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Min of Supply RoF
(Explosives) Thermal
Properties of Systems
Nitric Acid, Sulphuric
Acid - Water

MINISTRY OF SUPPLY

ROYAL ORDNANCE FACTORIES

(EXPLOSIVES)

THE THERMAL PROPERTIES OF THE SYSTEMS NITRIC ACID - WATER AND NITRIC ACID - SULPHURIC ACID - WATER

Memorandum No. 17

Thermal Properties of the Systems

Nitric Acid - Water

and

Nitric Acid - Sulphuric Acid - Water

Summary:-

Data in the literature on the thermal properties of the systems HNO_3 - H_2O and HNO_3 - H_2SO_4 - H_2O have been collated and interpolated. From the results of the interpolation tables of specific heats, boiling-points, heat contents, vapour compositions and heat contents of vapour have been constructed which should facilitate the solution of practical problems.

Introduction:-

Industrial problems in acid mixing and nitric acid concentration often require for their solution various thermal data on the systems HNO_3 - H_2O and HNO_3 - H_2SO_4 - H_2O. A deal of data is available in the literature but this has never been brought together and interpolated in an easily available form. The usual method of presenting data on the ternary system is the triangular diagram, which is more difficult to interpolate than a rectangular coordinate diagram. It has been pointed out by several authors that such data can be presented quite as easily by rectangular diagrams, since the composition of a three-component system is fully defined by the weight percentages (or mol-fractions, or weight ratios etc.) of only two components. Even so, very little use has been made of this simplification in the case of the nitric acid-sulphuric acid-water system. Such data as is available on specific heats, heats of dilution and mixing, boiling-points, vapour-composition and heat content of vapour have been examined by the author, and interpolated graphically. From these graphs various tables have been drawn up which have been designed to facilitate the solution of problems.

In compiling the heat content tables the pure components, H_2O, H_2SO_4, HNO_3, have been taken as reference substances, with zero heat contents at 25°C. Thus the heat content of an acid of

a given composition at a temperature of T°C. is made up of two parts, the heat of mixing the pure components at 25°C. and the heat required ro raise the mixture from 25°C. to T°C. Heat contents are all expressed in centigrade heat units per round (C.H.U's per lb. = K gm. Cals./Kgm).

In order to keep the tables to reasonable proportions data are only presented for concentration intervals of 5% (HNO_3 or H_2SO_4) and temperature intervals of 5°C. Where intermediate concentrations or temperatures are being considered linear interpolation by inspection will be satisfactory in most cases, but where this is not so the data of the tables may be graphed as nests of curves on rectangular coordinates. The heat contents of the system HNO_3 - H_2SO_4 - H_2O at 25°C. can be presented thus:- plot heat content against sulphuric acid concentration for each nitric acid composition - giving curves for 5%, 10% ..... 95% HNO_3.

For certain parts of the systems the data in the literature are scanty (boiling points of the ternary system for example), and the processes of graphical interpolation and extrapolation may have introduced inaccuracies. Within the ranges which are most important in practice, however, it is felt that any errors are comparatively small, and that the tables are sufficiently accurate for practical purposes. Notes follow on the sources of data used, and the methods of interpolation.

PART I. THERMAL PROPERTIES OF THE BINARY SYSTEM HNO_3 - H_2O

(1) Heats of Dilution of Nitric Acid

The heat evolved on mixing pure nitric acid and pure water has been measured by Berthelot (1) and Thomsen (2), both of whom covered a range of mixtures from 100% HNO_3 to 1.72% HNO_3. For the heat of infinite dilution, Berthelot obtained 7.18 kilogramme-calories per gram-mol. while Thomsen obtained 7.493. More recently Forsythe and Giauque (3) measured the heats of infinite dilution of pure HNO_3, the monohydrate $HNO_3.H_2O$ (77.77% HNO_3) and the trihydrate $HNO_3.3H_2O$ (53.83% HNO_3) obtaining a value of 7,971 ± 10 gm. - calories/gm. mol. for the pure acid. In view of the precautions taken by the latter workers, their value has been accepted in preparing these tables, also their values for

the hydrates. Wilson and Miles (4) have presented data on the differential heats of solution of HNO_3 and H_2O for 90%, 80%, 70% and 60% HNO_3. Of these, the data for 60% HNO_3 are very doubtful and the values for 70% HNO are also suspect. Only the 90% and 80% HNO_3 data have therefore been used to compute additional heat of dilution data. In addition to these data of Forsythe and Giauque, and Wilson and Miles the data of Berthelot and Thomson have also been used, neglecting the values for the heat of infinite dilution. All have been plotted on a rectilinear diagram as centrigrade heat units per pound (C.H.Us/lb.) of residual acid against the percentage HNO_3 in the residual acid. A smooth curve has been drawn through the points, and this curve used for interpolation. From this graph the heat contents of the system have been obtained and tabulated in table 1, column 2.

