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SURVEY OF NONMETALLIC LIQUID COOLANTS
FOR NUCLEAR-POWER PILES

By
H. L. Shaw
F. W. Boulger

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2

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American Cyanamid Company (Watertown)	1
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Army Chemical Center	15
Atomic Energy Commission, Washington	16- 20
Battelle Memorial Institute	21
Brookhaven National Laboratory	22- 24
Carbide and Carbon Chemicals Company (C-31 Plant)	25- 26
Carbide and Carbon Chemicals Company (K-25 Plant)	27- 30
Carbide and Carbon Chemicals Company (ORNL)	31- 38
Carbide and Carbon Chemicals Company (Y-12 Area)	39- 42
Chicago Patent Group	43
Chief of Naval Research	44
Dow Chemical Company (Pittsburg)	45
Dow Chemical Company (Rocky Flats)	46
duPont Company	47- 51
H. K. Ferguson Company	52
General Electric Company, Richland	53- 58
Hanford Operations Office	59
Idaho Operations Office	60- 63
Iowa State College	64
Knolls Atomic Power Laboratory	65- 68
Los Alamos	69- 71
Mallinckrodt Chemical Works	72
Massachusetts Institute of Technology (Kaufmann)	73
Mound Laboratory	74- 76
National Advisory Committee for Aeronautics	77
National Bureau of Standards	78
National Lead Company	79
Naval Medical Research Institute	80
Naval Research Laboratory	81
New Brunswick Laboratory	82
New York Operations Office	83- 84
North American Aviation, Inc.	85- 86
Patent Branch, Washington	87
Savannah River Operations Office	88
Sylvania Electric Products, Inc.	89
U. S. Naval Radiological Defense Laboratory	90
UCLA Medical Research Laboratory (Warren)	91
University of California Radiation Laboratory	92- 95
University of Rochester	96- 97
Vitro Corporation of America	98- 99
Western Reserve University (Friedell)	100
Westinghouse Electric Corporation	101-102
Wright Air Development Center	103-105
Technical Information Service, Oak Ridge	106-120

3
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5
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**SURVEY OF NONMETALLIC LIQUID COOLANTS
FOR NUCLEAR-POWER PILES**

to

NEPA PROJECT

from

BATTELLE MEMORIAL INSTITUTE

by

H. L. Shaw and F. W. Boulger

May 26, 1950

INTRODUCTION

This report summarizes the information obtained during a comprehensive review of the literature directed toward the identification of nonmetallic materials of possible usefulness as liquid coolants in nuclear-power piles. This work was conducted at Battelle Memorial Institute during the period from November 11, 1949, to May 5, 1950.

The proposed operations of nuclear-power piles make necessary a consideration of new liquid coolants. For this purpose, materials having maximum melting points of 1000°F. were of interest. Compounds having boiling points as low as 1200°F. were of interest, but boiling points above 2200°F. were considered preferable. The combination of thermal properties and density of the material was of particular importance. A formula devised by NEPA, in which the thermal properties and density of the material were considered, was used to indicate the desirability of any particular compound as a liquid coolant. This formula is expressed as follows:

$$\frac{C_p \times K}{D} = N,$$

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where:

C_p = Heat capacity in BTU/lb., °F.

This may be considered as a coolant line factor, and the larger the value, the smaller the coolant line can be.

K = Thermal conductivity in BTU/ft.², ft., hr., °F.

This may be considered as a heat-transfer factor and high values are desirable.

D = Density in lbs./ft.³.

This may be considered as a radiator weight factor and should be as low as possible.

N = Overall desirability factor. This should be greater than 0.0004 at room temperature.

For the compounds that met these general requirements, according to the NEPA formula, additional information was to be sought. This additional information was to consist of the following:

1. Boiling point, as a function of pressure.
2. The effects of temperature on the vapor pressure, viscosity, thermal expansion, thermal conductivity, specific heat, and electrical conductivity.
3. Hazards in handling.
4. Chemical reactivity.
5. Availability.

SUMMARY

Approximately 190 materials appeared to have melting and boiling temperatures in the range suitable to warrant their consideration as

liquid coolants for nuclear-power piles. A paucity of thermal-conductivity and heat-capacity data prevented further estimates of suitability of all but nine of these materials. Of these nine nonmetallics, only sodium hydroxide appeared to offer possibilities when considered according to the NEPA formula. Experimental determinations of viscosities and thermal properties are desirable on some of the materials.

LITERATURE SURVEY

The literature search for compounds having possibilities for use as liquid coolants was begun by locating the compounds or systems of nonmetallics having melting and boiling points within the limitations set by NEPA. The maximum melting point of interest was 1000°F. The boiling points of the materials preferably were to be above 2200°F.; materials having boiling points as low as 1200°F., however, might be of interest.

The melting and boiling points for sixty-five chemical compounds are listed in Table 1. Several of these compounds have melting points slightly over 1000°F. and boiling points slightly under 1200°F. Boiling-point values for a number of compounds were not found in the literature. The available density values for the compounds are also listed in Table 1.

Generally, when the melting point is under 1000°F., the boiling points are lower than 1700°F. Six of the compounds, however, have boiling points over 2200°F. Potassium hydroxide, sodium cyanide, lithium hydroxide, and sodium hydroxide have fairly high boiling temperatures combined with relatively low densities. Sodium cyanide, however, has a melting point of 1045°F., slightly above the limit desired. This value might vary,

TABLE 1. MELTING AND BOILING POINTS AND THE DENSITY OF A NUMBER OF
CHEMICAL COMPOUNDS HAVING MELTING POINTS UNDER 1000°F.

Compound Formula	Melting Point			Boiling Point			Density		
	°F.	°C.	Ref.	°F.	°C.	Ref.	g./cc.	lb./ft. ³	Ref.
AgBr	813	434	(1,2)	1292	700	(2)	6.473	404	(1,2)
AgCl	851	455	(1,2)	2822	1550	(1,2)	5.56	347	(1,2,8)
AgF	815	435	(1,2,7)	2102	1150	(9)	5.852	366	(1,2,7)
AgPO ₃	900	482	(1,2)	-	-	-	6.37	398	(1,2)
AlCl ₃ .NH ₄ Cl	579	304	(2)	1112	600 in H ₂	(1)	-	-	-
As ₂ S ₃	572	300	(1,2)	1300	707	(1,2)	3.43	214	(1,2)
CaI ₂	1067	575	(1,2)	1325	718	(1,2,7)	3.956	247	(1,2,7)
				Partial Decomposition in air (7)					
CdBr ₂	1053	567	(1,2,7)	1765	963	(1,2,7)	5.192	324	(1,2,7)
CdCl ₂	1054	568	(1,2)	1760	960	(1,2)	4.047	252	(1,2,7)
				S.P. 1765	963	(11)			
CdI ₂	730	388	(1,2)	1315	713	(1,2)	5.67	354	(1,2)
							5.54-5.73	346-358	(7)
CsLiCl ₂	673	356	(1)	-	-	-	-	-	-
CsBrO ₃	738	420	(1)	-	-	-	-	-	-
CsN ₃	598	314	(1)	-	-	-	-	-	-
CsNO ₃	777	414	(1,2)	1364	740	(13)	3.685	230	(1,2)
	765	407	(1,2)	D	D	(2)			
CsOH	521	272	(1,2,7)	-	-	-	3.675	229	(1,2,7)
Cs ₂ S ₂	860	460	(1,2,7)	> 1472	800	(1)	-	-	-
Cs ₂ S ₃	422	217	(1,2,7)	1436	780	(1,2)	-	-	-
Cs ₂ S ₅	410	210	(1,2,7)	-	-	-	2.806	175	(1,2)
Cs ₂ S ₆	367	186	(1,2,7)	-	-	-	-	-	-
CuBr or									
Cu ₂ Br ₂	936	504	(1,2,7)	2453	1345	(1,2)	4.718	294	(1,2)
CuBr ₂	928	498	(1,2,7)	D to CuBr		(7)	-	-	-
CuCl or	792	422	(1,2)	2490	1366	(1,2)	3.53	220	(1,2,7)
Cu ₂ Cl ₂	779-824	415-440	(7)	2714	1490	(11)			

