another important consideration in the design of storage tanks is related to self-heating of the hydrogen peroxide. This behavior, thoroughly discussed in Ref. 4.56, can be briefly summarized by the following comments from that discussion:

"All hydrogen peroxide solutions decompose at a finite rate, and this decomposition releases a relatively large amount of heat (1200 Btu/1b of hydrogen peroxide consumed). Consequently, every hydrogen peroxide storage vessel must continually transfer heat to its surroundings. a corollary being that such storage vessels are always warmer than the surroundings. The magnitude of this temperature difference is established by the balance between heat released by decomposition and heat transferred to the atmosphere. The actual mechanism, of course, involves a gradual temperature rise in the contents of the vessel until the rate of heat transfer to the surroundings becomes equal to the rate of heat liberation by decomposition. However, the rate of heat transfer to the atmosphere increases only linearly with temperature, while the rate of decomposition increases exponentially. As a consequence. for any particular storage vessel there exists a critical decomposition rate beyond which the rate of heat liberation will always exceed the rate at which heat can be transferred to the surroundings. Once a storage vessel passes the critical condition, a self-accelerating decomposition will set in which, unless checked. may reach a very high rate. As hydrogen peroxide solutions are nearly impossible to detonate and vapor explosions are possible only over very strong solutions, the primary hazard is due only to pressure rise and possible rupture of the container."

Because of this potential effect in storage, the design of any hydrogen peroxide storage container should incorporate features which control self-heating. Assuming various hydrogen peroxide decomposition rates, a maximum safe-tank size can be calculated for a given hydrogen peroxide concentration stored at a given temperature in a given tank material (Ref. 4.56). Hydrogen peroxide tankage should be located so as to permit free movement of the surrounding air, and since heat dissipation from the tank is necessary to prevent self-heating, the insulation of hydrogen peroxide storage vessels under normal earth ambient storage conditions should be prohibited. Because knowledge of impending

self-heating is desirable, adequate instrumentation should be provided for all bulk storage tanks; this instrumentation is discussed more thoroughly in Section 4.4.2.11.

4.4.2.1.4

Surface Area Effects. One of the important considerations in the design of hydrogen peroxide storage tanks is the effect of surface area. This is discussed in many other sections of the handbook, and the system designer should be well aware of its contribution to the decomposition of hydrogen peroxide. With proper knowledge of this effect, it can be minimized by proper design. Since the current highpurity of propellant-grade hydrogen peroxide minimizes the homogeneous decomposition reaction, the primary cause of decomposition results from the heterogeneous reaction. This is the controlling reaction under the normal ambient storage conditions assuming inadvertent contamination of the hydrogen peroxide does not occur in sufficient quantities to initiate the homogeneous reaction mechanism.

Surface area effects, which are the basis of the heteregeneous reaction, can be minimized by optimizing container design for minimum surface area per unit volume (the ultimate design being a sphere). Further optimization requires a minimum number of storage containers. Previous production plant storage data show that the active oxygen loss in the storage of hydrogen peroxide can be reduced 50 percent by going from an 8000-gallon storage tank to a 25,000gallon storage tank (Ref. 4.25). Since such volumes are not practical for many applications, compromises have to be made with respect to convenience of handling and minimum quantity required at the storage site for assurance of continuing operation.

4.4.2.2

<u>Piping Systems</u>. Information of a general and specific nature relating to pipe, pipe material, and piping installation is extensively covered in Ref. 4.57 through 4.60.

4.4.2.2.1

System Design. All piping used in the storage, venting, and transfer of hydrogen peroxide should be designed in accordance with Sections 3 and 6 of Ref. 4.57. Allowable tensile stresses for pipe materials are listed in Table 12 of Ref. 4.57. Material specifications for pipe, fittings, valves, flauges, tubing, and boltings are listed in Table 8 of Ref. 4.57.

In design of hydrogen peroxide piping systems, all piping and items of equipment, especially values and pumps, should be designed for complete drainage on shutdown. This can be accomplished by providing easily accessible draincocks at the low points and by placing equipment containing dams, such as some types of values, in vertical rather than horizontal positions. A piping system which holds hydrogen peroxide in stagnant pools, even if properly vented, may be subject to excessive corrosion even when fabricated from the recommended raterials of construction.

There should be no places in the flow system where hydrogen peroxide can be trapped for any period of time without a vent path or a relief arrangement. Since hydrogen peroxide solutions will constantly decompose at a slow but steady rate, the resulting gas, if completely confined, could eventually build up sufficient pressure to cause rupture. "Dead ends," of which a Bourdon tube gage is an example, should be avoided since foreign material can accumulate in these spots. Ball, plug, and gate valves are examples of valve designs where the hydrogen peroxide can be trapped when the valve is closed; if one of these types of valves

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is to be used, the cavities must be vented to relieve any gas formation. It is recommended also that the number of valves in a system be kept to a minimum to prevent trapping of the hydrogen peroxice between valves.

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In the use of pumps in the system where the point of pump discharge is lower than the storage tank liquid level, the pump suction line from the top outlet should have a valved vacuum breaker to prevent siphoning after the pump is stopped. The pump installation should also be designed to prevent hydrogen peroxide from flowing back to the storage tank upon pump shutdown.

4.4.2.2.2 <u>Pipes and Fittings</u>. Pipe and welding fittings are normally manufactured according to standard thickness and weight, as proposed by the American Standards Association. Adherence to these standards in the design of hydrogen peroxide piping systems will eliminate unnecessary cost in the purchase of pipe and will facilitate purchases in small lots. Pipe wall thicknesses should be determined in accordance with Ref. 4.57, Section 2, Chapter 4, Paragraph 214 (-3).

> The most compatible piping for hydrogen peroxide service is 1060 aluminum, and this material is generally recommended, particularly if the liquid hydrogen peroxide is to remain in long-time static contact with it. However, where greater strength or hardness is required over that of aluminum 1060, or where other aluminum alloys (3003 and 6063) may be more readily obtainable in piping, other Class 1 or Class 2 aluminums may be used. Piping of 300-series stainless steel may also be used in certain Class 2 (Section 4.2.1.2) applications.

Welded and flanged construction is recommended in hydrogen peroxide piping with a minimum of fittings and joints. Bends are preferred to elbows, and joints should be stud-ends with lap joint flanges or flanges welded to the piping. The use of stainless steel and galvanized or aluminum-clad holting with galvanized steel back flanges is recommended, because rusting of carbon steel would afford a source of possible contamination of the piping when the flanges are opened. If possible, threaded fittings and connections should be avoided; however, where they must be used, it is recommended that the tapered pipe threads be sealed with Teflon thread tape. Normal pipe thread compounds must never be used.

4.4.2.2.3 <u>Pipe Hangers and Supports</u>. Pipe supports, hangers, anchors, guides, and braces should be designed to prevent excessive stress, deflection, and motion in operation of the system, or too large a variation in loading with changes in temperature, and to guard against shock or resonance with imposed vibration and/or critical conditions. Design and selection of the pipe supports should be in full accordance with Section 6, Chapter I of Ref. 4.57. Additional information is included in Ref. 4.58 through 4.63.

4.4.2.2.4

<u>Flexible Connections</u>. A corrugated, seamless hose of 304 or 316 stainless steel, with open pitch construction and welded flanged ends is recommended as a flexible connection for hydrogen peroxide service. Flexible hose lines with Teflon or Silicone S-5711, fitted with flanged connections, also have been successfully used. Another type of flexible connection that has been applied successfully in hydrogen peroxide service is aluminum piping with swing joints of stainless steel and Teflon.

4.4.2.2.5 <u>Identification</u>. Hydrogen peroxide piping should be identified in accordance with MIL-STD-101A(10). The primary warning color (band) is green. The secondary warning color (arrow) is blue.

4.4.2.3 <u>Stainless Steel Tubing and Fittings</u>. Tubing and fittings of 300 series stainless steel are used almost exclusively for pressurized hydrogen peroxide systems. (It should also be noted that the X-15 experimental aircraft uses an all stainless-steel hydrogen peroxide system.) All systems designed with stainless-steel tubing should conform to MIL-T-8808A (for type 321) MIL-T-8606A (for type 347), or MIL-T-8504 (for type 304). Fittings should conform to AN or MS standards for flared tube fittings.

4.4.2.4 <u>Valves</u>. Selection of valves for hydrogen peroxide service imposes certain design requirements that are more stringent or critical than with most other propellants. The design should be such that trapping of hydrogen peroxide in any part of the valve is impossible during any operation cycle of the valve. As a result, globe or Y-type valves are usually recommended for hydrogen peroxide service. Modification of some types of gate, plug, and ball valves to provide self-venting has also permitted their use in certain applications.

> Materials used in approved hydrogen peroxide valves are normally Class 1 or 2 (see Section 4.2.1.2). Stainless steels 321 and 347 have been employed successfully as valve materials; however, some aluminum alloy valves have been subjected to severe galvanic corrosion when used in conjunction with stainless-steel poppets or fittings. A metal-to-Teflon (or Kel-F) seal between the plug and valve seat is normally

preferred over metal-to-metal contact. Materials approved for gaskets are normally used as valve packing.

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4.4.2.5 <u>Relief Devices</u>. The preferred relief device for hydrogen peroxide systems is a rupture disk. The relief device should be rated at not more than 100 percent of the vessel or system rating when used as a primary relief device or 105 percent when used as a secondary relief device. Sizing of the device should be large enough to prevent the pressure from rising 10 percent above the maximum allowable working pressure, of the system under any projected condition. Burst relief devices on hydrogen peroxide tank cars are designed to relieve at 45 psig pressure.

- 4.4.2.6 <u>Regulators</u>. Regulators are used primarily to supply regulated nitrogen gas for transfer, purge, and control systems. The selection of a regulator for service in hydrogen peroxide systems depends upon its particular intended service. If the regulator is in an attendant system which cannot be contaminated with hydrogen peroxide, no special requirements are necessary. However, when contamination is a possibility, the regulator materials must conform to compatible material specifications.
- 4.4.2.7 <u>Pumps</u>. Fumps manufactured from wrought or forged 300-series stainless steel (304, 316, 321 and 347) and pumps made with aluminum alloys B356, 356, or 43 which also have a 300-series stainless-steel shaft, are recommended for pumping hydrogen peroxide. Cast stainless steel should be avoided because it is subject to chromium leaching, which seriously contaminates the propellant and hastens decomposition. Selfpriming pumps should be used for transferring hydrogen peroxide from tank cars or storage tanks with top outlets;

the pump normally used in this service is a 2-inch, selfpriming centrifugel. Where higher pressure or low capacities are desired, a special rotary pump is recommended.

Pump shafts should be stainless steel, and any packing must be made of compatible materials. Where used, packing should be rings of either Teflon or Vitrium, lubricated with a fluorinated hydrocarbon; excessive gland tightening of the packing should be avoided, because overheating could result in the rupture of the gland. Stainless-steel mechanical seals with glass-filled Teflon and ceramic faces are recommended. All pumps should be equipped with drain valves and, where desired, temperature alarms to warn against overheating.

4.4.2.8 <u>Filters</u>. Liquid filters have been used in hydrogen peroxide storage and transfer systems to maintain propellant cleanliness from insoluble contaminants. Because of the massive surface area available (for promoting heterogeneous decomposition), the filter should be selected from Class 1 or 2 materials, and should be located where it is not constantly immersed in the liquid (such as the inlet or outlet of a transfer line). Also, it should be located for easy and repeated opening and cleaning. A 25-micron, type 316 stainless-steel filter with a 1000-sq in. minimum element area (100 gpm H_2O_2 at 15 psi ΔP) has been used successfully in large handling systems.

4.4.2.9 <u>Gaskets</u>. The selection of gaskets for hydrogen peroxide service is related to the type of service to be provided. Materials normally used as gaskets are Teflon, Kei-F, certain silicone rubbers, some polyvinyl plastics, Koroseal 700, pure tin, and either a combination of spirally wound stainless steel and Teflon (Flexitallic) or a Teflon

envelope over asbestos. The metal-containing gaskets are usually recommended for high-preasure and vacuum systems; however, contact between dissimilar metals should be avoided to prevent galvanic corrosion. The use of certain elastomeric meterials as gaskets sust be avoided because the plasticizer or filler material may be incompatible or impact sensitive (see Section 4.2.2).

4.4.2.10 <u>Lubricants</u>. The use of lubricants in propellant-grade hydrogen peroxide service should be minimized or avoided wherever possible. Results of compatibility tests (Section 4.2.2.6) indicate that only the fluorinated hydrocarbons are sufficiently compatible with hydrogen peroxide to be considered, and even these materials may react under certain conditions.

4.4.2.11 Instrumentation. In the design of instrumentation internal probes or sampling tubes for hydrogen peroxide storage and handling systems, the proper selection of compatible materials is the primary consideration. Dissimilar metals in contact with hydrogen peroxide demonstrate a tendency for electrolytic corrosion, with the more concentrated solutions showing less galvanic action. However, even with 90 w/o hydrogen peroxide, the use of dissimilar metals should be avoided. Attempts at insulating one metal from the other by a plastic have not been very effective in past applications where intermittent wetting occurs. If two dissimilar metals must be in contact, the anodic metal should have a larger surface area than the cathodic metal. In addition, the use of soldered joints (particularly silver solder), which is common in various types of probes and sensors should be avoided (because of catalytic decomposition of the hydrogen peroxide).

As noted previously, "dead ends," which are those places that could be filled with hydrogen peroxide without permitting adequate recirculation of the fluid, should be avoided wherever possible. (A common example of this in instrumentation design is the typical Bourdon tube pressure gage.) The disadvantage of having a dead end in a piece of apparatus is that there is a possibility that small impurities will accumulate in the dead end until extensive hydrogen peroxide decomposition results. If dead ends cannot be avoided, they should be placed above the low point in the system so that liquid hydrogen peroxide solutions will not collect in them.

4.4.2.11.1 Pressure Gages. If gages are required or used in hydrogen peroxide service, they should be constructed of compatible materials and meet the other considerations noted above. Where Bourdon tube-type pressure gages are used, their design and assembly should allow for proper passivation and inspection of the gage inlet, and there should be no welds in contact with the hydrogen peroxide. For example, a stainless-steel diaphragm held between two bolted stainless-steel flanges should be used in conjunction with a Bourdon tube pressure gage, with the assembly placed in a vertical position. Gas legs and diaphragm protectors have also been used with success in preventing direct exposure of the gages to liquid hydrogen peroxide.

4.4.2.11.2

<u>Storage Tank Temperature-Measuring Devices</u>. A study of temperature-measuring devices for high-strength hydrogen peroxide storage systems has been reported in Ref. 4.64. A summary of this study, shown in Table 4.32, illustrates the presently available techniques. Selection of any one of these techniques is dependent upon the requirements of the particular facility. However,

regardless of which technique it used, its limitations, operating characteristics, and relationship to potential "red line" conditions must be fully understood by facility personnel to ensure the usefulness of the system.

In consideration of the various techniques described in Table 4.32 , the surface measuring system with its sensing point at the bottom of the tank (Method 3) would be less affected by high vapor space temperature than any of the other measuring devices. The Manufacturing Chemists' Association (Ref. 4.65) has, in effect, recognized this technique as a suitable method by stating."The temperature of a tank may be monitored by temperature indicators attached to the exterior of the tank below liquid level which records the temperature automatically or an operator may record the temperature on schedule." While not directly measuring liquid temperature, such a system would show tank temperature changes (although it would probably be unsuitable for inventory purposes). Using a dial thermometer, this type of system would be the most economical direct temperature indicating system.

The use of a dial thermometer inserted in a thermal well below the liquid level (Method 4) would more closely indicate the true liquid temperature and be less affected by ambient temperatures than surface mounted systems. High vapor space temperature would not affect such a system unless the liquid level fell below the well.

Another type of surface measuring system (Method 7) encompasses the vapor space using a capillary sensing element which is sensitive to the warmest spot along its length. However, any time the vapor space is warmer than the liquid, this instrument will indicate the vapor space tank surface temperature rather than the liquid. One organization reported that it was necessary to set the

alarm point of such a system at 145 F to eliminate false alarms resulting from sun heating effects transferred into the vapor space. One manufacturer of this type of instrument does not recommend it for this use.

Another organization reported the use of an averaging surface measuring system covering the lower quadiant of the tank (Method 6). This system was affected in a manner similar to that of Method 7 at lower liquid levels, but to a lesser extent, since it averages the temperature rather than selects the warmest spot.

The Weston System (described as Method 10), using a resistance temperature element installed from top to bottom of the tank in a well, will average the liquid temperature from the liquid level to the bottom of the tank. A manual switch is provided to change the temperature-sensitive segment of the element to that position below the liquid level in up to six steps. This system gives good average liquid temperatures at any one vertical plane in the tank. Several elements installed in one tank or in several tanks could be used with one indicator. Such a system is expensive but might prove extremely valuable in the checkout of a new storage area, particularly by a group inexperienced in hydrogen peroxide handling and storage.

The use of automatic temperature alarms connected to the sensing device would be of little value in determining self-heating of the tank in the early stages. For example, in cold weather, self-heating could be progressing very rapidly by the time the alarm point set for 120 F would be reached. Conversely, in hot weather, the effects of the sun coupled with low liquid levels could result in frequent false alarms at this temperature. As a result of these false alarms, the alarm would soon be ignored (or if the alarm were set high enough to eliminate the false

alarms, it might provide a false sense of security). An alarm system could be set up to operate on a given temperature differential between ambient and storage temperatures; however, this involves additional expense.

It is generally recommended that the use of continuous plots of tank (with any of the indicated devices) and ambient temperatures be used as the method of evaluating storage conditions, at least until personnel have sufficient experience to evaluate the facilities properly.

4.4.3 <u>System Fabrication and Assembly</u>

Hydrogen peroxide storage and transfer systems are similar to those employed for handling ordinary fluids, except for materials of construction. Pump motors, solenoid valves, electrical switch-gear, and other electrical equipment in the hydrogen peroxide transfer and storage systems should be selected and installed in accordance with the requirements of the National Electric Code, Article 500, Class 1, Division 2. All seals and joints in the propellant system should be periodically and frequently inspected for leaks and damage.

In the layout, placement, and arrangement of operating systems and units, ample spacing should be provided for proper maintenance clearances and adequate ventilation. In many cases, the removal, replacement, and servicing of valves, pumps, piping sections, instrumentation, and other equipment must be done by personnel in protective clothing. Ample room and access must be provided for use of tools and for easy movement of equipment. Where possible, equipment, valves, and lines should be located so that

maintenance and service work can be accomplished from a position above the piping level to prevent propellant drips and leaks from falling on personnel.

Prior to fabrication and assembly of the system, the materials and equipment to be used should be carefully selected from the recommended lists as given in Section 4.2.2 and 4.4.2. Any questionable or unknown (with respect to compatibility) material or piece of equipment, which is to be used in the system, should be thoroughly checked in accordance with the procedures given in Section 4.2.1. In addition, the identity of each material used in the fabrication and assembly of hydrogen peroxide systems must be ensured; test kits are available for the identification of metals in the field (Ref. 4.66).

These selections should be judiciously reviewed by knowledgeable personnel who have had prior experience in the operation of hydrogen peroxide facilities. The selected materials and equipment should then be cleaned, passivated, and "activity" checked and the system fabricated and assembled according to the considerations given in the following paragraphs.

- 4.4.3.1 <u>General</u>. In the fabrication and assembly of hydrogen peroxide systems, the user is again reminded of general "rules of thumb" that should be observed in the design, preparation, and assembly of the system. These are noted as follows (Ref 4.25).
 - 1. All hydrogen peroxide tanks should be designed with a minimum surface-to-volume ratio for maximum storage stability (i.e., a sphere is the optimum shape).

- 2. All storage tanks, vessels and drums should be designed so that sampling of their contents may be accomplished without the use of a sample thief or insertion of any device into the storage container.
- 3. Various seamless stainless-steel tubing can be used for high-pressure systems, but the 304L, 316L, 321, or 347 alloys should be used if welding is required.
- 4. Stainless-steel and aluminum components should not be coupled in the same system because electrolytic corrosion may result.
- 5. Free-machining, stainless-steel alloys should not be used.
- 6. Cast stainless-steel components should not be used unless the particular casting is thoroughly proved to be suitably compatible with hydrogen peroxide.
- 7. All markings should be removed from stainless-steel plates before they are formed into a tank.
- 8. Lap joints should not be used in fabrication of materials. Lap joints provide cracks, crevices, etc. (which cannot be readily cleaned), and may furnish a source of contamination; they also provide dead spaces for retention of hydrogen peroxide.
- 9. Clean rolling equipment must be used in material fabrication.
- 10. Head forming dies should be free of rust and smooth.
- It is often advisable to degrease and passivate the tank head and bottom closures prior to fabrication.
 This eliminates difficulties in future tank and system passivations.

- 12. Flux and carbon formed in fabrication should be cleaned from welded areas in stainless steels by a 300 series stainless-steel wire brush. Any inclusions remaining should be ground out. For the grinding of cast surfaces, welds, and weld spatter on surfaces that will contact propellant-grade hydrogen peroxide, a clean white aloxide (aluminum oxide) abrasive is recommended.
- 13. Carborundum is <u>not</u> recommended for grinding because the iron in the carborundum is catalytic with hydrogen peroxide.
- 14. Metallizing or sprayed metal coatings are not suitable techniques for preparing surfaces for hydrogen peroxide service. It is possible for the hydrogen peroxide to seep behind the coating or an exposed edge, and cause the coating to blister.
- 15. Sandblasting is not recommended because it reduces the compatibility of metals with hydrogen peroxide due to the formation of a porous or pitted surface. The rougher surface decreases its compatibility with hydrogen peroxide.
- 16. Mechanical polishing of aluminum alloys is not advisable because of the possibility of introducing materials which are not compatible and could cause decomposition of the hydrogen peroxide. Electrochemical polishing (anodization) of aluminum is the recommended method.
- 17. If an aluminum system is employed, it should be anodized per Specification Mil-A-8625 (with no dyes), followed by a 1-hour rinse in boiling distilled water.
- 18. Aluminum materials and components should be handled carefully to prevent the possibility of embedding metal particles in the surface.
- 19. Hydrogen peroxide system components should not be brazed or silver soldered.

- 20. All plastic materials must be checked for metal particles, inclusions, etc., prior to use. The entrapment of organic solvents in porous materials should be avoided during cleaning operations.
- 21. Chromic acid solutions should not be used for cleaning because chromium is one of the better decomposition catalysts for hydrogen peroxide.
- 4.4.3.2 <u>Welding</u>. In general, the standards for welding pipe will conform to Chapter 4 of Ref. 4.57. Pipe fittings should be procured from reputable sources who permanently mark their fittings as to: (1) manufacturer, (2) size and sched-ule of pipe, and (3) material and heat code. The fittings should be of the butt-welded type to facilitate system cleaning and purging operations. A typical set of stand-ards for the acceptance of pipe welds is as follows:
 - 1. Cracks of any nature, whether crater, underbead, transverse, longitudinal, or parent metal will be cause for rejection.
 - 2. Crater cracks which are determined to be only surface defects may be removed by machining or grinding. They need not be rewelded provided buildup is not less than 10 percent nor more than 30 percent of the metal thickness, nor if drop-through is not less than flush nor more than 30 percent of the metal thickness.
 - 3. Normally acceptable defects occurring in conjunction with or adjacent to cracks will be cause for rejection if they occur within a distance of 2 inches each way from the crack.
 - 4. Butt joints will have 100-percent penetration throughout 100 percent of the linear length of the weld.

- 5. Any lack of fusion will not be accepted.
- 6. Undercut, excessive drop-through, and excessive roughness will be cause for rejection. Folds in drop-through will be accepted if they are not greater in depth than 10 percent of the thickness of the parent metal.
- 7. Porosity or inclusions occurring in the weld metal, exclusive of the weld reinforcements, in which any radiographic image is darker than the parent metal or larger in its greatest dimension than 15 percent of the parent metal thickness will be rejected.
- 8. Porosity and inclusions in the weld reinforcement will be acceptable provided they do not extend through the surface of the reinforcements and provided they do not result in an objectionable stress riser.
- 9. Porosity and inclusions whose greatest dimensions are equal to or less than 15 percent of the parent metal thickness will be acceptable to the extent of one pore per inch of weld length.
- 10. Tungsten inclusions located in the penetration zone will be accepted provided the greatest dimension of any particle is not over 25 percent of the parent metal thickness.

In the welding of hydrogen peroxide systems, specific considerations must be observed to ensure the passivation and compatibility of the fabricated and assembled system with hydrogen perexide. These considerations, noted in Ref. 4.25, are essentially dependent upon the design of tanks and equipment, which should be such that good welding techniques and machining practices can be readily utilized. Since weld splatter on surfaces which will contact the hydrogen peroxide will cause excessive decomposition, the design should allow for removal of weld splatter if it should occur.

Stainless-steel welds exposed to hydrogen peroxide should also be machined smooth if possible; however, aluminum welds should not be wire brushed or machined because this may introduce impurities and thus do more barm than good. Allowance for good machining will result in smooth surfaces which will cause less decomposition of the hydrogen peroxide than rough or poorly machined surfaces.

4.4.3.2.1 <u>Aluminum Alloys</u>. Weldability of Aluminum and Aluminum alloys varies over a wide range. The same procedures and techniques are employed in welding aluminum and its alloys as are used in welding other weldable alloys. In general, the less constitutents in the alloy, the more weldable the alloy.

> The wolding rod to be selected should be of the same composition as the parent metal. Unlike other alloys, the aluminum alloys do not lose any appreciable amount of the alloying clements during welding. In most cases, dissimilar aluminum alloys, which can be welded individually, can also be readily welded in combinations; the welding rod to be used should be of the harder material in the combination (i.e., in welding aluminum alloys 1060 and 5652, a 5652 rod would be used). The use of 5-percent silicon rods such as 43S, which are commonly used in aluminum welding, is not recommended for propellant-grade hydrogen peroxide service. During passivation and contact with hydrogen peroxide, such welds turn black and may cause decomposition of the solution. If use of the 43S rod is required, subsequent sulfuric acid anodization is necessary to stop the weld from turning black during passivation. During anodization, there may still be some blackening of 43S welds, but this discoloration does not seem to be a prior indication of an active site. Normally, a 5254 welding rod is recommended for welding of the 6061 alloy to other alloys.

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Aluminum welds should not be wire brushed or machined if at all possible, because impurities may be introduced into the metal. In instances where wire brushing is a necessity, a 300 series stainless-steel brush will be used, and care must be taken to confine the brushing to the immediate weld area.

Automatic inert-gas welding processes, such as the Aircomatic or Sigma processes, give excellent results when used with the proper welding rod. The welds, in general, are nonporous, soft, and uniform. Electrode tip cups should be of stainless steel rather than copper (or other such materials) because the latter might melt into and contaminate the weld.

Ilcliarc inert-gas welding is, in general, a satisfactory process. Although it has many of the advantages of the automatic processes, it does have the disadvantage of "spitting" of tungsten from the tungsten electrode into the weld when the arc is initiated and when the arc is discontinued; these exposed tungsten deposits will cause decomposition of the hydrogen peroxide. The tungsten "spitting" may be decreased and, in many cases, eliminated by using a pure tungsten electrode, striking the arc on a separate piece of material and carrying the weld into the work, and then discontinuing the arc on a separate piece. For inert-gas welding, where the welding rod is not coated, it is recommended that strips be cut off the work scrap and used as the welding rod. Stainless-steel electrode tip cups should be used,

The weld resulting from the metal-arc process has two disadvantages: (1) porosity, and (2) brittleness. These characteristics are highly undesirable in hydrogen peroxide systems, and for this reason, the inert-gas processes are usually preferred and recommended. The metal-arc process

can be used, however, for structural aluminum welding (such as tank supports or ramps,) and is quite suitable for this purpose.

Oxyncetylene gas welding also has two undesirable features (for hydrogen peroxide system welds) when compared to the inert-arc processes. These are: (1) the excessive heat required causes warpage, and (2) the flux tends to be trapped in the weld. However, the welds are satisfactory from a strength point of view and, if the noted disadvantages can be tolerated, this process is acceptable. Oxyncetylene gas welding has been utilized for pipe and small parts made of aluminum when highly skilled and experienced welders are available. This sections can be welded more satisfactorily with this type of welding. Napolitan welding flux or its equivalent is recommended for use in gas welding.

4.4.3.2.2

Stainless Steel. Inert-gas and metal arc-welding processes are satisfactory in the welding of stainless steel for hydrogen peroxide systems. The inert-gas process is preferred because the inert-gas blanket results in a weld with less foreign material. In general, thoriated tungsten electrodes are used. Standard welding procedures should be used for both of these processes, and it is necessary that all welds be of high quality, smooth, homogeneous, and free of inclusions and blowholes. Carbide precipitation during welding must be avoided by the use of stabilized alloys such as 347 or 321 or the extra low-carbon alloys, 304 or 316.

After a weld is completed, all weld scale should be removed with a 300 series stainless-steel brush, and the inner weld surface should be ground with a white aloxide wheel to a maximum 32 rms finish. Any installation of a flange or discharge pipe at the low point of a hydrogen peroxide tank should be welded from the tank interior and ground smooth prior to welding the bottom closure in place.

> NOTE: A carborundum wheel should not be used for grinding, or else iron will be deposited in the metal surface.

A narrow and thin stainless-steel backing ring should be installed at the weld placement in vertical tanks.

Polishing of stainless steels following welding is generally unnecessary but, for certain borderline cases, it may improve the compatibility of the metal with the hydrogen peroxide by smoothing the surface. In general, the smoother surface will provide a lower rate of hydrogen peroxide decomposition. For mechanical polishing, a wet or dry paper (aluminum oxide abrasive) with a kerosene labricant can be used.

Electropolishing of stainless steel has also been effective in improving the compatibility of steel for hyd.ogen peroxide service. For routine hydrogen peroxide applications, electropolishing is not required because stainless steel is usually only applied in limited contact time service. For special applications, electropolishing of stainless steel might be justified, and in such cases, standard electropolishing techniques should be used.

4.4.3.3 <u>Brazing and Soldering</u>. Brazing and soldering techniques are not recommended for application in hydrogen peroxide systems. The joints produced by these methods are usually incompatible with the propellant. 4.4.3.4 <u>Mechanical Joints</u>. The advantages of relatively leak-free all-welded transfer systems are obvious. From a practical standpoint, however, some type of joint, whether flanged or otherwise, is required to provide adequate system flexibility. Small valves and components should be selected with AN flared-type connections. Large valves and components should be selected with flanged connections. Instrumentation connections should be of the AN type, and can be provided by welding boss fittings on large pipelines or by installing tee fittings on small lines.

4.4.3.5 <u>Inspection</u>. In the construction, installation, and modification of hydrogen peroxide systems, inspection is important to ensure quality of materials; adherence to design specifications; and proper fabrication techniques. Before installation, each piece of equipment, such as pumps, flex joints, valves, filters, etc., will be inspected and tested for:

1. Cleanliness

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- 2, Proper lubricants (if allowable)
- 3. Leakage, internal and external
- 4. Pressure-proof test
- 5. Sealant and gasket materials
- 6. Proper operation
- 7. Freedom from defects
- 8. Adherence to applicable specifications--type, size, rating, dimensions, etc.

Piping and tubing sections will be inspected and tested for:

1. Conformance to design specifications and building codes

- 2. Identity and quality of materials of construction
- 3. Adequacy of supports; freedom from "cold spring"
- 4. Cleanliness

- 5. Proper fabrication workmanship
- 6. Proof-pressure and leak tests
- 7 Proper installation of flex joints

Electrical installations and equipment will be inspected and tested for:

- 1. Conformance to design specifications and applicable codes
- 2. Adequate grounding
- 3. Insulation resistance
- 4. Circuitry continuity and proper termination
- 5. Workmanship and fabrication technique
- 6. Proper support of conduits and wiring

Instruments (flowmeters, gages, transducers, etc.) will be shop tested, and calibrated and certified with due regard to using conditions, fluid density, operating range, material identity, repeatability, end scaling capability. These instruments must be inspected for cleanliness prior to installation.

Roads, buildings, structures, etc., should be inspected for conformance to design specifications and building codes.

4.4.3.6

<u>Hydrostatic and/or Pneumatic Tests</u>. All components and tanks to be placed in hydrogen peroxide service should undergo applicable hydrostatic and/or pneumatic proor testing before they are cleaned and passivated.

> NOTE: Hydrostatic testing should be conducted with water.

After passivation, all proof and leak testing should be conducted only with deionized or distilled water, or with clean, filtered, hydrocarbon-free nitrogen gas or air.

DECONTAMINATION AND DISPOSAL

The initial step in the decontamination of equipment or facilities and subsequent disposal of hydrogen peroxide is its dilution with large quantities of water. All facilities which store and handle hydrogen peroxide should be equipped with an adequate water supply to ensure a maximum dilution of the hydrogen peroxide prior to its flush into the facility drainage system. Normally, dilution to 3 w/o H_2O_2 or less should be completed before the hydrogen peroxide solution is dumped or pumped into the drainage system (which should terminate in a large body of water). Further dilution is required before dumping into a public water table. Under <u>no</u> circumstances should hydrogen peroxide be dumped into sewers or drains that lead to public water tables, unless this maximum dilution has been performed at the originating site.

4.5.1

4.5

Equipment Decontamination

Equipment being removed from service, temporarily flushed of residual propellant, and/or being decontaminated of possible impurities, is normally flushed with distilled or deionized water. Emergency decontaminations may use water supplied by the normal facility water or "firex" (fire-fighting equipment) systems. Once flushed from the equipment, the hydrogen peroxide should be diluted further with facility or "firex" water.

Facility Decontamination

The decontamination of gross spillage or leakage at a facility is best accomplished through the use of a facility floor flush or a flooding water spray system. Large-volume fire hoses may be used as a substitute technique, but the method of attack should preclude washing concentrated hydrogen peroxide solutions into the drainage system ahead of the dilution water. Ordinary garden-type hoses can be used for small spills or for rinsing hydrogen peroxide from the outside of equipment.

> CAUTION: Unless an emergency exists (and massive water spray of equipment is required), care should be taken in flushing the outside of the equipment to prevent water damage to the attendant electrical and control systems.

All facility flushing should be thorough and can be conducted with normal facility water.

4.5.3 Drainage

4.5.2

All hydrogen peroxide facility drainage ditches (or other spillage catch basins) should be open and lined with impervious acid-resistant concrete. These ditches and catch basins should be kept clean of debris and combustible material. The use of the hydrogen peroxide drainage system for other chemical dumps should be prohibited unless an adequate water flow is maintained to ensure maximum dilution and drainage system flushing of all chemicals. The main drainage ditch should be supplied with a large water flush outlet at the highest point of hydrogen peroxide drainage and should be fenced from the facility to the catch basin. The design of the facility should be such that all areas are adequately drained by gravity into the main drainage system.

4.5.4 Catch Basins

Because hydrogen peroxide dumping into public water tables can be potentially hazardous if it has not been sufficiently diluted, most facilities utilize a catch basin which either stores the water for facility recirculation or acts as a settling or dilution pond prior to drainage into a public water table. In either situation, the hydrogen peroxide is diluted or reacted further with other chemicals (contained in the catch basin) to form water solutions that are nontoxic.

4.5.5 Final Dilution Requirements

Although local, state, and federal codes are not sufficiently clear with respect to regulation of hydrogen peroxide dumping into public streams, lakes, etc., it has been generally accepted that dilution to less than 3 w/o H_2^{0} concentration is required to ensure human safety.

In a bioassay study conducted by the Academy of Natural Sciences of Philadelphia for E. I. duPont de Nemours and Co. (Ref. 4.67), a concentration of 165 ppm H_2O_2 in water at ~70 F (with a dissolved oxygen content of 5 to 9 ppm) resulted in a 100-percent mortality rate of fish (4 to 10 centimeters long) of the Lepomis macrochirus Raf. (bluegill) species, which had been exposed to the contaminated water for a period of 24 hours. The resulting 24-hour TL (maximum threshold limit) for these species was 65 ppm at a solution pH of 7 and 90 ppm at a solution pH of 8.5.