(2) Boiling Points

Creighton and Githens (5) have recorded the boiling points of nitric acid water mixtures. Their data have been interpolated graphically and the results presented in column 3 of table 1.

(3) Specific Heats

The specific heats of the binary system were measured by Pascal and Garnier (6) at 20°C. Recently new data have been presented on the three component system HNO_3-H_2SO_4-H_2O by Morgan, Bender and Capell (7) for temperatures of 40°C, 60°C, 80°C. and 100°C. In view of the range of temperatures covered in the latter work these data have been used both for the binary and ternary systems, although on extrapolation they give values for 20°C. several per cent lower than Pascal and Garnier's. Specific heats of the two component system were plotted against % HNO_3 for each of the temperatures 40°C, 60°C, 80°C. and 100°C., and smooth curves drawn through the points. Data were interpolated from these curves for each 5% interval of nitric acid concentration. At each concentration the values obtained were plotted against temperature, and the nearest straight line drawn through the four points. The linear relation was assumed in view of the appearance of the points, and lack of sufficient data to enable the true curve to be drawn. It is considered that the error introduced by this is not large enough to affect

the practical value of the tables. The specific heat data are presented in table 1, in columns 4 and 5, the term A representing the specific heat at 0°C. obtained by extrapolation, B representing the constant in the assumed linear equation for the temperature variation of specific heat.

(4) Heat Contents of HNO_3 - H_2O Mixtures at the Boiling Points

The data presented in column 6 of table 1 have been computed from the data in the other columns:-

Heat content per pound at boiling point = Heat content per pound at 25°C. + $(t - 25)\left(A + \left(\frac{t+25}{2}\right)B\right)$

Where t is the boiling point in °C.

$A + \left(\frac{t+25}{2}\right)B$ = Mean Specific heat between 25° and t°

(5) Composition of Nitric Acid Vapour in Equilibrium with Boiling Acid

These data have been interpolated from the values recorded by Carpenter and Babor (8), and are presented in the last column of table 1.

(6) Heat Contents of Mixtures at Various Temperatures

The data of table 2 have been computed in the same manner as the heat contents at the boiling point (see Section 4 above).

(7) Total Heats of Nitric Acid Vapour

These are presented in table 3 and have been computed from the following equation:-

$$Qt = \frac{P.V_N}{100} + \frac{(100 - P)}{100} V_W + Ht$$

Where Qt = Total heat per pound of nitric acid vapour at t°C.
P = % HNO_3 in vapour.
V_N = Latent heat of vaporisation of HNO_3 (per pound) at t°C.
V_W = " " " " " H_2O " " " "
Ht = Heat content per pound for liquid of the same composition as the vapour at t°C_2.

This equation applies only if there is no association in the vapour phase, and Forsythe and Giauque (3) have shown that this condition is satisfied. It is also based on the assumption that t°C. is sufficiently low to prevent decomposition of HNO_3. For this reason the temperature range covered by table 3 has been limited to 150°C. to 80°C., this being the most useful practical range. The values given for the higher temperatures in this table will be somewhat inaccurate depending on the degree of decomposition of HNO_3, but the magnitude will not be great enough to make much material difference.

V_N has been calculated from the value for latent heat of vaporisation of HNO_3 at 25°C. computed by Forsythe and Giauque (3) from the experimental data of Wilson and Miles (4), the heat capacities of the vapour given by the former authors (based on spectroscopic evidence), and the heat contents of the liquid. ($V_N(25°)$ = 9,355 gm. calories/gm. mol. HNO_3).

PART II. THERMAL PROPERTIES OF THE TERNARY SYSTEM $HNO_3 - H_2SO_4 - H_3O$

(8) Heats of Mixing

In computing the heat contents at 25°C (table 4) McDavid's (9) experimental data have been used, and the heats of mixing recalculated using mean specific heats interpolated from the data of Morgan, Bender and Capell (7).

(9) Boiling Points

The figures presented by Berl and Samtleben (10) were the best which could be found in the literature. For some parts of the system the data are scanty, but the interpolated values given in table 6 should be sufficiently accurate for practical use.