TABLE 1. (Continued)

Compound Formula	Melting Point			Boiling Point			Density		
	°F.	°C.	Ref.	°F.	°C.	Ref.	g./cc.	lb./ft. ³	Ref.
Cu ₂ Cl ₂	806	430	(12)	-	-	-	-	-	-
CuCl ₂	928	498	(1,2,7)	1819	993	(1,2,7)	3.054	191	(1,2,7)
	1166	630	(14)	(D. to CuCl)			3.387	212	(14)
InCl	437	225	(2,16,17)	1022	550	(2)	4.185	261	(2)
				1126	608	(15,16)			
InCl ₂	455	235	(2,16)	1022-1058	550-570	(2,16)	3.655	228	(2,16)
InI	664	351	(1,2,7)	1320	715	(1,2,7)	5.31	332	(1,2)
K ₂ CrSO ₇	662	350	(1)	-	-	-	-	-	-
KHS	851	455	(1,2)	-	-	-	2.0	125	(2)
K ₂ S ₂	878	470	(1,2,18)	-	-	-	-	-	-
KOH	716	380	(1)	2408	1320	(1,2)	2.044	128	(1,2,7)
	680	360	(2,7,12)	2421	1327	(11)	2.12	132	(19)
KPb ₂ Cl ₅	824	440	(1)	-	-	-	-	-	-
2KCl.PbCl ₂	914	490	(2)	-	-	-	-	-	-
K ₂ S	884	471	(1,2)	-	-	-	1.805	131	(1,2)
LiBr	1016	547	(1,2)	2309	1265	(1,2)	3.464	216	(1,2,7)
LiI	835	446	(1,2,7)	2174	1190	(1,2)	4.061	254	(1,2,7)
LiKCO ₃	959	515	(1)	-	-	-	-	-	-
LiOH	842	450	(1,2)	D 1695	924	(21)	1.43	89.3	(1,2)
	833, 864	445, 462	(7)				1.46	91.0	(20)
NaCN	1045	563	(1,2)	2725	1496	(1,2)	1.596	100	(22)
NaSCN	1044	563	(1)	-	-	-	1.73	108	(23)
	549	287	(2)	-	-	-	-	-	-
	613	323	(12)	-	-	-	-	-	-
NaOH	604	318	(1,2)	2534	1390	(1,2)	2.13	133	(1,2)
	612	322	(12)	2512	1378	(11)	2.02	126	(19)
Na ₂ S ₂	833	455	(1)	-	-	-	-	-	-
	885	474	(24)	-	-	-	-	-	-
Na ₂ SO ₄ .CdSO ₄	1022	550	(1)	-	-	-	-	-	-

TABLE 1. (Continued)

Compound Formula	Melting Point			Boiling Point			Density		
	°F.	°C.	Ref.	°F.	°C.	Ref.	g./cc.	lb./ft. ³	Ref.
PbBr ₂	704	373	(1,2)	1680	916	(1,2)	6.66	416	(1,2)
	(a) 685-716	363-380	(7)				6.57-6.67	410-417	(7)
PbCl ₂	934	501	(1,2,7)	1742	950	(1,2)	5.85	365	(1,2)
				1738-1749	942-954	(7)	5.78 to 5.90	361-368	(7)
PbI ₂	756	402	(1,2)	1751	954	(1,2)	6.16	385	(1,2)
	662-756	350-402	(7)	1582-1767	861-964	(7)	6.02-6.21	376-388	(7)
RbBrO ₃	806	430	(1,2)	-	-	-	3.68	230	(1,2)
RbNO ₃	590	310	(1,2)	-	-	-	3.11	194	(1,2)
	581	305	(12)	-	-	-	-	-	-
RbOH	572	300	(1,2,7)	-	-	-	3.203	200	(1,2,7)
	574	301	(25)	-	-	-	-	-	-
RbFSO ₃	579	304	(1,2)	-	-	-	-	-	-
RbPbCl ₃	824	440	(1)	-	-	-	-	-	-
RbPb ₂ Cl ₅	793	423	(1)	-	-	-	-	-	-
SbF ₅ ·2SbF ₃	734	390	(1)				4.188	261	(1)
SnBr ₂	421	216	(1,2,7)	1148	620	(1,2,7)	5.117	320	(1,2,7)
	441-450	227-232	(7)						
SnCl ₂	475	247	(1,2)	1150	623	(1,2)	3.952	247	(7,)
				Partial D		(7)	-	-	-
				1117-1126	603-608	(7)	-	-	-
				1206	652		-	-	-
SnF ₄	-	-	-	1300	705	(1,2,7)	4.78	298	(1,2,7)
				S 1382	750	(7)			
SnI ₂	608	320	(1,2,7)	1328	720	(1,2,7)	5.28	330	(1,2,7)
Sr(OH) ₂	995	535	(28)	D 1310	710	(29)	3.035	189	(30)
TlBr	860	460	(1,2)	1,99	815	(1,2)	7.557	472	(1,2,7)
	842	450	(7)						

TABLE 1. (Continued)

Compound Formula	Melting Point			Boiling Point			Density		
	°F.	°C.	Ref.	°F.	°C.	Ref.	g./cc.	lb./ft. ³	Ref.
TlCl	806	430	(1,2,7)	1482	806	(1)	7.00	437	(1,2,7)
				1328	720	(2,7)			
TlF	621	327	(16,31)	1211	655	(16,31)	8.36	522	(16,31)
				572	300	(2,7)			
TlI	824	440	(1,2,7)	1516	824	(1,2)	7.09	433	(1,2,7)
				1472-1515	800-824	(7)	-	-	
				V. at red heat		(7)	-	-	
ZnBr ₂	741	394	(1,2,7)	1202	650	(1,2)	4.219	264	(1,2)
				1287	697	(7)	-	-	
				1197	647	(7)	-	-	
				1247	675	(7)	-	-	
ZnCl ₂	689	365	(1)	1348	732	(1,2)	2.91	182	(1,2,19)
	504	262	(2)	1321-1350	716-732	(7)	-	-	(7)
	541	283	(12)	-	-		-	-	
	554	290	(7)	-	-		-	-	
ZnI ₂	835	446	(1,2,7)	1155	624	(1,2)	4.666	291	(1,2,7)
Zn ₃ P ₂	>788	420	(1,2)	2012	1100	(1,2)	4.55	284	(1,2)

(a) One investigator reported that PbBr₂ becomes plastic below the melting point.