Internal regulations used by the Rocketdyne Division of North American Aviation, Inc., have established a maximum concentration of 100 ppm II_2O_2 for water dumped into public water tables; these regulations have been accepted by local, state, and federal authorities.

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1. 1. 1. 1.
Concentre weight perc	tion, cut H ₂ 0 ₂		Storage	0. 1088 year, (2)
Initial	Final	Material	months	weight percent
	Unstabilize:	1-90 м/э- <u>Ц</u> о ₂	(Stored ⁽³⁾)	1945-1948)
90.5	88.6	_(4)	30	0.254
90.5	89.1	-	30	0.210
90.5	87.8	-	30	0.381
90.5	89.3	-	30	0.169
90.5	89.3	-	36	0.169
90.5	88.7	-	30	0.254
Unst	bilized 90 v	w o 11,0, (Sto	red ⁽³⁾ 11, 19	54 to 12/1955)
91.25	89.27	1060 A1	13	0.00
90.72	90.56	1960 VI	13	0.063
90.91	90.45	5052 Al	13	0.425
88.13	87.54	5652 Al	13	0.54
90.91	90.81	5254 Al	13	0.039
90.61	90.17	<u>5274 Al</u>	13	0.20
U	stabilized	98 w o H ₂ 0 ₂ (Stored ⁽³⁾ 8]	1960 to 5/1963)
08 50	08 27	(4)	1 7	0.021
90.75	07 64		33	0.021
98.8	98.31	-	33	0.086
98.59	98.28	-	33	0.054
98.8	98.36	-	33	0.077
98.14	97.79	-	33	0.061
98.8	98.34	-	33	0.098
98.14	97.43	-	33	0.125
Stabil	ized Torped	o-Grade H ₂ 0 ₂	(Storage ⁽³⁾	Completed 8/1962)
90	88.51	1060 A1	<u>Ú2</u>	0.12
00	86.75	1060 Al	63	0.26
<u>N</u>	-		-	

STORAGE STABLE TY OF HYDROGEN PEROXIDE (1)

TABLE 4.1

Dat taken from Re

(2)02 less year docs not correspond with concentration change

Ambient storage in 30-gallon drum (S/V = 0.38 in.⁻¹)

(4) Drum material unknown; assumed to be aluminum alloy

A COMPARISON OF THE RATE OF DECOMPOSITION OF 90 w \circ INDROGEN PEROXIDE MANUFACTURED IN 1947, 1953, AND 1965⁽¹⁾

	EI	lect o	f Temperature	
		Rat	e of Decompositi	on (AUL)
Temperature, F	1947 ⁽²⁾		1953 ⁽³⁾	1965 ⁽⁴⁾
86	1% per year	0.5 t	o 1.0≸ per year	0.02 to 0.01; per year
151	1% per week	10% p	er year	0.1% per year
212	2% per day	4% pe	r week	1% per year
	[]			
-	Eff	ect of	Contamination	
-			Decomposition	Rate at 212 F
Additiv	e to 90 w,'o 11	$2^{0}2$	1947 ⁽²⁾	1965 ⁽⁵⁾
Non	e		2% per day	1% per day
A 1	10 mg/liter		2% per day	-
Cr	0.1 mg/liter		96% per day	2% per day
Cu	0.01 mg/liter		24% per day	10% per day
Cu	0.1 mg/liter		85% per day	66% per day
Fe	1.0 mg/liter		15% per day	25% per day
Zn	10 mg/liter		10% per day	-
Su	10 mg/liter		2% per day	

(1) Data reported as generalized criteria from tests using assorted test parameters and techniques; data generally represent tests under minimum S/V conditions.
(2) Data reported in Ref. 4.3
(3) Data reported for 99+ w/o H₂O₂ in borosilicate glass containers (lef. 4.5)
(4) Data reported in Ref. 4.1
(5) Data reported in Ref. 4.4

CRITERLA FOR CLASSIFICATION OF MATERIALS FOR INDROGEN PEROXIDE SERVICE

ON THE BASIS OF LABORATORY TESTS (REF. 4.25)

ass Material Stabilization of ADL Week Stabilization of ADL Othor Observati 1 Metals 86 F 150 F Test, percent Othor Observati 1 Metals 0.2 5.0 95 No other effect on H_002 or n impact sensitive to 5 kg-met 1 2ladder Material 0.2 5.0 95 No other effect on H_002 or n impact sensitive to 5 kg-met 1 2ladter Material 0.2 5.0 95 No other effect on H_002 or n impact sensitive to 5 kg-met 1 2lastics for diaphrages 0.4 6.0 95 No other effect on H_005; sli 2 Metals stationes 0.4 6.0 90 No other effect on H_005; sli 2 Netals stell 0 95 No other effect on H_00; sli 0 2 Metals stationes 0.0 80.0 90 No other effect on H_00; sli 0 2 Metals station for ease 0.0 80.0 90 No other effect on H_00; sli 0 3 statoeffect					Minimum	
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Metals0.25.095No other effect on H ₀ O ₂ or n impact sensitive to 5 kg-met kg-metPladder Material (plastics for diaphragms, drums and liners)0.25.0951000100051000Plastics for diaphragms, drums 		Material	86 F	150 F	z ź Test, percent	Other Observations
Impact sensitive to 5 kg-meet Impacts for (plastics for (plastics for (indiaphragmas, drumms) and liners) and liners) fishtics for 0.4 6.0 95 Plastics for 0.4 6.0 95 Plastics for 0.4 6.0 95 97 98 98 90.0 90		Metals	0.2	0.	95	No other effect on $H_2 0_2$ or material and non-
and liners)ord0.46.09595Plastics for Geskets, Tubing, etc.0.46.095No other effect on H2O2; sli0:11 and Greases1.010.095No other effect on H2O2; sli0:11 and Greases1.010.090No other effect on H2O2; sli0:12 and Expul- steel)6.080.090No other effect on H2O2; sliPlastics for 0- steel)6.080.090No other effect on H2O2; sliPlastics for 0- 		Bladder Material (plastics for diaphragme drume	0.2	0.0	95	<pre>impact sensitive to 5 kg-meter impact at 212 F</pre>
0il and Greases1.010.095No other effect on H2O2; aliMetals (stainless6.080.090No other effect on H2O2; aliPlastics for 0- sion Devices6.080.090No other effect on H2O2; aliPlastics for 0- sion Devices6.080.090No other effect on H2O2; aliFlastoners sion Devices6.080.090No other effect on H2O2; aliFlastoners sion Devices6.595.090No other effect on H2O2; aliFlastoners (biadder material)6.595.090No other effect on H2O2; aliOils and Greases (biadder material)6.080.090No other effect on H2O2; aliOils and Greases (biadder material)6.090No other effect on H2O2; aliOils and Greases (biadder material)6.090No other effect on H2O2; aliOils and Greases (biadder material)6.090No other effect on H2O2; ali	· · · · · · · · · · · · · · · · · · ·	and liners) Plastics for Gaskets, Tubing, O-rings, etc.	0.4	6.0	95	
Metals (stainless 6.0 80.0 90 No other effect on H_2O_2 ; slisteel) 6.0 80.0 90 No other effect on H_2O_2 ; sliPlastics for $0 6.0$ 80.0 90 No other effect on H_2O_2 ; slirings and Expul- 6.0 80.0 90 No other effect on H_2O_2 ; slision Devices 90 No other effect on H_2O_2 ; slision Devices 95.0 90 No other effect on H_2O_2 ; sliflastomers 6.5 95.0 90 No other effect on H_2O_2 ; sliflastomers 6.5 95.0 90 No other effect on H_2O_2 ; sliflastomers 6.5 95.0 90 No other effect on H_2O_2 ; sliflastomers 6.0 90 No other effect on H_2O_2 ; sliflastomers 6.0 90 No other effect on H_2O_2 ; sliflastomers 6.0 90 No other effect on H_2O_2 ; sliflastomers 6.0 90 No other effect on H_2O_2 ; sliflastomers 6.0 90 No other effect on H_2O_2 ; sli		0il and Greases	1.0	10.0	95	
Plastics for 0- rings and Expul- sion Devices6.080.090No other effect on H202; sli swelling, embrittlement. or blistering accepted; non-imp to 3 kg-meter impact at 212Elastomers (bladder material)6.595.090No other effect on H202; sli blistering accepted; non-imp to 3 kg-meter impact at 212Elastomers (bladder material)6.595.090No other effect on H202; sli 		Metals (stainless steel)	6.0	80.0	06	No other effect on H ₂ O ₂ ; alight bronzing of the metal allowable, but no corrosion
Elastomers (bladder material) 6.5 95.0 90 No other effect on H ₂ 02; sli (bladder material amount of elas material accepted; non-impact 3 kg-meter impact at 212 F 0ils and Greases 6.0 80.0 90 No other effect on H ₂ 02; non-		Plastics for 0- rings and Expul- sion Devices	6.0	80,0	06	No other effect on H_20_2 ; slight blcaching, swelling, embrittlement. or occasional blistering accepted; non-impact sensitive to 7 kr_meter impact sensitive
Oils and Greases6.080.090No other effect on H202; non- to 7 kg-meter impact at 212 F		Elastomers (bladder material)	6.5	95.0	06	No other effect on H202; slight beaching, or loss of small amount of elasticity of the
		Oils and Greases	و، 0	80.0	. 06	3 kg-meter impact at 212 F No other effect on H ₂ O ₂ ; non-impact sensitive to 3 kg-meter impact at 212 F

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TABLE 4.3 (Concluded)

Elastomers burned, swollen, dissolved, disother corrosion products; slight attack may Metals pitted and corroded during or after disintegrated, after 1 week of test; non-Surface may be embrittled, bleached, blisat 212 F; excessive H202 decomposition ap-Non-impact sensitive to 3 kg-meter impact Plastics disintegrated, burned, blistered tered or lose elasticity; non-impact senburned; any material which is impact sen-Bronzing and staining, but not rusting or May become partially bleached, distorted, impact sensitive to 3 kg-meter impact at Oils and Greases melted, disintegrated, integrated, blistered, gummy; loss of sitive to 3 kg-meter impact at 212 F sitive to 3 kg-meter impact at 212 F Other Observations proaching catalytic rate elasticity be allowed 212 F tejt Stabilization of ${\rm H_2^{0}_2}$ After Test, percent Minimum 15⁽¹⁾ 15(1) $_{15}^{(1)}$ $15^{(1)}$ 100/24 bours 100/24100/24 bours μ**ε**ι 100/24 hours hours Maximum Amount 150 of AOL/Week 11.0 86 F 11.0 Oils and Greases | 11.0 11.0 **Oils and Greases** Material Elastomers El astomers Plastics Plastics Metals Metals Class m m m 4 3

(1) The stability of the ${
m H_2^0}_2$ after exposure to the material.

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH ALIMINUM ALLOYS⁽¹⁾

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		8								_																			-
Commenta		Used successfully as pur impeller and quick dis- connect					Limited use			Not recommended	Not recommended	Not recommended	Not recommended			Not recommended	Not recommended	Pumps, valves, housings	For coating use	Not recommended	Not recommended	Not recommended	Not recompaded		Storage tanks, piping	Storage tanks	Storage tanks, piping	Storage tanks. piping	
Effect On Material		Noae (3)	None	Nome		~ ~	None	None		Stained	None		Corroded		None	None	None	None	None	None	None	None	None		None	None	None	None	
Percent ⁽²⁾ Stability After Test	1	4-26	0	1	ł	ł	1	1	I	!	1	I	o	1	ł	•	I	98.0	0.86			ł	I		8.8	0.86	1	6.86	
Percent AOL per Veek at 151 F	1	8	100	17.8	1	1	28.7	1		20.0	39.5	4.96	100.0		100.0	100.0	50.0	2.8	3.9	8,96	100.0	100/3 days	100/3 days		1.5	1.5	3.0	1.5	-
Percent AOL per Month at 86 P	1		1	1		1	1	1	1	1	1			1	1	1		1	I		1	I	1		0.3		4.0	4 "0	
Class		2		2		-	N	a	4	0	2	m		2	'n	*	¢1	-		ĥ	-	-#	-7		-	I	3	-	
H2 ⁰ 2' weight percent	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8		8	8	8	8	
Source		0.P.V. Corp. (Kam Lok)	Prontier Bronse	Alcos	I	I	Lafaer	1	ł	Alcon	Alcom	Alcon	1	I		Alcos	Alcos	Alcon	1	Alcos	Alcon	Alcos	Alcon		Alcos	Alcos	Alcon	Alcon	
Material	Cant 13(11)	¥104	10 A	÷	428(12)	238 (11)	130	11508(11)	214(11)	21 4B	2147	11120	218	355(11)	355	35%	3.968	955a	1356	A360	750	N750	1. 30	Vrencht	1060	1060 (99.6)	1100 (28)	1160	
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TABLE 4.4 (Continued)

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		B2 ⁰ 2, veight		Percent AOL per Month	Percant AOL per Veek	Fercent ⁽²⁾ Stabillty	Effect On	
Material	Source	percent	Class	at 86 F	at 151 F	After Test	Material	Comments
Wrow At								
1260	Alcos	8	-	1	1.5	8°.86	None	Storage tanks, piping
1260	Alcon	8	1	1	$_{2.1(5)}$	0.96	None	Storage tanks
1260	Alcos	8		ł	1.2(6)	6.96	None	Storage tanks
1260 Pretreated ^(7, 13)	Alcoa	8	1	ł	0.7 to 0.8 ⁽⁷⁾	I	None	Storage vessels, piping
1260, Protreated ^(8, 13)	Alcos	8	-	1	2.5(7)	I	None	Storage vessels, piping
1360(10)			-	1				
2014 (148)	I	8	-	1	100.0	ł	None	Mot recommended
2017 (178)	Alcon	8	*	1	100.0	I	None	Not recommended
2017, H2S0, Anodized	Alcom	8	n	1	23.3	1	None	Limited service life (1 to 2 years)
2024 (245)	Colonial Alloys	8	~	I	16.4	ł	None	Not recommended
2024 (245)		8	-	ł	100.0	I	None	Not recommended
2024, Hardas Costed	Anachrome	8	n	l	20.6	50.3	Coating dissolved in spots	Not recommended
2024, Chromic Acid, Anodized	Colonial Alloys	8	-3	1	100.0	I	None	$\mathrm{H}_{2}\mathrm{S0}_k$ anodized is better
2024, R ₂ 80, Anodized	Alcos	8	ŕ	1	15.0	1	None	Limited service life
3003 (JB)	Alcon	8	~	ļ	13.8	4. 4 6	None	Various uses, piping
4043 (43B)	Alcos	8	¢,	1	52.0	8. 8	None	Not reconnended
5052 (728)	Alcos	8	~	ł	8.3	1	None	Tubing, pipe
5052 (528)		8	-ï		2.6	1	None	Storage vessels
90%2, Chromie Acid Anodized	Colonial Alloys	8	C4	ł	11.0	I	None	H ₂ SO ₄ anodized is better
7072, H230, Anodized	Alcom	8	51	1	5.0	1	None	Limited service life (1 to 2 years)
30.54 (34s)	Alcon	8		1	I	1	None	Tubing, pipe
50.36 (368)	Alcon	8	~	1.5	13.1	1	None	Tubing, pipe
86.06	1	8	8	1	1	1	None	I
5066(9)	I	8	(N	1	1	1	None	ł
5234 (XP943)	Alcoa	8	<u>(</u>	1	0.3	0.96	None	Storage tanks, piping
20.5	Alcon	8		I	1.7	0.06	Mone	Storage tanks, missile tankag
5254-0	Alcos	8	1	1	0.3	96.0	None	Storage tanks, piping

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> Must be checked before using Must be checked before wing Must be checked before using Limited merrice life (1 to 2 years) Limited merrice life (1 to 2 years) Limited service life (1 to 2 years) Limited service life (1 to 2 years) Storage tanks, compensate $\mathrm{H}_{Z}^{\mathbf{S}0_{4}}$ anodised is better Bleaching, Needs farther checking spotting Storage tanks, piping Subject to corrosion Pipe and ather item Commute Pipe and tubing Storage vessels ł Contings Bffect On Material Slight dulling None(3) Dulls finish Pitted None 1 Хове None None None Yone Уопе None None None None None None Percent⁽²⁾ Stability After Test 1.96 **1**.8 98.7 69.8 52.3 98.0 Į 1 1 89.4 8.06 87.2 64.2 0.98 97.4 0. 8 97.8 ł ł Percent AOL per Veek at 151 P 8.4 5.2 15.5 23.2 5.2 3.6 24.7 26.5 0.3 5.0 42.0 4.1 2.4 ÷.5 3.3 1 1.7 3.1 2.9 Percent AOL per Month at 86 P 1.3 1111111 I ł 1.6 1 1 1 1 1 1 £ 1(3) Class Ċ1 ŝ CN ĊN N CI ~ ŝ m m ŝ N H2⁰2, weight percent 88888888 8 8 8 8 * * * * * * * 8 8 8 Voodue rd-Governo Colonial Alleys Alcom (Keystone Chromium) Stolle Corp. Stolle Corp. Stolle Corp. Source (Keystone Chromium) (Keystone Chromium) Reynolds Reynolds I Reynolds I Beynolds Alcom Alcon Alcon Alcon Alcon 6061, Chrowie Acid Anodized 4.9% BNO, Passiveted Hard Cost (Senford) 0.002 Inch Thick 0.001 Inch Thick 0.003 Inch Thick 6063 (6 m)⁽⁹⁾ Detergent Vashed Whit Putinted 6061, R₂80₄ Anodized Material 96<u>9</u> (17) 96<u>92-0</u>(13) Bard Coat Tablag Sheet (519) 1909 162-1526 6063(14) 9-22.96 Vrescht <u>6</u>61

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Material	Source	H2 ⁰ 2' weight percent	Class	Percent AOL per Month at 86 F	Percent AOL per Week At 151 P	Percent ⁽²⁾ Stability After Teat	Mffect On Material	Commente
Vively								
6363	Alcon	8	5	I	7.6	<u>9</u> 6.2	None	Various uses
7072 (728)	Alcon	8		ł	2.1	1	None	Cladding material
7072 (728)	Alcon	8	-	1	4.1	1	None	Storage Tessels
7075 (758)	Lafaer	8	-4	I	100.0	0	None	Not recomended
			-					

(1) hets taken from Ref. 4.25 unless otherwise noted

12-0-0-0

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(2)Stability essentially defined as (100 - A0L) percent from test of 24 hours at 212 F (3)Field experience above this alloy to be subject to corrosion if not protected by anodising

(4) Previously considered Class 2 (Ref. 4.40)

(5) Test temperature 74 C (165 F)/week, pretroated 90 v/o HgO2 24 hours at 66 C (151 F)
(6) Test temperature 74 C (165 F)/week, pretreated with Alexa treating solution No. 1 48 hours at room temperature (7) Rempine preheated with 90 v/o HgO2 for 24 hours at 66 C (151 F)
(8) Test temperature 74 C (165 F)
(9) Reference 4.40

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(10) Reference 4.41

(11) Reference 4.42

(12)Beference 4.43
(13)Beference 4.29

(14) **"**eference 4.44

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH STAINLESS STEEL ALLOYS⁽¹⁾

		E,0,,				Percent		
		i i i		Percent AOL per Manth at R6 P	Percent AOL per Veek at 151 F	Stability ⁽²⁾ Aiter Teat	Effect on Material	Comerts
		8	6		19.0	1	Bronsed	Machined Darts
101	Portland Copper and Tark Warks	8	n	I	20.0	57	Slight stain	Machimed parts, end-use components
10	Arde Portland Corp.		8	1	8.7	ĸ	Pressed	Eigh-pressure taskage
106	Ards Portland Carp.	8	8	1	4.2	đ	Slight stain	Bigh-preserve taabage,
cryogenically prestrained)								200,000 pet 71ets
20	Waitehead	8	2	-	21.0	0.68	Brons ed	Machimad parts, tubing
202	Varieus suppliers	8	2	Excellent se	rvice record	1	1	Machined parts, tabing
8								
(pereus)		8	n	1	ì	1	Bronsed	
303 C	Allegheny-ladium	06	n	1	6 -96	ł	Heavily bronzed	Not recommended
ş	Ailegheny-Ladim	96	2	1	40.0	(()4	Br onsed	Machine purts, tebing
\$¢	Allegheny-ladium	8	2	1	12.0	1	Slight bronsing at bigher temperatures	Tubing, machined parts
304 (extrm low carbom)	Allegbery-Ledium	90	2	1	58.6	1	Broozed	Test tasks, mobiled tasks
69	Carnegie	8	8	1	54.2	I	Bronsed	Machined parts
310	Carmegie	8	2	I	37.1	1	Bronsed	High-acid tamb, M202 component baths
316	Republic	8	~	1	19.8	1	Bronsed	Muchined parts
316	Republic	8	ы	I	53.0	1	Bronsed	Machined components
3167)		96	*	!		_		
(extra low carbon)	Armeo Steel	8	8	1	10.5	1	I	Test vescels, muchimed parts
317	Allegheny-India	8	2	I	36.0	1	Brossed	Machined parts; 302, 304, 315 preferred
318	Allegtery-ladium	8	8	I	¥°69	1	Bronsed	Machined parts; 302, 30%, 316 preferred

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		H.O.,				Percent		
Material	Bource	ve ight percent	Clase	Percent AOL per Month at 86 F	Percent AOL per Veek at 151 P	Stability ⁽²⁾ After Temt	Effect on Material	Comenta
916	Umiem Steel Co.	8	5	1.91	62.3	1	Br ozz ed	Machined parts; 302, 30%, 316 preferred
319L	Union Steel Co.	8	•	15.1	75.3	1	Broused	Machined parts; 302, 304. 316 preferred
ផ្តែ	Carriegie	8	8	1	37.0	1	Bronsed	Test tanks, 347 proferred
S.	Gurnegie	8	0	ł	30.0	1	Br ouzed	Heat treatable; de met ezceed 40 kc([i])
6 2	Bytrematic, Inc.	8	~	I	5.5	ł	delaish Iled	10 te 15 rue⁽¹²⁾ fizish , machined parts
ŝ	Crame Valve Co.	8	-	ł	100	1	Dr cased	Not recommended, rough finish
50%	Crame Walve Co.	8	n	ł	30.0	١	Bronsed	Machined compensats
8	Universal Cyclops	8	2-3	I	100	١	Bronsed	Rough finish
242	Curnerie	8	8	I	57	ł	Bronzed	Gas generators; thrust motors
742	Various suppliers	8	2	Excellent servic	e record	١	1	Fresure vessels
22	Whitebeed Metals	8	8	I	$13.2^{(4)}$	١	Slightly bronzed	Machined components
747	Whitehead Metals	8	2	1	1	0.0%	Slight bronzing at high temperature for all samples	I
(beat treat I)	Ailegheny-Lodium	8	r	I	7.8	8	Heavy bronzing	High-pressure vensels, 160,000 pai yield
AN 350 (heat treat II)	Alleghery-Ladian	8	.	1	314.6	ĸ	Yery heavy browsing	High-pressure vessels, Rc ⁽¹¹⁾ above 42
266 117	Allegheng-Ladium	8	n	Į	74.9	1	Bronzed	High-pressure vessels
410	Diesel Regineering	8	4	l	4.16	16.6	Busted	To be avaided
416	Bendix	8	-	I	8	ÿ	Busted	To be avoided
420	Lee Co.	8	-	1	100/18 heurs	0	Rusted	To be availed
430	Alliethen-Ladim	06	-	1	74.4	37.5	Rested	To be availed
431		96	-#	ł	100	٥	Rusted	To be avoided
140	Bendir	Co	4	1	100/24 bears	٥	Rusted	To be avoided
(36 to 58 mc/12)	Beadix	. 9 6	3(3)	2.5	100/13 hears	١	Slight breased	Refer to note (0)
10 to 20 mm/""/)								

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This alloy mark multible for use with lower than 90 percent Lydy communications; Migh-present-system components. betw to mote (6) To be evolded To be seelided The second Breach in when phase and inter-face; very alight breacing in liquid Rffoot m Samily browse Slight stals T PERI Pre-۱ ١ Percent ABL per Btability⁽²⁾ Wook at 151 P Miter Test 1 L 0 0 l 111 1 ł I L -90 te 100 43.0 100/48 bears 0. 2 28.0 5..5 100.0 ł <u>8</u> 8 8 L Persent AGL per Henth at 86 7 5.8 I I I111 ł 1 ŧ ł ł ł Class 3(3) n a Q m **e**i Ċį n m ŝ H202' weight percent * * * 8 888 8 8 8 3 8 8 Allegherg-ladim Armee Steel Innes Bleel Irace Steel mee Steel met Steel Thes Steel In Blanl i Bradic 445 446 446 615 10-9 Id(10) 12-4 Id(9) 17-4 Id(9) Maleuni ad MC(11), 50 17-7 PE (TT-AS MC(11),120-grit enerteae finich. buffed, special passivetien) 17-7 PE (45 BC(11), pickled to provent inter-gramelar attack; special passivation) 17-7 PH (77-45 MC 120-grit ewrises fizimi; special passivation) (45 mC(11), 120 prit evrices finish, sietre-pailshee) 17-19-19-19 (77-15 MC(11) wilded, 120-1711 mrfaco fizich: special peedintica) Material (presperate) (i) *

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		H202.		Persent AOL per	Percent AOL per	Percent Statility ⁽²⁾	Effect =	
Material	Segree	percent	Class	Meath at 26 P	Meek at 151 P	After Tout	Material	Camerica
Carpeter 20	Carpenter Steel	8	~	1	100	1	Dr ensed	Satisfactory room temperature use
Deriver 20	Deriren Co.	8	n	1	199	1	Browsed	Satisfactory room tongerature not
Derimet 7 ⁽⁸⁾		8	4	I	ł	1		
Misco-O-Boves	Bases Valve and Machinery	8	9		2	I	None	Machiae parta
Malia-Wilstabrite	Malia & Co.	8	8	1	ĸ	I	Storae	Spr inc.
15-7 Mo (Comt. A.T.S.)	Air Jesearch Mr. Co.	8	n	ł	*	0. %	Beavily bronzed	Machine parts, gas presenter
15-7 16	Air Research Mg. Co.	8	n	I	21.6	1	Heavily broased. Juguid phase	Machine parts
Preloy Type (70)		8	r	ł	2	I	Beavily bromed	Machime parts
Riginesh J Stainless Steel Peress Vire(10)		8	-	1	1	I		
300 Baries Stainless 2toel Profit Comment(10)		8	4					
Type yog Byter		8	4	t	I	I		
Type Jogs Power Competition		8	4	ł	ł	1		
Type 326 Perder Commet(10)		8	4	1	I	1		

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(Concluded) TABLE 4.5

Miterial Bearce wight percent (dian Percent (dian<			E,0,				Percent		
77P 316 (10) Towar 90 h -	Ma ter ia l	Beurce	weight percent	Class	Percent ADL per Heath at 86 7	Percent ADL per Veek at 151 F	Buability ⁽²⁾ Mur Test	Effect en Material	Cameric
Insent I718 Jarajot-General 90 2 5(13) 94 Run, 36 have at 146 tenerate mertine Lanel I718 Jarajot-General 90 4 - 100 C Barrer breading Bat recentle Lanel I718 Jarajot-General 90 4 - 100 C Barrer breading Bat recentle Lanel I718 Jarajot-General 92 2 - 5(13) 94 Run recentle Lanel I718 Jarajot-General 92 2 - 5(13) 94 Run recentle Lanel I718 Jarajot-General 93 4 - 100 0 Barrer breading Lanel I718 Jarajot-General 93 4 - 100 0 Barrier frame and for release and fo	77 31613) Ca Parter		8	*	1	1	1		
Zassel X-718 Asrojet-Greenil 90 4 100 C Barrent browning Ref recommended Zassel X-718 Asrojet-Greenil 90 4 5(13) 91 Ref recommended Zassel X-718 Asrojet-Greenil 92 2 - 5(13) 91 Ref recommended Zassel X-718 Asrojet-Greenil 92 2 - 5(13) 91 Ref recommended Zassel X-718 Asrojet-Greenil 92 2 - 100 0 Ref recommended for selection Zassel X-718 Asrojet-Greenil 93 4 - 100 0 Ref recommended for selection Zassel X-718 Asrojet-Greenil 93 4 - 100 0 Ref recommended for selection Zassel X-718 Asrojet-Greenil 93 4 - 100 0 Ref recommended for selection	Incouel I-718	Aerojet-Geseral	8	61		5 ⁽¹³⁾	\$	Russ, 28 hours at	Righ temperature service
Income 1718 Annel 1718 Annel 1718 Annel 1718 Manual	Zacessi X-718	Aero jet-Besers I	8	-	ł	8	J	Bervre breatlag	Bet reconciled
Incent I-716 Arrelet dereral 99 4 100 0 Earry breating Ret recented for artends and article artends article artends (151 7) 451 451 451 451 451 451 451 451 451 451	Incess 1 1-718	Arre fet-deserai	8	~	I	5 ⁽¹³⁾	*	Receiver 7 Marys Receive 24 Insuran at 22 C (111 - 1	Righ-temporature mort
after 7 days at high-temperature service	Incomel I-718	Aere Jot-Beseral	8	4	I	100	Q	Berry breasing	For recommended for ortended
								after 7 days at 66 C (151 P)	bigh-temperature service

(1)]hts takes from Ref. 4.25 unless otherwise meted

(2) Saw function 2, Table 4.4 (3) Purcent \mathbb{E}_{2}^{0} remining after 7 days at room temperature (4) Burlilland 90 percent \mathbb{E}_{2}^{0} most (5) Burlies finish must be better than 10 rms; avoid elevated-temperature \mathbb{E}_{2}^{0} Service (6) Additional test data available from PRC Corp. for earbirs with special worface treatments is contact with stabilised \mathbb{E}_{2}^{0} . (7) Burleronce 4.40

(B) Reference 4.42

(9) see also Bef. 4.45

(10)Beferrance 4.30

(11) Monitoril Martmess C scale (12) Burface fisish-reat mass square

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CHPATIBILITY OF EXDROGEN PERONDE WITH FURE METALS(1)

		H202, weight		Percent AOL Per Week	Percent (2) Stability (2)	
Material	Source	percent	Class	at 151 F	After Test	Effect on Material
Aluminum (See Table 4.2)		06 			l	1
Beryllium			-5* '	190	0-	Fitted
Cadari ca						Pitted
Caroni a						Very slightly soluble
Cobalt						Slightly soluble
Columbium	Нетаць-Сегталу					Pitted
Copper						Very slightly soluble
Gold						None
Iron						Rusted
Lead						Dissolved
Magnesium						Slightly soluble
Manganese						None
Mercury						Violent decomposition
			_			of H2 ⁰ 2
Molybdenum						Dissoived
Nickel						None
Platinum			-	•	-	None
Silicon	General Electric Co.	-	2	3.5	67	Slight surface duiling

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(Concluded)

		H_0_		Doroon+ AM	Davaant	
	-	weight		Per Week	stability(2)	•
Material	Source	percent	Class	at 151 F	After Test	Effect on Material
Silver		<u>.</u>	4	100	0	Attacked
Sodium			な	100		Violent decomposition
						and flame
Tantalut	Fansteel Met. Corp.		1(3)		1	None
Tin-C.P.	Baker Chem. Co.		2	28.7		None
Titanium	Rem-Cru Titanium, Inc.	<u> </u>	4	100	0	Pitted
Tungsten			4	100	0	Dissolves
Zinc			4	100	0	Pitted
Zirconium		-		3.2		None

(1) Date taken from Ref. 4.25

(2) See footnote 2, Table 4.4

(3)Based on Service Experience

COMPATIBILITY OF HYDROGEN PEROXIDE WITH METAL ALLOYS⁽¹⁾

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		H202,		Percent AOL Per Veek	Percent (2) Stability	
Material	Source	percent	Class	at 151 F	After Test	Effect on Material
Aluminur Oxide, Flame-Plated on Armco 17-7 PH	Linde Co.	06	7	100	1	One rust spot
Beryllium-Bronze	1				Q-	None
Beryllium-Nickel						None
Chemallcy B-3	Electro-Alloys Div.					Pitted
Chlorimet	Durimet			•	•	· None
Chromeloy Coated Steel (4)	1			1	}	•
Croloy 16-13-3(3)				100	0-	
Dow Metal JIA	Dow Chem. Co.					None
Dow Metal MA	Dow Chem. Co.					None
Duriron (cast)	Deriron					None
Elgiloy	Elgin Watch Co.					Bronzed
Fanweld "0"	Fansteel Met. Corp.		->-	-		Моде
н-975	Carbide & Carbon		r	06	1	None
Hastelloy "A"(5)	Haynes-Stellite Corp.		-4	100	0	Some rust in solution
Hastelloy "B"	Haynes-Stellite		4	/001	0	None

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TABLE 4.7

Effect on Material Discolored Bronzed Bronzed Bronzed Bronzed Bronzed Bronzed Bronzed Bronzed Bronzed Rusted None None None None None **Percent** (2) Stability After Test ${
m H_2}{
m 0_2}$ evaporated completely 100/48 hours 100/72 hours Percent A0L 100/3 hours 100/3 hours 100/1 hour 65 to 72.7 **Per Week** at 151 F 3 hours 97.8 16 hours 26.1 100/ 100/ 100 100 100 100 100 100 Class percent H202, Weight 6 Haynes-Stellite Corp. International International Source Illium Corp. Nickel Corp. Nickel Corp Haynes-Stellite Haynes Cl712-3 Haynes C3087-3 Haynes M1516-3 Hastelloy "C" Hastelloy "D" Haynes F 17-3 Haynes L1316 Inconel "X" (Full Hard) Haynes L #3 Material Illium "G" Haynes 1.6 **Haynes 25** Haynes 12 Haynes 6 Haynes 3 Inconel

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Heavy brozzing after 7 days at 66 C (151 F) Effect on Material None, 24 hours at 66 C (151 F) None, 24 hours at 66 C (151 F) Slightly stained Slightly stained Slightly stained Slightly stained Severe bronzing after 7 days Busted None None None None None None None Percent Stability⁽²⁾ After Test 92.5 96.3 88.8 95.1 0 94 34 O 0 0 0 0 C Percent AOL at 151 F Per Week 16 hours 0.6⁽³⁾ 5⁽⁷⁾ ₅(7) 82.1 51.2 60.3 45.3 100/ 18 100 100 100 100 100 100 100 (Continued) Class C) 2 C) 3 4 percent H2O2, Weight 8 90 <u>8</u>. 98 98 Haynes-Stellite Corp. Keystone Chromium Keystone Chromium Keystone Chromium Keystone Chromium Kennametal, Inc. Kennametal K-138 Kennametal, Inc. Kenname tal K-501 Kenname tal, Inc. Kennametal, Inc. Aerojet-General Aerojet-General Aerojet-General Aerojet-General International International Nickel Corp. Nickel Corp. Westinghouse Source Ni-Resist Alloy Kennametal K-JH Refractalloy 26 Kennametal K-M Kanegin Mated Multimet N-155 Inconel X-718 Jnconel X-718 Inconel X-718 Inconel X-718 Sample 13 Sample 3 Hateris. Mild steel Sample 7 Monel

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			H ₂ 0 ₂ , weight		Percent AOL Per Week	Percent (2) Stability	
	Material	Source	percent	Class	at 151 F	After Test	Effect on Material
	Refracialloy 27 ⁽⁶⁾	J	06	ξ		1	1
	Refractalloy 70	Westinghouse		r	100	0	None
	Rene' (Nickel Base)	Muskegon		4	100	0	Bronzed
	Steel, Mild	Commercial		4	100	0	Rusted
7	Steel, Mild	Keystone-Chromium		Q	0.9 ⁽³⁾	94.2	Slightly stained
	Super Alloy, S-588	Allegheny-Ludlum		4	100	0	None
	Super Alley, S-590	Allegheny-Ludlum	1	4	100	5	None
	Tantung	Allegheny-Ludlum		4	100	0	None
2	Timkin 16-25-6	Timkin Roller Brg.		5	50	ļ	Slight bronzing
290		. oo				• • • • • • • • • • • • • • • • • • •	
)	Tin-Plated Mild Steel	Keystone Chromium		2	0.6 ⁽³⁾	6.7	Slight staining
	Titanium Bl20 VCA	Crucible Steel Co.		4	100	0	Severely discolored
	Titanium, Cl20 AV	Crucible Steel Co.		4	100	0	Severely discolored
	UCC-Star "J" Metal	Union Carbide			100/ 4 hours	I	Bronzed
	Utiloy 3	Utility Steel Foundry		4	100/ 2 hours	1	None
	Utiloy 20	Utility Steel Foundry		4	100/ 2 hours		None
	Utiloy H	Utility Steel Foundry		4	100/ 3 hours		None
	Utiloy NH	Utility Steel Foundry		4	100/ 2 hours	!	None