(10) Specific Heats

The methods of interpolation and presentation are the same as described for the two component system (see Part 1, section 3), the process being repeated for each 5% interval of H_2SO_4 concentration. The data of Morgan, Bender and Capell (7) were used

for the reasons previously given. The interpolated data are presented in tables 5 (a) and 5 (b).

(11) Composition of Vapour in Equilibrium with Boiling Acid

The data of table 7 have been interpolated from those of Carpenter and Babor (8). Where no values are given there is some doubt about the true composition, due to the high boiling points, and H_2SO_4 and decomposition products of HNO_3 may occur. The values are only given where the vapour is a mixture of H_2O and HNO_3.

(12) Heat Contents of Mixtures at Temperatures other than 25°C.

These quantities are not given in view of the extent of the tables required. They are easily calculated from the following equation.

$$Ht = H_{25} + (t - 25)\left(a + b\frac{(t + 25)}{2}\right)$$

Where Ht = Heat content per pound at t°C.
H25 = " " " " " 25°C. given in table 3.

The first bracketted term represents the temperature increment from 25° to t°C., and the second bracketted term is the mean specific heat between the two temperatures, 'a' and 'b' being given in tables 5 (a) and 5 (b) respectively.

Example of the Use of Tables

From weak nitric acid of strength 60% and 95% H_2SO_4 a mixed acid is to be made of composition 20% HNO_3, 60% H_2SO_4. The component acids are at 20°C., and water at 15°C. It is necessary to know the heat to be dissipated from the mixture to give a product at 20°C.

For a materials balance the following weights of acid and water must be mixed to give one pound of product.

Weak nitric acid	= 0.333 lbs. per lb. mixed acid.
Strong sulphuric acid	= 0.6316 " " " " "
Water	= 0.0351 " " " " "

From the table 2 60% HNO_3 has a total heat content at 20°C. of -52.0 C.H.U's per lb., while 95% H_2SO_4 has a heat content of -21.6 C.H.U's per lb. at 25°C. from table 3.4 It will therefore have a heat content of $-21.6 - 5 \times (0.340 + (22.5 \times 5 \times 10^{-4}))$ C.H.U's per pound at 20°C. (from tables 5a and 5b), that is -23.4 C.H.U's per lb. Water, of course, will have a heat content of -10 C.H.U's per lb., referred to 25°C. The total heat introduced per pound of mixed acid can now be completed:-

Heat in 60% HNO_3	=	0.3333 x -52.0	= -17.33	C.H.U. per lb. product
" " 95% H_2SO_4	=	0.6316 x -23.4	= -4.78	" " " "
" " water	=	0.0351 x -10	= -0.35	" " " "
		Total	-32.46	

From table 4 the product has a heat content of -64.1 C.H.U's per pound at 25°C., with a specific heat of 0.446 at 0°C. and a specific heat correction of +0.00005 per °C. (from tables 5a and 5b). The heat content at 25°C. is therefore given by

$$-64.1 - (25-20)\left[0.446 + \frac{(25 + 20)}{2}(0.00005)\right]$$

$$= -64.1 - 5\left[0.446 + 22.5\ (0.00005)\right]$$

$$= -64.1 - 2.24 = -66.34 \text{ C.H.U's per lb.}$$

This is the heat remaining after mixing, so the heat dissipated (= heat entering - heat leaving) = -32.46 -(66.34)
= 33.88 C.H.U's per lb. of product.

The tables can be used in a similar manner for heat balance computations in connection with concentration processes.

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(4)	WILSON AND MILES,	TRANS. FARADAY SOC., 1940, 36, 356
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TABLE 1

Properties of the Binary System HNO_3 - H_2O

Thermal properties of liquid mixtures of nitric acid and water.

(1) Total heat content at 25°C referred to pure HNO_3 and pure H_2O at 25°C in Kgm cals/Kgm or C.H.U^S/lb.

(2) Boiling points at 1 atmosphere pressure.

(3) Specific heat data:- Specific heat at t°C = A + Bt where A = specific heat at 0°C.

(4) Total heat content at boiling point - Kgm. cals/Kgm. or C.H.U^S/lb. - referred to pure components at 25°C.