Notes: S = Sublimes
 V = Volatilizes
 D = Dissociates
 SP = Sublimation Point

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depending on impurities which might be contained in a commercial product.

Table 2 lists 125 binary or ternary systems of chemical compounds; all of these systems contain compositions which melt below 1000°F. The table lists the melting and boiling points of the individual components, the eutectic temperature or the lowest freezing temperature of the system, and the range in composition having a melting temperature under 1000°F.

The boiling temperatures of the particular compositions of interest apparently are not known. There also appears to be no way of predicting the boiling point of a particular eutectic composition. The systems having one component which sublimates or dissociates, however, might show sublimation or dissociation at the interested composition, for instance, systems which contain FeCl_2 , AlCl_3 , or alkali-metal nitrates. The systems of low-boiling constituents may give a low-boiling temperature for the composition of interest in the system.

Most of the systems, however, offer composition ranges which might be of interest as liquid coolants. Many of the individual constituents have melting points above the specified maximum temperature of 1000°F. (537°C.). Additions of other compounds having a melting point either higher or lower than 1000°F., however, produce suitable melting points.

Appraising the various materials by the NEPA formula requires heat-capacity and thermal-conductivity values for each compound.

Table 3 lists the heat-capacity data for all of the compounds which were listed in Table 1. Experimentally determined heat-capacity values were available for only about one-third of the compounds. These generally were for the halides. Heat-capacity data for the liquid condition also were available for a few of the compounds.

TABLE 2. EUTECTIC TEMPERATURE AND COMPOSITION, AND THE RANGE IN COMPOSITIONS HAVING MELTING POINTS UNDER 1000°F.

System	Boiling Point of Components, °F. (c)			Melting Point of Components, °F. (c)			Eutectic Temperature (a)		Eutectic Composition (b)	Range in Composition Under 1000°F. (b)	Ref.
	1	2	3	1	2	3	°F.	°C.			
As ₂ O ₅ - 3H ₂ O·As ₂ O ₅	D599	--	-	D599	2390	-	1008	54.2	58% 3H ₂ O·As ₂ O ₅	None†	(32)
As ₂ S ₃ - Ag ₂ S	1305	D	-	572	1517	-	(1)876 (2)750	469 399	12% As ₂ S ₃ * 4% As ₂ S ₃ *	10 - 100% As ₂ S ₃ *†	(7)
CaO - P ₂ O ₅	5162	8657	-	4662	1045	-	896	480	7% CaO*	4 - 8% CaO*	(32)
CaCl ₂ - NaCl	>2912	2575	-	1431	1477	-	932	500	36% CaCl ₂	- - -	(7)
CaCl ₂ - AgCl	>2912	2822	-	1431	784	-	747	397	10% CaCl ₂	- - -	(7)
CaCl ₂ - CuCl	>2912	2491	-	1431	851	-	837	447	12% CaCl ₂	- - -	(7)
CaBr ₂ - NaBr	1488	2534	-	1346	1368	-	955	513	60% CaBr ₂	50 - 62% CaBr ₂	(7)
CdCl ₂ - NaCl	1760	2575	-	1044	1468	-	738	392	45% NaCl	- - -	(7)
CdCl ₂ - KCl	1760	S2732	-	1044	1425	-	(1)720 (2)734	382 390	30% KCl 70% KCl	- - -	(7)
CdI ₂ - CdF ₂	1315	3196	-	725	2012	-	Mutual solubility		- - -	- - -	(7)
CdI ₂ - CdCl ₂	1315	1760	-	725	1045	-	680	360	70% CdI ₂	- - -	(7)
CdI ₂ - CdBr ₂	1315	1765	-	725	1053	-	Mutual solubility		- - -	- - -	(7)
CdI ₂ - KI	1315	2588	-	725	1252	-	365	185	48% KI	0 - 80% KI	(7)
CoCl ₂ - LiCl	1920	2467	-	S1432	1116	-	984	529	60% CoCl ₂	55 - 65% CoCl ₂	(7)
CoCl ₂ - ZnCl ₂	1920	1350	-	S1337	572	-	572	300	(Eutectic at MP of ZnCl ₂)	65 - 100% ZnCl ₂	(7)
CoCl ₂ - SnCl ₂	1920	1153	-	S1332	478	-	464	240	95% SnCl ₂	55 - 100% SnCl ₂	(7)
CoCl ₂ - PbCl ₂	1920	1742	-	S1335	912	-	795	424	80% PbCl ₂	60 - 100% PbCl ₂	(7)
CuCl - BiCl ₃	2491	837	-	795	435	-	374	190	85% BiCl ₃ *	0 - 100% BiCl ₃ *	(7)
FeCl ₂ - ZnCl ₂	S	1350	-	1238	572	-	572	300	(Eutectic at MP of ZnCl ₂)	50 - 100% ZnCl ₂ †	(7)
FeCl ₂ - SnCl ₂	S	1153	-	1238	478	-	464	240	96% SnCl ₂	50 - 100% SnCl ₂ †	(7)
FeCl ₂ - PbCl ₂	S	1742	-	1238	912	-	790	421	72% PbCl ₂	45 - 100% PbCl ₂ †	(7)
FeCl ₃ - BiCl ₃	599	837	-	568	435	-	342	172	24% FeCl ₃ *	0 - 100% FeCl ₃ *	(7)
(B.P. probably under 1200°F.)											(7)
FeCl ₃ - CuCl	599	2491	-	568	795	-	(1)583 (2)505	306 263	48% FeCl ₃ * 85% FeCl ₃ *	0 - 100% FeCl ₃ *	(7)
FeCl ₃ - ZnCl ₂	599	1350	-	568	504	-	417	214	68% ZnCl ₂ *	0 - 100% ZnCl ₂ *	(7)
FeCl ₃ - TiCl ₄	599	1328	-	568	788	-	(1)511 (2)424	266 218	25% FeCl ₃ 35% FeCl ₃	0 - 100% FeCl ₃	(7)
FeCl ₃ - PbCl ₂	599	1742	-	568	934	-	352	178	50% FeCl ₃ *	0 - 100% FeCl ₃ *	(7)
KBr - CuBr	1346	2453	-	1346	896	-	360	182	67% CuBrΔ	35 - 100% CuBrΔ	(7)
KNO ₃ - AgNO ₃	D752	831D	-	642	410	-	268	131	62% AgNO ₃	0 - 100% AgNO ₃ †	(7)
K ₂ MoO ₄ - MoO ₃	1675	8	-	1699	1463	-	918	492	52% MoO ₃	47 - 55% MoO ₃	(7)
KF - LiF	2732	3049	-	1616	1598	-	918	492	52% LiF	48 - 56% LiF	(32)
KF - LiF - NaF	2732	3049	3092	1616	1598	1814	849	454	44% Kf, 46% LiF, 10% NaF	32 - 53% KF, 38 - 52% LiF, 0 - 17% NaF	(32)
KCl - AlCl ₃	S2732	S352	-	1429	374 (2.5 atm.)	248	120	65	65% AlCl ₃	45- to 100% AlCl ₃ †	(32)
KCl - LiCl	S2732	2467	-	1429	1135	-	671	355	42% KCl	15 - 58% KCl	(32)
KNO ₃ - NaNO ₃	D752	D716	-	633	585	-	449	231	70% NaNO ₃	All compositions	(32)
KNO ₃ - LiNO ₃ NaNO ₃	D752	-	716	633	491	585	248	120	53% KNO ₃ , 29% LiNO ₃ , 18% NaNO ₃ *	All compositions	(32)
KNO ₃ - LiNO ₃ -	D752	-	-	633	491	1082	242	117	62% KNO ₃ , 23% LiNO ₃	All compositions under approx. 90% Ca(NO ₃) ₂ *	(32)
Ca(NO ₃) ₂									15% Ca(NO ₃) ₂		(32)
K ₂ CO ₃ - Li ₂ CO ₃	D	D	-	1636	1144	-	(1)916 (2)934	491 501	53% K ₂ CO ₃ * 75% K ₂ CO ₃ *	47 - 78% K ₂ CO ₃ *	(32)