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TABLE 4.7 (Concluded)

Katerial	Source	H202, weight percent	Class	Percent AOL Per Week at 151 F	Percent Stability After Test	Effect on Material
Vorthite	Worthington Corp.	06	3	100		Bronzed
106-6 1	Universal Cyclops Steel	90	r	100		Bronzed

(1) Data taken from Ref. 4.25 unless otherwise noted

(2)_{See} Footnote 2, Table 4.4

(3)_{Test} conducted at room temperature rather than 66 C (151 F)

(4)Reference 4.40

(5)_{Reference 4.46}

(6)Reference 4.42

(7)Based on 1-day test

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH. OLYETHYLENE AND HALOGENATED POLYETHYLENES

		E 202.		Percent AOL Per Namth	Persent A0L	Percent ⁽²⁾ Stability		
Material	Searce	Percent.	C]	at 86 7	at 151 P	After Test	Effect de Material	C rea te
	Allied Chemical	8	1	9.0	1.2 ⁽⁵⁾	0.66	Ĭ 	Bladder mterials, drus liners
	Allied Chemical	8	-	0.5	0.5	9.0	Ĩ	Tank Haers, bladders
N. 1909	Belmast Probling	8	-		10.2	78.5	Beverly blistered	Not recommended for 12 7 and
abber .	110 .14	8	4	!	I	ł	Severly blishered	1
· Propylese (10 460)	Fajay Chemical	8	4		42.0	0.0	Blistered	July reconciled
	DuPont	8	•		1	I	Burface attack and melorate blistering (I week at 150 F)	ł
78 57-166 (10)	Julyant	8	3		I	1	Noderate surface attack (1 week at 151 P)	I
(10)	Mam. Ma. & Mc.	8	*	I	12.1	6.8	Bllstered	1
2140	Seals Bastern, Inc.	8	-	1	2.6	0.96	Blistered	Net recommended for extended 1997
2140	Mine. Min. & Mic.	8	1	1.0	1	0.00	Xee	O-rings, seals bladders
2140	Man. Ma. & Mr.	8	2	1	1.1	8.5	Very slight blistering	ł
	Seels Bartern, Ise.	8	~	I	0.3	99.0	Heme after 24 hours at 56 C	But recommended at this temporature
2140 ⁽⁴⁾	Minn. Min. & Mfg.	8	1	5°.0	I	0. %		O-rings, see is, Madders
2140	Alm. Ma. 4 Mg.	8	-	I	I	0.96	Blisters after 24 berrs at 66 c (151 F)	1
2141. Klastener	Minn, Min, & Mg.	8	n	I	2.9	8.1	Swillen and bilistered	1
1121	Seals Mattern, Inc.	8	1	i	2.4	8 .6		0-riags, seels, bladders
4121	Seals Butern, Inc.	8	I	I	0.9 ⁽⁵⁾	99.3	Nome	0-rings, secis, bladders
100141-1 mi	Bestatefler Cerp.	8	7	I	3.6	I	Xar	Eigh-pressure heat
100141-1 m	Resistefler Corp.	8	8	1	6.7	1	- T	Eigh-pressure heat
1100	U. S. Stamevare	8	n	1	1 9-3	0.0	Pertially bleebed	Ret recented
ĩ	Polymer Corp.	8	~	1	₽, ₽	33.1	Non e	Purther testing required
(#Parts) 0/06/40	Witre Asses.	8	*	1	1	1	Distategrated, 2202	Not recommended
	This ist Supplies	8	6	I	9. 4	I	Kome	Salı
8-2	Dullant	8	-	I	100.0	1	Sample destroyed (1 hear)	Uman ti stactory
Geneticet	Netal Boos & Tablag	8	-	I	74.2	2.0	Serere attack	Unsetisfactory
()	Bertastes-Husha than	8	-	1	100.0	I	Blistered and cwilm	unantistactery

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Comerts	Unex the feetery	Umma tisfaetery	•	Mat recommended	Seale, guatete	ł	See Is	Geskets, seels, seets	Bigh-temperature service, weale, rests	Gasheta, semis, seate	Seals	Gaskets, souls, soute	Gaaketa, semia, semte	Gaskets, souls, south	Gestets, seals, seats	Not recommind	Use stàer compounds	1	Gaakets, seels, seets	Gasteta, semis, sente	O-rings, gaskete	Ermiteien bladdere	Bladder meterial	Ergelsten bladders	Bladder mterial
Effect de Material	Budly realles	Bilstered and realles after		Mederate surface attack	Note at room temperature; east ignite with 90 to 90 percent \mathbb{H}_{2}^{0} if bested above 160 ?	Kar	Xone		ten	Very alight hardening		Slight bard maing	Blistering and blesching	Slight blistering	Blightly tacky	Blistered and distorted	Bleeched	Blenebed	Kate	Slight blicterime	Naderate marface attack; slightly sticky	Yery alfght blesching	Yery elight bleeching	Yory alight bisaching	Yery elight bleebing
Persont ⁽²⁾ Stability After Test	1	١		ĸ	9.9 86.6	ł	١	١	0. 8	97.8	0°.86	₹.¥	93.2	0.72	95.7	1	١	١	7.7	2 .2	5 .	0.72	0.72	0.1	0.46
Persent AOL Per Veek	100.0	100.6		0.61	9.0 F	8 .3	1.3	3.5	2.9(1)	• .5	0.73	9.0	e. e	3.6	8	18.5	19.0	9.0	3.6	3.2	6.4	5.1	5.1	9.8	6.3
Percent AOL Per Namth at 86 F	1	1		1	l	ł	1	I	ł	ł	1	1	ł	1	1	1	1	1	ł	I	1	ł	I	I	I
Class	-	-		•	~	61	1	Ţ	-	1	1	61	•	~	8	'n	ñ	¢1	1	2	~	8	2	ณ	8
≣2 ⁰ 2° weight percent	8.	8		8	8	R	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Beartee	Reybouton-Numberton	Bybutu-Habatta		Gesten Milder Co.	Quantral Bloctric	1	Ham. Ma. 4 Mg.	Mism. Min. & Wg.	Num. Hin. 4 Mg.	Num. Nia. & Nig.	Nim. Ma. & Mg.	Minn. Min. & Mig.	Minn. Min. & Mig.	Mama. Ma. & Mg.	Mise. Min. & Mrg.	Niem, Min. & Wig.	Niam, Nia. & Mig.	Minn, Min, & Mig.	Milma, Mila, è Mig.	Mian. Nia. & Xfg.	Liser, Ise.	Pirestees firs & Miber	Piretas firs a Mibber	Pirestees Tire & Bubber	Pirntees Tire & Mubber
Ma turial	Rymles Y-Sc.4 (Brey)	Bymitm Y-153-4 (Black)		Rystem 0-Ring (OCR 98-5)	Lruthame 101 (irrediated polyribyleme)	Ea1-P	tel.	Lol-? (mylacticized)	Ka1-7 600 ⁽³⁾	Eal-7 800 (Lat 5649)	Ka1-7 800	Eal-F 620 (04026)	E41-P 3700 ()	Eal-P 7780, Eal-P 800 (96-90)	Lal-7 9900 (mpigmetud)	Eal-7 5900 (gam)	Ea1-7 5900-121	Zel-# 7900-61	Ka1-P 5940, Ka1-P 800 (94-90)	Kel-P 5906, Kel-P 800 (75-90)	Keirs 0-24 (cpt. 7/61-24	511- D316	E.1-P Dy16	Eat - Land	Ea1-7 0705

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Commercia		Smale	I	Plartic line, comparts	Plastic emperate	O-riago, seels, cestings	Seels, centings	Pecelbly plastic pipe and tube use		Ket recommended	Not recommended	Not recommended except for reem temperature use	Laboration and	laboratory me	Yer service below 100 7	Not recommended for high tempera- tare	ł	1	Pilter media	Plastic perts	Tabe and pipe fittings	1	I	I	-
Effect in Material		Slight bleeking	Blanched and elightly dis- terted	Blastbal	Blasebed	1	Yery elight bleaching	Bleached from elive to grey	Bluebut frue alive to gray	Discolored, swelles	Semples because brittle	Bleeched slightly	Name at room temperature; can detomate with H ₀ O, if heated	Hene; see (6)	Vill detemate at melting peint of plantic	Mase	1	He apparent rvelling, but some blocching (1 day at room temperature)	že	Slight bleaching	Slight bleaching	Bleeched slightly	Nabe	Blacked	Kone
Percent ⁽²⁾ Stability After Test		8 .0	0.19	97.1	99.0	ð. ð	8 , 9	96.0	95.0	97.0	90.06	64.0	ŝ.	95.0	ł	0. B	1	I	0.96	0. 8	9 8.3	1	<u>95.5</u>	0.0	79.2
Percent ACL Per Veet at 151 F		1.1	3.8	2.1	1.9	I	1.3	1.4	2.9	4.0	6.6	4.7	1.0	2.3	2.3	2.9 ⁽³⁾	ļ	1	4.1 ⁽⁵⁾	6.3	1.7	5.9	6°£	5.5	15.6
Ferent AOL Per Henth at 86 T	I	1		I	1	0.7	1	1	1	I	1	1	1	1	l	1	1	I	1	I	1	1	1	1	1
Class	~	R	2	~	~	1	61	N	N	-	-	r	~	e	8	~	4		0	8	2	8	51	*	3
E202: wight percent	£	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Seurce	Nim. Nia. è Niç.	Witre Asses.	Table Turnu, Esc.	Gaseral Electric	Yeples	Devid Clerk Co.	Devid Clark Co.	Bercules Peeder	Berowles Pewder	Witze Assoc.	Kam-E-Quip Corp.	callet Corp.	Durant	DuPast 1	Serers 1	General Electric	Plas Carp.	Der Chan.	M11 7 414.	Polymer Corp.	Tabe Turns, Inc.	Dizee Carp.	DuPont	Dizen Cerp.	Dixee Corp.
Ma terta I	Eel-P Elastemer 5160	Liner	Kyner-Yinylidene	Lemma Plantic Tube	The Ir and -73-223	(LI (M1 (LI)))	(T = 1)	Partan 9215 ⁽⁵⁾	Peet as 9215	Polyouter M-85	Polyathylene (peress)	Polyethylese (black)	Polyethylese	Pulyuthyless ⁽⁶⁾	Polystbylene (pure unpigmented)	hulyethyles I.D. ⁽³⁾	Polyethylese 72-2(10)	Pelyster Jac Face ⁽¹¹⁾	Polypesso E-51 ⁽³⁾	Pelypence I-51	Polypropylane (black)	Min (Trile has)	Bulon (Teflen base)	Mice '1'	Below "3"

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	j	202, ••1221	Class	Percent AOL Per Namth at 86 P	Ferenat AUL Per Veek	Perest(2) Bushilty After Test	titeet die Historial	3
	Merth Amerian Ariation	8	~		2.6	0.5	Slight blaching	Bladder mterial
710	North American Aviation	8	61	[.1]	3.4	0.66	Yery slight bluebing	Excellent clastemor
m 183 ⁽⁹⁾	Merth American Aristica	8	8	6.6	1.1	6. 8	Very elight bleebing	Bladder muterial
T1.00 135	Berth American Aristian	8	~	5.1	2.4	3 .0	Yery alight bleaching	Blæédera
Tieme 31-2	North American Arlation	8	~		12.0	0. 8	Slight bleebing	Ergeleten Miskders
71	Marth American Aviation	\$	n	0.51	12.0	0. 8	Sitcht bleeching	liadd or s
View if dee -Plaeride	Pull Piltmitien Corp.	8	-	£.9	1	9.9 8	į	Filter media
Vigilidas-Plaeride	All Filtration Corp.	8	8	1	1.5	97.0	The set of three samples above low stability	Filter andla
aces of all all all all all all all all all al	Prince Mubber Co.	8	N	1	2.7	1	preses shares	Tel reconcile
Vintes 1 (247; black)	Durent	8	61	1	36.8	1	Elightly testy	I
VILLE & (271-71 77345)	Parter Bassefia	8	8	ė.75	1	9. S	Excellent service record	Q-rings, disphrages, bladders
Vites A (271-7)	Parter Baseofia	8	4	1	1	I	Blisters after 3 days at 15: P	I
TILE & (271-7: 77-55)	Purior Longia	\$	0	8 .0	1	5	Excellent service experience	O-rings, seals, bladders
Titem A (03-190 M 31)	Beals, Inc.	8	3	l	15.6	9.5°	T.e.	Ortings
VILL A (05-160 B 31)	B. T. Goodrich	8	3	!	15.4	8	, and	Orrings, seels
Vites A (VILA); black)	Benitt Beinim	8	5	!	9.00	5 2.3	Blistered and realled: blacebod to blas color	Bot recommended for service there 120 F
711mm 1-0070	Mebels Befaering	8	8	1	1.3	0.70	X	O-rises, blatters
Vita 4-17004 (19)	Precision Bulber	\$	ı	!	1	I	No moticenble attack im I day at room temperature, aerere mitack im I day at 200 P	I
VILLE A-88-271-70 ⁽¹⁵⁾	attiline actor G.	8	ł	ţ	١	I	We meticemble strack in 1 day at 150 P; miser attack in 1 day at 200 P	I
Viten A-070-070 (13)	Btillises Miller Co.	8	1	1	١	I	No moticemble strack im 1 day at 150 7; minor strack im 5 days at 200 F	1
Tites B (805)	Durant.	8	64	1	9.0	\$` \$	No effect after 72 bours at 151 F	0-riage, seels, bladdorn
Titm B (805)	Defect	8	-	1.0	9.6	0. 8	No effect after 72 hours at 151 F	O-rings, seels, bladders

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		12°2.		Portent ADL	Person 136	Purset (2)		
Meterie]	Course	Ĩ	Class	4 9	at 151 P	Actur Tool	Block in Neterial	ł
Beeted Pret 2265 ⁽⁸⁾	Man. Ma. & Mr.	8	1	i	1.1	e.	Ĩ	Pils storial
Bertek Park 15/10 ⁽³⁾	Niam. Nia. 4 Nig.	8	-	I	1.1	。 8	2	Pilm mterial
7+/1= (+1+)	DuPant	8		1	8	÷.	i	Milas an
Terlies, 100X FB	by at	8	~	i	3.6	10 8	1	Bet effectively best sealedis
fortae, 5-adilititor (amiéod 1000)	Pro-	8	r	•. % (2 M		°, R	Ĩ	ł
Tellas Tapa	2001	*	~	6.3	3.8	1	i	
Terla Tax, ar 73e1(10)	Duran	8		1	ł	1	I	1
Teflem Taps, 747(10)	Mam. His. & Mg.	8	-	1	1	1	1	1
Tofian-Improgrammed ⁽¹⁰⁾ Blass Cloth	The second se	8	~		1	1	1	I
Terlian Volded	Prinet.	R	-	e. F	2.7	1	Tree	Seals, Martiers
Tellam (ringia)	is a	S .			2.6	ř.	I	Bealls, guthite
Teflam (fuel cell) ⁽⁵⁾	Dielestris Corp.	8			3 .2 ⁽⁵⁾	0.72	I	Bladder miterial
Terline and Plannint	Petur Arrential	8	2	1	1.11	ŝ	Ĩ	Desting for burbles flor motor
Mayorutan Taflan ^{(B} , 14) (Tuel aell)	bielectric Corp.	*	"	ł	4.2	0. 8	Yory elightly blanded	Bladder mterial
Dispersion Tellas TPE ^(B.,K)	Prest	8		I	0.33	e, X	Mase	Task Harr, Watters
Terline Pasi Call	Chemoglavers, In.	8	-	1	3.3	°. ¥	i	Ergeleten bladdern
Tellm Past Call	Dieleetris Corp.	8	۳.	1	5.93	9.10	Yory alightly bloached	Bryaletten Diadeors
Terla Parl Call	Pielectriz Corp.	8	81	1	(e)0'¥	0. K	Yory alight blacking	Braileise Madders
741 m 77 Call	Changiann, In.	\$	ñ	1	3.6	5.6	Blandad	Brailes Maders
	7-0-1	8		1	1.5 ⁽³⁾		ł	Bladder Glerial
Terlas, Greadilla ⁽¹²⁾ Terlas, Robbane ⁽¹²⁾ Mairida-Fillad				11-		· · · · · · · · · · · · · · · · · · ·	amaire in 24 bears seetre in 26 bears	11
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keteria l	Jean te	1202: 1202:	Class	Persent AGL Per Mairth at 86 7	Persent AOL Per Veck	Percent ⁽²⁾ Stability After Test	Mfeet On Material	Commente
ritem 3 (805)	Durant.	8	-	1	3.6	0. 8	7 days at 151 F, alight bilsteriag	Bet reconded
114m B (805)	Level		-	1	9.0	\$.\$	No offect to 72 bours	O-riags, seals, bladders
ritem # (5187) ⁽¹⁵⁾	1	8	3-3	1	15 percent field loss	I	ł	Orrings, seels
The Builling and	Duran	8		0.1	1	o. 8	Kai	Gesterts, semis
lites B-Ours Ks. 23 fites M-Ours Hs. 805	Benla Bertern, Ite. Debes	88	n n	11	9.0 9.0	0.16 1.	Yery slight blictering Svolles and moterate blicters	Ket recommended for temperatures above 120 7

(1) but them from first A. A. P) million obtained out of $(1)^{2}$ by a final from that A. A. P) million is a finite A.A. (2) γ days at γ is (165 Y) (3) γ mains stronge at 20 th 22 C (do the 72 Y) (4) γ much statistic for the above 20 C (do the 72 Y) (5) 1 under at 90 C (120 Y) (6) $\beta_{\text{Mail set that is fitted if heated above 71 C (160 Y) when contacting 90 or 91-partoni <math>\mathbb{R}_{2}^{0}_{2}$ (9) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (10) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (11) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (11) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (12) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (13) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (14) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (15) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (16) $\beta_{\text{Mail set that } \chi_{10}^{0}$ (17) $\beta_{\text{Mail set that } \chi_{10}^{0}}$

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH POLYVINYLCHLORIDE AND CO-POLYMERS⁽¹⁾

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		8202,		Percent AOL Per Veek	Percent ⁽²⁾ Stability	
107.204 84				- 167 -	ALVEL 2014	TELLEVEN IN TOPIN
Alanel Tubing		8	n	10.3	1	Bebrittied
Bultares (200 (grey)	Belta	8	8	3.0	ł	Ycae
Theelite(b)	ł	8	ı	1	I	Retained resiliency, but decreased in tensile strength; swelling; bleached
3000 118	B. P. Goodrich	8	*	8.5 (4 days)	85.6 (k days)	Hilly white, blietered, distorted
Home 40% (yellow)	B. P. Goodrich	8	~	8.0	1	Bissolied and became brittle
(cros 2042 ⁽⁵⁾	B. F. Goodrich	8	4	I	1	ł
Gene 8372 ⁽⁵⁾	B. F. Geodrich	ŝ	*	1	I	I
Been PVC	B. P. Goodrich	ß	61	1	85.0	Slight bleeching
Geess FUD Pipe (7)	B. F. Goodrich	\$	8	1.3(3)	85.0	Slight bleesing
Grey ⁽⁷⁾	B. T. Goodrich	8	n	10.6	97.0	Blight bleebing
I.P.S. Uscalite	Stritt and Priebe	8	*	7.2	8.98	Severely attacked and blistered
Tareseal 116	B. F. Goodrich	8	n	23.0	ł	Blacked and have and
Kerneel 116 (melded) ⁽⁵⁾	B. F. Goodrich	ŝ	n	ł	1	I
Koreseel 117 (melded)	B. F. Gecürich	\$	n	16.0	I	Bleached and hardened
Koroseal 117 (calendered)	B. P. Coefrish	8	*	I	1	1
Laroseal 700	B. F. Geodrich	8	8	2.9	1	Slightly swilles, bleached, and stiffened
Ecrosem1 700 (molded) ⁽⁵⁾	B. 7. Goodriah	8	~	ł	1	Blached
Koroseal 700 With Hysar 1041 Plasticizer	Prince Bubber	8	-	14.9	0.0	Blistered and bleached
Ecroscal Pipe (grey)	B. F. Goofrich	8	~	10.5	37.0	Siight bleeching
lacefler (transitoent)	Incofler Plastic Fab.	8	m	10.1	1	Blistered and blesched
lacoflex (white)	Lacofler Plastic Fab.	Ş	r	11.2	1	Darkened, slight blistering
Marvinel 218-200	U. S. Bubber	8	*	100/2 hears	1	Sample became tacky after 1 bear
Marvinel 218-201	U. S. Rabber	8	*	100/1 hear	1	Deformed, charred
Marrinel NE-3005	U. S. Babber	8	4	100/1 hour	1	Sample become tacky
Marvinel M-6010	U. S. Bubber	8	4	100/1 hour	1	became tacky and deformed
Plieria ⁽⁵⁾	Goodyear Tire	8	લ	ł	1	1
PVC	Walwarth Pipe	8	~	1.2	* 8	Nederste blesobiag
Pre	Walvorth Pipe	8	8	10.5	86.0	Noderate blesching
Two contracts of the second se	Prince Rubber	8	m	1.61	87.7	No abange
PVC, NGIA	Vance	\$	2	5.5	90.4	Bleached and s'ight blistering

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TABLE 4.9 (Concluded)

		H202,		Percent AOL Per Veek	Percent ⁽²⁾ Stability	
Material	Source	percint	Class	at 151 F	After Test	Effect On Material
PVC, Bigid	Witchesd	8	~	7.5	0.96	Blasched
PPC, Sheet (dark grey)	Prince Bubber	8	n	13.0	87.0	Slight blenching
Balbatez, E-310V(6)	1	8	•	1	1	Betained resiliency but decrease in Semaile strength: svelling; bleached
Sara	Dev Chemical	8	6	12.3	1	Bleechod
Sarua Bubber Q-167	Dow Chemical	8	-	1	1	hind
Treasfles Tabing	Irvington Varmish & Insulation	8	4	1.1	1	Blistered bedly
Tygen B-20	U. S. Stoneware	8	m	2.3	1	Bienched, blistered, and slightly distorted
Tygen B-32	T. S. Stoneware	8	~	2.2	I	Bleached, blistered, and slightly distorted
Types B-63	U. S. Stoneware	8	<u>~</u>	1.7	1	Bleached, blistered, and slightly distorted
Tygen B-71	U. S. Stoneware	8	r	3.5	1	Bleached, blistered, and slightly distorted
Tygen B-72	U. S. Stoneware	8	<u> </u>	1.0	I	Bleached, biistered, and slightly distorted
Typem B-136	U. S. Stoneware	8	n	2.0	1	Bleached, blistered, and slightly distorted
Types 8-22-1	U. S. Stemere	8	-	1	I	Blistered and svollem
Typen TI-105	U. S. Stemeware	8	-	I	1	Blistered and svollen
Types 2807	U. S. Stoneware	8	*	1	1	Disintegrated
Tygen 3400	U. S. Stepewere	8	-	1	1	Embrittled and swellen
Tygen 3603	U. S. Stemente	8		I	1	Svellen
Tygen 3604 A	U. S. Stoneware	8	5	I	1	Baccases spague
Tyges 3604 B	U. S. Stoneware	8	5(•)	1	1	because opaque
Viey1 79159	U. S. Bubber	8	5	2.7	1	Slight epages; small blisters
Vieylite VS 1710	Bakelite Div.	8	n	2.3	I	Turned opeque; slight blictering
Vinylite Ym-9947 ⁽⁵⁾	Union Carbido	8	8	ł	1	Turned epsque; slight blistering
Visylite VU 1900	Bakelite Div.	8	n	2.5	1	Turned opaque; slight blistering
Vinylite VE 1907	Bakelite Div.	8	n	3.0	1	iwrned epaque; slight blistering
Vinylite We 1914	U. S. Mabber	8	8	1.5	1	Blistered slightly, bleached
Visylite VU 1920	Bakelite Div.	8	~	2.0	1	Turned opeque; slight blistering
Vimylite VU 1990	Bakelite Div.	8	m	2.4	I	Turned opseque; slight blistering
Visylite VU 1940	Takelite Div.	8	<u> </u>	2.0	1	Turned opaque; slight blistering
Vinylite TU 1940	U. S. Bubber	8	8	1.6	Î	Bleeched
(i)			3			
^{1.1} Data taken frem Beferen (c)	nce 4.25 unless otherwise	noted	5	mend on servic	e experience	<pre>(7)Beference 4.29</pre>
<pre>(2)Paotaete 2, Table 4.4 (2)</pre>				eference 4.40		
(J)Tested at 86 F			R(a)	eference 4.45		

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH SILICONE RUBBER COMPOUNDS(1)

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Effect Or Material	None	ł	None	Kardened	Nane	Slight swelling	Slight bleeching, eveiled, distorted	Hard coned	Cracked; bleached	Blistered and warped slightly	Blistered	None	Slightly hardened	Soft; pitted	Hardemed and broke	Slight bleaching and avelling	Slightly blacked	Lost elasticity	Embrittled	Lost elasticity	Slightly blistered	None	Curled	lost elasticity	Blistered and embrittled	Slightly blietered; bisachad	Pubrittled	Blightly bleached	Slightly bleached	Slightly bleached	No moticeable attack; miterial bleached (168 hears at 200 F)
Percent ⁽²⁾ Stability After Test	91.3	1	ł	I	I	ł	ł	ł	I	1	ł	I	ł	1	1	ł	68.1	ł	ł	1	ł	1	1	ł	I	6.5	I	99.1	0.96	\$. \$	1
Percent AOL Per Week at 151 F	16.7	34.3	72.4	9.5	95.0	48.5	89.0	47.5	45.0	31.9	32.2	27.7	18.3	1	29.6	13.3	17.8	37.8	71.0	43.4	39.3	24.9	92.6	16.7	5.0	6.7	17.7	7.4	5.7	7.3	ł
Class	2	4	64	-	r	0	r		4	~	r	-	'n	1	4	Q	m	n		r	m	2	4	r	n	(1	r	6	2	~	1
H2 ⁰ 2* weight percent	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	\$	8	8	8	8	8	8	8	ŝ	8	ŝ	8	<u>8</u>	8
Source	Dow-Corning	General Electric	General Electric	General Electric	General Electric	General Electric	General Electric	General Electric	Gemeral Electric	Hedber	Parker Appliance	General Electric	Dov-Cerning	Dow-Corning	Linear Inc.	Dev-Corning	Linear Inc.	Dov-Corning	Dev-Corning	Dow-Corning	Dov-Cerning	Dev-Corning	Dev-Coming	Dow-Corning	Dow-Corning	Bewitt-Robins, Inc.	Farge Bubber				
Kateria	Pluorosilicone 18-53	GE 4078-217-1	GE 1240	GE 12601	GE 12062	GE 12650 (unpigmented)	GE 12650 (pigmented red)	GE 12670	GE 12670 (pigmanted brown)	GE 19060 (pigmented)	GE 15080	GE 81223	GR X7181	Hadbar No. 8000-71 ⁽³⁾	Parkone Maite 467-1 0-Ming	SE 470 (unpigmented)	Silectic 172	Silestic 160	Silentic 160 0. ring	Silmetic 161	Silastie 181	Silastic 240	Silestie 250	Ellastic 261	Bilmetic 675	Bilastie 6-125	Eilastie 7-180	Silactic 9711	Silastic 9711	Bilectic BR-9711	Bilieese 8-9711 ⁽⁴⁾

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TABLE 4.10 (Concluded)

No apparent attack (1 day at 200 F); alightly attached aftar 156 bears at 200 F Bleeched slightly No moticemble attack (1 day at 200 P); alight brittlamees after 3 days at 200 F Vold unifforted; slight bluebing, mottling Completely disintegrated at 72 hears So pitting, swiling, or bloaching He avelling, pitting, or bleaching Effort On Material Bluebed and elightly method Swellod, pitted, very seft Lost flexibility; eracked ł Lost some elasticity Small white blisters Bleeched completely Slight distortion Blistered No effect Bwilled i i i lage l line. Ĩ ġ lone Percent⁽²⁾ Stability After Feet 8. 0. 3.5 118 1 % 97.0 0.**%** 63.8 0.0 0.0 ł ł 1 1 1 1 1 1 1 1 1 I I I 1 1 1(4)Reference 4.45 Percent AOL Per Veek at 151 7 16-percent fluid loss in 24 weeks 10.1; Pailed Pathed 13.6 16.1 5.15 10.3 15.0 13.0 8 17.4 13.4 15.0 18.3 f.a 20.2 22.4 6.0 ¥6.5 ۱ ١ I 1 Class 2-3 ¥. 1 T ce R ¢1 ~ ~ 2 wight persent **≣**20² 8 8 8 8 8 8 8 8 8 8 8 8 Competient Bril Mibber mostleet Bril Miller Compositicat Mare Uniber lovitt-Robbins, Inc. Proteice Miller 7. 5. Been Iab. T. S. Bacen Lab. Stalwart Miller Stilles Miber Stillans Rabber Stillmen Bebber Stillma Mibber Btilles Mibber Source Plaitic Bubber Union Carbido Tales Carbido **Dates** Carbide Union Carbido Parter Seal Doo-Corning Dev-Cerrifing P.B.P. THE REAL The second Limer Preter Pater 0-Ring No. 005-18057(3) 0-Ring No: SB277-70(3) Silicens Miller SP570 Silicens Miller SP570 Silisene Muhier S2559 Silicen hebber SR5590 0-Ring No. TH 1057(3) Silicent Oreing(3) Contrast V399-7 Siletic E-2000-1-480 Bilastis 20-79631(6) Silicent O-ring(5) No. 5-475-7 0-21mg No. 945-70⁽³⁾ Bilantie 9711 Velded Vith 8-2200 51110000 407-3-217-1 Silleese W7-3-437-1 Siliece 7-11775(5) Siliense E-104 Siliense O-ring Me. Shi9-90 Silises Th-lov7 Silises Th-lov7⁽⁴⁾ Stiltene H-115(k) Stiltene Miber(k) Com. 78-075 (c) Bilisone K-1076⁽⁶⁾ 81110000 X-7181 81110000 Y-1419⁽⁶⁾ Silicene E 655 Billesse T-1749 Mterial ÷

(1) Inte taim free Beforence 4.25 mloss othervise noted
 (2) Prochasta 2, Table 4.4
 (3) Informate 4.50

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(5) Beforence 4.49

(6) Reference 4.40

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH GENERAL RUBBERS AND PLASTICS (1) .