Acid Concentration % HNO_3	Heat content at 25°C. C.H.U^S/lb.	Boiling Point °C.	Specific Heat Data		Heat content at Boiling Point C.H.U^S /lb.	Vapour from boiling acid % HNO_3
			A	B x 104		
0	0	100	1.000	0.	+ 75	0
5	- 6.3	100.5	0.928	+ 5.0	+ 66.3	0.1
10	- 12.4	101.0	0.862	+ 9.5	+ 57.4	0.2
15	- 18.3	102.0	0.793	+ 14.5	+ 49.6	0.5
20	- 24.0	103.5	0.727	+ 19.0	+ 42.7	1.0
25	- 29.5	105.5	0.674	+ 22.0	+ 36.5	2.2
30	- 34.5	108	0.626	+ 24.0	+ 30.7	4.0
35	- 39.3	110	0.585	+ 24.3	+ 24.8	7.2
40	- 43.4	112.5	0.547	+ 25.0	+ 19.5	11.8
45	- 46.5	114.5	0.515	+ 25.3	+ 15.5	17.5
50	- 48.6	116.5	0.488	+ 25.0	+ 12.7	25.9
55	- 49.6	118.5	0.480	+ 20.5	+ 9.7	35.4
60	- 49.5	120	0.473	+ 17.0	+ 7.3	46.4
65	- 48.3	121.5	0.463	+ 15.1	+ 7.0	59.8
70	- 46.2	121.5	0.452	+ 13.5	+ 6.8	74.9
75	- 42.9	119	0.445	+ 11.1	+ 6.4	85.4
80	- 38.4	115.5	0.438	+ 8.5	+ 6.6	92.6
85	- 32.1	108.5	0.428	+ 6.7	+ 8.2	96.2
90	- 23.9	102	0.418	+ 5.5	+ 11.0	98.2
95	- 13.3	95	0.409	+ 4.3	+ 17.3	99.6
100	0	86	0.398	+ 3.5	+ 25.5	100.0

TABLE 2

Heat contents of mixtures in the binary system HNO_3 - H_2O, in Kgm. cals/Kgm. or C.H.U/lb, referred to the pure components at 25°C.

% HNO_3	Heat contents at various temperatures in C.H.U/lb.												
	0°C.	10°C.	20°C.	30°C.	40°C.	50°C.	60°C.	70°C.	80°C.	90°C.	100°C.	110°C.	120°C.
0	-25.0	-15.0	- 5.0	+ 5.0	+15.0	+25.0	+35.0	+45.0	+55.0	+65.0	+75.0		
5	-29.7	-20.4	-11.0	- 1.6	+ 7.9	+17.4	+27.0	+36.6	+46.3	+56.0	+65.8		
10	-34.5	-25.6	-16.8	- 8.0	+ 1.0	+10.0	+19.1	+28.3	+37.6	+47.0	+56.5		
15	-39.0	-30.8	-22.9	-14.5	- 5.9	+ 2.5	+11.2	+20.2	+29.2	+38.8	+47.8		
20	-42.9	-35.5	-27.9	-20.1	-12.2	- 4.1	+ 4.2	+12.7	+21.4	+30.3	+39.4		
25	-46.8	-40.0	-32.8	-25.8	-18.1	-10.8	- 2.8	+ 5.5	+14.0	+22.0	+30.5		
30	-50.7	-44.3	-37.7	-31.0	-23.9	-16.6	- 9.0	- 1.2	+ 6.9	+15.2	+23.7		
35	-54.5	-48.5	-42.0	-35.9	-29.4	-22.2	-15.1	- 7.5	0.0	+ 7.8	+16.4	+24.8	
40	-57.9	-52.3	-46.4	-40.3	-33.9	-27.3	-20.5	-13.4	- 6.1	+ 1.5	+ 9.4	+17.5	
45	-60.3	-55.4	-49.7	-44.5	-37.7	-31.5	-25.0	-17.9	-10.9	- 4.0	+ 3.9	+11.7	
50	-61.6	-56.6	-51.3	-45.8	-40.0	-34.0	-27.7	-21.2	-14.4	- 7.4	- 0.1	+ 7.4	
55	-62.5	-57.5	-52.1	-47.0	-42.1	-35.5	-29.6	-23.5	-17.0	-10.5	- 3.5	+ 3.5	
60	-61.8	-57.0	-52.0	-46.9	-41.6	-36.1	-30.4	-24.6	-18.6	-12.4	- 6.0	+ 0.5	+ 7.3
65	-60.0	-55.4	-50.7	-45.8	-40.6	-35.5	-30.0	-24.3	-18.8	-13.0	- 6.2	0.0	+ 6.4
70	-57.9	-53.3	-48.6	-43.8	-38.8	-33.7	-28.4	-23.0	-17.5	-11.8	- 6.0	- 0.1	+ 6.0
75	-54.1	-49.6	-45.2	-40.7	-35.7	-30.7	-25.9	-20.7	-15.2	-10.2	- 4.2	+ 1.3	
80	-49.6	-45.2	-40.7	-36.1	-31.4	-26.6	-21.8	-16.9	-11.9	- 6.8	- 1.6	+ 3.7	
85	-42.8	-38.5	-34.0	-29.5	-25.0	-20.4	-15.8	-11.0	- 6.8	- 2.0	+ 3.0		
90	-34.6	-30.4	-26.1	-21.7	-17.3	-12.9	- 8.4	- 3.9	+ 0.7	+ 5.3	+10.0		
95	-22.7	- 9.0	-16.0	-10.6	- 6.5	- 1.5	+ 3.0	+ 6.4	+10.9	+15.8			
100	-10.0	- 6.0	- 2.0	+ 2.0	+ 6.1	+10.2	+14.4	+18.6	+22.8				