TABLE 2. (Continued)

System	Boiling Point of Components, °F. (c)			Melting Point of Components, °F. (c)			Eutectic Temperature (a)		Eutectic Composition (b)	Range in Composition Under 1000°F. (b)	Ref.
	1	2	3	1	2	3	°F.	°C.			
LiBr - BaBr ₂	2309	-	-	1026	1557	-	901	483	24% BaBr ₂	10 - 33% BaBr ₂	(7)
LiBr - SrBr ₂	2309	D	-	1026	1189	-	851	455	33% SrBr ₂	13 - 65% SrBr ₂	(7)
LiCl - CaCl	2467	23458	-	1135	1195	-	608	320	42% CaCl Δ	15 - 75% CaCl Δ	(7)
LiCl - CaCl ₂	2467	2912	-	1135	1431	-	925	496	62% CaCl ₂ *	50 - 70% CaCl ₂ *	(32)
LiCl - BaCl ₂	2467	2840	-	1135	1764	-	950	510	73% BaCl ₂ *	66 - 75% BaCl ₂ *	(7)
LiCl - SrCl ₂	2467	-	-	1135	1603	-	918	492	48% SrCl ₂	- - -	(7)
Li ₂ MoO ₄ - Na ₂ MoO ₄	--	-	-	1301	1267	-	867	464	50% Na ₂ MoO ₄	35 - 70 Na ₂ MoO ₄	(7)
Li ₂ WO ₄ - Na ₂ WO ₄	--	-	-	1368	1301	-	918	492	48% Na ₂ WO ₄	42 - 65% Na ₂ WO ₄	(7)
LiCl - NaCl	2467	2575	-	1135	1474	-	1026	552	28% NaCl	None	(32)
LiNO ₃ - Ba(NO ₃) ₂	--	D	-	491	1098	-	482	250	20% Ba(NO ₃) ₂ *	0 - 60% Ba(NO ₃) ₂ (decomposes above 60%)	(32)
Li ₂ CO ₃ - Na ₂ CO ₃ D	D	D	-	1144	1564	-	(1)950 (2)950	510 510	39% Li ₂ CO ₃ *	37 - 50% Li ₂ CO ₃ *	(32)
Li ₂ SO ₄ - K ₂ SO ₄	-	-	-	1580	1969	-	980	530	44% Li ₂ CO ₃ *	20% K ₂ SO ₄ *	(32)
LiBr - LiF	2309	3049	-	1017	1598	-	847	453	20% K ₂ SO ₄ *	85 - 98% LiBr*	(32)
LiCl - LiF	2467	3049	-	1135	1598	-	905	485	89% LiBr*	76 - 90% LiCl*	(32)
LiCl - Li ₂ CO ₃	2467	D	-	1135	1144	-	943	506	80% LiCl*	28 - 46% Li ₂ CO ₃ *	(32)
LiNO ₃ - Li ₂ CO ₃	-	D	-	491	1144	-	482	250	40% Li ₂ CO ₃ *	0 - 25% Li ₂ CO ₃ *	(32)
									2.1% Li ₂ CO ₃	(decomposes above 600°C.)	(32)
MgCl ₂ - NaCl	2574	2575	-	1312	1477	-	806 - 842	430/450	45/38 MgCl ₂	33 - 52% MgCl ₂	(7) (32)
MgCl ₂ - KCl	2574	52732	-	1312	1429	-	(1)878 (2)799	470 426	34% KCl	- - -	(7)
MgCl ₂ - CuCl	2574	2491	-	1312	784	-	766	408	75% KCl	- - -	(7)
MgCl ₂ - AgCl	2574	2822	-	1312	851	-	846	452	95% CuCl	- - -	(7)
MgBr ₂ - NaBr	-	2534	-	1292	1368	-	808	431	90% AgCl	- - -	(7)
MgBr ₂ - KBr	-	2516	-	1292	1346	-	633	334	42% MgBr ₂	35 - 52% MgBr ₂	(7)
MoO ₃ - K ₂ O·MoO ₃	S	-	-	1463	1682	-	(1)896 (2)896	480 approx.	35% MgBr ₂	20 - 65% MgBr ₂	(32)
MoO ₃ - Na ₂ O·MoO ₃	S	-	-	1463	1269	-	(1)930	499	48% K ₂ O·MoO ₃	38 - 56% K ₂ O·MoO ₃	(32)
MnCl ₂ - SrCl ₂	2174	-	-	1202	1602	-	930	499	53% K ₂ O·MoO ₃	22 - 30% Na ₂ O·MoO ₃	(32)
MnCl ₂ - BaCl ₂	2174	2840	-	1202	1742	-	936	503	25% Na ₂ O·MoO ₃	38 - 57% SrCl ₂	(7)
MnCl ₂ - ZnCl ₂	2174	1350	-	1202	527	-	527	275	54% SrCl ₂	20 - 50% BaCl ₂	(7)
MnCl ₂ - SnCl ₂	2174	1153	-	1202	482	-	451	233	36% BaCl ₂	40 - 100% ZnCl ₂	(7)
MnCl ₂ - PbCl ₂	2174	1742	-	1202	923	-	766	408	95% SnCl ₂	45 - 100% SnCl ₂	(7)
NaNO ₃ - AgNO ₃	D716	831D	-	586	408	-	423	217(peritectic)	70% PbCl ₂	45 - 100% PbCl ₂	(7)
NaF - BeF ₂	3092	-	-	1814	1472	-	698	370	80% AgNO ₃ (approx.)	All compositions	(7)
NaF - PbF ₂	3092	2354	-	1814	1515	-	1004	540	43% BeF ₂	38 - 61% BeF ₂	(32)
NaCl - AlCl ₃	2575	5352	-	1477	374	(2.5 atm.)	230	110	68% PbF ₂	None	(32)
Na ₂ O·P ₂ O ₅ - 2NaO·P ₂ O ₅	-	-	-	1157	1805	-	1022	550	63% AlCl ₃	48 - 100% AlCl ₃ †	(32)
NaCl - NaF - Na ₂ O·CrO ₃	2575	3092	-	1477	1814	-	979	526	32% 2NaO·P ₂ O ₅ *	None	(32)
PbCl ₂ - NaCl	1742	2575	-	925	1468	-	772	411	- - -	- - -	(32)
PbCl ₂ - LiCl	1742	2467	-	925	1125	-	770	410	27% NaCl	0 - 40% NaCl	(7)
PbCl ₂ - KCl	1742	52732	-	925	1418	-	(1)770 (2)761 (3)777	410 405 414	45% LiCl	0 - 80% LiCl	(7)
PbCl ₂ - RbCl	1742	2534	-	925	1319	-	(1)770 (2)765 (3)777	410 407 414	20% KCl	0 - 72% KCl	(7)
PbCl ₂ - AgCl	1742	2822	-	925	855	-	590	310	50% KCl	All compositions	(7)
PbCl ₂ - CaCl ₂	1742	2912	-	925	1431	-	873	467	(1) 20% RbCl (2) 37% RbCl (3) 60% RbCl	59.5% AgCl	(7)
PbCl ₂ - SrCl ₂	1742	-	-	925	1580	-	-	-	16% CaCl ₂ *	0 - 25% CaCl ₂ *	(7)
									Mutually soluble	75 - 100% PbCl ₂ •	(7)