Material				E.O.				
Arrylan Bahers Ma-12 Imerican Mananer Filter of List Affect Field Process Class Process Class Process Class Process Proces	Materia]	, , ,		veight		Percent AOL Per Woek	Fercent ⁽²⁾ Stability	
Active Rubber RA-12 American Monome 90 4 - T_0^0 Tarmed Mach: sample pertially disaoned in 2 at 2 a			Source	percent	Class	at 151 F	After Test	Effect On Material
Arrylan BL-5 American Member 50 90 4 100.0 </td <td>Acrylon Rubber BA.</td> <td>-12</td> <td>American Monomer</td> <td>8</td> <td>4</td> <td>1</td> <td>1</td> <td></td>	Acrylon Rubber BA.	-12	American Monomer	8	4	1	1	
Attpress C Restit Mobiles 90 1 100 1 150 Rassis No. 90 Restit Mobiles 90 1 97 1 1000 1 Rassis No. 90 Restit No. 90 Restit No. 90 Restit No. 90 1 1000 1 Rassis No. 90 Restit No. 90 Restit No. 90 Restit No. 90 Restit No. 90 1 Rassis No. 90 Restit Restor 1000 Restit Restor 1000 Restit Restor 1000 1 Restit Restor 1000 Rassis Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 1 Rass Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Rest Restor 1000 Restor 1000 Restor 1000 Restor 1000 Rest Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 1000 Restor 10	Acrylon EA-5		American Monomer	\$				1202 unmed black; sample partially dissolved in 2 du
Brails No. 90 Brainport Decomposed in 1 hour Brail No. 90 Bishop Mr. 90 1 00.0 - 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 51 50				R	•	1	1	$\mathrm{H}_2\mathrm{O}_2$ turned black; sample partially dissolved in 2 da
Thread is No. 50 Relation Mo. 50 Relation		•	Hewitt Robbins	8	-4	100.0		
Name NSuper NMark NSoft S(T)MyCl Balber 1305Into IalMyCl Balber 1305Into IalMyCl Balber 1305Into IalMyCl Balber 1305Narbar (RL)SMMyCl Balber 1315Narbar (RL)SMMyCl Balber 1315Narbar (RL)SMMyCl Balber 1315Narbar (RL)SMMyCl Balber 1315Narbar (RL)SMMyCl Barr 1415Narbar (RL)SM	Biselin No. 50		Bishop Mfg.	8	2	0 7		
Name of 3Name of 3	Bora N			5	, , ,		1	Slightly blistered
Neyl Haller AUGEato Lab90410-0Peri Haller AUGPeri Haller AUGPeri Haller AUGPeri Haller AUG	Buna s(3)			R., 1	4		ł	
Bryll Median SR-361Alto IAA304100.0-Softened to sticty mas in 24 hoursOrtikike (maturat coler)Merian Chen, Div3047.6-Benut teleyand teleyand in 24 hoursDefout304100.0-7.6Benuttitele, seoilen, solution activity mas in 24 hoursDefout304100.0-50100.0-100.0Bena Ratif504100.0-55.0DistituegratedBena Ratif8: P. Goorich304100.0-55.0DistituegratedBran Ratif8: P. Goorich304100.0-55.0DistituegratedBran Ratif100.04100.0-100.0-Bano residerBran RatifBran Ratif-100.0-100.0-Bano residerBran RatifBran Ratif-100.0-100.0 </td <td>The second second second</td> <td></td> <td></td> <td>8</td> <td>4</td> <td>1</td> <td>1</td> <td></td>	The second second second			8	4	1	1	
Partylized (actuar)Mathem Chen, Div.9045.0Becaue totoBecaue toto11.2 MonthPartylized (actuar)DataData2.647.6Bertitied, avoilen, solution turned yailowPartylized (actuar)DataBabilData2.64100.0DisaticedPartolet No.Shoil (Chen.B. F. Goodrich904100.0DisaticedRatane PlasticB. F. Goodrich904100.055.0DistintegratedRatane PlasticB. F. Goodrich904100/1 hours-PlassicedRate N X78-1-1 (black)F. S. Becon Laho904100/24Borrs-Rareg vi (aubeuto-Barge (corp.)904100.0-DisaticedRareg (restored)Barge (corp.)904100.0-DisaticedRareg (restored)Barge (corp.)904100.0-DisaticedRareg (restored)Barge (corp.)904100.0-DisaticedRareg (restored)Bargeton Labo904100.0-DisaticedRareg (restored)Bargeton Labo904100.0-DisaticedRared (restored)Bargeton Labo904100.0-DisaticedRared (restored)Bargeton Labo904100.0-DisaticedRared (restored)Bargeton Labo904100.0-DisaticedRarol L-778B	ChtCV-1200200 Thene Little		Zaso Lab	8	4	100.0		Softanad to attick a set
Statistic fasterai color)Marban Case, Div.9047.6Behrittled, scolles, solution targed yellowSpeid fasterai (1)DuffortB. F. Goodrich904100.0DissolvedDissolvedSpeid mean (1)B. F. Goodrich904100.0DissolvedDissolvedDissolvedSpeid mean (1)B. F. Goodrich904100.0DissolvedDissolvedSpeid mean (2)B. F. Goodrich904100/1 hour-Sample fail apartSpeid mean (2)F. S. Bacon labs904100/24 Hours-DissolvedSpeid mean (2)F. S. Bacon labs904100/1 hour-Bustisting dissolvedSpeid mean (2)F. S. Bacon labs904100.0-DissolvedSpeid mean (2)F. S. Bacon labs904100.0-DissolvedSpeid with dissolvedEnvert Corp.904100.0-DissolvedSpeid with dissolvedEnvert Corp.904100.0-DissolvedSpeid with dissolvedEnvert Corp.904100.0-DissolvedSpeid with dissolvedEnvertedBuschen labs904100.0-Speid with dissolvedEnviron labs904100.0-DissolvedSpeid with dissolvedEnviron labs904100.0-DissolvedSpeid with dissolvedEnviron labs904100.0-	Daty I Mubbar SR-38	34		8	4			box verse to suicky mist in 24 hours
DuritionDuritionDuritionDuritionDuritionconstionsolutionsolutionEntane FlaartShall Chen904100.055.0DistintegratedEntane FlaartEntane FlaartEntane Flaart904100/1100.0100.0Entane FlaartEntane FlaartEntane Flaart904100/1100.0100.0Entane FlaartEntane FlaartEntane Flaart904100/1100.0100.0Enter N 478-1-1 (black)F. S. Bacon Iaba904100/2Hours200/2Enter N 478-1-1 (black)F. S. Bacon Iaba904100.0	Cyclelao (matural	color)	Marbon Chem. Div	8	· •		1	Became tacky
whenheatn(3)Sharar theritDescription0.01100.0DistrictedExtansPlastic \mathbb{B} \mathbb{F} (Godrich $\mathbb{9}$ $\mathbb{4}$ 100.0 $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Garlock No. 5681 (Terline \mathbb{B} \mathbb{F} (Godrich $\mathbb{9}$ $\mathbb{4}$ 100/1 hour $\mathbb{10}$ $\mathbb{10}$ Garlock No. 5681 (Terline \mathbb{B} \mathbb{F} (Godrich $\mathbb{9}$ $\mathbb{4}$ 100/1 hour $\mathbb{10}$ $\mathbb{10}$ Hore No. 7681 (Terline $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 5681 (Terline) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 5681 (Terline) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 5681 (Terline) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 111ed Phenolic) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 111ed Phenolic) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 111ed Phenolic) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 111ed Phenolic) $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 11et $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ $\mathbb{10}$ Hore No. 11et $\mathbb{10}$ $\mathbb{10}$	Delita	•	Tri Boat	R 8		0.7		Embrittled, swollen, solution turned vellow
Extant FlatticB. F. Godritch904100/1 hour55.0DisintegratedHyren Restands arborationGarlook Re. 5541 (TatlawGarlook Re. 5541 (TatlawGarlook Re. 5541 (Tatlaw100/1 hour-Sample fell apartHyren Restands arborationB. F. Godritch904100/1 hour-Sample fell apartHyren Restands arborationEvent RestandEvent Restand-Sample fell apartHyren Rest (InterpretedEvent Rest (Interpreted)Event Corp.904100.0Hyrel Hyrel L-775Event Rest (Interpreted)Event Rest (Interpreted)-Platatily dissolvedHyrel L-776Event Rest (Interpreted)Event Rest (Interpreted)100.0Hyrel L-776Event Rest (Interpreted)904100.0Hyrel L-777Event Rest (Interpreted)Event Rest (Interpreted)100.0Hyrel L-778Event Rest904100.0Hyrel L-778Event Rest904100.0				8		100.0		Dissolved
Status PlatiteB. F. Goodrich9046.075.0DisintegratedReview 10, 5611(arriock Pa king904100/1 hourSample fell apartRever PA 478-1-1(basetos)P. S. Bacoa Laba904100/24 Hours-Sample fell apartRever PA 478-1-1(basetos)Rever Corp.904100/24 Hours-PlanolitelyRever PA 478-1-1(baseto)Rever Corp.904100/24 Hours-PlanolitelyRever O (phenolite)Rever Corp.904100.0-PlanolitelyRever O (phenolite)Hour Laba904100.0-PlanolitelyRevel L-775Rever Corp.904100.0-PlanolitelyRevel L-776Rever Corp.904100.0-PlanolitelyRevel L-776Rever Corp.904100.0-PlanolitelyRevel L-776Rever Corp.904100.0-PlanolitelyRevel L-777Rever Corp.904100.0-PlanolitelyRevel L-778Rever Corp.904100.0-PlanolitelyRevel L-778Rever Corp.904100.0-PlanolitelyRevel L-778Rever Laba904100.0-PlanolitelyRevel L-778Revel L-778Revel L-778Planolitely-PlanolitelyRevel L-778Revel L-778Revel L-7			Shell Chem.	8	-1			
Garlock No. 5681 (Testian- impregrated anbeston)Garlock Pa king-904100/1 hour-9.0Distributes partHarge Value F. S. Bacon LabsP. S. Bacon Labs904100/1 hour-Panel tell spartHarge Value FunctionHarge Corp.P. S. Bacon Labs904100/1 hour-Panel tell spartHarge Value FunctionHarge Corp.P. S. Bacon Labs904100.0-Panel tell spartHarge Value FunctionHarge Corp.904100.0-Panel static Panel staticPanel static Panel staticPanel static Panel staticPanel static Panel staticHarge Value HardenHarge ValueHarge ValuePanel static Panel static904100.0-Panel static Panel staticHarge Value HardenHarge ValueHarge ValuePanel static Panel static904100.0-Panel staticHarden Labs 	Estane Plastic	•	B. F. Goodrich	8	4	y		1
Impregnated arbeston $100/1$ Hour-Sample fell agetHyer PA 472-1-1 (black)P. S. Bacon Labs 90 4 $100/24$ Hours-Sample fell agetHyer PA 141Haves Corp. 90 4 $100/24$ Hours-Partially dissolvedHaves 60 (phenolic)Haves Corp. 90 4 100.0 -Partially dissolvedHyer 14-772Houghton Labs 90 4 100.0 -BlastereddistortedHyer 14-773Houghton Labs 90 4 100.0 -BlastereddistortedHyer 14-774Houghton Labs 90 4 100.0 -BlastereddistortedHyer 14-775Houghton Labs 90 4 100.0 -BlistereddistortedHyer 14-775Houghton Labs 90 4 100.0 -BlistereddistortedHyer 14-776Hours	Garlock No. 5681 (1	Teflon-	Garlock Pa kine	۲. ۲.		0.0	22.0 II	Disintegrated
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filled phenolic)Harver Corp.904100.0Partially dissolvedHarver 60 (phenolis)Harver Corp.904100.0DissolvedHyrol 4-77 C (clear)Houghton Labs904100.0DissolvedHyrol 4-77BHaver Corp.904100.0DissolvedHyrol 4-77BHoughton Labs904100.0DissolvedHyrol 4-77BHoughton Labs904100.0DissortedHyrol 4-77BHoughton Labs904100.0DissortedHyrol 4-77BHoughton Labs904100.0DissortedHyrol 4-77BHoughton Labs904100.0DissortedHyrol 4-77BHoughton Labs904100.0DissortedHyrol 4-78BKonniHoughton Labs904100.0DissortedHyrol 4-78BKaber)Houghton Labs904100.0DissortedHyrol 4-78BKaber)Houghton Labs904100.0DissortedHyrol 4-78BKaber)Houghton Labs904100.0DissortedHyrol 4-78BKaber)Houghton Labs904100.0DistortedHyrol 4-78BKaber)Houghton Labs904100.0DistortedHyrol 4-78BKaber)Houghton Labs904100.0DistortedHyrol 4-78BKaber)Houghton Labs904100.0DistortedHyrol 4-78	Baves 41 (sabeston-			R	4 ·	00/24 HOUTE		Dissolved completely
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Hypeol 4-77 C (clear) Houghton Labs 90 4 100.0 103.00 Hypeol 4-77b (amber) Houghton Labs 90 4 100.0 103.00 Hypeol 4-77b (amber) Houghton Labs 90 4 100.0 - Blastered; distorted Hypeol 4-77b Boughton Labs 90 4 100.0 - Blastered; distorted Hypeol 4-78 Brown Houghton Labs 90 4 100.0 - Blistered; distorted Hypeol 4-784 (white) Houghton Labs 90 4 100.0 - Blistered; distorted Hypeol 4-786 (amber) Houghton Labs 90 4 100.0 - Blistered; distorted Hypeol 4-780 4-780 - Blistered; distorted Blistered; distorted Hypeol 4-780 10-780 - Blistered; distorted Blistered; distorted Hypeol 60008 4	Haveg 60 (phenolic)		Haver Corn	8			- <u></u> .	
Hymol 4-77bEasterHoughton Labe904100.0	Hysol 4-77 C (clear		Hanehton Taba	R 8	ar .	0.001	<u>, I</u>	lesolved
Hysol 4-77E Bushered Blistered distorted Hysol 4-77E Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-77E Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-77E Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78B Horen Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78B Horen Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78D Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78D Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78D Houghton Labs 90 4 100.0 - Blistered distorted Hysol 4-78D Houghton Labs 90 4 100.0 -	Hreel 4-770 (asher)	·		R (4	100.0		lleached; distorted
Wreel 4-77Houghton Labs904100.0	Allegal L. TTP			8.	-8"	100.0	<u>е</u> 	llistered; distorted
Wysol 4-788 (white)Houghton Labs904100.0	Handler Provide Street		Houghton LAbs	8		100.0	- 	listered: distortad
Hysol 4-780 (white)Houghton labs904100.0-Blistered; distortedHysol 4-78B (brown)Houghton Labs904100.0-Blistered; distortedHysol 4-78D (amber)Houghton Labs904100.0-Blistered; distortedHysol 4-78D (amber)Houghton Labs904100.0-Blistered; distortedHysol 4-78D (amber)Houghton Labs904100.0-Blistered; distortedHysol 6000B (amber)Houghton Labs904100.0-Blistered; distortedKralite (Kraylite)U. S. Rubber90326.7-Sunlien and distorted			Houghton Labs	8		160.0	م ا	teterste for the second se
Hysol 4-78B (brown)Houghton Labs904100.0	mysol 4-784 (white)		Houghton Labs	8	-7	100.0		Den for the state of the state
Hysel 4-78C (amber)Houghton Labs904100.0	Bysel 4-78B (brown)		Toughton Labs	8	 -/1		۹ 	ulstered; čistorted
Hysel 4-78D (amber) Houghton Labs 90 4 100.0	Hysel 4-78C (amber)		Ioughton Labs	8	·	100.00		listered; distorted
Rysol 6000B (amber) Houghton Labs 90 4 100.0	, Hysel 4-78D (amber)		loventon Isha		r .	0.001		listered; distorted
Kralite (Kraylite) U. S. Hubber 90 3 26.7	Rysol 600B (amber)		onehton Tabe	R 8	at .	0.001	A	listered; distorted
$\begin{bmatrix} \\ \end{bmatrix} \begin{bmatrix}$	Eralite (Freelite)			 R	4	100.0	<u></u>	urtially dissolved
	(a) II (BIR) an II and	-	J. S. Rubber	8	m	26.7	5 	willer and distants

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TABLE 4.11 (Concluded)

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····			H202'	ų. Vieto	Percent AOL	Percent ⁽²⁾	
	Material	Source	velght percent	Cless	Per Week at 151 F	Stability After Test	Effect On Material
	Lexus	General Electric	8	2 2	2.1	0.72	Slight bleeching
	Helman No. 1077	Mechanical Products	8	-1	100.0		Partially dissolved
	Methyl Methacrylate ⁽³⁾	Whitehead Metal Products	8	-4	. F :	ł	Softened
	"A" "A"	DuPont	8	-	5.0	1	None
	Mylar "B"	DuPont	8	1	1.7		Уоде
	Neoprene Pure Gom	Spray Dip	8		· · · · ·	1	Ignited and burned
	Neoprene SR 365-B	Eclipse Pioneer Div., Bendix Aviation	8	4	100.0	1	Ignited and burned
	Nylca	DuPont	8	افد	100.0	I	Ignited and burned
	Orles (5)	1	8	F		1	
70	Penton (3)	liercules Chemical	8	53	1 88 1 2 1	: : []	ł
	Phenol-Porma Idehyde	Durez Plastics Div., Hooker Electrochem	8	42	100.0	1	Ignited
	Pleriglass	Rohe and Haas	8	47	100.0	1	Softened and partial solution
·, ·	Polystyrene (Polyfler)	Plax Corp.	8	2	9.1	I	None
•	Polymrethene (green)	Dunlap	8	r	8.5	50.2	Partially dissolved
	Polyurethane (tan)	B. F. Goodrich	8	r	56.0	59.9	Completely dissolved
	Polyurethene (bleck)	B. F. Goodrich	8	-41	98.5	0.0	Completely dissolved
	Thiokol EC-801-1P2	Thiokol Chem. Corp.	8	4	100.0		Burst into flame
<u></u>	Thickel 7000 PA	Thickel Chem. Corp.	8	- F	100.0	1	Dissolved
	Thickel 3000 ST	Thickel Chem. Corp.	8	4	· :]	1	1
	Thiokol 1620 AH	Thickel Chem. Corp.	8	-		1	I
							•

(1)Data taken from Beference 4.25 unless otherwise note
 (2)Pootnote 2, Table 4.4
 (3)Beference 4.40

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH LAMINATES, DIAPHRAGMS, AND ADHESIVES⁽¹⁾

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	Material	Seurce	H2 ⁰ 2' weight percent	Class	Percent AOL Per Veek at 151 P	Percent ⁽²⁾ Stability After Test	Effect da Material
<u> </u>	Chemelic HI-411 (Toflem fibergiass)	U. 8. Gasket	8	2(3)	11.5	.1	Bleached during sereening
	Dureid 2600 (fiber-reinferced Teflen)	Regers Carp.	8	'n	14.7	70.1	Nee
,	Pairpress PS 57-167 (Vitem A, 116 glass)	De.Peet	8	r	29.0	91.6	Mederate blistering and surface attack
	Pairpress P5 57-168 (Vites A, Dacros)	Durent	8	R	23.0	% .\$	Mederate surface attack
	Pairpress (Vitom A)						
	30006	Duffeert	8	61	1.01	I	Kess
	2085	DuPont	8.8	010	51.9	I	
	7009 80-080 (1/32 imeh)	DePont	88	2	× •	11	Neac Neac
	Glass Besins	Oven-Illineis Tech. Center	8	1	1.3	97.5	Keae
	Kel-7 Dacros, Dispiraga-VL-1101m4	Vermay Lalos, Inc.	8	-	9 5.0	1	Contings and Decrem asparated in 2 day
	Kel-F 5160 Diaphregn	Michels Bagineerian	8	0	30.6	1	Slightly blistered and tasky
	Kel-7 5300 (grey) Diaphrage	Michols Engineerial	8	0	13.7	1	Slightly blistered and tacky
	Kel-? 5300 (grey) on Daeren Diaphragn	Michels Engineering	8	~	4 3.8	، ، ا	Yone
	Korda Flor (Teflem-coated glass fabric)	Chicago Gasket	8	61	2.5	0.72	Neae
	Polyester Fiberglass						
۰ <u>،</u>	Duracer 1000	Will Corp.	8	5	25.9	19.7	Bleached
	2000-5	Vill Corp.	88	171	18.6	21	Bleached
÷	6-0009	Will Corp.	3 8 	 F) (*'	4-12		Biesched Riesched
	•	Will Corp.	8	Ē	15.0	10.7	Pissolveé
,	Ped.	Buffale Forge	8	n	12.0	- 2.62	Discolored and bleeshed
•	Strev	Buffale Forge	8	n	22.0	28.0 	Discolored and bleached
	सर्व देवा वे का	Heil Process & Byuipment	8	n	27.4	67.0	Slightly disselved and bleached
	9711 Silicene Seal Vasher DC, Chemiec 607 Afhesive an Aluminum	Kirthill Bubber	8	ŕ	11.6	9995 1 1	
	Bilastic DC-9711 em Daerem Diaphragm	Kirkhill Bubber	8	m	9.7	*	Bleached and distorted
<u> </u>	Viryl-Coated Fiberglass	Birm Hig.	8	m	8.94	•••; 	Kee
	9711 Eilieeme Semi Washer DC A4094 Adhesive (Dev Corming Silicate base) em Alenieeme	Kirkbill Bubber	8	r	15.5	69.1	

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(1)Data taken from Reference 4.25
(2)Prostante 2, Table 4.4
(3)After 24-beur screening at 151 F

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COMPATIBILITY OF HYJ)ROGEN PEROXIDE WITH POROUS MATERIALS (1)

Effect in Material	Xene	None	Blesched	Blached		Resiliency destanced	Realliency decreased	Realliency decreased	Kees	Kome	Kone	Less brittle	None	None	Deep breating	Broazed and rusted	Br on a ed	Brenzed heavily	Bransed	1	I	Completely bleached	Noze	Completely bleached	Bleached white	None	Кове
Percent ⁽²⁾ Stability After Test	1	1	1	1		1	I	ł	ilon basel	1	1	88.0	1	¥.₹	1	1	1	1	1	1	I	0.67	86.0	83.1	none rescining	ł	97.0
Percent AOL Per Vsek at 151 F	100/3 days	19.0	0.02	0.92		2.0	3.0	6.0	Classificat on exper	18.0	100.0	9.8	16.0	14.0	100.0	100/2 hours	100/2 1/2 hours	100/24 hours	100/24 hours	100/2 hours	100/5 hours	20.0	17.0	15.3	100.0	28.2	17.0
Class	'n	C1	n	n		CN	2	8	0	8	F	2	8	2		4	- r	4	æ	-	-	3	8	r	r	6	2
H2021 weight	8	8	8	8		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Source	LAVA COPP. of America	Nerten Abrasives	DuPont	DePont		Mat. Pilter Media Corp.	Mat. Filter Medin Corp.	Nat. Filter Media Corp.	Filtres Corp.	Mat. Pilter Media Corp.	Bendis Filter Div.	Pall Filtration Corp.	Selas Corp. of America	Pall Filtration Corp.	Pall Filtration Corp.	Calif. Insv. of Tech.	Ampler Div.	Titefler, Inc.	Pall Filtration Cerp.	S-I-C Reserveb Assoc	Remasselaer Poly. Inst.	Pall Filtration Curp.	Pall Filtration Corp.	Pall Filtration Corp.	Nat. Filter Media Corp.	Net. Filter Media Corp.	Selas Corp.
Material	Al-61 Mag, Peress Ceramic No. 395	Alendam Oride, Porces-RA-96	Armalem-Teflem Polt (impregnated)	Armie	Daeren Cleth	Dars-2100	Dae-2101	Dec-2102	Filtres C Steme (55 micrem)	Blass Cleth 6-206-C	Pereley-30288 Wire	Perous Kel-7 (15-aderos pere)	Porema Percelain (1.4 micron)	Percens Teflom (9-micron pore)	Eigimesh (Stainless-Steel Wire	Sintered 300-Series Stainless- Steel Fewder Compact	Sintered 302 Stainless-Steel Powder Cempact	Sintered 316 Stainless-Steel Powder Compact	Sintered 316 Stainless-Steel Powder Compact	Bintered 7025 Stainless-Steel Powder Campact	Sintered 316 and Cb Stainless- Steel Powder Cempact	Teflem Cloth (25 grade)	Teflos Cloth-Repeat (25 grade)	Teflem Cloth (40 grade) Teflon Felt (impregnated)	Teflon Cloth T-2300	Teflon Cloth 7-2305	Zirconium Silicate (10 misron)

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(2)_{See} Postnote 2, Table 4.4

(1) Data taken from Reference 4.25

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH LUBRICANTS (1)

		H2 ⁰ 2' veight		Percent AOL Per Week	Impact ⁽²⁾
Material	Source	percent	Class	et 151 F	Sensitive
Alkaterge C	Commercial Solvents	8	4	ł	Yes
Amino Silane Oil and Grease	ł	8	4	1	Yes
Apiezon Hard Wax "W"	J. G. Biddle	8	4	Excessive	1
Arochlor 1221	Monsanto Chem.	8	4	ł	Yes
Arochlor 1232	Monsanto Chem.	8	4	ł	Yes
Arochlor 1242	Monstanto Chem.	8	4	1	Yes
Arochlor 1248	Monsanto Chem.	8	4	ł	Tes
Arochlor 1254	Monsanto Chem.	8	ন্দ্র	1	Yes
Berdahl	Bardahl Corp.	8	4	ł	Yes
Carum 200	Esso Labs	8	4	5.2	Tes
Ceresin Wax	1	8	ব	1	Yes
CPE-1	Carbide and Carbon	8	4	1	Yes
Dichloro-bis-tri-fluoromethyl Benzene	Hooker Electro-Chem.	8	r	3.3	H ₀ (3)
Dichlorohexafluorobutene	Hooker Electro-Chem.	8	r	9.2	No ⁽³⁾
Fluorolube FS	Hooker-Electro-Chem.	8	2	4.2	No ⁽²⁾
Fluorolube FS + 5-Percent Fluorolube Light Grease	Hooker-Electro-Chem.	8	2	1	(C) ON
Fluorolube Heavy Grease 10214	Hooker-Electro-Chem.	8	8	1.7	No ⁽³⁾
Fluorolube Oil 10213	Hooker-Electro-Chem.	8	2	1.0	No ⁽⁵⁾
Fluorolube S	Hooker-Electro-Chem.	8	2	2.5	No ⁽³⁾

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		H ₂ 0 ₂ ,		Percent AOL	
Material	Source	weight percent	Class	Per Week at 151 F	Impact ⁽²⁾ Sensitive
Fluorolabe T	Hocker-Electro-Chem.	8	2	8.5	No ⁽³⁾
Fluorslube Oil, S-30	Hooker-Electro-Chem.	8	5		No ⁽⁴⁾
Fluorolube Grease, Hg-1200	Hooker-Electro-Chen.	8	3		No ⁽⁴⁾
Fluorolube Grease, GR-560	Hooker-Electro-Chem.	8	2		No ⁽⁴⁾
Forwalation:					
F-9	Monsanto Chem.	8	4	ł	Yes
0s-16	Monsunto Chem.	8	4	I	Yeu
05-22	Monsanto Chem.	8	4	ł	Yes
08-23	Monsanto Chem.	8	4	1	Yes
0S-27	Monsanto Chem.	8	4	1	Yes
05. –28	Monsanto Chem.	8	4	ł	Yes
08-30	Monsanto Chem.	8	4	ł	Хев
0S-32	Monsanto Chem.	8	4	I	Тев
0S-33	Monsanto Chem.	8	4	1	Yes
08-JJ	Monstanto Chem.	8	4	1	Yes
08-35	Monsante Chem.	8	4	1	Yes
0%-37	Monsanto Chem.	8	4	1	Yes
(JP38982	Monsento Chem.	8	4	ł	Yes
Skydrol (uncolored)	Monsento Chem.	8	4	1.0	Yes
Helocarbon 0il 8-25-AV	Halocarbon Products Corp.	8	2	1.8	No ⁽³⁾

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TABLE 4.14 (Continued)

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		H ₂ 0 ₂ ,		Percent A0L	. (2)
Material	Source	veignt	Class	Per week at 151 F	Impect' Sensitive
Halocarbon 0il 10-21	Halecarbon Products Corp.	8	2	2.9	No ⁽⁵⁾
Halocarbon Heavy Oil 10-25 ⁽⁶⁾	Halccarbon Products Corp.	8	3		l
Halocarbon Light Oil 11-14	Halcearbon Products Corp.	8	ଷ	2.1	No ⁽³⁾
Halocarbon Medium Oil 11-21 ⁽⁶⁾	Halocarbon Products Corp.	8	3		ľ
Halocarbon Stopcock Grease	Halccarbon Products Corp.	8	ର	1.8	No ⁽⁴⁾
Halocarbon High Temperature ⁽⁷⁾	Halocarbon Products Corp.	8	2	1	No ⁽⁴⁾
Emolocarbon Grease, 25-10(7)	Halocarbon Products Corp.	8	5	ł	No ⁽⁴⁾
Hexachlorobutadiene	Hooker Electro-Chem.	8	3	3.7	No ⁽³⁾
Hexachloropropylene	Hooker Electro-Chem.	8	4	100.0	ļ
H-2 Hydraulic Fluid ⁽⁶⁾	R. M. Hollingshead Corp.	8	6	8	ł
Hydraulic Fluid RPM	Standard Oil of Calif.	8	4	1.4	Yes
Hydraulic Oil-Houghton Safe 620	Honghton	8	r	7.1 ⁽⁵⁾	1
Kel-F Alkane	Minn. Min. & Mfg.	8	3	1.0	No ⁽⁴⁾
Kel-F Light Oil No. 1	Minn. Min. & Mfg.	8	3	1.7	No ⁽³⁾
Kel-F Heavy 0il No. 10	Minn. Min. & Mfg.	8	5	3.2	No ⁽³⁾
Kel-F No. 90 Grease	Mino. Min. & Mfg.	8	3	33.2	No ⁽⁴⁾
Lindo HF (tricresyl phosphate)	Celanese Corp.	8	4	1	Yes
Lindol HFX	Celanese Corp.	8	4	I	Yes
Láqui-Moly Concentrate	Climmar Melybdenum	8	4	I	Yes
Lubriseal	Arthur H. Thomas	8	4	1	Yes

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TABLE 4.14 (Continued)

		H2 ⁰ 2° veight		Percent AOL Per Week	Impect ⁽²⁾
Material	Source	percent	Class	at 151 F	Sensitive
Mi1-6-3278	1	8	4	1	Yes
W11-6-4.343	I	8	4	1	l
Mireral Oil	Various	8	4	1	Yes
Parafiin	Various	8	4	1	Yes
Perfluorolube Grease PCD-759	DuPont	8	3	10.5	No ⁽³⁾
Perfluorolube 011 FC-331	DuFont	8	6	1.4	No (3)
Perfluorolube 0il FC-332	DuPont	8	2	1.7	No (3)
Perfluorolube Oil FC-333	DuPont	8	5	1.4	No ⁽³⁾
Perfluorolube Oil FC-334	DaPont	8	0	8.0	No ⁽⁷⁾
Perfluorolube 0il FC-335	DuPont	8	5	1.0	No ⁽³⁾
Petrolatur	Va rí ου θ	8	4	I	Yes
Polychloropentane (stabilized)	Hooker Electro-Chem.	66	4	1	Yes
FR-240AC Grease ⁽⁹⁾	DuPont	8	I	1.6	1
PB-240AC Grease (9)	Dul'ont	86	I	1.6	ł
Renex	Atlas Powder	8	4	1	Yes
Silicone XF 224	Dow-Corning	8	4	1	Yes
Silicone Grease DC-11 ⁽⁸⁾	Dow-Corning	%	3-4	I	Yes
Silicone Oil DC-7	Dow-Corning	8	4	I	Yea
Silicone Oil DC-44	Dow-Corning	8	4	ł	Yes
Silicone 0il DC-200	Dow-Corning	%	1 1	1	Yes
Silicone Oil DC-550	Dow-Corning	6	4	1	Yea

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(Concluded)

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Impact⁽²⁾ Sensitive Yes Yes Yes Yes Yes Хев Yes Yes ł l Percent AOL Per Week at 151 F 8.4 (ppt ł 1 I ļ Class percent weight $^{\rm H}_{2}0_{2},$ 8 ଝ 8 888 8 88 8 Carbide & Carbon Chem. Commercial Solvents **General Electric General Electric** Source Dow-Corning Dov-Corning Dow-Corning Texaco DuPont 1, 1, 2, 2, Tetrafluoroethyl Dodecylether Silicone Oil GE 2V3733 Texaco Uni-Temperature Silicone Oil GE 51346 Silicone Oil DC-792 Silicone Oil DC-710 Material Silicone 0il DC-701 Tributyl Phosphate Ucon Hydrolube U-4 Tectyl

formed

 $\begin{pmatrix} 1 \\ 2 \\ 2 \\ No wright-distance 4.25 unless otherwise noted <math>\begin{pmatrix} 2 \\ 3 \\ 3 \end{pmatrix}$ No wright-distance data were given with the positive results $\begin{pmatrix} 1 \\ 3 \\ 4 \end{pmatrix}$ Non-impact sensitive to 1 kg-m at room temperature

¹/Ncn~impact sensitive to 100 ft-1b at room temperature

Non-impact sensitive at 1 kg-m at room temperature, but clouded during 150 F, 7 day test

Reference 4.40 6

Reference 4.29, 4.40 Reference 4.43

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from an external source caused the loss of one of the 90-percent H₂02 and one of the 98-percent H₂02 samples. The results are therefore from a single analysis (Ref. 4.44) Contamination (9) These tests were conducted by zmearing the grease on the walls of the container.

Ref. 4.51 tested a number of fluorolubes with 90-percent H_20_2 at 10 kg-m impact sensitivity and found none which were 100-percent negative under these conditions. NOTE:

TABLE 4.14a

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH POTENTIAL LUBRICANTS (1)(2)

NO VISIBLE REACTION

Halogenated Aliphatic Hydrocarbons

Polytetrafluorocthylene (solid)

Tetrafluoroethylene-hexafluoropyropylene copolymer (solid)

Polychlorotrifluoroethylene (molecular weight ≤ 800)

Polychlorotrifluoroethylene (molecular weight > 800)

Perfluorokerosene

Dispersion of Polytetrafluoroethylene in Trichlorotrifluoroethane (solid) Perchloropentacyclodecane (solid)

Perfluorodiethylcyclohexane (mixed isomers)

Dichlorodecafluoroheptane

Chlorofluoro Hydrocarbon (approximate molecular weight 725)

Chlorofluoro Hydrocurbon (approximate molecular weight 1000)

Fluorinated Hydrocarbon (77.4 percent F; approximate molecular weight 640) Polychlorotrifluoroethylene (approximate molecular weight, 775; 80 percent halogens)

Silicon Compounds

Silicon Fluorides

Tri(p-trifluoromethyl phenyl) Silicon Fluoride

Trilaurysilicon Fluoride

Tris (3,5,5-trimethv¹hexyl) Silicon Fluoride

Dimethylpolysiloxanes

Dimethylpolysiloxane (2 to 500 Cs)

Fluoropolysiloxanes

 $HCF_2(CF_3)_5CH_20[Si(CH_3)_20]_nCH_2(CF_2)_5CF_2H$, Fluoropolysiloxane, n = 1-26

TABLE 4.14a(Continued)

NO VISIBLE REACTION (Continued) Cyclic Fluorosiloxanes

> Cyclic Fluorosiloxane (solid) CH₃(R)SiOSi(CH₃)(R)OSi(CH₃)(R)O

$$R = CF_3 CF_2 CF_2 CH_2 -$$

Cyclic Fluorosiloxane (solid) $CH_3(R)SiOSi(CH_3)(R)$

Fluorosiloxane Elastomer (solid) Made From $CF_3(CH_2)_2Si(CH_3)C_2$

Cyclic Fluorosiloxane (solid)

$$CH_3(R)SiOSi(CH_3)(R)OSi(CH_3)(R)O$$

 $R = CF_3CF_2CF_2CH_2^-$

Mixed Cyclic Fluorosiloxane (solid) $CH_3(R)Si0[Si(CH_3)(R)0] Si(CH_3)(R)0$ $R = CF_3CF_2CF_2CH_2 - n = 3$ and higher

Dimethylpolysiloxane-Cyclic

Fluoropolysiloxane Blends

Fluorosiloxane Grease (No. 33 + inorganic gelling agent)

Fluorosiloxane Grease (No. 34 + inorganic gelling agent)

Mixed Dimethylpolysiloxane and Cyclic Fluoropolysiloxane

Mixed Dimethylpolysiloxane (average molecular weight < previous compound)

Halogenated and Nonhalogenated Aromatic Hydrocarbons

3-Heptyl-m-terphenyl Isopropyl-m-terphenyl

Dinonylnaphthalene (mixed isomers)

1,3-Bis (trifluoromethyl) Benzene

TABLE 4.14a (Continued)

NO VISIBLE REACTION (Continued)

2,3,5,6-Tetrachlorofluorobenzene (solid)

1,3,5-Trimethy1-2,4,6-Trifluorobenzene (solid)

1,3,5-Trimethy1-2,4-Difluorobenzene

Hexafluorobenzene

2,5-Dichlorobenzotrifluoride

2-Fluorobiphenyl (solid)

3,3'-Difluorobiphenyl (solid)

4,4'-Difluorobiphenyl (solid)

3,6,4'-Trifluorobiphenyl (solid)

Esters

Mixed Fluoroalkyl Camphorates Fluoroalkyl-HCF₂(CF₂)_n CH₂- n = 3,5,7 Bis-lH, lH, 5H-perfluoropentyl Camphorate Bis-lH, lH, llH-perfluoroundecyl Camphorate (solid) Tetrabutyl Pyromellitate Mixed Fluoroalkyl Pyromellitates Bis (2,2,3,3,4,4,5,5,-octafluoropentyl)3-methylglutarate Bis (2,2,3,3,4,4,5,5,6,6,7,7,-dodecafluoroheptyl)3-methylglutarate 2,2,3,3,4,4,-Hexafluoropentyl 1,5-bis (trimethyl acetate) Bis(1-methylcyclohexylmethyl) Sebacate Poly (1,1,5,5-tetrahydrohexafluoropentamethylene adipate)(solid) Bis (2-ethylhexyl) Chlorendate Dibutyl Chlorendate

Nitrogen Compounds

Hexadecytriphenylurea

2,2'-Dinitrophenyl Ether (solid)

4,4'-Dinitrophenyl Ether (solid)

TALE 4.14a (Continued)

NC VISIBLE REACTION (Continued)

2,6-Difluoro-3,5-dinitrochlorobenzene (solid)

2,4-Dinitro-5-fluorobromobenzene (solid)

Perfluorotributylamine

Perfluoro Compounds

Polytetrafluoroethylene (solid)

Tetrafluoroethylenc-hexafluoropropylene Copolymer (solid)

Perfluorokerosene

Perfluorodiethylcyclohexane (mixed isomers)

Mixed Perfluorocyclic Ether, $C_8F_{16}O$ (five- or six-membered ring with side chain, oxygen in the ring)

Perfluorotributylamine

Perfluorodihexyl Sulfide

4-Chloro-3,5-difluoronitrobenzene (solid)

3,3'-Difluoro-4,4'-dimethoxybiphenyl (solid)

Ethers

Bis(m-phenoxyphenyl) Ether

1,4-bis(cresoxy) Benzene (mixed isomers)

 $CF_3CF_0(CF_0)_0SF_5$

2,2'-Dinitrodiphenyl Ether (solid)

4,4'-Dinitrodiphenyl Ether (solid)

4-Fluoru-6-methoxyacctanilide (solid)

3,3'-Difluoro-4,4'-dimethoxydiphenyl Sulfoxide (solid)

3,5-Difluoro-6-methoxyacetanilide (solid)

Mixed Perfluorocyclic Ether, $C_8F_{16}O$ (five- or six-membered ring with side chain, oxygen in the ring)

TABLE 4.14a(Concluded)

SOLUBLE IN 90-PERCENT H202 WITH NO VISIBLE SIGN OF REACTION

2,2,3,3,4,4,5,5-Octafluorohexyl 1,6-bis (trimethylacetate) 2,2,3,3,4,4,5,5-Octafluorohexyl 1,6-bis (3,3-dimethylbutyrate) Diethylene Glycol Succinate Polyester Chlorotetrafluorobenzotrifluoride p-bis(m-trifluoromethylphenoxy) Benzene

PARTLY MISCIBLE

2,4,6,3',5' Pentafluorobiphenyl (10-percent decrease in volume) 3,3' Difluoro-6,6' dimethoxybiphenyl (solid; 20-percent decrease in volume)

p-chlorobenzotrifluoride (20-percent decrease in volume)

SOME COLOR CHANGE

Bis(p-phenoxyphyenyl) Ether (solid) 3,5-Difluoronitrobenzene

GELLED ON MIXING

Tetrachlorodiphenyl Ethe (solid)

(1) Data taken from Ref. 4.33

(2) During testing, 1 milliliter (liquid) or 1 gram (solid) was mixed with 1 milliliter of 90 weight percent H₂0₂. 110-1-1

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RECOMMENDED JOINT SEALING COMPOUNDS FOR USE WITH⁽¹⁾ 90- AND 98-PERCENT HYDROGEN PEROXIDE

Name	Supplier	Formulation	Class	Remarks
Dixseel	Dixon Corp.	Teflon	1	Suitable for small-pipe scrvicc
T-Film	Eco Engineering	Dispersion Teflon-Water	1	Suitable for small-pipc service
Teflon Tape	Various	Teflon	1	Suitable for most applications

NOTE: Use sparingly to prevent carry-off into the H_2O_2 stream. Avoid threaded connections; use AN flares and flanges.