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TABLE 3

Heat Contents of Nitric Acid Vapour at different temperatures referred to the pure components at 25°C. Kgm. cals/Kgm. or C.H.Us/lb.

Temp. / HNO_3 in vapour	Heat Content in C.H.Us/lb.														
	80°C.	85°C.	90°C.	95°C.	100°C.	105°C.	110°C.	115°C.	120°C.	125°C.	130°C.	135°C.	140°C.	145°C.	150°C.
0	604	606	609	611	614	616	619	621	623	625	628	630	633	635	638
5	574	576	579	581	584	586	588	589	591	593	596	598	600	602	604
10	548	550	552	553	555	557	559	560	561	563	565	566	568	569	571
15	518	520	522	523	525	527	529	530	531	533	536	538	540	541	543
20	490	492	494	496	497	499	501	503	504	506	508	509	511	513	515
25	464	465	467	468	469	470	471	471	472	474	477	479	481	482	484
30	434	436	438	439	441	442	443	444	445	446	448	450	452	453	455
35	408	409	411	412	413	414	416	416	417	419	421	423	425	427	429
40	380	381	383	385	386	387	388	390	392	394	396	397	399	401	403
45	354	355	357	358	359	361	363	364	366	368	370	372	374	376	378
50	330	332	333	334	336	337	339	340	342	343	345	346	348	350	352
55	306	307	309	311	312	313	315	317	318	319	320	321	323	325	327
60	282	284	286	287	289	291	292	293	294	295	297	299	300	301	303
65	263	264	265	266	268	269	271	272	273	274	276	277	279	280	282
70	244	245	246	247	248	250	251	252	253	254	256	257	258	259	261
75	227	228	229	229	230	231	232	233	234	235	236	238	239	240	242
80	208	209	210	211	212	213	214	215	216	217	219	220	221	222	224
85	192	193	195	195	196	197	198	200	202	203	204	205	206	207	208
90	179	180	181	182	183	184	185	186	187	188	189	190	191	192	194
95	169	170	171	171	172	173	174	175	176	177	178	179	181	183	184
100	159	160	162	163	164	165	166	167	168	169	170	171	173	174	175

TABLE 4

Heat contents at 25°C of the ternary system HNO_3 - H_2SO_4 - H_2O in Kgm. cals/Kgm. or C.H.U^s/lb. referred to the pure components at 25°C.