TABLE 2. (Continued)

System	Boiling Point of Components, °F. (c)			Melting Point of Components, °F. (c)			Eutectic Temperature (a)		Eutectic Composition (b)	Range in Composition Under 1000°F. (b)	Ref.
	1	2	3	1	2	3	°F.	°C.			
PbCl ₂ - BaCl ₂	1742	2840	-	925	1764	-	-	-	Mutually soluble	80 - 100% PbCl ₂ *	(7)
PbCl ₂ - MgCl ₂	1742	2574	-	925	1312	-	851	455	17% MgCl ₂ *	0 - 35% MgCl ₂ *	(7)
PbCl ₂ - ZnCl ₂	1742	1350	-	925	500	-	-	-	Mutually soluble*	All compositions*	(7)
PbCl ₂ - CdCl ₂	1742	1760	-	925	1054	-	729	387	35% CdCl ₂ *	0 - 80% CdCl ₂ *	(7) (32)
PbCl ₂ - TiCl ₄	1742	1328	-	925	815	-	(1)730 (2)712 (3)804	388 378 429	17% PbCl ₂ 42% PbCl ₂ 74% PbCl ₂	All compositions All Compositions All Compositions	(7)
PbCl ₂ - SnCl ₂	1742	1153	-	925	477	-	-	-	mutually soluble*	All compositions*	(7) (32)
PbCl ₂ - PbF ₂	1742	2354	-	925	1515	-	849	454	10% PbF ₂	0 - 20% PbF ₂	(7)
PbCl ₂ - PbO	1742	-	-	925	1535	-	806	430	20% PbO*	0 - 38% PbO*	(7)
PbCl ₂ - BiCl ₃	1742	837	-	925	435	-	414	212	90% BiCl ₃	All Compositions	(7)
PbCl ₂ - PbBr ₂	1742	1681	-	925	691	-	-	-	Mutually soluble	All compositions	(7)
PbCl ₂ - PbI ₂	1742	1749	-	925	676	-	583	306	72% PbI ₂	All compositions	(7)
PbCl ₂ - PbS	1742	-	-	925	2023	-	826	441	22% PbS*	0 - 35% PbS*	(7)
PbCl ₂ - Pb ₃ (PO ₄) ₂	1742	-	-	925	1857	-	896	480	3% Pb ₃ (PO ₄) ₂	0 - 5% Pb ₃ (PO ₄) ₂	(7)
PbCl ₂ - KCl - NaCl	1742	52732	2575	925	1429	1477	(1)721 (2)729	383 387	71% PbCl ₂ , 11% KCl, 18% NaCl 48% PbCl ₂ , 38% KCl, 16% NaCl	- - - 0 - 6% Pb ₃ (AsO ₄) ₂	(7)
PbCl ₂ - Pb ₃ (AsO ₄) ₂	1742	-	-	925	1908	-	892	478	4% Pb ₃ (AsO ₄) ₂	0 - 6% Pb ₃ (AsO ₄) ₂	(7)
PbBr ₂ - PbF ₂	1681	2354	-	703	1515	-	660	349	10% PbF ₂	0 - 38% PbF ₂	(7)
PbBr ₂ - AgBr	1681	1292	-	703	792	-	529	276	45% PbBr ₂	All compositions	(7)
PbBr ₂ - PbO	1681	-	-	703	1638	-	660	349	14% PbO	0 - 42% PbO	(7)
PbBr ₂ - PbI ₂	1681	1749	-	703	676	-	493	256	50% PbI ₂	All compositions	(7)
PbBr ₂ - BiBr ₃	1681	847	-	703	426	-	401	205	80% BiBr ₃	All Compositions	(7)
PbI ₂ - PbO	1749	-	-	774	1638	-	689	365	30% PbO	0 - 45% PbO	(33)
PbF ₂ - PbO	2354	-	-	1571	1638	-	921	494	54% PbO	45 - 60% PbO	(7) (32)
PbF ₂ - NaF	2354	3092	-	1571	1904	-	1001	540	67% PbF ₂	None	(7)
PbF ₂ - PbI ₂	2354	1749	-	1571	752	-	721	383	15% PbF ₂	0 - 55% PbF ₂	(7)
PbI ₂ - AgI	1749	-	-	774	1026	-	651	344 (min.)	- - -	2 - 100% PbI ₂	(7)
PbO - V ₂ O ₅	-	D3182	-	1630	1274	-	896	480	50% PbO	43 - 52% PbO*	(32)
PbS - Ti ₂ S	-	D	-	2026	840	-	554	290	40% PbS	0 - 50% PbS	(7)
SnCl ₂ - CaCl ₂	1153	2912	-	475	1431	-	473	245	(Eutectic at M.P. % SnCl ₂)	85 - 100% SnCl ₂ *	(7)
SnCl ₂ - MgCl ₂	1153	2574	-	475	1312	-	473	245	(Eutectic at M.P. % SnCl ₂)	85 - 100% SnCl ₂ *	(7)
SnCl ₂ - Cu ₂ Cl ₂	1153	2491	-	475	795	-	342	172	75% SnCl ₂ *	All Compositions*	(7)
SnCl ₂ - ZnCl ₂	1153	1350	-	475	504	-	340	171	65% SnCl ₂ *	All Compositions*	(7)
SnCl ₂ - CdCl ₂	1153	1760	-	475	1054	-	444	229	90% SnCl ₂ *	20 - 100% SnCl ₂	(7)
SnCl ₂ - TiCl ₄	1153	1328	-	475	815	-	(1)570 (2)633 (3)352	299 234 178	20% SnCl ₂ 42% SnCl ₂ 73% SnCl ₂	All compositions - - - - - -	(7)
Sb ₂ S ₃ - SnS	-	2246	-	1013	1562	-	860	460	20% SnS*	0 - 35% SnS*	(7)
Sb ₂ S ₃ - PbS	-	-	-	1022	2037	-	806	430	12% PbS*	0 - 25% PbS*	(7)
Sb ₂ S ₃ - Ag ₂ S	-	D	-	1015	1548	-	(1)865 (2)851 (3)840	463 455 449	18% Sb ₂ S ₃ * 35% Sb ₂ S ₃ * 72% Sb ₂ S ₃ *	15 - 100% Sb ₂ S ₃ *	(7)
Sb ₂ S ₃ - Cu ₂ S	-	-	-	1013	2039	-	914	490	90% Sb ₂ S ₃ *	70 - 100% Sb ₂ S ₃ *	(7)
SiO ₂ - K ₂ O·SiO ₂ - Na ₂ O·SiO ₂	4046	-	-	3115	1789	1992	1004	540	69% SiO ₂ , 23% K ₂ O·SiO ₂ , 8% Na ₂ O·SiO ₂ *	None	(32)