Compounds Not Recommended

Compound

Supplier

- en fet

Calbar CB Pipe Seal Calbar Paint & Varnish **Crane Thread Lubricant** Crane Fel-Pro, C-5 Felt Products Mfg. Graphite Paste Key Graphite Goop (blue) Carl A. Pearson Goop (silver) Cari A. Pearson Cyl-Seal West Chester Chemical Molybdenite Pipe Dope Permatex, Aviation Form A Gasket No. 3 Monsanto Chemical **OS-18** Lubricant Pecora Paint Pecora Compound Plastic Metal No. 22 National Engineering Products **Rutland Fire Clay** Rutland Pipe Dope Monsanto Chemical Skydrol Weco No-Gall Well Equipment Mfg X-Pando X-Pando Corp.

TABLE 4.15(Concluded)

C	om	po	u	nd	

Kel-F Grease No. 90

Tin Plating on Aluminum 6061

Alcoa Thread Lubricant

Rectorseal No. 15

Supplier

Minnesota Mining & Mfg.

Alcoa Rector Well Equipment

(1)_{Recommendations taken from Ref. 4.25}

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COMPATIBILITY OF HYDROGEN PEROXIDE WITH CERAMICS, REFRACTORIES, AND MISCELLANEOUS MATERIALS⁽¹⁾

Bffect en Material	None	None	None	Destreyed	None				None	Ztched	None	None	None	None	Ignited	None			Dissolved at room temperature	Nene	None	Note	
Percent Stability After Test	•	1	1	1	1	1	1	1	•	Ľ	•	•	I	1	1	1	1	1	1	1	,	1	
Percent A0î per Veek at 151 P	100	100	17.5	I	19.1	ł	ł	ļ	100	100	100	100	8.5	12.6	1	100	I	ł	ł	ł	100	100	
Cless	ĩ	n	2	4	ล		-#	-	-4	-4	4	-4	0	2	-	-	-	2	4	4	-	4	
H202, weight percent	06																						+
Source		Buffalo Meter	American Lava	General Electric	Norton				General Electric	General Electric	General Electric	General Electric	Coors Porcelain	Coors Porcelaín		Norton			Lee	Vickers, Inc.	Pure Bond	Pure Bond	
Material	Agate (matural)	Arate (poliched)	Al-Si-Mag Porcelain	Alumina (bonded)	Alundum LA 116	Bunded Alumina Filter ⁽³⁾	Bonded Alundum MR ⁽³⁾	Boron Nitride	Carbolor 44-4	Carboloy 55-A	Carboloy 78	Carboloy 999	Ceramic AB-2	Ceramic Al-200	Charcoal	Crystalon (SiC)	Glass, Pyres (3)	Glass, Soft ⁽³⁾	Graphitar No. 30	Graphite P-546 ⁽³⁾	Graphite P-546, Silver Lapregnated	Graphite P-53,	Copper Lupregnated

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(Concluded) TABLE 4.16

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Material	Bource	H2 ⁰ 2' weight percint	Class	Percent AOL per Veek at i51 P	Percent (2) Stability After Test	<i>Bifect on Material</i>
Graphite P-59L, Copper Lupregnated	Pure Bond	0 6	4	100	ł	X.
Graphite P-692	Pure Bond		-#	Excessive	I	Kene
Larbate	Mational Carbon Div.		4	100	•	Xone
II Silicon Carbide	Carberunde	·	ß	1.2	95.5	Kone
Norbide	Nerton		8	15.6	ł	Kone
Porcelain (white, chemical)(3)			7	i	1	
Pyroceram ⁽³⁾	Corning Glass		1	I	I	Kone
Synthetic Sapphire (pelished)	Linde	···	1	0.8	1	None
Zirconium Bilicate	Selas Corp.	+	2	7.6	97	None

(1) lata taken from Bef. 4.25 unless otherwise noted
(2) Pootnote 2, Table 4.4
(3) Reference 4.40

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RESULTS OF EVALUATION OF PROTECTIVE COATINGS FOR 90 W/O HYDROGEN PEROXIDE SERVICE^(1, 2)

Lemaria		In Al 1060, 5-gmlloc contaimer tests, HyO2 concentration loss was 35.5 to 54.9 percent from 90.4 percent in 52 weeks	Difficult to obtain nonpermeable conting	Tends to be brittle; multithim layers are rewarding	In Al 1060, 5-galles container tests, 200 concentration loss was 0.7 percent in 39 weeks, and 22.9 percent in 79 weeks from 90.0 percent	No effect om sample; 95 percent stability ⁽²⁾ after test	No effect on sample; 96 percent stability ⁽²⁾ after test	No effect on sample; 92.2 percent rtability ⁽²⁾ after test	No effect upon exposure ta 90-percent H202 for 7 days at 66 C (151 F)	No effect upen miterial	No effect up on un teríal	Very slight bromsing after elevated H ₂ O ₂ service	No effect upon material
Applications		Dispersion-conted thermaplastic	Dispersion coating	Bladder	Dispersion conting (Uniform contings possible)	Spray ceating only (uniform coatings powsible)	Spray coating only (uniform coatings pessible)	Spray coating only (uniferm coatings pessible)	Glaas or Teflon cloth impregnated vith Viton A	Permed glass lining	Pormed glass lining	Plating	Plating
Percent AOL per Week at 151 P			,	I	ł	с. о	9.4	3.4	2.9(3) 0.5(3)	2.4	3.0	I	6
Class	t and	1	I	1	r	٦ ,	7	F	~		T	8	8
Sentree	t for long Time Center 90 v/o H2 ⁰ 2		Dielectrix	Dielectriz	H. V. Kellogg	Metal Cladding, Inc.	Metal Cladding, Inc.	Metal Cladding, Inc.	David Clark	Pfaudler Corp.	Pfaudler Corp.	Keystone Chromium	Keystone Chromium
M terial	Recommended Contings Splash Resistance to	Teflon	Teflon (TFE)	Teflon (TTE)	Kel-P	Kel-P on 1060 Al	Kel-7 on 5254 Al	Lei-P on 5652	(Viten A)	Glass Lining (clear, light grey)	Glass Lining (cobalt-colored glass)	Lauegin (electro- less nickel upon mild steel)	Kanegin Coated and Tin-Plated Metals

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TABLE 4.17 (Continued)

Remarka		Curtains, equipment covers	Drop cloths, curtains, covers for equipment	Curtains, cover eleths, etc.	Excellent field experience for painting metal surfaces	Coverings for various items	One small bliater in 48 hours; three aughl bliaters in 5 days (most favorable for splash resistance)	Coverings, splash shields	Coverings, splash shislds	Excellent coating for mild steel and other metals)	Very low $\mathbb{R}_{9}0_{2}$ loss upon $\mathbb{R}_{2}0_{2}$ contact	Blistered in 24 hours; me other effects noted	Blistered in 24 hours	Blistered in 24 hours	Blistered in 24 bours	Blistered in 24 hours
Applicatimus		Glass, Dacron, or Teflon cloth im- pregnated with Viton	Pilzs	Sheet for	Paint	Foil and film	Applied as ordin- ary peint	Film	Film	Plating	Plating	Applied as ordimary paint	Applied as ordinary paint	Applied as ordinary paint	Applied as ordinary paint	Applied as ordźnary peint
Percent AOL per Week at 151 F		ł	ł	ı	I	ł	I	ı	I	1	1	ł	ŧ	ı	1	t
Class	÷.	5	1	0	ı	1-2	ณ	1	r#	2	2	ı	1	I	1	1
Source	ts for Splash-Resistand [2 ⁰ 2	David Clark	DuPont	DuPont	Various suppliers	Various suppliers	National Engineering Products	DuPont	Various suppliers	Keystone Chromium	Keystone Chromium		U.S. Stoneware	Corrosite Cerp.	Corrosite Corp.	Corrosite Corp.
Material	Recommended Coating Service to 90 v/o H	Ommi (Yiton A)	Teflon (TFE sheet)	Viton A	Metallic Aluminum (norvolatile carrier)	Alucting Poil	Plastic Metal No. 22 (plastic paint)	Mylar (plastic)	Scotch Pak (piantic)	Kanerjin (electro- less nickel)	Tim-Plated Eanegin	Tygon Paint 7286 TP-81-Clear	Tygon Paint 71253 TY-107B	Corrosite No. 521	Corrosite No. 551	Corrosite No. 581

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TABLE 4.17 (Continued)

Heterial	Source	Class	Percent AGL per Week at 151 F	Applications	Braurica
Saran Bubber Q-1875	Dov Chemical	,	I		Softened and blistered in 1 week; specially
MV-Type No. 150	Gregg	1	1		applied of manufacturer Blistered in 48 hours
Amercoat No. 1262	Amvrican Pipe & Construction	1	3		Blistered in 43 hours
Reilex	Heil Process	1	r		One small blister in 24 hours; applied by
P-5, Co-Polymer	Metson Standard	I	1	Applied as ordin-	Blistered in 24 hours
Neolac Gray No. 8588	Chamberlain Engineering	1	!	Applied as ordin- ary paint	Blistered in 24 hours
Steelcote Stainless	Steelcote Mfg.	I	ļ	Applied as crdin- ary paint	Small blisters overnight

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Material			
		Results	Rearies
Coatings Not Recommende	d for 90 Percent B	2 ⁰ 2 Service	
Geon Later 31X	B. F. Goodrich	Blistered in 24 hours	Difficulty encountered in anglication
Flexcoat No. 1 Black	Bison Chemicals	Blistered in 16 hours	Blisters encountered in varor these
Lithgov LC-600 (grey)	Lithgov	Blistered in 24 hours	Applied by manufacturer
Amercoat Red	American Pipe & Construction	Blistered in 7 hours	
Prufcoat Medium Grey	Prufcoat Labs	Blistered in 24 hours	Applied by manufacturer
Lithgov LC-600 (brown)	Lithgov	Small blisters in 7 hours	Applied by manufacturer
Veloform P-10 CPP304	Firestone Rubber	Blistered heavily in 16 hours	Applied by fabricator
Cordo S-255 A	Cordo Chemical	Coating blistered in 12 hours	Applied by dipping
Cordo Plastic Coating (E-1 Resin + H-26 Activator)	Cordo Chemical	Ercensive H ₂ 02 decom- position and blister formation	Applied by laboratory per instructions
Chrom 11 of	I	High rate of H ₂ C ₂ decomposition and chrome leaching	Applied by manufacturer to low-carbon steel samples
Unichrome Druss Lining B-124-17	United Chromium	Heavy bliaters in 20 hours at 30 C; heavy blirters in 3 hours at 66 C	Applied by manufacturer
Ucilon System E Coating	United Chromium		
EX 53B Paint	American Paint		
Sealer BC 801 with Accelerator	Minnesota Mining & Mfg		
Penton Lining on 1060 Aluminum	Buffalo Lining & Fabricating		

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NOTE: The aluminum alloys all show good splash resistance. Any nonflammable plastics or metals listed in the previous tables having Class 1 through 3 are suitable for use as spligh resistant materials.

(1) Data taken from Ref. 4.25
 (2) Data taken from Ref. 4.29
 (3) Percent AOL/month at 86 F

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EVALUATION OF CLOTHING MATERIALS FOR CONTACT WITH 90 N/O HYDROGEN PERCENDE⁽¹⁾

		Percent AOL Der Monüh	Percent AOL per Veek	Inflam Drip	ability Tests	
Sample	Source	at 86 F	at 151 F	Clean	Soiled	Remarks
Permeable						
Dacron						
Monofilament	U.S. Rubber Co.	1.0	12.1	No effect	No effect ⁽²⁾	Apparently no damge
Heavy Pile	G. W. Borg Co.	0.5	13.0	No effect	No effect ⁽²⁾	Apparently no damage
Staple Fauric	Travis Fabrics, Inc.	0.8	13.4	No effect	No effect ⁽²⁾	Apparently no damage
Saran						
Monofilament	Saran Yarne Co.	0.5	6.0	No effect	No effect ⁽²⁾	Apparently no damage
Dacren-Vool						
55 to 45 percent	Deering Milliken	0.7	7.1	No effect	No effect	Veakened
Dyne l	Burlington Mills	ı	I	No effect	Burned	Partially dissolved at 66 C (151 P)
Saran (staple)	Saran Yarns Co.	1.3	0.4	No effect	Burned	Partially dissolved at 66 C (151 P)
Vinyon "N"	Milburn Co.	1.9	0.4	No effect	Burned	Partially dissolved at 66 C (151 F)
Impermeable						
Polyvizylchloride	Milburn Co.	0.2	3.6	Not tested	_	Hardens en prolenged contact at 66 C (151 P): bleaches
Plexigrip Zipper (vinyl)	Flexigrip, Inc.	1.0	89° *	No effect	Distorts	Hardens on prolonged contact at 66 C (151 P)

(1) Data taken from Ref. 4.25 (2) Some Dacron samp¹es may burn upon contact with 90 percent ${\rm H_2}^0_2$ when solled with catalyst.

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TABLE 4.18a

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CLOTHING MATERIALS NOT SUITABLE FOR USE WHEN HANDLING 90 W/0 HYDROGEN PEROXIDE(1)

	Effect of Sample	Effect of H ₀ 0
Sample	or H202	z z on Sample
Permeable		
Cotton, Drill	Moderate decomposition	Burns readily when soiled
Cotton, Bayon (50-50)	Moderate decomposition	Burns readily when soiled
Dacron, Viscose (50-50)	Moderate decomposition	Weakens considerably
Leather	1	Burns readily
Linen, Blesched	Moderate decomposition	Burns readily
Linen, Unbleached	Moderate decomposition	Burns readily when soiled
Rayon	Moderate decomposition	Burns readily when soiled
Silk, Degummed Fiber	ł	Dissolved
looð	Moderate decomposition	Weaks considerably; crumbles when touched
Impermeable		
Aluminized Cotton Duck	Moderate decomposition	Burns readily when soiled

(1) Data taken from Ref. 4.25

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COMPATIBILITY OF VARIOUS METALS WITH 98 W/O HYDROGEN PEROXIDE AT HIGH TEMPERATURES⁽¹⁾

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(Exposure at 270 F for 1 Hour)

	ut Change g Test ⁽²⁾ , H gram	[202 Concentration Change, percent	Appearance After Test ⁽³⁾
Inconel 718 ⁽⁵⁾	0.0003	11.7	Light bronzing of the metal
$\left[304 \text{ Stainless Steel} \left(\frac{4}{2} \right) \right]$ No	опе	14.5	Heavily bronzed
304 Stainless Steel ⁽⁵⁾ Not me	easured	ł	Sample of H_202 decomposed violently upon reaching 270 F. No change in specimen appearance.
316 Stainless Steel $\binom{4}{6}$ -(0.0008	6.8	Heavily bronzed
316 Stainless Steel (4) +(0.0013	1.2	No change in specimen appearance
347 Stainless Steel ⁽⁵⁾	0.0002	11.2	Lightly bronzed
747 Stainless Steel ⁽⁵⁾	0.0003	1.3	No change in specimen appearance
Hastellov-C ⁽⁴⁾ -(0.0014	0.6	Slightly bronzed
Bastelloy-X ⁽⁴⁾ -(0.0036	51.8	No apparent change
Equipment Test (Pyrex) No met	tal sample	0.6	No change in specimen appearance

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(Concluded)

(1) Data taken from Ref. 4.29. (2)

 $(2)_{\sf Weight}$ changes of less than 0,004 gram are not considered significant.

discernible difference in the surfaces of the blanks and the treated specimens (3) All specimens were examined at 100X after testing. In no case was there ary other than the reported color change.

room temperature, washed with tap water, rinsed with distilled water, blotted $(4)_{The}$ specimens were passivated by treatment for 4 hours in 70-percent $\mathrm{H}\mathrm{v0}_{3}$ at dry with filter paper, and then oven-dried at 220 F.

(5) The specimens were passivated by treatment for 2 hours in 2-percent Na2Cr2 $\dot{0}_7$ solution at room temperature, washed with water, immersed in a 20-percent HMO_7 solution, rinsed with distilled water, and then oven-dried at 220 F.

	· • • • • • • • • • • • • • • • • •	Exposure		Per	cent	
Material Form(2)	Surface Condition	Temperature, F	Time, days	V 01	Stabi- lity	Ехровите Вевропве
1060 Alloy	Unanodized RMS 96	110	10	0.2	92.3	No effect
1060 Alloy, H12 Temper	Unanodized RMS 89	110	10	0.2	92.4	No effect
1060 Alloy	Anodized RMS 96	110	10	0.3	97.2	No effect
1060 Alloy, H12 Temper	Anodized RMS 89	110	10	0.3	97.5	No effect
1060 Alloy	Unanodized	75	10	0.6	98.8	No effect
1060 Alloy	Una modized	40	10	0.7	99.0	Discolored
1100 Alloy	Unanodized RMS 20	110	10	1.4	95.2	White coating
1100 Alloy	Anodized RMS 20	110	10	2.0	96.7	Grey coating

COMPATIBILITY OF 90-PERCENT HYDROGEN PEROXIDE WITH 1060 AND 1100 ALUMINUM ALLOYS⁽¹⁾

(1)_{Data taken from Ref. 4.10, 4.12, and 4.13.}

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(2) Passivation procedure CVA10-62a; no surface treatment; surface/volume ratio = 0.38 in. -1

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COMPATIBILITY OF 90 W/O HYDROGEN PEROXIDE WITH 6061-T6 ALLMINUM SHEET⁽¹⁾(2)

			Per	cent	Exposure		
Surface Condition	Passivation Procedure	Surface Posttreatment	AOL	Stabi- lity	Temperature, F	Time, days	Exposure Response
Upanodized RMS 11-14	CVA 10-62a	None	5.4	94.2	151	1~	Frosty sheen
Unancdized RMS 47	North American LA 0110-003	None	3.1	93.8	151	1-	Spotty, dull
Unanodized RMS 65	North American IA 0110-003	None	2.9	96.2	151	[-	Spotty, dull
Unanodized RMS 91	North American LA 0110-003	None	2.3	97.3	151	(-	Spotty, dull
Unanodized RMS 207	North American LA 0110-003	None	2.3	97.0	151	(~	Spotty, dull
Unanodized RMS 351	North American LA 0110-003	None	3.4	96.3	151	(-	Spotty, dull
Unanodized	North American LA 0110-003	None	2.9	92.4	151	(-	No effect
Unapodized	CVA 10-62a	l AOL cycle exposure	1.8	96.9	151	[~	Dull discoloration
Unanodized	CVA 10-62a	2 AOL cycles exposure	0.5	98.5	151	1-	Light sunting
Unanodized	CVA 10-62a	"Farrelok" 2 AOL cycles	1.7	95.5	151	1	No effect

 $(2)_{\text{Thickness}} = 0.063 \text{ in.; surface/volume ratio} = 0.38 \text{ in.}^{-1}$ ۲ (1) Data taken from Ref. 4.14, 4.15.

TABLE 4.21 (Continued)

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			Dere	ent	Exposite		
Surface Condition	Passivation Procedure	Surface Posttreatment	70¥	Stabi- lity	Temperature, F	Time, days	Exposure Response
Unanodized	FMC Bulletin 10'i	l AOL cycle 7 days at 151 F	1.5	7.7	151	1-	Spotted
Unanodized	FMC Bulletin 104	2 AOL cycles 7 days at 151 F	1.6	97.2	IŢI	l -	Spotted, frosted
Unanodized	North American LA 0110-003	None	2.9	92.4	IÇI	t -	No effect
Unanodized	North American LA 0110-005	1 AOL cycle 7 days at 151 F	1.3	97.9	151	1~	Dill grey color
Unanodized	North American LA 0110-003	2 AOI cycles 7 days at 151 F	1.0	98.3	151	t -	No effect
Unanodized	North American LA 0110-003	None	12.0	86.0	151	t -	No effect
Unanodized RMS 21	FMC Bulletin 104	None	1.1	97.3	110	10	No effect
Unanodized RMS 21	North American LA 0110-003	None	0.9	97.7	110	10	No effect
Unanodized RVS 21	Walter Kidde 520007	None	1.5	1.16	110	10	No effect
Unanodized RMS 21	McDonnell 13002	None	2.2	92.9	110	10	White deposit
Unanodized PVS 21	CVA 10-622	None	2.3	97.4	110	10	Wlite deposit

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TABLF 4.21 (Continued)

			Perc	ent	Exposure		
Surface Condition	Procedure	Surface Posttreatzent	AOL	Stabi- lity	Femperature, F	Time, days	Exposure Response
Unanodized RMS 66	CVA 10-62a	None	2.6	82.4	110	10	No effect
Unanodized RMS 100	CVA 10-62a	Мопе	2.4	85.4	110	10	No effect
Anodized RMS 13-18	CVA 10-62a	None	6.2	91.7	151	۲~	Frosty, spotty
Anodized RMS 7	North American LA 0110-003	None	0.7	5.16	151	(-	Uniformly dulled
Anodized RMS 44	North American LA 0110-003	None	0.9	97.5	151	1-	Uniformly dulled
Anodized RMS 27	North American IA 0110-003	None	1.2	1.76	151	l -	Uniformly dulled
Anodized RMS 202	North American IA 0110-005	None	1.1	97.8	151	(-	Uniformly dulled
Anodized RMS 380	North American LA 0110-003	None	1.1	97.8	151	1-	Uniformly dulled
Anodized	CVA 10-62a	None	2.9	96.8	151	{-	No effect
Anodized	CVA 10-62a	1 AOL cycle 7 days at 151 F	2.1	97.6	151	1-	No effect
Anodízed	CVA 10-62a	2 AOL cycles 7 days at 151 F	1.5	98.2	151	(-	No effect
Anodized	CVA 10-62a	"Farrellok"	64.6	0.0	151	1-	No effect

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TABLE 1.21 (Continued)

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Spotty, frosted Exposure Response No effect surface Time, days 10 1~ 1~ [`~ ۲.r-1 1~ r-1-Exposure Stabi-| Temperature, 151 151 151 101 110 151 151 151 151 F= 0.0 95.4 97.2 98.0 93.8 90.3 76.9 2.16 95.3 lity Percent 2.61.4 1.8 7.3 2.7 1.7 4.4 2.1 5.1 **JOL** 2 AOL cycles 7 days at 151 F **G**., [⁷ 7 days at 151 F 2 weeks storage 2 weeks storage 2 weeks storage in polyethylene Posttreatment in 100 percent 7 days at 151 7 days at 151 2 AOL cycles l AOL cycle Surface l AOL cycle "Farrellok" RH at 160 F "Farrellok" in N2 gas at 160 F None None North American North American LA 0110-003 North American North American Passivation LA 0110-003 Procedure LA 0110-005 LA 0110-003 CVA 10-62a CVA 10-62a CVA 10-62a CVA 10-62a CVA 10-62a *S/V Ratio 0.38 in.-1 Condition Anodized Anodized Anodized Surface Anodized Anodized Anodized Anodized Anodized Anodized

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TABLE 4.21 (Concluded)

			Per	cent	Exposure		
Surface Condition	Passivation Procedure	Surface Posttreatment	AOL	Stabi- lity	Temperature, F	Time, days	Exposure Response
Anodized .S/V Batio 0.76 in1	North American LA 0110-003	None	3.5	67.3	110	10	Frosted surface
Anodized S/V Batio 1.15 in1	North American LA 0110-003	None	5.6	43.8	110	10	Frosted surface
Amodízed S/V Ratio 1.53 in1	North American LA 0110-003	None	7.8	26.8	110	10	Spotty, frosted surface
Amodized S/V Ratio 1.91 in1	North American LA 0110-003	None	7.8	0.0	011	10	Frosted surface
Anodized BMS 66	CVA 10-62a	None	5.5	4.49	110	10	No effect
Anodised Res 100	CVA 10-62a	None	3.8	80.8	110	10	No effect

Mottled bronzing Spotty bronzing Spotty bronzing Spotty bronzing Spotty bronzing Slight bronzing Spotty bronzing Light bronzing Exposure Response Stabi-86.8 6.18 85.9 83.4 95.9 80.1 €.06 90.1 lity Percent AOL 0.6 12.3 10.0 6.5 10.7 11.4 4.6 3.7 Temperature, Time, days ~ 10 10 ~ ~ ~ Exposure 7.10 110 151 151 151 151 151 151 £. 35-percent $H_20_2^{(3)}$ 35-percent $H_2 O_2^{(3)}$ 35-percent $E_20_2^{(3)}$ 35-percent $H_20_2^{(3)}$ 35-percent $R_2 0_2^{(3)}$ 35-percent $H_20_2^{(3)}$ **Postireatment** Surface None None Condition Surface EMS 174 **RMS 256 RMS 5-8** RMS 45 BMS 66 INCE 14 THE A **ENS 14** Material Form (2) Annealed Annealed Sheet Sheet Sheet Sheet Sheet Sheet Sheet Sheet

COMPATIBILITY OF 90 v/o HYDROGEN PEROXIDE WITH 504 STAINLESS STEEL⁽¹⁾

(1) Data taken from Ref. 4.14 and 4.15

(2)
Passivation procedure CVA 10-62a; surface/volume ratio = 0.38 in.⁻¹

(3)_{Posttreatment was in 35-percent hydrogen peroxide inhibited with 0.03-percent phosphoric acid}

COMPATIBILITY OF 90 v/o BYDROGEN PEROXIDE WITH 316L STAINLESS STEPS.(1)(2)

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			Exposure		F		
Surtace Condition	Procedure	Surfact Posttreatment	Temperature. F	Time, days	YOL	ceut Stability	Expresse Response
Sheet Stock 1	t = 0.063				4	, , ;	
RMS 48	CVA 10-62a	None	110	10	4.2	85.5	Spotty bronze
RMS 80	CVA 10-62a	None	110	10	3.6	87.1	Spotty bronze
RMS 48	CVA 10-62a	35 -percent $H_2^{0}_2$	110	10	2.2	83.3	Spotty bronze
RMS 80	CVA 10-62a	35 -percent H_2^{0}	110	10	2.0	86.1	Spotty hronze
RMS 13	FMC Bulletin 104	None	011	10	5.4	95.7	Slightly bronzed
RMS 13	North American LA 0110-005	1 None	011	10	4.6	96.7	Slightly bronsed
INS 13	Walter Kidde 520007	None	011	10	7.0	95.2	Slightly bronzed
RMS 13	McDonnell A/C 13002	None	011	10	7.8	95.4	Slightly bronsed
RMS 13	CVA 10-62a	None	110	10	7.5	95.1	Slightly bronzed
Emery Paper Buffed	CVA 10-62a	35-percent H ₂ 0 ₂	75	10	1.4	97.6	Uniformly bronzed
Emery Paper Buffed	CVA 10-62a	35-percent ${ m H_20_2}$	0ħ	10	1.2	0.66	Lightly bronzed

TABLE 4.23 (Concluded)

Uniformly bronzed Uniformly bronzed Exposure Response Lightly bronzed Lightly bronzed Lightly bronzed Lightly bronsed Lightly bronzed Percent OL Stabi-95.5 93.6 95.5 98.8 92.8 97.3 97.6 3.3 4.1 <u>ی</u> 3.0 0.6 1.1 1.1 AOL Time, days 2 10 3 S m ~ 3 Ехровите Temperature, 110 110 110 110 110 110 110 35-percent \mathbb{H}_20_2 **55-percent** H₂0. **35-percent** \mathbb{H}_2^{0} 35-percent $\mathbb{R}_2^{0_2}$ Posttreatment Surface None Nonc None **Passiva**tion Procedure Walter Kidde 520007 Walter Kidde Walter Kiúde CVA 10-62a CVA 10-62a CVA 10-62a CVA 10-62a 520007 520007 **Condition** Surface Tubing RMS 8 Ø œ 90 œ BACS 8 Ø Sing SWE SWE SING

(1) Data taken from Ref. 4.11, 4.12, and 4.18

(2)
(2)
Sheet stock; surface/volume ratio = 0.38 in.⁻¹

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COMPATIBILITY OF 90 v/o HYDROGEN PEROXIDE WITH 321 STAINLESS STEEL⁽¹⁾(2)

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Surface Condition	Passivation Procedure	Surface Posttreatment	Exposu Temperature, F	e Time, days	A0L	Stabi- lity '	Exposure Response
0.063-Inch S	heet Stock						
Buffed	CVA 10-62a	None	151	2	10.3	2.78	Spotty bronse
Emery Paper Buffed	CVA 10-62a	l ACL cycle 7 days at 151 F	151	2	3.7	97.8	Spotty bro nse
Emery Paper Buffed	CVA 10-62a	2 201 cycles 7 days at 151 P	1 5 2	2	3.6	98.6	Blue-bronze
Emery Paper Buffed	CVA 10-62a	35-percent H202	151	1-	7.0	93.1	No effect
Emery Paper Buffed	CVA 10-62a	35-percent H ₂ 0 ₂ , 1 AOL cycle 7 days at 151 F	151	~	3.1	97.8	Light bronze
Emery Paper Buffed	CVA 10-62a	35 -percent $H_2 O_2$; 2 AOL cycles 7 days at 151 F	151	2	2.6	98.6	Light bronze
Buffed	CVA 10-62a	"Farrellsk"	151	2	14.6	76.6	Uniform bronze
Emery Paper Buffed	CVA 10-62a	"Farrellok," 1 AOL cycle 7 days at 151 P	151	2	4.4	97.6	Uniform bronze

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TABLE 4.24 (Continued)

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Surface	Dancientia	Surface			Per	cent	
Condition	Procedure	Posttreatment	Temperature, F	Time, days	AOL	Stabi- lity	Exposure Response
0.04.7-Inch S	hert Stock						
Fmery Paper Buffed	CVA 10-62a	"Farrellok" + 2 AOL cycles 7 days at 151 F	151	2	3.8	98.3	Orange-bronze
Baery Paper Buffed	North American LA 0110-003	None	151	~	18.5	59.1	Uniform bronze
Emery Paper Buffed	North American LA 0110-007	1 AOL cyclε 7 days at 151 F	151	~	6.4	94°5	Spotty bronze
Emery Paper Buffed	North American LA 0110-007	2 AOL cycles 7 days at 151 F	151	~	4.7	97.8	Brown-bronze
Emery Paper Buffed	CVA 10-62a	2 weeks storage in dry N ₂ gas	151	1-	5.2	94.7	Spotty bronze
Emery Paper Buifed	CVA 10-62a	2 weeks storage polyethylene bag at 160 F	151	7	4	94.1	Uniform bronze
Emery Paper Buffed	CVA 10-62a	2 weeks storage 100-percent RH at 160 F	151	[~	4.8	94.9	Uniform bronze
RMS 4-6	CVA 10-62a	None	151	2	2.9	5.46	Light bronze
RMS 96	CVA 10-62a	None	110	10	2.9	85.7	Bronzed
RMS 50	CVA 10-62a	None	110	10	3.6	83.2	Urregular bronze
RMS 96	CVA 10-62a	35 -percent $R_2^{0}_2$	110	10	1.7	86.9	Spotty bronze

TABLE 4.24 (Continued)

Time, days A0L Stability Exposure Response Severely bronzed Severely bronzed Severely bronzed Severely bronzed Severely bronzed Spotty bronze 0.0 0.0 82 8 55.5 11.6 0.0 Percent 20.6 35.2 51.6 88.2 2.9 10.01 10 10 10 10 10 10 Exposure Temperature, F 110 110 110 110 110 110 35-percent $H_2^0_2$ Posttreatment Surface None None None None None Passivation LTV 308-20-3 LTV 308-20-3 LTV 308-20-3 LITV 308-20-3 LTV 308-20-3 Procedure CVA 10-62a **0.067-Inch Sheet Stock** Buffed, S/Y Batio 0.38 in.-1 Buffed, S/V Eatio 0.75 in.-1 S/V Batio 1.15 in.-1 Buffed. S/V Ratio Buffed, S/V Batio 1.91 in.-1 1.53 in.⁻¹ Condition Surface Baffed, RUES 50

TABLE 4.24 (Continued)

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Surface	Passivation	Surface	Exposur	e	Pe	rcent	
Condition	Procedure	Posttreatment	Temperature, F	Time, days	AOL S	tability	Exposure Response
0.25-Inch Tu	bing						
Emery Paper Buffed	Detergent clean	None	110	10	2.9	90.2	Yellow-bronze
Emery Paper Buffed	LTV 308-20-3	None	110	10	5.1	93.5	Faint yellow
Emery Paper Buffed	LTV 308-20-3 ENO ₅ Sol. 75 F	Oven-baked at 750 F	110	10	ن: 1-	94.3	Mottled tan-blue
Emery Paper Buffed	Detergent clean	Oven-baked at 750 F	110	10	2.6	4.68	Iridescent straw-copper
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 600 F	110	10	5.0	74.7	Irídescent gray-bronze
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 700 F	011	10	3.3	81.9	Iridescent gray-bronze
Enery Paper Buffed	LTV 308-20-3	Oven-baked at 750 F	110	10	2.2	88.2	Iridescent gray-orange
Emery Paper Buffed	LTV 308-20-3	Oven-baked at 800 F	011	10	[. 0	97.6	Light pink- straw color
RMS 12	CVA 10-62a	35-percent H202	011	10	2.4	95.1	Slightly bronzed
RMS 12	Walter Kidde 520007	None	110	10	2.8	94.8	Slightly bronzed
Buffed, S/V Ratiol 1.91 in.	LTV 308-20-3	None	110	10	16.4	0.0	Light bronzing

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TABLE 4.24 (Concluded)

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Severely bronzed Slightly bronzed Slightly bronzed AOL Stability Exposure Response Lightly bronzed Lightly bronzed No effect No effect 0.0 95.5 96.9 96.0 96.6 98.3 97.6 Percent 22.5 2.2 1.3 0.7 1.4 1.1 Time, days 10 3 5 ഹ 5 m m E. posure Temperature, F 110 110 110 110 110 110 110 35-percent H_20_2 35-percent H_20_2 35-percent H_20_2 Posttreatment Surface Naze None None None North American LA 0110-003 Passivation Procedure Walter Kidde Walter Kidde Walter Kidde CVA 10-62a CVA 10-62a CVN 10-62A 520007 520007 520007 0.25-Inch Tubing 8/V Batio 1.91 in.-1 Surface Condition Buffed, **RMS** 12 **RMS 12** 12 **RMS** 12 BMS 12 **BMS 12** SIN

(1) Data taken from Ref. 4.13, 4.14, and 4.15 (2) Surface/volume ratio = 0.38 in.⁻¹

COMPATIBILITY OF 90 v/o HYDROGEN PEROXIDE WITH SELECTED STAINLESS STEEL ALLOYS (1) (2)

	Time, Exposure days Response	7 No effect	10 No effect	10 No effect	10 Darkeneu, scotty	10 Eesvily brouzed	10 Heavily bronzed	10 Heavily bronzed
Exposure	Temperature,	151	110	011	110	110	110	110
	Percent Stability	0.0	65.3	30.3	21.2	24.5	24.8	58.5
	Percent AOL	55.7	10.7	13.0	19.7	18.9	15.8	13.3
	Surface Posttreatment	None	None	None	None	None	35-percent H202	None
	Passivation Procedure	CVA 10-62a	Walter Kidde 520007	Walter Kidde 520007	Walter Kidde 2 '0007	Walter Kidde 520007	CVA 10-62a	CVA 10-62a
	Surface Condition	RMS 7-8	RMS 87	RMS 40	RMS 113	RMS 113	RVS 58	RMS 57
	Steel Alloy	17-H PH Sheet	17-4 PH Sheet, HT R-900	17-4 7월 Sheet, 표 R-900	17-4 FH Sbeet, HT R-900	17-4 PH Sheet Hr R-900	17-7 PH Sheet, HT TH-1050	17-7 PZ Sheet, HT TH-1050

(1) Data taken from Ref. 4.15
(2) Surface/volume ratio = 0.38 in.-1

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TABLE 4.25 (Concluded)

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						Exposure	_	
Steel Alloy	Surface Condition	Passivation Procedure	Surface Posttreatment	Percent AOL	Percent Stability	Temperature, F	Time, days	Exposure Response
302 Cold Drawn Wire	RVS 94	CVA 10-62a	J5-percent ${\rm H_20_2}$	4.3	32.8	110	10	Slightly bronzed
302 Cold Drawn Wire	RWS 94	CVA 10-62a	None	3.7	90.1	110	10	Severely bronzed
347 Sheet	RMS 88	CVA 10-62a	None	3.4	86.5	110	10	Bronsed
347 Sheet	RMS 88	CVA 10-62a	35-percent H ₉ 0 ₉	2.2	83.0	110	10	Bronsed
347 Sheet	RMS 39	CVA 10-62a	None	4.0	84.9	110	10	Bronzed
347 Sheet	RMS 39	CVA 10-62a	35 -percent H_20_2	3.5	83.6	110	10	Dull bronze

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COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH VICONE 185 ELASTOMER⁽¹⁾ (2)

Bleached Exposure Bleached Bleached Bleached Bleached Bleached Bleached Response Bleached Bleached Bleached Stability Percent 98.9 99.5 92.0 93.6 4.66 99.4 4.66 98.9 98.7 99.4 Percent AOL 2.5 6.0 0.9 6.0 0.2 0.5 0.8 0.3 0.8 0.4Time, days ~ 10 20 10 10 2 10 20 20 10 Exposure Temperature 110 40 160 110 110 110 110 110 110 5 Бч 5-percent HNO₃ 5-percent HNO₃ 5-percent HNO₇ Posttreatment Surface None None None None None None None North American LA 0110-603 North American McDonnell A/C Walter Kidde 520007 FMC Bulletin 164 Passi vati on Procedure LA 0110-003 CVA 10-64a CVA 10-64a CVA 10-64a CVA 10-64a CVA 10-64a 3002

Data taken from Ref. 4.12 and 4.16
 0.063-inch sheet stock; surface condition as fabricated

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COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SILASTIC 9711 ELASTOMPR SERVER (1) (2)

		Expoeur	8			
Surface Posttreatmen	ţ	Temperature, F	Time, days	Percent AOL	Percent Stability	Exposure Response
Norae		160	~	6.5	98.8	Sli gh t blister
None		151	2	5.3	99.2	No effect
l AOL cycle 7 days at 151]	GL	151	2	5.8	98.9	Dimpled, spotty
2 AOL cycles 7 days at 151 F		151	2	5.5	1.66	Opague blisters
"Farrellok"		151	7	3.4	99.2	No effect
"Farrellok" 1 AOL cycle 7 days at 151 F		151	~	4.1	99.2	Spotty
"Farrellok" + 2 AOL cycles 7 days at 151 F		151	~	4.1	1.66	Opaque blisters
None				4 .8	99.2	No effect
l AOL cycle 7 days at 151 F		151	~	4.8	99.2	Dimpled,
2 AOL cycles 7 days at 151 F		151	2	4°6	99.2	Opeque blisters
Йопе		151	2	5.2	4.06	No effect

⁽¹⁾ Data taken from Ref. 4.16 and 4.17
(2) Sheet thickness = 0.063 inch; surface/volume ratio (S/V)= 0.38 in.⁻¹
except where otherwise noted

TABLE 4.27 (Continued)

No effect No effect No effect No effect No effect No effect Opaque Blisters Bleached Response Bleached Bleached Exposure Spotty Stabi lity Percent 98.9 0.66 98.6 9.06 96.9 99.0 98.8 99.2 97.4 4.66 99.3 Percent AOL 5.5 5.2 2.9 3.2 5.2 5.7 5.7 4.3 3.7 **2**.8 1.7 Time, days r~ ~ ~ **P**-~ 7 ~ 10 10 10 10 Exposure Temperature, 151 151 110 110 110 110 151 151 151 151 151 ш polycthylene bag at 160 F F=4 2 AOL cycles 7 days at 151 F 2 weeks storage 2 weeks storage 2 weeks storage 100-percent RH 1 AOL cycle 7 days at 151 J 5-percent HNO₃ iu dry N₂ gas Posttreatment Surface at 160 F None None None None None (s/v = 0.76/in.)North American Passivation Walter Kidde 520007 Procedure Walter Kidde 520007 Walter Kidde Walter Kidde LA 0110-003 CVA 10-64a CVA 10-64a CVA 10-64a CVA 10-64a CVA 10-61/1a CVA 10-64a 520007 520007

TABLE 4.27 (Concluded)

		Exposure				
Passi vation Procedure	Surface Posttreatment	Temperature, F	Time, days	Percent AOL	Percent Stability	Ехровите Response
Walter Kidde 520007	Acros	110	10	5.3	6.2	No effect
(8/Y = 1.15/in.) Valter Kidde 520007	None	110	10	6.9	98.0	No effect
(S/V = 1.53/in.) #21ter Kidde	None	110	10	2.9	99.1	No effect
(s/v = 1.91/in.)						