%H_2SO_4 \ %HNO_3	Heat contents at 25°C in C.H.U^s per pound of mixed acid																			
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	0.0	- 6.3	-12.4	-18.3	-24.0	-29.5	-34.5	-39.3	-43.4	-46.5	-48.6	-49.6	-49.5	-48.3	-46.2	-42.9	-38.4	-32.1	-23.9	-13.3	0.0
5	- 9.0	-15.5	-21.0	-26.5	-31.6	-36.5	-41.0	-44.7	-47.8	-49.6	-51.1	-51.3	-50.5	-47.8	-44.7	-39.8	-33.8	-25.8	-15.7	- 0.6	
10	-17.7	-23.7	-28.8	-33.6	-38.5	-43.0	-46.3	-48.8	-51.0	-52.3	-52.8	-52.3	-50.0	-46.0	-42.1	-35.5	-28.0	-17.8	- 1.3		
15	-26.3	-31.5	-36.1	-40.5	-44.7	-48.4	-50.8	-52.7	-53.8	-54.6	-54.0	-52.9	-48.5	-43.7	-37.7	-30.3	-20.0	- 1.8			
20	-34.6	-39.2	-43.4	-47.3	-50.5	-53.2	-54.9	-55.9	-56.6	-56.4	-55.1	-52.2	-46.2	-40.3	-31.7	-22.5	- 2.6				
25	-42.5	-46.8	-50.0	-53.3	-55.9	-57.3	-58.3	-58.7	-59.0	-57.2	-54.4	-49.5	-42.7	-33.7	-24.3	- 3.6					
30	-49.8	-53.4	-56.2	-58.7	-60.7	-61.3	-61.7	-61.1	-60.8	-56.8	-52.1	-44.6	-37.2	-25.6	- 4.8						
35	-56.5	-59.4	-61.8	-63.6	-65.0	-64.5	-64.5	-62.3	-59.8	-54.2	-47.0	-37.7	-27.8	- 6.3							
40	-62.4	-64.8	-66.5	-67.2	-68.1	-67.0	-65.9	-61.5	-56.0	-49.2	-39.2	-27.0	- 7.8								
45	-67.4	-69.2	-69.7	-69.8	-69.8	-68.3	-64.3	-57.6	-50.6	-41.2	-28.4	- 8.9									
50	-71.3	-72.1	-72.3	-71.6	-70.5	-67.0	-59.8	-52.3	-42.3	-28.5	- 9.4										
55	-74.2	-73.7	-72.9	-71.9	-70.0	-61.8	-53.5	-43.6	-29.6	- 9.5											
60	-76.1	-74.9	-73.5	-70.8	-64.1	-54.5	-44.3	-30.0	- 9.4												
65	-77.2	-74.5	-72.5	-65.7	-55.9	-44.5	-31.2	- 9.2													
70	-76.6	-72.8	-67.0	-57.5	-44.7	-30.5	- 9.0														
75	-73.5	-67.5	-57.2	-45.0	-30.0	- 8.6															
80	-67.0	-57.3	-44.2	-30.0	- 8.1																
85	-56.4	-43.5	-29.1	- 7.2																	
90	-40.8	-25.4	- 6.0																		
95	-21.6	- 3.8																			
100	- 0.0																				

TABLE 5 (a)

Specific heats (a) at 0°C of mixtures in the ternary system HNO_3 - H_2SO_4 - H_2O
Specific heat at t°C. = a + bt, where b is given in table + (b)

% H_2SO_4 \ % HNO_3	Specific heat of mixture at 0°C.																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	1.000	0.928	0.862	0.793	0.727	0.674	0.626	0.585	0.547	0.515	0.488	0.480	0.473	0.463	0.452	0.445	0.438	0.428	0.418	0.409	0.398
5	0.958	0.890	0.827	0.763	0.707	0.656	0.613	0.576	0.544	0.513	0.497	0.478	0.462	0.450	0.440	0.431	0.425	0.417	0.410	0.394	
10	0.919	0.847	0.785	0.730	0.677	0.632	0.590	0.561	0.525	0.502	0.484	0.469	0.451	0.438	0.430	0.417	0.413	0.405	0.392		
15	0.884	0.817	0.755	0.700	0.648	0.608	0.568	0.535	0.510	0.487	0.470	0.455	0.440	0.425	0.413	0.402	0.393	0.390			
20	0.849	0.778	0.719	0.667	0.620	0.582	0.548	0.517	0.493	0.473	0.455	0.440	0.428	0.414	0.402	0.394	0.388				
25	0.810	0.738	0.682	0.635	0.593	0.558	0.528	0.500	0.481	0.461	0.444	0.430	0.417	0.406	0.394	0.388					
30	0.773	0.704	0.653	0.608	0.573	0.540	0.510	0.490	0.471	0.453	0.436	0.425	0.410	0.402	0.388						
35	0.726	0.665	0.621	0.582	0.550	0.520	0.499	0.474	0.459	0.438	0.423	0.410	0.400	0.393							
40	0.680	0.632	0.591	0.558	0.530	0.503	0.480	0.456	0.440	0.423	0.409	0.397	0.388								
45	0.634	0.595	0.560	0.531	0.505	0.481	0.458	0.440	0.423	0.408	0.394	0.382									
50	0.591	0.560	0.533	0.506	0.482	0.460	0.439	0.423	0.409	0.397	0.388										
55	0.552	0.529	0.507	0.484	0.463	0.444	0.424	0.412	0.398	0.388											
60	0.519	0.502	0.484	0.463	0.446	0.430	0.416	0.400	0.388												
65	0.488	0.475	0.460	0.443	0.429	0.416	0.402	0.388													
70	0.460	0.448	0.436	0.424	0.412	0.402	0.388														
75	0.442	0.434	0.421	0.410	0.398	0.388															
80	0.437	0.418	0.406	0.400	0.387																
85	0.428	0.401	0.388	0.385																	
90	0.386	0.385	0.373																		
95	0.340	0.369																			
100	0.321																				