TABLE 2. (Continued)

System	Boiling Point of Components, °F. (c)			Melting Point of Components, °F. (c)			Eutectic Temperature (a)		Eutectic Composition (b)	Range in Composition Under 1000°F. (b)	Ref.
	1	2	3	1	2	3	°F.	°C.			
TlNO ₃ - TlI	806	1515	-	401	792	-	401	205	(min. at M.P. of TlNO ₃ , peritectic at 90% TlNO ₃ , 215°C.	All compositions	(7)
TlNO ₃ - NaNO ₃	806	D716	-	401	576	-	324	162	76% TlNO ₃	All compositions	(7)
TlNO ₃ - KNO ₃	806	D752	-	401	642	-	360	182	62% TlNO ₃	All compositions	(7)
TlCl - BiCl ₃	1328	837	-	804	435	-	(1)680 (2)302	360 150	12% BiCl ₃ 67% BiCl ₃	All compositions	(7)
WO ₃ - K ₂ O·WO ₃	-	-	-	2683	1634	-	(1)1004 (2)995	540 535	48% K ₂ O·WO ₃ 55% K ₂ O·WO ₃	None	(32)
NaOH - KOH	2534	2408	-	604	680	-	369	187	49% KOH*	All compositions	(7)
KOH - RbOH	2408	-	-	680	572	-	583	306	65.6*	- - -	
NaOH - RbOH	2534	-	-	604	572	-	(1)459 (2)459	237 237	48 + 83 +	All compositions	(7)

(a) Numbers in parentheses indicate more than one eutectic composition.

(b) • indicates weight per cent, Δ indicates gram-molecules per cent, + indicates atomic per cent. All others in molar per cent.

(c) D indicates dissociation; S indicates sublimation.

† (probably decomposes)

‡ (probably sublimes)

TABLE 3. HEAT CAPACITIES⁽¹⁾ FOR COMPOUNDS LISTED IN TABLE 1.

Compound Formula	Temperature			Heat Capacity, C _p , BTU./lb., °F.	Literature Reference
	°F.	°C.			
AgBr	32	0	(s)	0.0695	(5)
	61	16	(s)	0.0659	(4)
	80	27	(s)	0.0668	(3)
		15-98	(s)	0.0739	(7)
	> 813	434	(1)	0.0794	(3)
	932	500	(1)	0.0760	(5)
AgCl	32	0	(s)	0.0848	(5)
	66	19	(s)	0.0842	(4)
	80	27	(s)	0.0856	(3)
	122	50	(s)	0.0906	(5)
	32-66	0-19	(s)	0.0878	(7)
	59-208	15-98	(s)	0.0911	(7)
	59-212	15-100	(s)	0.0908	(7)
	61-482	16-250	(s)	0.0950	(7)
	61-572	16-300	(s)	0.0957	(7)
	320-716	160-380	(s)	0.0978	(7)
	> 851	> 455	(1)	0.1115	(3)
	914	490	(1)	0.1290	(5)
AgF	RT	RT	(s)	(0.0883)	(10)
AgPO ₃	RT	RT	(s)	(0.126)	(10)
AlCl ₃ .NH ₄ Cl	RT	RT	(s)	(0.248)	(10)
As ₂ S ₃	RT	RT	(s)	(0.116)	(10)
CaI ₂	RT	RT	(s)	(0.0633)	(10)
CdBr ₂	32-86	0-30	(s)	0.0656	(7)
	32-122	0-50	(s)	0.0669	(7)
	32-158	0-70	(s)	0.0631	(7)
CdCl ₂	80	27	(s)	0.0959	(3)
	32-86	0-30	(s)	0.0936	(7)
	32-122	0-50	(s)	0.0953	(7)
	32-158	0-70	(s)	0.0970	(7)

TABLE 3. (Continued)

Compound Formula	Temperature			Heat Capacity, C_p , BTU./lb.°F.	Literature Reference
	°F.	°C.			
CdI ₂	32-86	0-30	(s)	0.0526	(7)
	32-122	0-50	(s)	0.0527	(7)
	32-158	0-70	(s)	0.0528	(7)
	77-441	25-227	(s)	0.0518	(34)
CsLiCl ₂	RT	RT	(s)	(0.113)	(10)
CsBrO ₃	RT	RT	(e)	(0.0936)	(10)
CsN ₃	RT	RT	(s)	(0.0142)	(10)
CsNO ₃	RT	RT	(s)	(0.125)	(10)
CsOH	RT	RT	(s)	(0.0835)	(10)
Cs ₂ S ₂	RT	RT	(s)	(0.118)	(10)
Cs ₂ S ₃	RT	RT	(s)	(0.079)	(10)
Cs ₂ S ₅	RT	RT	(s)	(0.0925)	(10)
Cs ₂ S ₆	RT	RT	(s)	(0.106)	(10)
CuBr	RT	RT	(s)	(0.0864)	(10)
CuBr ₂	RT	RT	(s)	(0.1295)	(10)
	77-441	25-227	(s)	0.174	(34)
CuCl	80	27	(s)	0.1175	(3)
	RT	RT	(s)	0.1383	(7)
	> 792	422	(l)	0.1595	(3)
CuCl ₂	80	27	(s)	0.1415	(3)
	136	58	(s)	0.1390	(5)
InCl	RT	RT	(s)	(0.0827)	(10)
InCl ₂	RT	RT	(s)	(0.1002)	(10)
InI	RT	RT	(s)	(0.0514)	(10)
	77-441	25-227	(s)	0.0615	(34)

TABLE 3. (Continued)

Compound Formula	Temperature			Heat Capacity, C _p , BTU./lb.,°F.	Literature Reference
	°F.	°C.			
K ₂ CrSO ₇	RT	RT	(s)	(0.1559	(10)
KHS	RT	RT	(s)	(0.193)	(10)
K ₂ S ₂	RT	RT	(s)	(0.163)	(10)
KOH	RT	RT	(s)	(0.223)	(10)
KPb ₂ Cl ₅	RT	RT	(s)	(0.0785)	(10)
2KCl.PbCl ₂	RT	RT	(s)	(0.145)	(10)
K ₂ S	RT	RT	(s)	(0.162)	(10)
LiBr	80	27	(s)	0.143	(3)
LiI	80	27	(s)	0.0975	(3)
LiOH	32	0	(s)	0.327	(5)
	122	50	(s)	0.356	(5)
LiKCO ₃	RT	RT	(s)	(0.247)	(10)
NaCN	RT	RT	(s)	(0.290)	(10)
NaSCN	RT	RT	(s)	(0.242)	(10)
NaOH	< 612	322	(s)	0.480	(3)
	> 612	322	(1)	0.510	(3)
NaOH + 2%Na ₂ CO ₃	> 651	344	(1)	0.4828	(6)
Na ₂ S ₂	RT	RT	(s)	(0.211)	(10)
Na ₂ SO ₄ .CdSO ₄	RT	RT	(s)	(0.175)	(10)