COMPATIBILITY OF 90 w/o HYDROGEN PEROXIDE WITH SELECTED VITON ELASTOMERIC MATERIALS⁽¹⁾ (2)

			Exposur	e			
Material Form	Passivation Procedure	Surface Posttreatment	Temperature, F	Time, days	Percent AOL	Percent Stability	Erposure Response
Fluorel 2141 1/16-Inch Sheet	North American LA D110-003	None	160	~	4.3	98.2	Blistered, swelled
Fluorel 2141 1/16-Inch Sheet	North American I.A 0110-003	Nome	110	10	1.1	98.8	No effect
Parker V359-7 Batch 04107	CVA 10-64a	None	151	~	11.5	91.9	Blistered, exudate
Parker 77-545 Batch 03888	CVA 10-64a	None	151	2	5.9	95.6	Blistered, distorted
Stil lman SR-27-770	CVA 10-64a	None	151	7	2.4	98.6	Light blister
Viton A Parker V359-7	CVA 10-64a	None	110	10	2.5	95.0	Bleached black to grey
Viton A Parker V359-7	CVA 10-64a	5-percent HNO ₃	110	10	2.4	85.8	Bleached black to grey

(1) Data taken from Ref. 4.16 and 4.17
(2) Surface condition as fabricated; surface/volume ratio = 0.38 in.

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COMPACTIBILITY OF 90 w/o HYDROGEN PROXIDE WITH SELECTED PLASTICS⁽¹⁾

			Tryosur	e			
Material Form ⁽²⁾	Passivation Procedure	Surface Posttreatment	Temperature, F	Time, days	Percent AOL	Percent Stability	Erposure Response
Aclar 220 5-Mil Sheet	North American LA 0110-003	Nome	160	2	0.5	98.7	No effect
Aclar 22C 2-Mil Sheet	CVA 10-64a	None	110	10	0.5	92.4	No effect
Aclar 22C 2-Mil Sbeet	CVA 10-64a	5-percent ANO ₃	110	10	0.1	91.5	No effect
Aclar 22C 5-Mil Sheet	FMC Bulletin 104	None	110	10	0.0	99.3	No effect
Aclar 22C 5-Mil Sheet	North American LA 0110-003	Мове	110	10	0.0	99.2	No effect
Aclar 22C 5-Mil Sheet	Walter Kidde 520007	None	110	10	0.2	99.4	No effect
Aclar 22C 5-Mil Sheet	McDonnell A/C 13002	None	110	10	0.0	99.2	No effect
Aclar 22C 5-Mil Sbeet	CVA 10-64a	None	110	10	0.0	99.5	No effect

(1) Data taken from Ref. 4.17
(2) Surface/volume ratio = 0.33 in.-1

TABLE 4.29 (Concluded)

			Exposul	ę			
Material Form ⁽²⁾	Passivation. Procedure	Surface Posttreatment	Temperature F	Time, days	Percent AOL	Percent Stability	Ехрозиге Везропзе
Aclar 22C 20-Mil Sheet	North American LA 0110-003	None	110	10	0.1	99.1	No effect
Aclar 33C 5-Mil Sheet	CVA 10-64a	None	110	10	1.2	98.7	No effect
Aclar 33C 5-Mil Sbeet	CVA 10-64a	5-percent HNO ₃	011	10	2.1	6.79	No effect
"Fluorogold" Polytetra- fluoroethylene	CVA 10-64a	None	151	r-	2.7	93.8	Bleached gold to white

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COMPATIBILITY OF 90 w/o EXTROGEN PEROXIDE WITH SELECTED COMPOSITE MATERIALS(1) (2)

			Erposur	e			
te	Surface Condition	Passivation Procedure	Temperature, F	Time, ďays	Percent AOL	Percent Stability	Exposure Response
n	Unanodi zed	Worth American	160	~	10.6	87.2	No effect
 U	As fabricated						No effect
R	Unanodizeđ	North American	160	2	10.2	92.9	Silastic
1126	As fabricated						aluminum aluminum
A1	Unanodized	North American LA 0110-003	160	2	15.2	83.0	Slight adheaion
85	As fabricated						Al-Vicobe
A	Unanodized	North American	160	7	10.2	90.6	Al etched, Flinnel
2141	AL fabricated						blistered
	Anodized	FMC Bulletin	151	2	3.3	95.4	Frosted
A1	Anodized	PC17					AL BULLACE
Al	Anodized	IMC Bulletin	151	2	14.1	78.4	White oxide
	Buffed	F01					Bronzed
Al	Anodized	FWC Bulletin	151	-٦	14.0	30.6	White oxide
	Buffed	104					Bronzed

(1) Data taken from Ref. 4.11
(2) Surface/volume ratio = 0.38 in.-1

(Concluded)

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Thin oxide Thin oxide Exposure Response No effect No effect Severely bronzed Severely bronzed Bronzed Bronzed **Percent** Stability 45.2 98.3 89.8 91.5 85.6 Percent AOL 24.0 0.4 3.7 4.9 2.4 Time, daye 2 ~ 10 2 20 . **.** . Exposure Temperature, 110 110 110 110 151 fμ FMC Bulletin 104 Passivation Procedure Surface Condition Anodized Anodized Anodized **Anodized** Buffed Buffed Buffed Buffed Buffed Buffed **Composite** 6061-T6 A1 6061-T6 A1 6061-T6 Al + 316L SS 316L SS + 316L SS 1060 A1 **321 SS** 321 SS **321 SS** +

HETEROGENEOUS DECOMPOSITION RATE OF HYDROGEN PEROKIDE

AS A FINCTION OF SURFACE PREPARATION⁽¹⁾

				Decombol	sition Rate at	212 F
H_0	Surface		v/s	()vers]]	Blank ⁽³⁾	(C) 1
22,	Type	Preperation ⁽²⁾		day-1	day-1	ca/day
90 ⁽⁴⁾	1260 Aluminum	a,ö, b	1.90	0.0626	6000.0	0.032
8,	1260 Aluminum	a,b,g,b	2.29	0.0309	0.0144	0.0072
6	1260 Aluminum	a,b,i	1.71	0.0168	0.0008	1600.0
90	1260 Aluminum	a,b,g,i	2.18	0.0164	0.0042	0.0056
90	1260 Aluminum	a, b, j	2.06	0.0148	0.0009	0.0067
60	1260 Aluminum	a, b, j, g	2.66	0.0093	0.0048	0.0017
8	1260 Aluminum	a,b,k	1.65	0.0135	0.0009	0.0077
8	1260 Alumeinum	a, b, g, k	2.19	0.0098	0.0053	0.0021
8	1260 Aluminum	Ъ	2.01	0.0459	0.0051	0.020
8	1266 Aluminum	8 ,9	2.08	0.0325	0.0111	0.0103
8	301-T Stainless Steel	a,c,j	1.85	3.84	0.0019	2.07
8	301-T Stainless Steel	a,1	2.15	3.03	0.0011	1.41
8	301-T Stainless Steel	8,c,B	2.25	5.47	6000.0	2.42
8	2014 Aiuminum	a,b,e,f	1.01	0.150	0.0066	0.141
8	2014 Aluminum	a,b,e,f,g	0.95	0.0156	0.0139	0.0018
8	2219 Aluminum	a,b,e,f	0.95	1.8	0.008	1.9
8	2219 Aluminum	a,b,e,f,g	1.02	0.196	0.142	0.053

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(Continued)

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k2,⁽⁵⁾ 0.0016 0.0048 0.0089 0.0252 0.0043 0.0020 0.0115 0.0033 0.0065 0.0033 0.0084 ce/day 0.0140 0.0151 0.0124 0.0111 0.0134 0.0066 0.0207 0.149 0.028 0.026 0.024 0.047 <u>F</u> Decomposition Rate at 212 day -l 0.0010 0.0032 0.0665 0.0009 0.0008 0.0090 0.0063 0.0013 0.0063 0.0024 0.0647 0.0126 0.0011 0.0063 0.0025 0.0024 0.0011 0.0015 0.0027 0.0068 0.0015 0.0050 0.0127 0.006 Blank day-1 0.0364 0.0682 0.0066 0.0168 0.0717 0.0124 0.0535 0.0709 0.0562 0.0108 0.0191 0.0783 0.0154 Overall 0.0856 0.0723 0.0589 0960.0 0.0098 0.0145 0.0202 0.0210 0.343 0.02040.124 رتا روز 4.39 4.67 2.07 1.97 2.93 2.97 2.97 2.75 7.75 6.02 6.02 2.49 1.05 2.32 4.30 4.24 6.97 2.8 2.29 4.53 3.3 2.33 S/S a, b, c, f, g a, b, e, f, g Preparation a, b, e, f, g a,b,e,ĩ,g a,b,e,f,g a,b,e,f,g a,b,e,f,g a,b,e,f,g a,b,e,f,g a, b, e, f, g a.b.e.f.g a,b,e,f,g a,b,e,f,g B,b,e,f a,b,e,f g, s, t 8, 8 9 1,**8** 8, 9 ົ Surface 5052 Aluminum 5052 Aluminum 5052 Aluminum Aluminum Al uninum Aluminum Aluminum Aluminum Aluminum Aluminum Aluminum Aluminum Alumainum 7039 Aluminum muimul. Aluminum 1260 Aluminum 5052 Alminum 5052 Aluminum 5052 Aluminum Aluminum Type 5052 <u>H</u> Ē Teflon Teflon Tin on Tin on Tin on Tin on Kel-F Xel-F 7039 7039 260 7039 7039 7039 7039 7039 50 7039. 7039 7039 H202' */o

TABLE 4.31 (Continued)

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				Decompo	lition Bate at	212 F
E.0.,	Surface		N∕S	Overall	Blank	k ₂ ,(5)
0/2	Type	Preparatico		day-1	day-1	ce/day
$(2)^{(2)}$	Tin on 1260 Aluminum	p	2.61	0.0541	[40.0	0.0191
); (06	Tin on 1260 Aluminus	2 , 2	2.62	0.0712	0.0395	0.0121
36	Tin on 1260 Aluminum	đ	2.15	0.0315	0.0047	0.0124
90(7)	Tin on 1260 Aluminum	g, u	2.22	0.0397	0.0261	0.0061
				Decombos	iition Rate at	: 17é F
98	301-T Stainless Steel	8. 8	1.66	1.37	0.000	0.82
8	J01-T Stainless Steel	8 , K	2.10	1.31	0.004	0.62
8	301-T Stainless Steel	a,c,e,1,5	1.83	1.12	0.001	0.61
8	301-T Stainless Steel	a,c,e,1,g	1.83	1.29	0.659	0.34
8	347 Stainless Steel	a,c,e,ľ,g	1.72	0.944	0,001	0.55
8	347 Stainless Steel	2,c,e,1,6	1.72	1.38	0.544	0.48
8	AM355 Stainless Steel	a,c,e,ľ	1.74	1.13	0.000	0.64
8	AM355 Stainless Steel	a,c,e,1,g	2.39	2.15	0.146	0.84
8	Almar 18-250	a,c,e,f	1.85	0.074	0.001	0.039
8	Almar 18-250	a,c,e,f,g	2,15	0.095	0.006	0.041
8	Almar 18-250	a,c,e,f,g	1.95	0.187	0.006	£60°0
68	Almer 18-250	a, c, e, f, g	2.11	0.189	0.004	0.088
8	Almar 18250	a, c, e, 1, g	2.14	0.086	0.005	0.038
6 8	Almar 18-250	a, c, e, 1, g	2.05	0.112	0.002	0.054
8	301-T Stainless Steel	a,c,j	1.85	î.68	0.000	0.91
છ	J01-T Stainless Steel	B, C, G, j	2.24	1.67	0.029	0.72
8	J01-T Stainless Steel	e.g ,]	2.76	1.21	0.088	14.0
8	Jol-T Stainless Steel	₽ , C, B	2.25	1.49	0.000	0.66
8	301-T Stainless Steel	₿,C,g,≣	2.76	3.11	0.243	1.04
8	J01-T Stainless Steel	n,p	2.15	1.16	0.001	0.54

(Concluded) TABLE 4.31

1				Decompos	ition Rate at	77 F
^{H20} 2,	Surface		s/v	0veral1	Rlank	1 r (5
0 7	Type	Preparation	Т. <u></u>	dey-l	dav -1	nn 2 ° cm∠dav
90	347 Stainless Steel	a.c.e.f.g	1.72	0.00588	0.00182	0_00936
				Decompos	ition Rate at	70 E
06	J01-T Stainless Steel	a,c,e.f,g	1.83	0.00035	0.00010	0.00014

(1) Data taken from Ref. 4.9

(2) Surface preparation according to Table 4.31a

With treatment g after repeated replacement of ${
m H}_20_2$, the blank is determined after test and removal of the sample. The blank includes the homogeneous decomposition by contaminants and the heterogeneous decomposition due to the vessel walls, including any contaminants absorved (3). For samples without treatment g, the blank is determined before addition of the test sample. there.

 $(4)_{90}$ w/o H_20_2 containing 3.4 x 10^{-5} $\mathrm{Jg}/1$ Na $_2$ Sn(OH) $_6$ and 6.9 x 10^{-5} $\mathrm{mg}/1$ HNO $_3$ stabilizer

 $(5)_{K_2}^{\sim}$ represents a specific rate constant for an assumed first order reaction at the liquid-surface interface

(6) 98 w/o H_20_2 containing 8.4 x 10^{-6} mg/l tin stabilizer

 $(7)_{0,0} \sqrt[w]{o} H_2^{0} \sqrt[c]{c}$ containing no stabilizer

TABLE 4.31a

PROCEDURES USED FOR SURFACE PREPARATION IN TABLE 4.31

<u>Note</u>	Preparation Procedure
a	Sample degreased in aromatic solvent followed by a rinse in acetone, all at room temperature
b	Sample submerged in 1-percent NaOH for 10 minutes at room temperature
C	Sample submerged in 10-percent NaOH for 16 hours at room temperature
d	Sample submerged in 1-percent HNO ₃ for 5 minutes at room temperature
e	Sample submerged in 35-percent HNO ₃ for 16 hours at room temperature
f	Sample submerged in HP-90 until used for test, at room temperature
8	Sample submerged in stabilized HP-90 at the tomperature of the test for 1- to 16-hour periods, followed by repeat treatments with fresh HP-90 until steady-state conditions appear to be achieved
h	Sample submerged in fused stearic acid for 1 hour at 80 to 100 C immediately after treatment by Procedure b
, i	Sample submerged in 2-percent ethylene-diaminetetraacetic acid in 30 -percent H_2SO_4 for 30 minutes at 80 to 90 C
j	Sample submerged in 1-percent disodium ethylenediaminetetraacetic acid in 35-percent HNO3
x	Sample submerged in fused phthalic anhydride for 1 hour at 140 to 150 C immediately after treatment by Procedure b
1	Sample submerged in Viscasil 100,000, then wiped dry with absor- bent tissue
=	Sample submerged in 85-percent H_PO4 for 16 hours at room temperature

TABLE 4.31a

1 .

Note

(Concluded)

Preparation Procedure

- n Sample submerged in 35-percent HNO_x for 1 hour at 50 to 70 C
- p Sample submerged in 1-percent Viscasil in benzene, dried, resubmerged, and dried
- q Sample anodized in 25-percent H₂PO₄ at 1 amp/sq decimeter for 6 minutes at room temperature
- Samples submerged in 2-percent NaOH for 2 hours, then in 2-percent HNO₃ for 10 minutes, then zincated. Samples zincated in 16-percent Na₂ZnO₂ 40-percent NaOH solution for 30 seconds at room temperature. Samples were then rinsed well and submerged in 2-percent HNO₃ for 1 minute. Samples were then zincated again, rinsed, and submerged in 2-percent HNO₃ for 1 minute again. Samples were then electroplated by submerging in 6.4-percent stannous sulfate, 5.0-percent sulfamic acid, 0.5-percent dihydroxydiphenyl sulfone solution with the current on and maintained for 6 minutes at room temperature at 0.022 amp/cm² (20 amp/sq ft). Samples were then rinsed well and submerged in HF-90 for 20 hours.
- t Samples previously plated by procedure s were given an additional tin plate by submerging in 5.0-percent stannous sulfate, 5.0percent sulfuric acid, 5.0-percent sodium sulfate, 0.4-percent gelatin, 0.2-percent m-cresol solution with the current on and maintained for 6 minutes at room temperature at 0.022 amp/cm². Samples were then rinsed well and submerged in HD-90 for 20 hours.
- u Samples were treated as in procedure ^B through the first zincating step. Samples were then zinc electroplated in 0.05-percent zinc chloride, 0.05-percent sodium cyanide, 1-percent sodium hydroxide solution for 1 minute at room temperature at 0.022 amp/cm². Samples were then rinsed and submerged in 2-percent HNO₃ for 1 minute and then tin electroplated as in s. The tin plate was then fused in a furnace at 265 C and then tin electroplated a second time. Samples were then rinsed well and submerged in HP-90 for 20 hours.

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	Method s	Advantages	Disadvantages	Approximate Cost
	. Bare hand on tank surface	A. Low cost B. Unlimited number of sens- ing points	A. Poor accuracy	
5.	. Temperature-sensitive paint on tank surface	A. Low cost B. Large areas could be covered	 A. Limited number of sensitive temperatures B. Adversely affected by H₂S, S0₂ and NH₃ 	\$25 to \$50
κ.	. Spot surface temperature consisting of bimetallic dial thermometer with sen- sitive part in aluminum block affixed to lower section of tank surface and insulated (used by Shell Chemical without alarm)	 A. Low cost B. Actual temperature indication C. Linear temperature scale D. Not affected by high vapor space temperature 	A. Some ambient temperature effects	\$ 50 to \$ 75
4.	. Same as No. 3 but instal- led in thermal well helow liquid level	 A. Relatively inexpensive B. Measures actual liquid temperature C. Linear temperature scale D. Not affected by high vapor space temperature E. Not affected by ambient 	A. Nozzle required	\$75 to \$100
5.	. Spot surface or thermal well installation using gas-filled thermal system with or without alarm contacts	Same as $3 \text{ and } l_4$	Same as 3 and 4	\$200 to \$350
6.	Surface temperature con- sisting of gas-filled dial thermometer with sensitive part in contact	 A. Nozzle not required B. Measures average surface temperature C. Linear temperature scale 	 A. Same ambient effects B. Vapor space temperature would affect temperature indication at low liquid 	\$300 to \$400

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COMPARISON OF THE VARIOUS METHODS OF TANK TEMPERATURE

MEASUREMENT IN ORDER OF INCREASING COST (REF. 4.64)

\$200 to \$350	\$300 to \$400	\$400 to \$500	\$ 300 to \$ 500	\$ 1,000+	\$2,000 to \$2,500
Same as 3 and 4	 A. Same ambient effects B. Vapor space temperature would affect temperature indication at low liquid level 	 A. Thermal system tends to record warmest tempera- ture along capillary 1. Would record vapor space temperature any time vapor is warmer than liquid B. Cost Cost Cost Cost Cost Cost Cost Cost Cost Some range of the second of the s	 A. Would average vapor space and liquid surface temperature B. Good surface contact required C. Some ambient effect D. Cost 	A. Cost B. Maintenance C. Must enter tank with probe D. Must know liquid level	A. Cost B. Maintenance
Same as 3 and 4	A. Nozzle not required B. Measures average surface temperature C. Linear temperature scale	A. Nozzle not required B. Contacts large surface area C. Permanent temperature record	Same as 7 plus D. Linear temperature scale E. Indicates average surface temperature	A. Up to six liquid levels B. Average temperatures below liquid level	 A. Could also record ambient temperature B. Permanent visual record of all temperatures C. Linear scale
5. Spot surface or thermal well installation using gas-filled thermal system with or without alarm contacts	 6. Surface temperature con- sisting of gas-filled dial thermometer with sensitive part in contact with a section of the tank from horizontal centerline to bottom of the tank. Insulation applied. 	7. Surface temperature (Belly-Band type) recorder 1 consisting of vapor ten- sion capillary and insulated	8. Same as 7 except using gas-filled capillary system	9. Weston Average Resistance Tank Temperature System consisting of an indicator switch to dial in the proper resistance corres- ponding to the liquid level	<pre>10. Multi-Point Temperature Recorder with or without alarm contact. (Used by Shell Chemical without alarm.) (</pre>

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Figure 4.1. Stability of Hydrogen Peroxide as a Function of Concentration (Ref. 4.2)



Figure 4.2. Typical Decomposition Rates for Various Hydrogen Peroxide Samples at 32 F (Ref. 4.6)







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Figure 4.4. Heterogeneous Decomposition of 90 w/o Hydrogen Peroxide at Various Temperatures (Ref. 4.1)

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(a) Ref. 4.1

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Figure 4.5. Decomposition Rates of 90 Weight Percent Hydrogen Peroxide-Water Solutions as a Function of Surface-to-Volume Ratio











Figure 4.8. Effect of Stabilisation of 98 Weight Percent H_2^{0} as a Function of Temperature (Ref. 4.7)





Figure 4.10. Volume of Oxygen Liberated per Year From the Decomposition of Hydrogen Peroxide at a Rate of 0.1 Percent AOL/Year



HYDROGEN PEROXIDE CONCENTRATION, W/O

Figure 4.11. Pressure Increase in a Sealed Container Resulting From Hydrogen Peroxide Decomposition at a Rate of 0.1 Percent AOL/Year

SECTION 5: TRANSPORTATION

SHIPPING CONTAINERS AND VEHICLES

Approved hydrogen-peroxide shipping containers are available in the following capacities (Ref. 5.1, 5.2):

Reagent quantities: 1 pint (3/4 pound) (1.C.C. Regulation 73.266)

Drum quantities: 30 gallons (300 pounds) (I.C.C. Regulation 42D)

Tank cars: 4000, 6000, and 8000 gallons (I.C.C. Regulation 103-A-AL-W)

Tank trucks: 2000 and 4000 gallons (I.C.C. Regulation MC $310-H_90_9$)

Portable tanks: any desirable size (I.C.C. Special Permit)

All hydrogen peroxide storage or shipping containers are equipped with a dustproof vent to relæase oxygen produced from decomposition and to prevent the possibility of contamination.

5.1.1

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Reagent Quantity Containers

Reagent quantity containers are glass bottles with dustproof vents on top. For concentrations above 52 w/o H_20_2 , the glass container capacity should not exceed 1 quart (Ref. 5.3). When packing these containers for shipping, I.C.C. Regulation 73.266, Specifications 15A, 15B, 15C, 16A, and 19A apply (Ref. 5.2). The applicable reagent bottles must be packed in a metal container vented at the bottom and packed in another metal container vented at top. Cushioning material shall be used between the bottle and inner container

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and between the inner and outer metal containers. Cushioning material shall be vermiculite or the equivalent in an amount at least 10 times the volume of the solution shipped, and shall be wet with at least 10-percent water by volume to which a stabilizing agent has been added (Ref. 5.2). These containers should then be crated in a wooden box.

5.1.2 Druma

There are two types of drums available for shipping concentrated hydrogen peroxide. One is a double-head drum suitable for all freight shipment, and the other is a single-head drum suitable only for full-carload and full-truckload shipments. The vent on the double-head drum opens into the compartment between the two heads. This compartment will trap any H_2O_2 lost through splashing or leakage (Ref. 5.4, 5.5).

Both types of drums are fabricated according to I.C.C. Specification 42D (Ref. 5.2). Each of these drums is made of high-purity aluminum with a vented closure in the top head. The rated capacity does not exceed 30 gallons, and side openings are not permitted. The closure is sealed to prevent removal in transit. The top head should be plainly marked "KEEP THIS END UP" or "KEEP PLUG UP TO PREVENT SPILLAGE." For shipments other than carload or truckload lots loaded by consignor and unloaded by consignee, the drums must be of a design and venting arrangement approved by the Bureau of Explosives.

The approximate tare weight of a single compartment drum is 42 pounds, and that of a double compartment drum is 50 pounds. The net filling weights of 70 and 90 percent hydrogen peroxide are 280 and 300 pounds, respectively. These weights correspond to about 26 or 27 gallons of liquid in the drum. The volume will vary with temperature (Ref. 5.4).

5.1.3 Tank Cars

Tank cars suitable for hydrogen peroxide use are available in 4000-, 6000-, and 8000-gallon capacities. These cars, constructed according to I.C.C. Specification 103A-AL-W (Ref. 5.2), are cylindrical, fusion-welded aluminum tanks with a dome containing a manhole, a vent with a porous-stone filter to exclude dust, an unloading dip-pipe, a fill connection, and a bursting disk designed to blow out a 45-psig pressure. The temperature of the hydrogen peroxide is measured by a thermometer or thermocouple carried in a protective aluminum tube inside the tank or fastened to the tank's outside wall below the liquid level; the outside thermometer or thermocouple is insulated with glass wool (Ref. 5.1). All fittings, gaging, venting, loading, discharging, and air-inlet devices are constructed of materials compatible with hydrogen peroxide. Venting devices are of a type approved by the Bureau of Explosives.

5.1.4 <u>Tank Trucks</u>

I.C.C. Specification MC-310- H_2O_2 (Ref. 5.2) applies to shipment by tank trucks with 2000- to 4000-gallon capacity. These trucks, which have been specially constructed for hydrogen peroxide service, are equipped with complete unloading facilities, including a connecting hose and fittings for attachment to the consignee's storage system (Ref. 5.1, 5.4).

5.1.5 Portable Tanks

Portable tanks, commonly of 500- and 1300-gallon capacity, are subject to I.C.C. Special Permits. These tanks, which can be filled at the plant and used as storage vessels at the user's site, offer many advantages, particularly for remote, overseas, or temporary sites.

5.2 SHIPPING REGULATIONS

5.2.1

For shipping, the I.C.C. has classified concentrated $H_2 O_2$ as a corrosive, "white label," liquid. Each container must be clearly marked "THIS SIDE UP" or "KEEP PLUG UP TO AVOID SPILIAGE." In addition, each container must carry the specification marking and number and the statement of the contents. "FOR HYDROGEN PEROXIDE USE ONLY" must be stenciled above the specification markings.

Commercial Air (Federal Aviation Agency)

When hydrogen peroxide is shipped by commercial air travel, the Official Air Transport of Restricted Articles, Tariff and Civil Air Regulations No. 49 regulates packaging and handling information.

Military Air (Department of Defense)

Regulations noted in AFM 71-4, Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft, and NAVWEPS 15-03-500 govern all hydrogen peroxide shipments by military aircraft.

5.2.3 <u>Waterways (U.S. Coast Guard</u>)

Hydrogen peroxide shipments on Coast Guard-controlled waterways are controlled by I.C.C. Regulations and U.S. Coast Guard Regulations NAV-CG-108, which note packaging and handling information.

Drums

5.3.1

To prevent spillage through the venting device, drums containing hydrogen peroxide should not be tilted or rolled during loading, transfer, or handling; they must be moved and stored in an upright position.

Siphoning or pumping are the recommended methods for emptying drums. The siphoning system is used when small quantities of hydrogen peroxide are involved. A siphon known commercially as the Model D Golden Thief Vacuum Pump (manufactured by the W&W Manufacturing Co., Box 9311, Chicago, Illinois) or its equivalent is usually used for transferring or sampling of small quantities of liquid. Although the vacuum portion of the noted device contains aluminum alloys unsuitable for peroxide use, the only part that contacts the solution is a compatible plastic tube. This siphon can be used for sampling tanks as well as drums and can deliver liquid from a considerable height. The plastic tubing and the sampling pump should be properly cleaned and passivated before use. Suitable cleaning and packaging between use times is also required. A combination of glass and plastic tubing is also possible in a siphon arrangement. Pouring or gas pressurization should be avoided in emptying drums containing hydrogen peroxide. (Gas pressurization can introduce contaminants or overpressurize the (Ref. 5.4). drum.)

Although direct pouring is not a recommended technique, a special hydrogen peroxide drum valve suitable for attachment to the standard 30-gallon drum is available from the Shell Chemical Company. This valve enables a direct pour from the drum and is suitable for short use times only (1 to 2 days) (Ref. 5.4). After being emptied, the drum (and compartments) should be completely flushed with clean water and drained. The bung cap should be replaced immediately and tightened securely. All pipelines and hoses should be drained when transfers are complete.

When emptying a drum by pumping or vacuum, a trap should be placed in the suction line to prevent feedback of the hydrogen peroxide into the container after withdrawal.

5.3.2 Tank Cars and Trucks

Tank cars and tank trucks may be unloaded by either pumping or pressurization with clean, dry, hydrocarbon-free nitrogen gas. The use of a self-priming pump is quite common and is particularly desirable when fast delivery under pressure is required. The majority of the pumps are a centrifugal design, although airdriven reciprocating pumps are also available. Pump unloading is recommended for both tank cars and trucks.

The pressure fed system (sometimes called the ejector system) is a method of feeding by gas pressurization and should not be used on drums or smaller containers. There are mixed feelings about pumping by this technique. In addition to the possibility of overpressurization that exists with this technique, it is felt by some organizations that the possible introduction of water or oil with the pressurant gas and/or the insertion of the pump inlet line into the supply tank offers the possibility of vehicle container contamination. Thus if this unloading system is used, it is recommended that the compressed air or nitrogen used for pressurization be filtered for entrained solids as well as water (water-pumped gas is preferred to oil-pumped gas), and its pressure carefully controlled.

The standard tank car compressed gas fitting has been designed for nitrogen. The gas pressurization line should be equipped

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with a suitable pressure reduction valve, a safety relief valve (set for approximately 15 psig), and a pressure gage. A pressure of 5 to 10 psig is normally sufficient to unload a 4000-gallon tank car in 2 hours. This will consume about 6- to 10-cu ft/min nitrogen. Pressures in excess of 15 psig should not be used. The compressed-gas feed line should be blown out before introduction into the hydrogen peroxide supply. Details of the unloading procedures should be obtained from the particular hydrogen peroxide manufacturer that supplies the tank car.

Tank truck unloading is normally handled by the hydrogen peroxide producer of his carrier. Each tank comes equipped with the necessary fittings, a hose, and a pump designed for hydrogen peroxide service. Trained drivers and/or other qualified personnel representing the producer are present to make the necessary connections for the unloading operation. After unloading a tank with pressure, the vent shall be opened at once. When pressure transfer is used on tanks, a line shall be attached to the safety vent and extended to the ground so that the vent may be quickly opened to stop the flow in an emergency. The tank should not be flushed after emptying unless it is to be entered for inspection or repair.

When either the tank car or truck have been emptied, the outside of the tank and the ground should be washed thoroughly wherever spillage of the hydrogen peroxide could have occurred during the unloading. All lines, hoses, and the pump should be drained free of hydrogen peroxide and flushed with clean water. All lines and hoses should then be covered with aluminum blind flanges or polyethylene bags to prevent contamination from dust (Ref. 5.4).