TABLE 5 (b)

Temperature corrections (b) for specific heats of mixtures in the ternary system HNO_3 - H_2SO_4 - H_2O. Specific heat at t°C = a + bt where a is given in table 4(a) and b is given below.

%HNO_3 / %H_2SO_4	Temperature correction for specific heat, b x 10^4																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	0	+ 5.0	+ 9.4	+14.5	+19.0	+22.0	+24.0	+24.3	+25.0	+25.3	+25.0	+20.5	+17.0	+15.1	+13.5	+11.1	+ 8.5	+ 6.7	+ 5.5	+ 4.3	+ 3.5
5	- 0.2	+ 3.8	+ 8.4	+12.6	+16.5	+18.2	+20.0	+20.0	+19.1	+17.3	+16.3	+14.8	+13.0	+11.8	+10.0	+ 8.6	+ 6.9	+ 5.5	+ 3.7	+ 2.7	
10	- 0.7	+ 3.2	+ 7.5	+11.0	+14.0	+15.2	+15.3	+15.0	+14.3	+13.2	+12.2	+11.1	+10.0	+ 9.0	+ 8.0	+ 6.9	+ 5.5	+ 4.3	+ 2.5		
15	- 1.4	+ 2.5	+ 6.5	+ 9.3	+11.5	+12.2	+12.0	+12.0	+11.4	+10.5	+ 9.5	+ 9.1	+ 8.5	+ 8.0	+ 7.2	+ 6.1	+ 4.1	+ 3.0			
20	- 2.0	+ 1.8	+ 5.6	+ 7.8	+10.0	+ 9.6	+ 9.2	+ 9.4	+ 9.0	+ 8.4	+ 7.8	+ 7.7	+ 7.6	+ 7.5	+ 6.5	+ 5.4	+ 2.8				
25	- 1.9	+ 1.4	+ 4.3	+ 5.7	+ 7.6	+ 7.7	+ 8.1	+ 8.1	+ 7.8	+ 7.4	+ 7.0	+ 6.8	+ 6.7	+ 6.3	+ 5.5	+ 4.7					
30	- 1.6	+ 1.1	+ 3.2	+ 4.7	+ 5.8	+ 6.5	+ 6.9	+ 7.0	+ 6.9	+ 6.5	+ 6.3	+ 6.0	+ 5.7	+ 5.1	+ 3.6						
35	- 0.3	+ 0.5	+ 1.5	+ 3.1	+ 4.0	+ 4.1	+ 4.6	+ 4.7	+ 4.6	+ 4.4	+ 4.2	+ 4.0	+ 3.9	+ 2.6							
40	+ 0.6	+ 0.0	0.0	+ 2.0	+ 2.8	+ 2.7	+ 2.5	+ 2.3	+ 2.2	+ 2.2	+ 2.1	+ 2.0	+ 2.0								
45	+ 1.4	+ 0.5	0.0	+ 1.4	+ 2.2	+ 2.5	+ 2.3	+ 1.9	+ 1.5	+ 1.2	+ 1.0	+ 0.6									
50	+ 2.2	+ 1.0	- 0.1	+ 0.7	+ 1.6	+ 2.2	+ 2.0	+ 1.5	+ 0.8	+ 0.2	+ 0.2										
55	+ 3.0	+ 1.3	- 0.2	+ 0.4	+ 1.0	+ 1.5	+ 1.6	+ 1.1	+ 0.5	+ 0.0											
60	+ 3.6	+ 1.6	- 0.3	+ 0.1	+ 0.5	+ 0.9	+ 1.2	+ 0.7	+ 0.2												
65	+ 4.5	+ 2.1	- 0.4	- 0.1	+ 0.2	+ 0.2	+ 0.8	+ 0.4													
70	+ 5.9	+ 2.7	- 0.5	- 0.3	- 0.2	0.0	+ 0.4														
75	+ 5.9	+ 2.0	- 0.6	- 0.4	- 0.4	- 0.2															
80	+ 4.4	+ 1.3	- 0.7	- 0.6	- 0.6																
85	+ 2.9	+ 1.5	- 0.8	- 0.8																	
90	+ 4.3	+ 1.7	- 0.9																		
95	+ 5.0	+ 1.5																			
100	+ 4.8																				