TABLE 3. (Continued)

Compound Formula	Temperature		Heat Capacity C _p BTU/lb., °F.	Literature Reference
	°F.	°C.		
PbBr ₂	32	0	(s) 0.0502	(5)
	80	27	(s) 0.0525	(3)
	122	50	(s) 0.0530	(5)
	61-208	16-98	(s) 0.0533	(7)
	> 910	488	(1) 0.0753	(3)
	1022	550	(1) 0.0779	(5)
	374-806	190-430	(s-1) 0.0534	(7)
	374-805	190-430	(s-1) 0.0532	(7)
	374-824	190-440	(s-1) 0.0709	(7)
	390-910	199-488	(s-1) 0.0566	(7)
	910-1089	488-587	(1) 0.0780	(7)
PbCl ₂	32	0	(s) 0.0649	(5)
	32	0	(s) 0.0650	(7)
	80	27	(s) 0.0660	(3)
	212	100	(s) 0.0681	(5)
	212	100	(s) 0.0665	(7)
	302	150	(s) 0.0678	(7)
	392	200	(s) 0.0692	(7)
	482	250	(s) 0.0704	(7)
	59-212	15-100	(s) 0.0667	(7)
	59-482	15-250	(s) 0.0682	(7)
	61-572	15-300	(s) 0.0693	(7)
	61-662	16-350	(s) 0.0704	(7)
	572	300	(s) 0.0741	(5)
		260-493	(s) 0.0778	(7)
	> 934	501	(1) 0.0978	(3)
	1004	540	(1) 0.121	(5) (7)
PbI ₂	32	0	(s) 0.0417	(5)
	64	18	(s) 0.0423	(7)
	80	27	(s) 0.0422	(3)
	212	100	(s) 0.0437	(5)
	57-230	14-110	(s) 0.0427	(7)
	320-599	160-315	(s) 0.0430	(7)
	> 774	412	(1) 0.0704	(3)

TABLE 3. (Continued)

Compound Formula	Temperature		Heat Capacity, C _p , BTU./lb.°F.	Literature Reference
	°F.	°C.		
RbBrO ₃	RT	RT (s)	(0.1145)	(10)
RbNO ₃	RT	RT (s)	(0.1655)	(10)
RbOH	RT	RT (s)	(0.122)	(10)
RbFSO ₃	RT	RT (s)	(0.155)	(10)
RbPbCl ₃	RT	RT (s)	(0.0776)	(10)
RbPb ₂ Cl ₅	RT	RT (s)	(0.279)	(10)
SbF ₅ ·2SbF ₃	RT	RT (s)	(0.128)	(10)
SnBr ₂	RT	RT (s)	(0.0668)	(10)
	77-441	25-227 (s)	0.0711	(34)
SnCl ₂	80	27 (s)	0.1000	(3)
	63-210	20-99 (s)	0.102	(5)(7)
SnF ₄	RT	RT (s)	(0.1345)	(10)
	77-441	25-227 (s)	0.151	(34)
SnI ₂	RT	RT (s)	(0.0499)	(10)
	77-441	25-227 (s)	0.0532	(34)
SrOH	RT	RT (s)	(0.1027)	(10)
TlBr	80	27 (s)	0.0443	(3)
	734	390 (s)	0.0526	(5)
	> 860	460 (l)	0.0562	(3)
	932	500 (l)	0.0800	(5)
TlCl	32	0 (s)	0.0520	(5)
	80	27 (s)	0.0526	(3)
	212	100 (s)	0.0542	(5)
	> 800	427 (l)	0.0593	(3)
	896	480 (l)	0.0590	(5)

TABLE 3. (Continued)

Compound Formula	Temperature			Heat Capacity, Cp, BTU./lb.°F.	Literature Reference
	°F.	°C.			
TlF	RT	RT	(s)	(0.0501)	(10)
TlI	RT	RT	(s)	(0.0374)	(10)
	77-441	25-227	(s)	0.0448	(34)
ZnBr ₂	RT	RT	(s)	(0.0825)	(10)
	77-441	25-227	(s)	0.0879	(34)
ZnCl ₂	80	27	(s)	0.134	(3)
	140	60	(s)	0.136	(5)(7)
ZnI ₂	RT	RT	(s)	(0.0583)	(10)
	77-441	25-227	(s)	0.0620	(34)
Zn ₃ P ₂	RT	RT	(s)	(0.1139)	(10)

(1) Brackets indicate values calculated by methods recommended in Reference Number 10. Other values were obtained by experiment.

Values from the different references checked fairly closely. The specific-heat value generally increased slightly with increasing temperature. Where specific-heat values for both solid and liquid conditions were available for comparison, the liquid condition showed a much higher specific-heat value.

Specific-heat values were estimated by the use of Kopp's law, where values could not be found in the literature. The values are for room temperature and are made up additively from the heat capacities of the constituent elements. The values are probably reliable to ± 25 per cent.

The hydroxides of sodium, potassium, and lithium appear to be promising, in that they have relatively high specific heats combined with low densities and fairly high boiling points.

The available thermal conductivity values for the compounds listed in Table 1 are given in Table 4. Data were found for only nine compounds.

In the solid condition, sample preparation seems to be an important factor in the thermal-conductivity value obtained. Poor checks are shown where more than one value is listed.

Two values for liquid sodium hydroxide were found. Kitzes⁽³⁵⁾, of Oak Ridge, determined the thermal conductivity at temperatures from 715° to 895°F. (382° to 432°C.) and obtained a value of 1.9 BTU/hr., °F., ft. Another value of 0.25 BTU/hr., °F., ft. was estimated for liquid sodium hydroxide at 1110°F. (600°C.) by Ellis⁽³⁶⁾, also of Oak Ridge. No values for solid sodium hydroxide were found in the literature.

TABLE 4. AVAILABLE THERMAL-CONDUCTIVITY VALUES FOR
THE COMPOUNDS LISTED IN TABLE 1.

Compound Formula	Temperature		Thermal Conductivity BTU./ft. ² ft. hr. °F.	Kind of Sample	Sp. Gr. of Sample	Reference
	°F.	°C.				
AgBr	32	0	0.594	-	5.9	(1)
AgCl	32	0	0.630	Artificial	3.06	(1)
AgCl	32	0	0.636	Natural	7.2	(1)
AgCl	80	RT	0.432	Pressed Powder	-	(1)
CuCl ₂	58	15	0.312	-	-	(1)
PbBr ₂	RT	RT	0.150	Pressed Powder	-	(1)
PbCl ₂	58	15	0.312	-	-	(1)
PbCl ₂	RT	RT	0.192	Pressed Powder	-	(1)
PbI ₂	RT	RT	0.138	Pressed Powder	-	(1)
TlBr	32	0	0.474	-	7.1	(1)
TlCl	32	0	0.567	-	6.6	(1)
NaOH	720-810	382-482	1.9	Liquid	-	(35)
NaOH	1112	600	0.25	Liquid	-	(36)

Desirability Factors

The NEPA formula was used to judge the suitability, for coolants, of the nine nonmetallics for which sufficient information was available. The data and the "desirability factors" obtained from the formula are given in Table 5. In most instances, the calculations were based on room-temperature values for specific heat and thermal conductivity. Thermal-conductivity values for liquid sodium hydroxide, however, were used.