5.3.3 Handling

When transporting hydrogen peroxide, the following handling procedures and safety precautions should be followed:

- At least two trained operators should always be assigned to any operation involving the handling, transfer, or storage of hydrogen peroxide.
- 2. Drivers and operators involved in deliveries of hydrogen peroxide should be instructed to identify the material as hydrogen peroxide of the correct concentration and grade. Carelessly calling it by another name such as "acid" may result in its being unloaded into the wrong tank with possible serious consequences.
- 3. Leaking pipes, hoses, pumps, etc., from concentrated hydrogen peroxide tank trucks or tank cars are fire hazards. The presence of combustible materials, especially wood, paper, or cotton waste, at the filling or unloading site, should be avoided. Spilled hydrogen peroxide should be immediately removed by flushing with copious quantities of water.
- 4. Operators unloading hydrogen peroxide should wear protective clothing and use only the designated equipment.
- 5. There should be water hoses, showers, and eye fountains in the immediate vicinity of the unloading area. The location and proper function of this equipment should be checked before beginning operation.

Sampling of hydrogen peroxide, if necessary, should be done only under very carefully controlled conditions and only by authorized personnel. All samples should be discarded after use and never returned to the storage container.

7. Sampling devices or any other material should not be inserted into a hydrogen peroxide container. Samples should be taken by pumping or draining from system feed lines.
- 8. If, for some reason, it is necessary to put some instrument, device, sampler, eic., into a hydrogen peroxide solution, the device must undergo the appropriate cleaning and passivation procedure. With each addition of a foreign body to hydrogen peroxide, the chance of contamination is increased.
- Freezing may cause localized concentrations of contaminants which, on thawing, may result in accelerated decomposition.
- 10. Freezing will cause concentration gradients to develop as the material thaws. Thorough agitation is required to ensure uniform concentration of the solution. Hydrogen peroxide solutions are difficult to freeze, and supercooling of 70 to 90 F is not uncommon. Handling, vibration, or motion of any kind should be avoided during possible supercooling periods to avoid freezing and subsequent concentration stratification.
- 11. Pressure vents should be shielded so that the possibility of dust return or other contamination is minimized.
- 12. Routine inspection of storage facilities should include hosing down storage containers as well as the storage area at regular intervals to minimize the accumulation of dust, dirt, debris, etc.
- 13. The outside of storage containers should be thoroughly cleaned before removal of outlet covers. This may be accomplished by means of an air hose, a water hose, or a combination of these.
- 14. Cleaning of the threaded sections before connection of the mating parts should be carefully done to minimize the possibility of contamination.

- 15. In the opening of a pipe line or similar item that has previously been used in transferring hydrogen peroxide, it should always be assumed that there may be some hydrogen peroxide left in the line, and a supply of water should be available.
- 14. Storage of equipment such as transfer hoses should provide for venting any pressure built up from decomposition of residual peroxide. All drained materials should be diluted and discarded.

5.4 REFERENCES

- 5.1 United States Government, Office of the Director of Defense Research and Engineering, Washington, D.C., <u>The Handling</u> and Storage of Liquid Propellants, January 1963.
- 5.2 General Services Administration, National Archives and Records Service, Federal Register Division, <u>Code of Federal Regula-</u> <u>tions</u>, Title 49, Chapter 1, "Interstate Commerce Commission," Parts 71 to 90, revised 1956.
- 5.3 Schumb, W. C., C. N. Satterfield, and R. L. Wentworth, <u>Hydrogen Peroxide</u>, A.C.S. Monograph 128, Reinhold Publishing Corporation, New York, 1955.
- 5.4 Shell Chemical Company, New York, New York, <u>Concentrated</u> Hydrogen Peroxide, H₂O₂. Properties, Uses, Storage, Handling, 2nd Edition, Report No. SC: 62-23, 1962.
- 5.5 McCormick, James C., Buffalo, New York, <u>Hydrogen Peroxide</u> Rocket Manual, F.M.C. Corporation, 1965.

6.1 HAZARDS

The potential safety hazards in dealing with hydrogen peroxide fall into the following general categories: detonation and/or explosion, uncontrolled decomposition, fires, and personnel injury. While these hazards may sound ominous, it must be remembered that similar hazards exist for various other compounds which are in widespread use and are safely handled by industry. If operating personnel are arried with knowledge of the potential hazards and how to avoid them, there is no reason why concentrated hydrogen peroxide cannot be safely employed in commercial processes.

6.1.1 Physiological Effects

6.1.1.1 <u>Vapor Inhalation</u>. Hydrogen peroxide solutions and vapors are nontoxic, but they are irritating to body tissue. This irritation can vary from mild to severe, depending upon the concentration of hydrogen peroxide. Concentrated hydrogen peroxide has little odor unless deliberately inhaled. The sensation is then somewhat like that produced by ozone or the halogens (Ref. 6.1).

Inhalation of hydrogen peroxide vapors causes irritation and inflammation of the respiratory tract and may result in burning of the nose and throat, running of the nose, and coughing. Prolonged breathing can produce swelling of the respiratory membranes or accumulation of fluid in the sinuses and lungs. Shorttime exposure will not cause lasting harm, but a physician should be notified in extreme exposure cases (Ref. 6.2. and 6.3). The toxicity leve? for 90 w/o hydrogen peroxide is expressed as a threshold limit value (TLV) of 1 ppm (1.4 mg/cu m) (Ref. 6.4

and 6.5). The TLV represents the average concentration over a normal work day to which the average human can be safely exposed on a daily basis without adverse effects.

The vapors can also irritate the eyes, producing burning, redness, and watering.⁽⁾ The effect is short-lived except in extreme or continuous exposure. When hydrogen peroxide contacts the eyes, the eyes should be flushed immediately with water.

6.1.1.2 <u>Cutaneous Exposure</u>. The vapors, mists, and solutions of hydrogen peroxide are very irritating to body tissues. When the liquid touches the skin, there is a burning sensation and the areas affected are bleached. If contact is brief, the effects will usually disappear within 2 or 3 hours. Continued exposure, however, will result in slight water blister formation which should heal quickly. Contact of the hydrogen peroxide with the more sensitive parts of the body, such as the thighs, neck, or under the fingernails, will cause more severe effects than contact with the hands. If hydrogen peroxide contacts the skin, the area affected should be flooded immediately with large quantities of water (Ref. 6.2 and 6.3). If the irritation does not subside after flushing with water and burns persist, a physician should be notified.

> Various experiments have been conducted with animals to show the effect of hydrogen peroxide on skin surfaces. With rabbits, it was observed that 90 w/o hydrogen peroxide applied to the skin was absorbed and caused death by gas embolism (rabbits are susceptible to embolism, however). Cats, guinea pigs, rats, pigs, and dogs, although much less susceptible to embolism, showed a greater reaction on the skin (Ref. 6.1). (There were no results showing possible lethal effects of H_2O_2 on these animals, however.)

In studies on human skin, 90 w/o hydrogen peroxide on the palms and fingertips, where the keratin is thick and nerve endings are abundant, causes strong prickling and formation of opaque white patches. This is extremely painful under the fingernails. "On other skin areas where the keratin is thinner, irritation occurs, but with less itching and the white appearance is confined to a few areas at the base of hairs. There is no evidence of penctration deeper than the first layer of skin, or stratum corneum, and all these effects disappear without trace" (Ref. 6.1, page 426).

6.1.1.3 <u>Ingestion</u>. If hydrogen peroxide is swallowed, e.g., during pipetting, it may cause bleeding and severe distention of the stomach due to the liberation of oxygen. In some cases, injection or ingestion of hydrogen peroxide can be fatal, depending upon the amount and concentration. Intravenous injections of dilute hydrogen peroxide solutions are more lethal than concentrated solutions, since the dilute solutions are able to penetrate the system more deeply before decomposition and blocking of the circulation occur (Ref. 6.1).

> In the mouth, an effervescence occurs as the hydrogen peroxide decomposes, giving a prickling sensation. At high concentrations, the effects in the mouth are heightened, to the point of painfulness, to say nothing of the hazard of burns; and such contact is to be avoided.

6.1.2 Fire Hazards

Hydrogen peroxide by itself is not flammable, but solutions of high concentration may react with combustible materials and generate enough heat to cause ignition. When involved in a fire, hydrogen peroxide actively supports combustion by liberating oxygen, and this results in a "flare" fire that may terminate in explosion. Elimination of air, however, does not control or put out the fire. Hot, concentrated, liquid hydrogen

peroxide (> 65 w/o), once ignited, will "burn" rapidly as a continuous, hot, nearly invisible vapor decomposition flame close to the surface of the liquid. Such a decomposition flame will continue without an external source of heat until the liquid is entirely consumed, unless the liquid concentration is reduced or the liquid is cooled sufficiently to extinguish the flame (Ref. 6.2).

Hydrogen peroxide solutions greater than 65 w/o can release enough energy to heat the decomposition products to a relatively high temperature (1382 F for 90 w/o solutions). Ignition of nearly inflammable material may then be expected. Solutions of less than 65 w/o may also cause fires due to the fact that upon exposure to air, water in the solution may evaporate faster than the peroxide, increasing the concentration of the latter. Naturally, the lower the initial concentration, the less likely this would happen (Ref. 6.2).

Fires can be started easily by dampening combustible materials with hydrogen peroxide solutions stronger than about 70 w/o, provided that the proper catalyst is present. In the absence of catalysts, many materials such as clean cotton or wood may not even react with 90 w/o hydrogen peroxide. (The absence of any catalytic material, however, is rather unlikely according to Ref. 6.6.) Secondary fires may also occur. Consumption of the hydrogen peroxide does not necessarily eliminate the fire. If the ignition temperature limit of any fuel-air mixture in the immediate vicinity has been achieved, combustion of these materials will continue. This may, however, occur at a considerably different burning rate.

An empirical test was devised (Ref. 6.7) to compare the flammability hazard of the various concentrations of propellant-grade hydrogen peroxide. A spill test was developed using a green felt of 90-percent wool and 10-percent vegetable fiber. (Numerous other organic materials were tried, but this was the first

material to give reproducible results.) The test simply consists of placing two drops of concentrated hydrogen peroxide on the piece of felt and measuring the time to visible flame. The ignition time decreases with increasing concentration as shown in Fig. 6.1.

Ignition (i.e., initiation of rapid decomposition) limits have been determined for hydrogen peroxide vapor (Ref. 6.8 and 6.9) for pressures above atmospheric; these data are presented in Fig. 6.2. The ignition limits of hydrogen peroxide are actually the ignition limits of the vapor and are, therefore, a function of the vapor-phase composition. In turn, this vapor-phase compsition is a function of the liquid temperature and the total pressure on the system. The ignition limits are not sharply defined but are general areas, as illustrated by the positive and negative test results shown in Fig. 6.2.

General areas where the vapor phase in contact with the liquid phase has reached the probable ignition level are shown in Fig. 6.3 (Ref. 6.10).

6.1.3 Explosion Hazards

Although hydrogen peroxide solutions are not ordinarily classed as explosives (see Section 4.4.1.1.2), certain conditions can exist in which a detonation or an explosive-like release of energy can occur. Typically, most "explosions" involving hydrogen peroxide are a result of decomposition of the hydrogen peroxide, which may occur as a result of gross contamination and/or excessive temperature rise of the hydrogen peroxide. The decomposition reaction produces large amounts of heat (which further accelerates the decomposition reaction) and gas with subsequent effects of gas overpressurization in any confining areas. The "explosion" usually results from the rupture of the confining surface and release of the gas pressure.

Normally, this decomposition process is relatively slow, and the final pressure release is preceeded by a slow thermal and pressure buildup. However, there are also conditions in which the decomposition process reaches an explosive rate. Although such conditions are usually associated with the vapor phase, separation of the cause-effect relationship between the liquid and vapor phases is difficult. In addition to the normal liquid-vapor equilibrium, the entrapment of vapor (and a subsequent vapor-phase decomposition within the liquid phase) is always possible with a material that decomposes so readily inte liquid and gaseous products.

6.1.3.1 <u>Vapor-Phase Hazards</u>. When the concentration of hydrogen peroxide in the vapor phase exceeds 26 mole percent (40 w/o) at atmospheric pressure, an explosive decomposition reaction is possible (Ref. 6.8 and 6.9). This limit is increased with decreasing pressures (43 w/o at 200 mm Hg and 70 w/o at 40 mm Hg) and decreased with pressures above ambient. Ignition of these concentrations may occur as a result of a spark, contact with a catalytic surface, or contact with a heat source in excess of 300 F.

> During vapor detonation velocity measurements (Ref. 6.8), a detonation velocity of 6700 ft/sec was recorded at atmospheric pressure in a minimum concentration of 50 w/o hydrogen peroxide. No detonations were observed in hydrogen peroxide vapor at total pressures of 42.6 and 99.5 psia. Measurements of detonation velocities in higher concentrations at atmospheric pressure were generally unobtainable because of spontaneous decomposition or premature ignition of the test gases.

> Under ordinary storage and handling conditions, explosive vapor concentrations are not reached. However, when heated under atmospheric pressure to temperatures of ~ 264 F, liquid concentrations above 75 w/o will produce vapor concentrations in the explosive range. These explosive regions correspond to the ignitable regions shown in Fig. 6.3 as a function of liquid composition, liquid temperature, and pressure.

6.1.3.2 Liquid-Phase Hazards. Although earlier experimental efforts, particularly those of the Germans, had indicated that liquid hydrogen peroxide solutions with concentrations greater than 88 w/o could be detonated, more recent efforts have demonstrated the absence of shock sensitivity in the liquid phase below concentrations of 95 w/o. However, there are still more conflicts in the data obtained from a variety of shock sensitivity tests on hydrogen peroxide concentrations greater than 95 w/o. Consequently, these higher concentrations are still considered (Ref. 6.11) potentially explosive under certain conditions. In addition, concentrated hydrogen peroxide solutions are thermally sensitive (see Section 6.1.3.1) although the direct participation of the liquid phase in detonations involving the heated vapor phase is questionable.

The validity of positive results from some types of sensitivity tests used in the early efforts on the hydrogen peroxide liquid phase are questionable (Ref. 6.12) for the following reasons:

- 1. Shock sensitivity in earlier work was usually done by setting off relatively large explosive charges in the hydrogen peroxide. This technique is questionable because the mixture of organic vapors from the explosive charge may have initiated the reaction, and the heat liberated by the explosive charge may vaporize enough hydrogen peroxide to result in a vapor explosion.
- 2. Thermal tests in early work were limited to open containers. Because of localized heating and distillation effects, it was not known what concentration of hydrogen proxide was actually involved in the explosion.
- 3. Subsequent sensitivity tests (Ref. 6.9) on the vapor phase above a hydrogen peroxide liquid phase of 90 w/o indicated that none of the detonations found in this concentration range involved the liquid phase.

The results of various experimental efforts, which have involved three primary areas of sensitivity testing (thermal sensitivity, shock sensitivity, and detonation propagation), are summarized in the following paragraphs to provide a guide to the potential explosion hazards of the hydrogen peroxide liquid phase.

6.1.3.2.1 Thermal Sensitivity. To expand previously available liquidphase thermal sensitivity data (summarized in Table 6.1) thermal sensitivity tests were conducted by duPont (Ref. 6.12) on hydrogen peroxide in open and in closed containers. The open-container tests (at atmospheric pressure) showed that the vapor above 90 w/o liquid hydrogen peroxide exploded at 248 to 284 F. The liquid did not explode but decomposed rapidly, producing temperatur + up to 752 F. Similarly tested 98-percent hydrogen peroxide vapor exploded at 212 to 248 F and gave evidence of liquid participation in the reaction. Results from tests on 35-percent hydrogen peroxide were similar to those with 90-percent hydrogen peroxide. In sealed glass bulbs, 90-percent hydrogen peroxide exploded at 320 to 356 F and the liquid was involved in the reaction; however, the explosions were attributed to pressure buildup from relatively slow decomposition. A low-order explosion was produced with 95 and 98 w/o hydrogen percxide at 248 to 284 F. The results of representative tests from these efforts are reprinted in Tables 6.2 through 6.4.

> In a further effort to determine liquid-phase participation in vapor-phase detonations resulting from thermal sensitivity, field tests (Ref. 6.12) were conducted using larger quantities of material. These tests, which eliminated the possibility of complete vaporization of the liquid, consisted of placing approximately 2 gallons of concentrated hydrogen peroxide in old, well-used "Albone" (35 w/o stabilized $H_2^{0}_2$) drums. These drums were placed in a pit with remote heat contol and temperature recording systems. The drums

were heated at a controlled rate, and the temperature-time profile of each was recorded. The following results were reported on the five tests run:

- Two gallons of 90 w/o hydrogen peroxide. The drum started belching four at 271 F. Much liquid was dispersed, but the stainless-steel container was undamaged.
- 2. Two gallons of 95 w/o hydrogen peroxide. Vapor ignited at 268 F and burned with several white puffs with no resulting damage to the stain ess-steel container.
- 3. Two gallons of 35 w/o hydrogen peroxide. Vapors ignited at 248 F. Burning continued for 30 seconds. Both ends of the drum were bulging and the thermocouple had been ejected from the drum during the test.
- 4. Two gallons of 95 w/o hydrogen peroxide. Vapors ignited at 295 F and burned for 3 minutes. The drum was undamaged.
- 5. Two gallons of 95.2 w/o hydrogen peroxide. At 289.4, the drum ruptured, spewing high-strength liquid hydrogen peroxide. The maximum pressure recorded was 75 psi.

It was concluded (Ref. 6.12) as a result of these tests and the other available data that in concentrations up to 95 w/o the liquid, or at least a good part of the liquid, does not participate (except to form more vapor from heat feedback) when vapor-phase burning or explosion occurs. This is true even though the adjoining vapor temperature exceeds 572 F. However, concentrated liquid hydrogen peroxide is susceptible to overheating, which makes possible the formation of vapor within the liquid phase and consequent "belching." Thermal hazards increase for liquid hydrogen peroxide concentrations above 95 w/o, even though direct participation by the liquid phase in resulting detonations is questionabl..

6.1.3.2.2 <u>Shock Sensitivity</u>. Hydrogen peroxide and hydrogen peroxidewater solutions are considered non-impact sensitive in both the solid state (low-temperature studies) and the liquid state up to 212 F (Ref. 6.2, 6.4, 6.6, 6.12, and 6.13). No impact sensitivity was noted (Ref. 6.13) for 98 w/o hydrogen percxide at 212 F and an impact height of 300 kg-cm.

Hydrogen peroxide grades of 90 and 98 w/o H_2O_2 have been subjected to adiabatic compression test loading rates of 231,000 lb/sec at 70 to 72 F and 160 F with no effect on the hydrogen peroxide. Loading rates of 3,000,000 lb/sec at 70 to 90 F have been achieved on 90 w/o hydrogen peroxide with no adverse effects (Ref. 6.3).

Shock tests with No. 20 PETN boosters set off in 30-gallon aluminum drums, and tests with 15 grams of Hercomite dynamite exploded in the same quantity at 70 to 72 F and 160 F showed no propellant detonation for 90 and greater w/o hydrogen peroxide solutions (Ref. 6.3).

Card gap tests, using an apparatus in which 30 gms of liquid sample was separated from a 30 gm tetryl charge by a thin (5 to 10 mils) aluminum membrane, indicated no evidence of detonation in 90, 95, and 98 w/o hydrogen peroxide (Ref. 6.12). The results of these tests are shown in Table 6.5, and are similar to those resulting from earlier tests conducted by the Navy (Ref. 6.3) to demonstrate the relative insensitivity of 90, 95.5, and 99.5 w/o hydrogen peroxide at ambient temperatures and 160 F.

Other types of shock sensitivity tests have also been conducted on 90, 95, and ~ 100 w/o hydrogen peroxide (Ref. 6.12 and Table 6.6). Although some of these data do indicate shock sensitivity in hydrogen peroxide concentrations above 95 w/o, the data are suspect (Ref. 6.12) because of potential vapor-phase detonation and contamination contributions.

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Although it is generally concluded that hydrogen peroxide solutions are not normally shock sensitive, it should be noted that hydrogen peroxide with additives (or contaminants) capable of being oxidized are highly impact sensitive. This sensitivity theoretically depends upon the concentration and type of additive and, in actual practice, upon the sample size and the method and type of impact. Various mixtures involving hydrogen peroxide of various concentrations with minimum (< 10 percent) quantities of organic materials such as ethylene glycol, ethyl alcohol, benzene, etc. have been found to be particularly hazardous (Ref. 6.11). These mixtures will detonate violently when subjected to the slightest mechanical shock with detonation velocities approaching those of nitroglycerine, TNT, RDX, etc.

6.1.3.2.3 <u>Detonation Propagation</u>. Under normal usage, it seems impossible to obtain a propagating detonation in hydrogen peroxidewater solutions. The only tests where a propagating detonation has been observed were under conditions of extreme confinement with an exceptionally heavy booster charge. Although these conditions are not likely to be encountered in any normal storage or handling condition, studies by the Navy (Ref. 6.11) have demonstrated some conditions at which hydrogen peroxide concentrations above 95 w/o will propagate a detonation.

> In another study (Ref. 6.3) propagation tests were conducted on 98-percent hydrogen peroxide by placing explosives (having energy rates of 1,860,000,000 ft-lb per second and pressure generation rates of 576,000 atmospheres which develop within 12.5 microseconds) in a 1.5-inch schedule-80 stainless-steel pipe. The pipe was connected to an aluminum drum containing 250 pounds of hydrogen peroxide. Although a detonation was set off in the pipe, the hydrogen peroxide was unaffected.

Similar results were obtained (Ref. 6.3) by the Bureau of Mines in tests on 99 w/o hydrogen peroxide contained in 0.5-inch tubing. A large booster charge was located in 1-inch tubing of hydrogen peroxide, which was connected to the smaller tubing. The detonation of the booster charge, which detonated the material in the 1-inch tube, failed to propagate into the hydrogen peroxide in the smaller tubing.

- 6.1.3.3 Explosion Potential Criteria. A criterion (Ref. 6.14) has been developed for the estimation of the potential explosive and detonation hazard of hydrogen peroxide systems. This involves the calculation of what is called the "critical excess energy" of the system and is the heat of reaction for the formation of all gaseous products from all compounds in the mixture. Before continuing with the correlation procedure, a discussion of balancing combustion-explosion type reactions seem appropriate. Briefly, these are the rules for balancing these reactions:
 - 1. Carbon is first oxidized to CO
 - 2. If additional oxygen remains, form water
 - 3. If additional oxygen remains, oxidize \overline{CO} to \overline{CO}_{0}

Addition of readily oxidizable metals to this system would introduce a step between 1 and 2; however, there are a number of qualifications to this procedure so that the reliability of this technique as a hazard criterion for metals is questionable.

After balancing the equation with the particular ratio of ingredients which are of interest, the heat of reaction is computed, assuming that all of the reaction products are in the vapor form. Heats of formation of the reactants in their actual form (solid,, liquid, or gas) and of the end products in their gaseous form, all based at 298 K, are used for this computation. A heat of reaction in excess of 450 cal/gm implies a possible explosive hazard for that particular mixture. A heat of reaction in excess of 900 cal/gm predicts a possible detonation hazard. These "critical energy" values were selected after a very careful study of experimental data accumulated from explosive and detonation tests on mixtures of organic compounds with concentrated hydrogen peroxide. A heat of reaction can be computed for a number of compositions and the compositions for the "critical excess energy" values of 450 and 900 cal/gm determined. These computed compositions may then be plotted to map out hazard areas in the use of mixtures of these materials. It should be noted, however, that these values are not infallible. Mixtures should always be tested experimentally before actual handling operations begin.

Expressions, which may be solved by pure mathematics, have also been generated for the determination of the critical energy compositions (Ref. 6.15). However, for those handbook users who are willing to balance the chemical equation, the following heats of formation of the common products of combustion are given. The heats of formation of various concentrated hydrogen peroxide solutions are shown in Fig. 2.12 to 2.13a and are discussed in Section 2.2.3.1 of this report.

C0 -26.417 kcal/mol at 293 K; molecular weight = 28.01 H₂0 -57.80 kcal/mol at 298 K; mclecular weight = 18.016 C0₂ -94.315 kcal/mol at 298 K; molecular weight = 44.010

Heats of formation or heats of combustion (from which heats of formation can be computed) of v large variety of organic compounds are available in practically all chemical handbooks.

In the computation of systems where the components are not mutually soluble or are not soluble in all proportions, consideration should be given to the possible existence of hazardous concentrations at

liquid-phase interfaces. The solubility of a large number of compounds in hydrogen peroxide is given in Table 4.14a, Section 4. This method of evaluation is not really appropriate for immiscible systems.

Despite the apparent success of the correlation methods, a safety hazard evaluation must always be obtained for a new system whenever the safety of personnel or equipment is concerned. These methods should only be used to define limits for experimental test design.

The explosive regions in systems of hydrogen peroxide and organic compounds surround the composition ratios of $H_2 O_2/organic$ compound which lead to complete reaction to carbon dioxide and water. Explosions are generally unobtainable if the final solution contains less than appreximately 30 w/o hydrogen peroxide.

The sensitivity of these explosive mixtures toward explosion is of the same order of magnitude as that for molten TNT or nitroglycerine. Oxygen-deficient mixtures or water-rich mixtures are less sensitive (to mechanical impact, for example) than oxygenhalanced or oxygen-rich mixtures. Explosions can be initiated by mechanical shock, explosive shock, heat, electric discharges, hot surfaces, etc.

The following factors should not be overlooked in the investigation of a new system:

 The possibility of reaction, such as the formation of performic acid in the system containing formic acid. In this case, the explosive region increases in area as a function of time because performic acid is generated at a measurable rate.

- 2. The addition of a new species such as sulfuric acid, which at high H₂SO₄/H₂O ratios caused the autodetonation of compositions which had yielded negative impact test results. This is usually a time-dependent reaction.
- Immiscible systems can explode at interfaces. Increased dispersion may cause an immiscible system to be as dangerous as a miscible system.
- Solids such as ion exchange resins, or plastics such as polyvinyl-chloride, can explode when saturated with concentrated hydrogen peroxide.
- 5. The first impact tests on a new system should probably be made at high hydrogen peroxide concentrations and low organic compound concentrations since this region is where the detonation limit is closest to the limit determined via impact test or cap-in-pipe test. For this same reason, definitive positive tests (as opposed to doubtful tests as often obtained with oxygendeficient mixtures) will be obtained in this region (Ref. 6.14)

6.2 HAZARD PREVENTION

As described in the Hazards Section (6.1), spills and leakage of hydrogen peroxide can result in hazards to both personnel and facilities. The best possible means of avoiding these hazards is to eliminate or minimize the potential cause factors. Effective reduction of leakage, spills, contamination, and other potentially hazardous situations can be best accomplished by the use of properly designed equipment and thoroughly trained personnel.

6.2.1 Eystem Integrity

The importance of the design integrity of propellant storage, transfer, and handling systems cannot be overemphasized. The systems should be reliable, operationally flaxible, and easy to maintain. Some of the suggested design criteria that should be incorporated in a system are:

- The system must be constructed of materials which are definitely known to be compatible with hydrogen peroxide.
- 2. The system will be designed and operated in such a manner as to prevent contamination of the system with known reactive materials.
- The number of mechanical joints will be reduced to a minimum, thus reducing the probability of propellant leakage.
- 4. The system will be designed to safely withstand the maximum operating pressure.
- 5. The transfer lines will be free of liquid traps.
- 6. An inert-gas (moisture-free) system must be provided to purge the transfer lines without the necessity of dumping the residual hydrogen peroxide or disconnecting any system joints.
- 7. The system components must be reliable, compatible with hydrogen peroxide, and properly serviced (cleaned and passivated).
- 8. Sufficient remotely activated control equipment must be provided to isolate portions of the system during emergencies or component replacement.

The continual observation of an operational system for possible malfunctions can prevent serious propellant spills.

6.2.2 Trained Personnel

Properly trained personnel are required to handle propellantgrade hydrogen peroxide. All personnel concerned with the handling, storage, or transfer of hydrogen peroxide should be thoroughly familiar with the following:

- 1. The nature and properties of propellant-grade hydrogen peroxide
- 2. Compatible materials of construction and the necessity of essential passivation techniques
- 3. Operation of the transfer and storage system
- 4. Toxicity and physiological effects of hydrogen peroxide
- 5. Operation and use of safety equipment and clothing
- 6. Fire and spill prevention techniques
- 7. Fire and spill control measures
- 8. Disposal and decontamination techniques
- 9. Local operating procedures and regulations
- 10. First aid techniques

No person should be allowed to handle hydrogen peroxide unless thoroughly familiar with the previously listed items and should be confident that the propellant can be handled safely with the equipment and facilities available. In addition, all operations should be controlled by a procedures checklist, which has been prepared and thoroughly checked by personnel most familiar with the potential problem areas. As further safeguards, close supervision should be maintained to ensure adherence to safety practices, and all operations involving the handling of hydrogen peroxide should be performed by groups of two or more persons.

6.3 HAZARD CONTROL

6.3.1 Facility Safety Equipment

Equipment for facility protection should consist of a water deluge system and fire hoses (chemical fire extinguishers are not to be used on hydrogen peroxide fires). This equipment should be strategically located and easily accessible. Other facility items to be provided for personnel protection include safety showers, eye wash fountains, and appropriately located first eid kits.

All operating personnel should be thoroughly familiar with the location and operation of each piece of safety equipment. The operating condition of the equipment must be verified periodically.

6.3.2 Spill Control

A propellant spill can be most efficiently controlled by performing the following steps in the order listed:

- 1. Stop the propellant-handling operations
- 2. Isolate the propellant tanks from the transfer lines by closing the necessary values (by remote control if possible)
- 3. Locate the source of the spill
- 4. Isolate the components affected by closing the necessary valves
- 5. Dispose of the spilled propellant

The performance of the first four steps should be automatic and can be performed in a very short time.

The disposition of the spilled propellant should not be too difficult, especially when propellant handling is performed during satisfactory weather conditions and the first four steps listed previously are quickly executed. Hydrogen peroxide spills can best be controlled by deluging the spilled propellant with large quantities of water. After the spill is controlled, the entire area must be thoroughly creaned to prevent the possibility of fire.

6.3.3 Fire and Explosion Control

Since most wooden flooring, straw, rags, clothing, leather, etc., contain enough catalytic material to cause rapid ignition with 90-percent hydrogen peroxide, proper precautions should be taken with this fact in mind. Storage areas for concentrated solutions should be of fireproof construction, and provision should be made for the flushing and draining of spillage.

Fires involving hydrogen peroxide should be controlled with water, because it dilutes the hydrogen peroxide and reduces the intensity of flare burning. The prompt application of copious amounts of water dilutes and cools, eliminating or minimizing the possibility of violent reaction. CHEMICAL FIRE EXTINGUISHERS SHOULD NOT BE USED.

To gain control, at least two parts of water for each part of hydrogen peroxide present should be applied. Because containers may hurst, creating a fragmentation hazavd, fighting these fires with hand lines is dangerous; therefore, prefire arrangements (i.e., the provision of fixed systems, etc.) should be made. In a hydrogen peroxide-fuel fire, every possible effort should be exerted to stop the flow of both fuel and hydrogen peroxide. If a fire breaks out nearby, containers of 90-percent hydrogen peroxide should be kept below 230 F to prevent vapor-phase explosions. A temperature-actuated sprinkler system on the storage tanks could be employed as a further precaution.

To prevent an explosion, hydrogen peroxide should be stored at a temperature low enough to prevent excessive gas formation due to decomposition. (A temperature below 145 F is recommended for

long-term storage as noted in Ref. 6.4). Hydrogen peroxide that has become contaminated or shows an abnormal temperature rise should be diluted and disposed of. Phosphoric acid (H_7PO_4) may be added as an emergency stabilizer to reduce decomposition (Ref. 6.4) before disposal.

6.4 PERSONNEL PROTECTION

6.4.1 Personnel Safety Equipment

The main personnel hazard in handling concentrated hydrogen peroxide is probably not from the contact of peroxide with the skin but the danger of burns caused by ignition of clothing. Protective clothing is necessary for all personnel handling concentrated hydrogen peroxide. Ordinary fabrics made of cotton, rayon, leather. or wool should not be used, because these are apt to ignite when splashed with hydrogen peroxide. Unnoticed splashes on ordinary clothing may cause fire sometime after the occurrence. Conventional permeable clothing of Dacron, Dynel, or Orlon, when used with eye goggles, gloves, and boots, normally gives adequate protection. For full body protection, vinyl coveralls or aprons of Koroseal or Neoprene should be used. The clothing must cover all parts of the operator's body and must be adjusted so as to prevent drainage into the gloves or boots. Permeable clothing wet with peroxide must be flushed with water and removed promptly, and the affected body parts must be thoroughly washed.

The hands and feet are always subject to contamination during the handling of liquid propellants or associated equipment. Gloves oud boots will keep hydrogen peroxide from touching the skin. (Leather reacts quite readily with hydrogen peroxide, however.) The gloves used should protect against hydrogen peroxide and also should allow free movement of the fingers. The vinyl-coated gloves, Type R-1, Mil-G-4244 (Ref. 6.16) meet these requirements. Surgical rubber gloves or lightweight Neoprene gloves are suitable for handling small parts. Since boots of the approved protective materials

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are not commercially available, an overboot, designed to be worn over regular safety footwear and high enough to fit comfortably under the protective trousers, is suitable. Boots made of natural or reclaimed rubber or GR-S may be used with reasonable safety if any contamination is washed off quickly. The boots should be frequently inspected to detect flaws which might result in personal injury. Severe foot burns can result from splashes on ordinary shoes.

Respiratory protection against vapors is not ordinarily required. Respirators approved for protection against hydrogen peroxide mists, however, should be available for use where exposure to the aerosol or mist is possible (Ref. 6.17 and 6.18).

In selection of protective clothing for $H_0 0_0$ handling, the degree of hazard involved and the workers' comfort and agility must be considered. Overdressing and use of protective accessories when not warranted can actually be hazardous. A hood and full suit of impermeable clothing is only required where danger of gross spillage or spray directly on the worker is involved. In a pump transfer operation of hydrogen peroxide above 50 w/o, at least one man should be fully outfitted with impermeable clothing if detachable equipment such as a hose is being used. For handling hydrogen peroxide in drum quantities and in pump transfers in a permanent piping system, the permeable uniform worn with face shield, or eye goggles, rubber gloves, apron, and boots or rubbers will be sufficient. When wearing permeable Dacron or Dynel shirts and trousers, it is good practice to wear Dacron or Dynel underwear and socks. Goggles which afford complete eye protection should be worn during all handling and transfer operations. Water must always be available and two persons must always be present when high-strength hydrogen peroxide is handled even if protective clothing is worn.

Protective clothing and accessories recommended for personnel handling propellant-grade hydrogen peroxide are listed in Table 6.7.

6.4.2 First Aid

IF HYDROGEN PEROXIDE CONTACTS THE SKIN. Flood the area involved with water. If burns are present, refer to a physician.

IF HYDROGEN PEROXIDE CONTACTS THE EYES. Flush immediately and freely with water for at least 10 to 15 minutes; or if water is not available, saliva can be used to absorb the hydrogen peroxide and decrease the effect upon the tender eye membrane (Ref. 6.3). This should be done if even minute quantities of solution have entered the eyes. For any case of exposure involving the eyes, refer to an eye specialist.

IF HYDROGEN PEROXIDE IS SWALLOWED. Encourage vomiting. Give lukewarm water freely and encourage belching if there is evidence of distention. Call a physician.

IF HYDROGEN PEROXIDE VAPOR OR MIST IS INHALED. Remove victim immediately from further expose . If irritation of the nose and throat is severe, refer to physician.

6.4.3 Medical Treatment

IN CASES OF EXTREME EXPOSURE OR CONTACT, OR PERSISTING IRRITATION, A PHYSICIAN SHOULD BE NOTIFIED.