TABLE 6

Boiling points of mixtures in the ternary system HNO_3 - H_2SO_4 - H_2O
(under one atmosphere pressure)

% HNO_3 / % H_2SO_4	Boiling Points °C.																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	100.0	100.5	101.0	102.0	103.5	105.5	108.0	110.0	112.5	114.5	116.5	118.5	120.0	121.5	121.5	119.0	115.5	108.5	102.0	95.0	86.0
5	100.5	101	102	103	105	107	110	112	114	116	118	120	121	120	118	113	108	100	93	84	
10	101.4	102	103	105	107	110	112	114	117	119	120	121	121	118	113	107	100	92	82		
15	102.3	103	105	107	109	112	115	117	119	121	121	120	117	112	106	100	92	82			
20	103.4	105	107	109	112	115	118	120	121	122	122	119	114	107	100	92	82				
25	105	107	110	113	115	118	120	122	122	121	118	113	107	100	93	83					
30	107	110	114	117	119	121	122	123	122	119	114	107	101	93	83						
35	109	114	117	120	122	123	123	121	118	113	108	101	94	85							
40	113	118	121	124	126	126	124	119	114	108	102	96	87								
45	118	123	127	130	129	124	120	114	108	102	96	89									
50	123	128	134	135	132	123	116	109	103	97	90										
55	130	136	138	135	127	117	111	104	96	90											
60	140	144	143	134	121	112	106	100	90												
65	151	153	144	128	116	109	102	95													
70	167	162	144	122	112	106	98														
75	185	163	139	118	110	102															
80	206	164	133	114	107																
85	232	169	127	116																	
90	266	175	121																		
95	306	152																			
100																					

TABLE 7

Composition of vapours in equilibrium with boiling mixtures in the ternary system HNO_3 - H_2SO_4 - H_2O

Liquid Compn.	Composition of Vapour in Equilibrium with the Boiling Acid % HNO_3																				
% HNO_3 / % H_2SO_4	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	-	0.1	0.2	0.5	1.0	2.2	4.0	7.2	11.8	17.5	25.9	35.4	46.4	59.8	75.0	85.5	92.5	96.5	98.5	99.5	100
5	-	0.2	0.6	1.2	2.0	4.0	7.0	11.2	17.5	25.0	36.0	49.5	63.0	76.0	86.0	92.5	97.0	98.5	99.5	100	
10	-	0.7	1.5	2.5	4.0	6.3	9.8	16.0	24.0	37.0	51.5	65.0	77.5	87.0	93.5	97.0	99.0	99.5	100		
15	-	0.9	1.7	3.3	5.5	8.5	14.0	23.0	37.5	52.0	66.5	78.5	87.5	94.0	96.5	98.0	99.5				
20	-	1.0	2.2	4.3	7.0	11.5	21.0	38.0	55.0	69.0	80.5	88.5	95.0	97.5	98.5	99.5					
25	-	1.2	2.6	5.5	9.5	19.5	36.5	54.0	68.0	80.0	90.0	95.5	98.0	99.0	99.5						
30	-	1.4	3.5	7.5	15.5	36.5	54.5	68.5	81.0	90.5	96.0	98.0	99.0	99.5							
35	-	2.2	5.0	11.5	32.5	52.0	68.5	81.5	91.0	96.0	97.5	99.0	99.5								
40	-	3.0	8.0	25.5	50.0	68.5	82.0	90.0	94.5	97.5	98.5	99.5									
45	-	4.2	15.5	46.5	68.0	83.0	93.0	96.5	98.5	99.5	99.5										
50	-	7.0	37.0	64.5	82.5	92.5	97.5	99.0	99.5												
55	-	15.5	59.5	80.0	92.0	97.0	99.0	99.5													
60	-	37.5	74.5	90.0	96.5	98.5	99.5														
65	-	63.5	80.0	95.5	98.0	99.5															
70	-	76.0	92.0	98.0	99.5																
75	-	86.5	97.0	99.0																	
80	-	92.5	98.5	99.5																	
85	-	96.5	99.5																		
90	-																				
95	-																				
100	-																				