The NEPA formula indicates that sodium hydroxide is the only non-metallic, for which data are available, showing promise as a liquid coolant at high temperatures. The other eight materials gave "N" values less than 0.0003. The NEPA "desirability factor" calls for a minimum value of 0.0004.

Auxiliary Information on Sodium Hydroxide

In the presence of air, fused sodium hydroxide is very corrosive at high temperature. Pure nickel, silver, and dense carbon or graphite are suitable containers for many applications⁽³⁷⁾.

The densities of sodium hydroxide, at various temperatures, measured by Arndt and Ploetz⁽³⁸⁾ were:

320°C., 610°F.	111.5 lbs./cu. ft.
350°C., 660°F.	110.5 Ditto
400°C., 750°F.	108.9 "
450°C., 840°F.	107.4 "

Arndt and Ploetz⁽³⁸⁾ reported the following values for the
of
coefficient/viscosity of sodium hydroxide at various temperatures:

TABLE 5. DESIRABILITY OF A NUMBER OF COMPOUNDS FOR USE
AS A LIQUID COOLANT. BASED ON THE "N" VALUE
OBTAINED IN THE NEPA FORMULA

Compound Formula	Specific Heat, CP, BTU./lb.,°F.	Temp. for CP Value, °F.	Thermal Conductivity, K, BTU./hr., °F., ft.	Temp. for K Value, °F.	Density, Lb./ft. ³	N ⁽¹⁾
AgBr	0.0668	80	0.594	32	404.1	0.000099
AgCl	0.0856	80	0.63	32	347.1	0.000156
CuCl ₂	0.1415	80	0.312	58	190.7	0.000231
PbBr ₂	0.0525	80	0.15	80	415.8	0.000019
PbCl ₂	0.068	80	0.312	58	365.2	0.000058
PbI ₂	0.0422	80	0.138	RT	384.6	0.000151
TlBr	0.0443	80	0.474	32	471.8	0.000045
TlCl	0.0526	80	0.567	32	437.0	0.000068
NaOH	0.480	<612	1.9	720 - 810	133.0	0.0068
	0.510	>612	1.9	720 - 810	133.0	0.0073
	0.480	<612	0.25	1112	133.0	0.000902
	0.510	>612	0.25	1112	133.0	0.00096

$$(1) N = \frac{CP \times K}{D}$$

where CP = Heat capacity in BTU./lb.,°F.
K = Thermal conductivity in BTU./hr., °F., ft.
D = Density in lbs./ft.³
N = >0.0004 to be desirable.

350°C., 660°F.	4.0 centipoises
400°C., 750°F.	2.8 ditto
450°C., 840°F.	2.2 "
500°C., 930°F.	1.8 "
550°C., 1020°F.	1.5 "

The vapor pressure of sodium hydroxide at 1110°F. (600°C.) is approximately 0.75 mm. of mercury⁽¹⁾. The relationship between vapor pressure and temperature, in the range from 1850° to 2655°F., is expressed by the formula:

$$\log_{10} p = 7.030 - \frac{0.05223 \times 132,000}{T},$$

where "p" is the vapor pressure in mm. of mercury

and "T" is the absolute temperature ($T = ^\circ\text{C.} + 273.1$).

The following values for the specific heat of sodium hydroxide, containing various amounts of carbonate, are given by Teraschkevich and Vishnevskii⁽³⁹⁾.

<u>Composition</u>	<u>Temperature Range</u>	<u>Average Specific Heat</u>
NaOH + 2.0% Na ₂ CO ₃	344 to 597°C.	0.4828 cal./g., °C.
NaOH + 3.9% Na ₂ CO ₃	357 to 647	0.4641 Ditto
NaOH + 8.5% Na ₂ CO ₃	340 to 558	0.4854 "
NaOH + 15.2% Na ₂ CO ₃	367 to 571	0.4704 "
NaOH + 19.7% Na ₂ CO ₃	361 to 554	0.4532 "

Reagent-quality sodium hydroxide contains one-half to two per cent sodium carbonate. Other grades are less pure. All grades are quite inexpensive and are readily available.

CONCLUSIONS

Sodium hydroxide possesses some properties desirable in liquid coolants operating above 1000°F. Additional information is needed on its chemical reactivity, viscosity, and electrical resistivity at various temperatures. The thermal conductivity of liquid sodium hydroxide is not known precisely. Information of the type suggested must be determined experimentally.

Lack of thermal conductivity data prevents evaluating the coolant characteristics of some nonmetallics with promising densities and specific heats. Table 6 lists materials considered of possible interest, which were selected because of their low densities and relatively high specific heats. Boiling points are unknown for six of the nonmetallics. The table gives the minimum value for thermal conductivity which each material would have to possess in order to have a desirable "N" value by the NEPA formula. The necessary thermal-conductivity values do not seem unreasonably high compared with those for halides quoted in the literature. Boiling-point and thermal-conductivity determinations on these materials are recommended.

A relatively large number of compositions in binary and ternary systems of nonmetallic components melt below 1000°F. Some with low densities may have heat capacities and thermal conductivities making them suitable for heat-transfer media. Some experimental work probably should be done on melts made from stable components with high boiling points in order to find suitable compositions.

HLS:FWE/GEH,ec
June 16, 1950

TABLE 6. NONMETALLICS OF POSSIBLE INTEREST* FOR LIQUID COOLANTS
IF FOUND TO HAVE SUITABLE THERMAL CONDUCTIVITIES*

Material	Approximate Melting Point, °F.	Approximate Boiling Point, °F.	Density, lb./ft. ³	Specific Heat, BTU./lb., °F.	Minimum Value of Thermal Conduct- ivity Desired BTU./hr., °F., ft.
LiOH	840	d 1700	90	0.36	0.10
NaCN	1045	2700	100	0.29	0.14
NaSCN	550		108	0.24	0.18
KOH	680	2400	130	0.22	0.24
KHS	850		125	0.19	0.26
K ₂ S	885		131	0.16	0.33
RbNO ₃	585		195	0.16	0.49
ZnCl ₂	365	1340	182	0.13	0.56
RbOH	570		200	0.12	0.67
Ca ₂ S ₅	410		175	0.09	0.75
Sr(OH) ₂	995	1310	190	0.10	0.76
CuBr ₂	930	2400	294	0.09	1.31

*A material is considered of interest, for liquid coolant applications, when the melting point is below 1000°F., the boiling point exceeds 1200°F., and the factor "N" exceeds 0.0004.

"N" = $\frac{\text{Specific Heat} \times \text{Thermal Conductivity}}{\text{Density}}$, in units indicated above. "d" indicating dissociation of the compound.

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