6.5 REFERENCES

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90- TO 100-PERCENT HYDROGEN PEROXIDE THERMAL SENSITIVITY DATA*

Liquid Systems:				
Conditions of Test	Temperature, F	ç0 percent	95 percent	98 to 100 percent
Glass Vials in Wood Metal Bath 0.1 to 0.2 milliliter ${ m H_2^{0}}_2$		Exploded at 302+ F S	low explosion	Explodes at 270+ F
Aluminum Tube, Nichrome-Wound, 5 milliliters ${\rm H_2}^{0}_2$	38 3 302	Rapid decomposition S	low explosion	Detonates
Melting Point Block-Aluminum and Glass Inserts		All decompose and expl 284 P and up	ode at temperat	ures of
Stainless-Steel Bomb		All slowly explode at	temperatures ab	07e 248 F
Vapor Systems:		H202 i	n Liquid, v/o	
Conditions of Test		90	100	
Boiling Liquid in Glass at Atmospheric Pressure		Vapor Explodes at 284 302 F. Liquid rapidly	to Vapor and explode a	d liquid at 307 P

were not referenced or otherwise detailed with regard to additional test parameters and tech-niques, are included as a general summary of the data preceeding the efforts reported in Ref. 6.12. *Data taken from work of various investigators and summarized in Ref. 6.12. These data, which

decomposes.

								_			_	
			i Bolle does not	boiling point.	why due to rela- tion.					Reaction Time, seconds	7.6	1.6
		Remri	ests indicate liquid	etomate even at its	ne explosion is prob Yvely slov decomposi	•				Pressure Rise, psi/sec	1400	5450
7 7	ly:	Time Eested, minutes	5	ים נ כו		135	4	11		Temperature, Final, F	519.8	559.4
	0-Percent $H_2^{0}0_{D}$ Dn	Explosion Temperature, P	374.0	404.6	4.04.6	347.0	345.2	321.8	s-Steel Bomb	Temperature, at Start, F	275.0	269.6
	aled Glass Bulbs 9	Starting Temperature, P	356.0	368.6	348.8	294.8	336.2	311.0	assivated Stainles n Aluminum Liner:	Quantity, milliliters	30	30
	In Sei	H202, grams	0.438	0.096	0.461	0.165	0.235	0.096	In a P With a	H202, V/0	90	95

THERMAL TESTS ON 90- TO 98-PERCENT H, 0, IN CLOSED CONTAINERS+

These tests indicate that none of the H2O2 detonates, but 98 percent is sharply more has adding hazardous. NOTE:

1.6 2.2

9020

609.8

287.6 269.6

<u>8</u> 8

95 98 #Ref. 6.12

H_O_						
tration,	Volume Charged, cc	Temperature Recorded	Initial Explosion Temperature, F	L L	۳. ۳	Remarks
06	15	Vapor	266	>572	>306	Vapor explosion
06	15	Vapor	234	377.6	93.6	Varor explosion
06	15	Vapor	287.6	370.4	82.8	Vapor explosion
06	15	Vapor	260.6	917.6	657.d	Vapor explosion
06	15	Vapor	255.2	465.8	210.6	Vapor erplosion
06	12	Yapor	267.8	645.8	378	Vapor explosiva
95	12	Vapor	235.4	₽ 58.6	227.2	Vapor explosion
95	12	Liquid	284.0	633.2	349.2	Vapor erplosion
95	13	Liquid	1	1	1	vapor explosion; blev thermocouple out
** 56	12	Liquid	276.8	305.6	28.8	Vapor explosion
65¥ ≭	12	Vapor	147.2	179.6	32.4	Vapor explosion; blev thermocouple out
** 56	12	Liquid	264.2	858.2	5 94	Vapor explosion; two reporte audible
**56	12	Vapor	276.8	392.0	115.2	Vapor explosion; two reports audible
86	12	Liquid	212	282.2	70.2	Vapor explosion
64	12	Liquid	203.0	309.2	106.2	Vapor ezplosion
86	12	Vapor	136.4	314.6	178.2	Vapor erplosion; glass vessel raptured
**86	12	Liquid	296.6	1		Vapor explosion; no temperature record
98**	12	Liquíd	212	1		Vapor explosion; glass ressel ruptured

THERMAL-DECOMPOSITION TESTS OF HYDROGEN PEROVIDE*

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#Ref. 6.12 ##Flask vpening covered with aluminum sheet

THERMAL-DECOMPOSITION TESTS OF HYDROGEN PEROXUDE*

(265-cc Closed Vessel)

° 0 0 0	Charged, cc 15 15	Explosion Temperature, I 287.6 262.4	7 FF	ΔT, F 126	Pastr Psigr 660	(dp/dt)max. psi/sec	Time to Pasts Beconds	Remarks No pressure record available No pressure rate or time
	25 25	248.0 280.4 275.0	404 528.8 518	216 248.4 243	1450		1/ 	No pressure record available
	15 15	284.0 284.0	485.6 440.5	201.6	800	- 210	> 3.5	No pressure record available
	25 15 25	294.8 269.6 280.4	536.0 559.4 465.8 600.8	241.2 289.8 185.4 722 2	1260 2500 1000	5450 1290 9000	1.6 2.85 2.95	No pressure rate or time

*Ref. 6.12

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TABLE 6.4

SHOCK-SENSITIVITY TESTS OF HEDROGEN PEROXEDE*

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(Modified Card-Gap Apparatus)

Results	ented apparatus; no apparent d amag e isher"	ented apparatus; no epperent damage isher	nted apparatus; no apparent damge sher	nted apparatus; no apparent d aange sher	nted apparatus; no apparent d amage sher	nted apparatus; no apparent damage sher	nted apparatus; no apparent damage sher	nted apparatus; 1.0 apparent da mage sher	nted apparatus; no apparent damage sher
	Frage to 'cr	Frage to cm	Fragmento cri	Frage to cru	Fragme to cru	Fragme to cru	Frage to cru	Fragme to cru	Fragme to cru
Disk Thíckness, míls	10	10	10	10	10	10	10	10	5
Tetryl Charge Weight, grams	14	14	14	14	33	£	£	14	33
Volume Charged, cc	4 0	1 4	04	04	04	04	40	04	24
Liquid Under Test	Vater	90-percent H202	95 -percent ${ m H}_20_2$	98-percent H ₂ 0 ₂	98-percent H202	95-percent H202	90-percent H ₂ 0 ₂	90-percent H ₂ 02	98-percent R_20_2
Test No.	~	2	n	-4"	5	9	~	80	6

*Ref. 6.12

		H_0, w/o	, ,
	90	95	100
Impact Tests		-No explosion	
Rifle Fire		No explosion	8
No. 6 rnd 8 Blasting Caps Alone		-No detonation 	
No. 6 and 8 Blasting Caps With Pentaerythritol	Incomplete	detonation ——	Complete
Ballistic Mortar	40 percent of TNF	80 percent	
Lead Block Enlargement	5 cc/gm	7 cc/gm	9 to 12 cc/gm
Explosion Velocity Aluminum Pipe	<100 meter/ sec	4500 meter/ sec	6200 meter/ sec
Closed Steel Tubes, 175 milli- liters H ₂ O ₂ + 50 grams Penthrite Primed With Fulminate	Ne Detonation	Detonated	

90- TO 100-PERCENT HYDROGEN PEROXIDE SHOCK SENSITIVITY DATA*

"Data taken from work of various investigators and summarized in Bef. 6.12. These data, which are not referenced or otherwise detailed with regard to additional test parameters and techniques, are included as a general summary of the efforts preceding the data reported in Ref. 6.12.

PROTECTIVE CLOTHING AND ACCESSORIES RECOMMENDED FOR PERSONNEL HANDLING CONCENTRATED HYDROGEN PEROXIDE*

Item	Description	Source
Shirts, Trousers	Dacron fabric, Polystyrene buttons, no front or side pockets, no cuffs	Worklon, Inc., N.Y., N.Y.
	Dynel Fabric	Mine Safety Appl. Co.
	100-percent Dynel Chem-Weave, medium weight	Chem-Wear, Inc., Darien, Conn.
Belts	Vinyl plastic, with plastic buckle	Numerous commercial sources
Undershirts	Dacron	Alamac Knitting Mills, N.Y., N.Y., Special lot, minimum order, 10 dowen
	Dacron-cotton (can be ignited if soiled)	Carmi-Ainsbrooke Corp., Carmi, 111inois
S hort s	Dacron	Carmi-Ainsbrooke Corp. Manhattan Shirt Co., N.Y., N.Y.
Socks	Knit Dacron, no elastic, white Dynel fabric	Holston Mfg. Co., Knoxville, Tenn. Numerous commercial sources
<u>fii</u> oe B	6-inch Neoprene Coated, No. 990 steel tou	Iron Age Div., Childs & Co., Inc., Pittsburgh, Pa.
Rubbers	Full, Neoprene with tongue	Numerous commercial sources
Boots	Neoprene, knee length	Numerous commercial sources
Goggles	No. 93 AV large nose, clear Willson Monogoggle	Willson Products, Inc., Beading, Pa.
	Model 293607 SAF-I-CHEM, Series 29 clear lens	U.S. Safety Service Co. Kansas City, Mo.
Face Shield	No. 324 clear Sellstrom face shield	Watson Co., Buffalo, N.Y.
Gloves	Sureseal, gauntlet, Vinyl or Neoprene, No. 116 lightweight for laboratory use. No. 136 medium weight for work use	Eurety Rubber Co. Carrollton, Ohio
Apron	8-mil vinyl plastic. Surgeon's type, extra long, overlapping in back, ties in front.	Milburn Co. Detroit 7, Mich.

*Bef. 6.19

(Concluded)

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Item	Description	Source
Coveralls	Vinyl plastic. One-piece, light weight disposable unit. Grey color	Mine Safety Appliance Co.
Сарв	Dacron fabric. Baseball type, with removable sunshade for neck.	Worklon, Inc.
	Dynel fabric	Chem-Wear Mine Safety Appliance Co.
Hood	8-mil vinyl methacrylate window, detachable head band, adjustable for size	Milburn Co. Detroit 7, Mich.
Impermeable Jacket	Fiberthin Raynster, Neoprene coated Nylon, MRS-107	U.S. Rubber Co. Washington, Ind.
Impermeable Overalls	Fiberthin Raynster, MRO-107	U.S. Rubber Co. Washington, Ind.
	OUTDOOR WINTER-WEIGHT PROTECTIVE	CLOTHING
Shirts	55-percent Dacron-45 percent wool Sport-type shirt, polystyrene buttons	Worklon, Inc. New York, N.Y.
Trousers	55-percent Dacron-45 percent wool No pockets, cuffs	Worklon, Inc. New York, N.Y.
Сар	100-percent Dacron pile lining, outer material	Borg Fabric Div. G. W. Borg Co. Delavan, Wisc.
Pants	100-percent Dacron pile lining, outer material	Borg Fabric Div.
Boois	Neoprene, insulated boots. Similar to U.S. Army all-rubber, insulated combat boots	Hood Kubber Co. Watertown, Mass.
Jacket	100-percent Dacron pile lining, outer material	Borg Fabric Div.

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Figure 6.1. Ignition Delay of Hydrogen Peroxide With Felt (Ref. 6.7)


Figure 6.2. Ignition Limits of Hydrogen Peroxide Vapor (Ref. 6.8)



Figure 6.3 Liquid Compositions Which Result in Ignitable Vapor Concentrations (Ref. 6.10)





SECTION 7: DECOMPOSITION

7.1 DECOMPOSITION MECHANISM

The decomposition of hydrogen peroxide may be represented by the equation:

$$H_2 0_2 - H_2 0 + 1/2 0_2$$

This decomposition process is irreversible. Kineticists studying this particular decomposition process can theoretically illustrate 10 to 20 intermodiate reactions which may exist in hydrogen peroxide decomposition; however, the above equation is the effective result of these intermediate steps in the decomposition. Although the rate controlling reaction has not been identified, it is generally believed that it is one involving an electron transfer.

Since its discovery, when Thenard (Ref. 7.1) reported on the effect of over a hundred materials on the decomposition reaction, many decomposition studies have been conducted on hydrogen peroxide in attempts to characterize the decomposition process. Throughout these studies, it has been recognized that hydrogen peroxide decomposition is a result of both homogeneous and heterogeneous reactions. This decomposition, when both the liquid and vapor phases of hydrogen peroxide exist, has been considered as the sum of five types of reactions:(1) homogeneous reaction in the liquid phase between the hydrogen peroxide and dissolved catalytic or oxidizable components; (2) heterogeneous reaction of the liquid phase with surfaces of the container and/or suspended particles; (3) heterogeneous reaction of a film of condensed hydrogen peroxide on surfaces in contact with the wapor phase; (4) heterogeneous reaction of the wapor phase on dry surfaces; and (5) homogeneous decomposition of the vapor phase (Ref. 7.1).

In a recent investigation (of. 7.2) to define the contributions of these individual reactions to the ambient temperature decomposition of 90 w/o hydrogen peroxide, reaction types (4) and (5) were ignored. Reaction type (4) probably does not occur when the temperature of the surfaces is below the hydrogen peroxide boiling point and the effects of reaction type (3) were considered insignificant at the temperatures under consideration. In addition, it was indicated that reaction type (1) could probably be separated into further types of reactions; however, for the purpose of the particular study, the liquid phase homogeneous decomposition was considered as being essentially ionic catalysis. The differences between reaction types (2) and (3) were considered to be in the effective concentration of hydrogen peroxide on the surfaces, the concentration of contaminants which may build up in this condensed liquid film, and in the concentration of inhibitors which would be present in the condensed film (unless agitation of the vessel caused frequent wetting and washing of all surfaces with the hydrogen peroxide liquid phase).

Assuming these three types of reactions are the only contributing effects to hydrogen peroxide decomposition in the ambient temperature range, the rate of decomposition can be represented by the following expression:

Through the use of various purification techniques, relatively inert surfaces, and the absence of a vapor phase, the experimenters of Ref. 7.2 were able to isolate, for all practical pur- ' poses, the effective homogeneous reaction rates of the liquid from 20 to 100 C (68 to 212 F). Using these data, the effects of solubly additives (such as stabilizers) on the liquid phase were also determined. Although the data resulting from this work varied from test to test and as a function of stabilizer concentration and type, temperature, and manufacturing process, the homogeneous decomposition rate of the stabilized and unstabilized liquid was generally found to be less than ~ 0.03 w/o active oxygen loss (AOL) per year at 100 C (212 F). In addition, it was indicated that for future comparisons of results at different temperatures or the estimation of decomposition rates at various temperatures, the activation energy for the homogeneous decomposition of hydrogen peroxide can be assumed to be 18 kcal/mole.

As a result of this work, the experimenters indicated that the predicted homogeneous decomposition rate of hydrogen peroxide would correspond to the following expression: $D_1 = 10^{-7.2} e^{-\frac{1800}{1.987T}}$ where $D_1 = homogeneous$ decomposition rate in weight fraction/year and T = temperature in K.

Using an overall decomposition rate with a correction for the effect of the homogeneous rate, heterogeneous decomposition rates were also determined in this study. Values were calculated for k_2 using experimental decomposition rates obtained for hydrogen peroxide storage in 5-gallon storage tanks fabricated from different materials. In these tests it was assumed that the rate constants for both vapor phase and liquid phase heterogeneous decomposition were equivalent at the lower temperatures

(on the basis that the rate of decomposition was sufficiently slow so that mass transfer of hydrogen peroxide to the vapor space surface was not the controlling rate); thus the heterogeneous decomposition rate for both phases was equivalent to k_2 (S/V) where (S/V) represented the total exposed surface area of the tank relative to the volume of the liquid hydrogen peroxide. Results of these tests indicated that k_2 for the different materials at 25 C (77 F) appeared to be as follows:

tin plate		0.286 weight fraction AOL, cm/year
5052 aluminum	=	0.0160 weight fraction AOL, cm/year
1260 aluminum	iiii	0.0065 weight fraction AOL, cm/year

Additional studies in this and the homogeneous area are being conducted by the same investigators and have been reported thus far in Ref. 7.3 and 7.4.

A study of hydrogen peroxide homogeneous decomposition rates in the complete absence of catalytic surface effects (Ref. 7.5) was attempted through the use of solid hydrogen peroxide as the container wall. Unfortunately, during the period of the contracted work, the desired experimental conditions were not obtained, although definitive techniques were proposed for future study. However, during the study, total decomposition rates were measured on several purified and stabilized grades of 90 and 98 w/c hydrogen peroxide in both the frozen (-60 and -30 C) and the cooled liquid (0 C) state. The resulting decomposition rates from these tests, which were effectively due to homogeneous decomposition effects, were below 0.023 w/o AOL/year.

Throughout the various decomposition studies that have been conducted on hydrogen peroxide, it has been generally indicated that the homogeneous decomposition rates of liquid hydrogen peroxide were found to be dependent upon:

1. Hydrogen peroxide concentration

- 2. Type of additives or contaminants present
- 3. Concentration of additives or contaminants
- 4. pH
- 5. Particular combinations of foreign materials present
- 6. Temperatura

Similarly, the heterogeneous reaction rates were found to be dependent upon:

- 1. Hydrogen peroxide concentration
- 2. Temperature
- 3. Passivation or cleaning technique
- 4. Surface area
- 5. Surface finish (area ratio)
- 6. Localized concentrations of impurities in the solid surface
- 7. Pressure (under certain conditions)

Numerous investigators have reported decomposition and stability data for hydrogen peroxide as a function of these variables and with hundreds of various materials. Because of the uncertainty involved in trying to se, arate any one of the contributing parameters in the decomposition process, illustrations of the individual parameters are not presented in this handbook. However, these decomposition data are summarized as total effects relative to engineering parameters such as storability (Section 4.1), materials compatibility (Section 4.2), passivation effectiveness (Section 4.3), etc., in other parts of this handbook.

For those users of this handbook who are interested in more details of various reaction rates and other aspects in the decomposition of hydrogen peroxide, the use of the previously referenced literature (Bef. 7.1, 7.2, 7.3, 7.4, and 7.5) as well as the use of references to literature on decomposition provided in the attendant bibliography (Section 8.9) will provide the basis for further investigation.

7.2 CONTROLLED DECOMPOSITION

The hydrogen peroxide decomposition process is used under controlled conditions to provide a high temperature gas as the working fluid for reaction control systems, auxiliary power units, turbopump drive, underwater propulsion, etc. Ordinarily, to achieve effective use of the decomposition process for these applications, the hydrogen peroxide must undergo a rapid and complete decomposition to H_20 and 0_2 within the confines of a combustion chamber; the decomposition must be immediately initiated upon entry to the chamber and must be completed upon exit. The process must occur smoothly without radical surges or oscillations in the working pressure. There have been two primary methods employed to initiate and maintain this type of a controlled decomposition of hydrogen peroxide in a combustion chamber: (1) catalytic decomposition and (2) thermal decomposition.

7.2.1 <u>Catalytic Decomposition</u>

Catalytic decomposition of hydrogen peroxide is, as implied, dependent on the use of a catalyst, either as a liquid in a fluid-type catalytic chamber or as a solid in a fixed bed chamber. In the use of a liquid catalyst, a suitable catalytic liquid is continuously injected into the combustion chamber with the hydrogen peroxide and ejected out of the combustion chamber with the decomposition gases. The liquid catalysts normally employed are aqueous solutions of calcium or potassium permanganate.

Solid catalyst beds normally consist of packed columns of porous materials or screens, which have been coated with the catalytic agent. The solid porous materials are usually referred to as catalytic stones and are activated by impregnation

with the catalytic agent contained in a solvent with subsequent removal of the solvent (usually by drying). Materials that have been commonly used for this type of solid catalyst are aqueous solutions of calcium or potassium permanganate, or the metallic nitrates. Calcium permanganate is usually prefered to potassium permanganate, primarily due to its higher solubility in water. The most effective results from this type of catalyst are usually obtained with alumina or carborundum particles as the porous carrier medium.

Silver is probably the best known and the most active catalyst for the decomposition of hydrogen peroxide. This catalytic material is usually applied in a ecreen type of configuration. Since pure silver has proven somewhat undesirable from a physical integrity standpoint (sspecially at the temperatures obtained in this type of application) and because of its high ant, the silver cutalyst is also used as a plating on brass, nicker, o' stainless steel screens. To further reduce the cost imposed by the silver, stainless or nickel screens are intermingled with the silver or silver coated screens, without reducing catalyst effectiveness; of course a minimum number (which is dependent on the particular configuration) of catalyst screens, is required for satisfactory oper tion. The use of the silver plated screens usually offers better initial starting characteristics than the catalyst does and provides more structural integrity in the bed; however, such screens are more subject to catalyst stripping during operation. Because the initial activity of previously unused silver catalysts is normally low, they are usually "activated" by pretreatement with samarium mitrate (by immersion) and hot fired in a furnace prior to their use in the catalyst pack.

Although the silver and the permanganate catalysts have been the catalysts of choice for most of the controlled decomposition concepts, there are a number of other types of materials which have been investigated as hydrogen peroxide catalysts. Identification of these different materials and a more detailed discussion of the catalytic decomposition process are contained in Ref. 7.1, 7.6, 7.7, and 7.8. A complete bibliography of other data in this area has been compiled in Ref. 7.9.

7.2.1.1

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<u>Catalyst Pack Design and Descriptions</u>. The permanganate liquid catalyst was initially used by the Germans during World War II for application in torpedo propulsion and in a gas generator to drive the turbopumps for the V-2 rocket. Although the liquid permanganate catalyst is still used for some underwater propulsion applications, the solid catalysts have proven to be more applicable to most of the present monopropellant hydrogen peroxide propulsion and gas generation concepts.

The first effective application of the solid catalyst concept was in the Redstone Missile gas generator system. This catalyst (Ref. 7.10) was used to decompose a 76 w/o hydrogen peroxide solution to provide working gases for a turbine which was used to drive the main propellant pumps of the missile system. The catalyst was a polysurfaced silicon carbide "stone" which had been impregnated with calcium permanganate. These "permanganate stones" (PMS) were screened to +16 mesh and packed into a catalyst bed of approximately 3 inches depth, where they were held in place by an inlet screen of 16 mesh and outlet screens of 16 and 80 mesh, supported by rigid perforated steel plates. A hydrogen peroxide flow rate of ~ 6.0 lbs/sec resulted in a bed loading rate of ~ 10 lb/sq in.-min and a 20-to 30-psi bed

pressure drop. The catalyst was required to give suitable operation for 600 seconds; the start transient was \sim 70-150 ms from propellant entry into the chamber to 90% Pc.

Although the FMS catalyst provided a suitable catalyst for 76 w/o hydrogen peroxide, the use of concentrations in excess of 85 w/o H_2O_2 stripped the catalytic material from the porous carrier. In addition, the FMS catalyst had a tendency toward fracturing or "dusting" in handling with a resultant loss in catalytic efficiency. Thus the development of a more suitable catalyst for higher hydrogen peroxide concentrations was sought.

In the middle 1950's, silver catalyst screens were developed for use with 90 w/o H_2O_2 . Since then, there have been a number of different types of silver catalysts developed for different applications. Each bed is unique to the application for which it is developed, thus each particular design may be slightly different. Because there are a number of different catalyst beds for decomposition of 90 w/o H_2O_2 in existence today, a listing of each in this handbook would be prohibitive. Therefore the description of a catalyst pack for 90 w/o H_2O_2 given in the succeeding paragraph represents a general description of the silver screen catalyst pack and does not represent any single design.

Silver catalyst screens may be (as mentioned previously) fabricated from pure silver or from silver plated-brass, -nickel, or -stainless steel screens. The screens are usually 16 to 20 mesh with a wire diameter of ~0.014 inches. Some specifications for catalyst screens call for a 66 to 71 percent light-transmission. After "activation" by samarium nitrate immersion and baking, the screens are packed into the combustion chamber (with a light force fit against the walls) at right angles to the combustion chamber. Usually

the packing is such that a stainless steel or nickel screen (inactive screen) is placed between two catalyst screens. The number of catalyst screens is dependent on system requirements (operational life, bed size, throughput, pressure drop limitations, start transients, etc.) and may vary from 15 to as many as 100 catalyst screens.

Usually, the bed is terminated with several "inactive" screens. Perforated stainless steel supports are used As screen retainers, and also may be placed at different points in the bed to act as anti-channel baffles. The entire column is compressed to some specified compacting pressure to limit pressure oscillations and assure reproducible performance (pressure drop, flow rate, temperature gradient, etc.) from bed to bed in the same hardware. Most silver screen catalyst beds are operated at bed-loadings of ~ 20 lb/sq in-min; these bed loading rates may vary although it should be noted that higher catalyst bed loading rates will result in higher bed pressure drops and silver erosion rates. Bed pressure drops usually run from 75 to 125 psi.

The standard silver and silver-plated screen catalysts were found to be inadequate for sustained decomposition of 90 w/o H_2O_2 that is pre-heated to temperatures above 100 to 150 F, or for concentrations of hydrogen peroxide with adiabatic decomposition temperatures above 1400 to 1500 F. Because many present applications involve preheating of the hydrogen peroxide (as a result of its use as a regenerative coolant) and the use of 98 w/o H_2O_2 which decomposes at ~ 1800 F, the development of a catalyst which retains physical strength and chemical reactivity above this temperature has been pursued.

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The initial development of a high temperature hydrogen peroxide catalyst was undertaken by Rocketdyne, first under company-sponsored funding and later under Contract NOas 56-1052J. Although this catalyst, which is described in Ref. 7.11, has been used successfully at Rocketdyne for several years in the decomposition of 98 w/o H_2O_2 , the catalyst's physical and chemical stability at temperatures of 2000 F is questionable. Thus under Air Force Contract AF04(611)-11208, FMC initiated the development of new decomposition catalysts for 98 w/o H_2O_2 . Their progress in these efforts have been reported in Ref. 7.12.

For those users of this handbook who are interested in the detailed design of catalyst beds for various concentrations of propellant-grade hydrogen peroxide, the use of data contained in Ref. 7.13, 7.14, 7.15, and 7.16, in addition to those already cited, are suggested.

Catalyst Poisoning. There are a number of impurities that 7.2.1.3 may be contained in hydrogen peroxide, which will cause catalyst poisoning or catalyst pack malfunction. Although these impurities are normally associated with those additives used in stabilization, any non-volatile contaminant or additive in the hydrogen peroxide is a potential catalyst poison. Residual or nongaseous products from the decomposition process, such as tin or aluminum, may act as a catalyst poison by depositing on the catalyst to decrease the effective catalytic surface or by physically plugging the flow paths. Other materials such as the nitrates, chlorides, and phosphates may cause excessive erosion and loss of catalytic material, which reduces the effective activity of the catalyst. Additives which act as stabilizers during hydrogen peroxide storage by complexing and "tying up" the activity of heavy metal ions also tend to complex with the catalyst material in the combustion chamber.

Although the particular details of catalyst poisoning by various potential contaminants are not completely understood, most of the important hydrogen peroxide catalyst poisoners have been identified. Attempts at characterizing limitations for each of the individual species and the contributions and limitations of their interaction have met with little success. However, the limitations (which were determined under an extensive Navy "crash" program and further refined through extensive use) placed on inorganic contaminants in the hydrogen peroxide by the procurement specification MIL-P-16005D (see Section 3.3) for 90 w/o hydrogen peroxide have been effective in controlling poisoning of catalysts used for decomposition of propulsion grade hydrogen peroxide.

7.2.1.3.1 Effect of Organics. For some time there has been considerable controversy over possible differences between hydrogen peroxide produced by the various production techniques with respect to silver-screen catalyst performance and failure. Organic contaminants found in hydrogen peroxide produced by the organic process (namely the anthraquinone and propane-derivative oxidation processes) were suspected of being responsible for various catalyst pack failures that occurred periodically in various hydrogen peroxide decomposition systems (Ref. 7.15), Although there were a few catalyst pack failures (in contrast to the many successful operations) during operation of the packs with organically derived hydrogen peroxide, there was a lack of clear-cut analytical evidence indicating that the organic contaminants were contributing causes.

> Because there was a belief that the higher carbon content of the organic materials either caused the reaction to exceed the melting point of the catalyst or caused a carbonate formation on the surface of the catalyst (to effectively poison it), a study was conducted by Rocketdyne (Ref. 7.11) to determine the potential effect of carbon content on

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catalyst performance. The performances of three types of organically derived hydrogen peroxide were compared with that from the electrolytic process in silver screen catalyst packs of the configuration used in the Rocketdyne Super Performance Aircraft Rocket Engine (Models AR-1, -2). The results from these tests indicated that the performance of one of the organically-derived hydrogen peroxides (with a carbon content of 150 to 200 mg/1) was equivalent or better than that of the electrolytically-produced reference hydrogen peroxide. The failure of the catalyst in the use of the other two organically-derived hydrogen peroxides (with similar carbon contents of 120 to 270 and 194 to 212 mg/l, respectively) was theorized to be a result of either (1) the specific nature of the carbon compounds present, (2) synergistic effects of organic and inorganic contaminants, or (3) synergistic effects of the purely inorganic impurities.

Later, after apparent improvements in the process for the manufacture of organically-derived hydrogen peroxide, production models of the Rocketdyne AR-2 engine system were qualified using 90 w/o hydrogen peroxide (which met the requirements of Mil-P-16005C)^{*} from the three manufacturers of propellant-grade hydrogen peroxide. No catalyst failures were experienced during these tests that were attributable to any particular type of hydrogen peroxide, either organically-or electrolytically-derived.

Recently, studies were conducted by the Air Force Rocket Propulsion Laboratory (Ref. 7.17), in which 90 w/o hydrogen peroxide (procured under Mil-P-16005D from the various manufacturing processes) was catalytically decomposed in an IR-99 gas generator using a simulated flight feed system. No differences were observed in the operation or performance between the three types of propellant-grade hydrogen peroxide.

*NOTE: Mil-P-16005C was superceded by MIL-P-16005D

It was concluded that "there was no evidence to indicate a desirability of a change in the current hydrogen peroxide specification".

As a result of these recent comparisons of hydrogen peroxide catalyst performance with both organically-derived and electrolytically-derived hydrogen peroxide, it is concluded that the propellant procured according to Mil-P-16005D requirements should not be detrimental to the performance of the present silver-screen catalysts. However, the roles of the individual contaminants of both types as well as their inter-relationship in catalyst poisoning are still not completely defined.

7.2.1.4 Operational Problems. Although reviews of the operational problems that frequently occur in the catalytic decomposition of hydrogen peroxide appear in many sources (including in particular, Ref. 7.1 and 7.15), a very adequate and concise discussion of the problems is given in Ref. 7.18 as follows:

> "It is now opportune to consider the various factors which lead to a loss of efficiency of a (catalyst-Ed.) pack.

The first is that of increase in pressure drop across the pack during use. In this case, although the pack is still active, it may become impossible to maintain the desired rate of flow of H.T.P. (propellant-grade hydrogen peroxide-Ed.) due to the increase of resistance to flow through the pack. Such increased resistance may be caused by the deposition of large amounts of non-catalytic material such as tin stabilizer. The deposition of precipitated silver dissolved from the entry end of the pack can also cause an increase in pressure drop if the amount of free space provided downstream is small. Increased pressure drops have also been observed when large amounts of silver were provided on the downstream gauzes (screen-Ed.). This effect may result from the partial fusion of the silver, causing the gauzes to become 'welded' together and is likely to be accentuated when H.T.P. of high concentration is used.

A second factor leading to the loss of catalyst pack efficiency is the erosion of silver. This may occur in two principal ways: (1) When the adhesion of the silver plating to the base metal of the gauze is poor, mechanical stripping of silver may occur at high flow rates of H.T.P. through the interstices of the gauzes. The type of silver catalyst known as 'activated silver' which is a loose powdery deposit of silver made by dipping copper gauze in ammoniacal silver nitrate solution, is particularly prome to mechanical stripping. (2) Erosion occurs by solution of silver metal in the liquid H.T.P. near the entry end of the pack: most of the dissolved silver is redeposited downstream but a small fraction is blown out, and this leads to a gradual reduction in the total amount of silver available. However, more important than the gradual overall loss of silver is the fact that the gauzes at the entry end of the pack eventually become completely stripped of silver and then cease to contribute towards the decomposition of the H.T.P. This leads to a gradual shortening of the effective length of the pack, the liquid phase penetrating further towards the downstream end. Eventually the penetration reaches the downstream end and the efficiency of the pack falls rapidly.

The use of H.T.P. at low ambient temperatures, and the repeated stopping and restarting of the decomposer when cold, both accelerate the loss of efficiency of a pack, due to an increased rate of erosion of silver. Since the rate of decomposition of hydrogen peroxide at a silver surface decreases with decrease in temperature, the use of a decomposer at low temperatures involves a greater penetration of the pack by liquid H.T.P. and in consequence a higher overall rate of solution of silver. As mentioned above, the rapid starting of a decomposer involves a greater penetration of H.T.P. than occurs during steady 'running,' and there is in consequence a higher rate of solution of silver during the starting period. Repeated stopping of the decomposer and restarting when it has cooled down will therefore lead to an overall higher rate of loss of silver than occurs during a continuous 'run.' It is also a consequence of the greater penetration of liquid during a start that a decomposer which is losing efficiency, but is still usable, may not restart satisfactorily from cold if the 'run' is stopped at a late stage during its potential life under continuous 'running' conditions.

In connection with the erosion of silver it is necessrry to consider the phenomenon known as 'channeling,' which is the term given to the preferential erosion of silver over certain parts of the gauze area. As a result of bhanneling'the gauzes become completely stripped of silver over certain areas whilst the rest of the gauze still retains silver. This process in turn, leads to penetration by undecomposed H.T.P. along the channels. This condition brings about very inefficient usage of the available silver on the pack, since once a bhannel' has been produced the H.T.P. begins to flow more freely along it than through other parts of the gauze area.*

Channeling' is caused by two principal factors, (1) irregular distribution of H.T.P. on the gauzes by the injector, and (2) the cooling effect at the periphery of the gauzes due to loss of heat to the surroundings. The presence of 'channeling'due to irregular distribution of H.T.P. is noticeable when an injector consisting of a number of holes in a plate is used, as each hole in the injector is matched by a channel on the gauze in the entry end of the pack. The cooling effect at the periphery of the gauze leads to a somewhat lower rate of decomposition in this region and a greater distance of penetration. This leads to more rapid erosion of silver at the periphery, and 'channeling' along the walls of the decomposer.

Finally, it is necessary to consider a third factor which can lead to loss of decomposition efficiency, namely loss of activity of the silver catalyst. This may occur in two major ways, (1) by the catalyst becoming covered with a layer of non-catalytic material, or (2) by direct chemical 'poisoning' of the catalytic surface. The first type of effect occurs whenever non catalytic material, such as alumina and tin oxide, is deposited on the gauzes downstream thereby reducing the efficiency of contact of H.T.P. with the catalyst surface. The second type of effect occurs when the H.T.P. contains contaminants which reduce the rate of decomposition at the catalyst surface."

^{*}Editor's Note: It is also believed that channeling can cause recirculation of the hot decomposition gases within the catalyst chamber. These gases can preheat the liquid stream entering the catalyst bed, which results in an increase in the normal decomposition temperatures in the bed. This increase in temperature is a probable major contributor to the failure of the present silver-screen catalyst packs.

7.2.2 Thermal Decomposition

The use of self-heating thermal chambers to maintain controlled decomposition of hydrogen peroxide has been limited to laboratory studies. In the thermal concept. the design of the decomposition chamber is similar to that employed in packed bed catalytic chambers, except that the chamber material is selected on the basis of thermal conductivity criteria rather than for catalytic activity. The thermal pack is heated with a "pilot light" either by diverting a small flow of hydrogen peroxide through a small catalyst chamber (and directing the decomposition gases into the thermal bed) or by hypergolic ignition slugs of fuel and oxidizer. When the thermal bed achieves a suitable temperature level, the main flow of hydrogen peroxide is initiated and the pilot flow is terminated. The assumed advantage of this operation is an elimination of most of the problems associated with the effects of temperature, poisoning, and erosion in the catalyst bed.

This concept was investigated with both 98 w/o (Ref. 7.19) and 90 w/o (Ref. 7.11) hydrogen peroxide and found to have limited usefulness. Although decomposition could be maintained with small bed loading rates, large propellant flows usually quenched the decomposition process within 3 to 5 seconds after "pilot light" termination. It was concluded that the slow rate of thermal decomposition of hydrogen peroxide caunot compete with the rates obtainable with catalytic decomposition.

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