literature value in addition to variations for samples of the same material.

RESULTS

The heat capacities (average of two determinations) for the hydrocarbon fuels investigated with the apparatus and procedure adopted for this study are listed in Table II using diphenyl ether as the reference fluid. Included in this table are density and viscosity data for each organic liquid evaluated by accepted standard techniques. Recently, Belenyessy *et. al.*[1] reported the experimentally determined heats of combustion for many of these complex saturated hydrocarbons and demonstrated the applicability of the Handrick method for correlating such heats of combustion.

In addition to compounds of miscellaneous structures, the major hydrocarbon groups investigated were: cyclohexanes, bicyclohexyls, tercyclohexyls, decalins and hydrindans. The purity of these compounds was established by gas chromatography and reported in the literature (*1*).

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LITERATURE CITED

(1) Belenyessy, L.I., Gudzinowicz, B.J., Reid, R.C., Smith, J.O., J. CHEM. ENG. DATA **7**, 66 (1962).
(2) Blacet, F.E., Leighton, P.A., Bartlett, E.O., *J. Phys. Chem.* **35**, 1935 (1931).
(3) Furukawa, G.T., Ginnings, D.C., McCoskey, R.E., Nelson, R.A., *J. Res. Natl. Bur. St.* **46**, 195 (1951).
(4) Ginnings, D.C., Furukawa, G.T., *J. Am. Chem. Soc.* **75**, 522 (1953).
(5) Hough, E.W., Mason, D.M., Sage, B.H., *Ibid.*, **72**, 5775 (1950).
(6) Osborne, N.S., Ginnings, D.C., *J. Res. Natl. Bur. St.***39**, 453 (1947).
(7) Porter, R.S., Johnson, J.F., J. CHEM. ENG. DATA **3**, 272 (1958).
(8) Spear, N.H., *Anal. Chem.* **24**, 938 (1952).
(9) Thompson Products, Inc. Cleveland, Ohio, Project 817, Rep. No. Ing. Er. 206, "Study of the Vaporization Cycle and Thermodynamic Properties of Petroleum Type Fuels," January 1958.

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Thermodynamic Properties of Inorganic Substances

VI. The High Temperature Heat Contents of Chromel-P and Alumel

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The heat contents of Chromel-P and Alumel, contained in platinum capsules, have been determined with a copper-block drop-type calorimeter. The results are represented by two equations. Thermodynamic functions are presented at 100° K. intervals.

IT IS OF INTEREST to know the high temperature thermodynamic properties of Alumel and Chromel-P, since these alloys are now extensively used in industry both as heaters and as thermocouples. No experimental data on heat contents for these materials were previously available at high temperature.

EXPERIMENTAL

The copper-block drop-type calorimeter, described previously by Margrave and Grimley (*2, 5*), has been used to determine high temperature thermodynamic data for a variety of inorganic substances (*3, 6, 7*). The apparatus has been calibrated electrically, and, in addition, samples of synthetic sapphire from the National Bureau of Standards have been run for comparison purposes (*2, 7*).

The samples of Chromel-P and Alumel were manufactured by the Hoskins Mfg. Co., Detroit, Mich. Chromel-P contains approximately 90% Ni and 10% Cr, while the composition of Alumel is approximately 72% Ni, 25% Mn, 2% Al, and 1% Si. Platinum capsules were used as containers in all of the measurements, and no evidence of reaction was noted. Data from the calorimeter have been processed on a CDC-1604 computer with a modified version of the program developed by Tilleux (*8*).

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RESULTS

The experimental results are summarized in Tables I and II. A least-squares fit of the experimental data provided the following equations for the high temperature heat content and the heat capacity for Chromel-P:

$$H_T - H_{298} = 0.08954\ T + 2.137 \times 10^{-5} T^2 - 28.60 \text{ cal./gram}$$

$$(\pm 0.8 \text{ cal./gram}; 403° < T° < 1378° \text{K.})$$

and

$$C_p = 0.08954 + 4.274 \times 10^{-5}\ T \text{ cal./gram/° K.}$$

Table I. Experimental Heat Contents for Chromel-P

T_1, Furnace ° K.	T_2, Calorimeter Temp., ° K.	$H_{T_1} - H_{T_2}$ Cal./Gram
402.96	298.79	11.31
413.86	298.70	12.86
497.81	299.06	21.68
514.86	299.13	23.69
610.96	299.24	34.48
626.01	299.24	35.32
740.36	299.34	50.51
835.96	299.66	59.70
859.76	299.67	63.89
964.36	299.88	76.47
967.06	300.06	78.16
1049.26	300.19	89.12
1100.36	300.21	94.11
1154.96	300.44	103.36
1177.56	300.36	106.95
1273.96	300.69	120.28
1303.86	300.47	122.95
1378.66	300.81	136.31

Table II. Experimental Heat Contents for Alumel

T_1, Furnace Temp., ° K.	T_2, Calorimeter Temp., ° K.	$H_{T_1} - H_{T_2}$ Cal./Gram
398.56	298.84	11.77
506.76	298.91	24.51
625.46	299.18	38.81
744.76	299.36	52.59
848.56	299.66	64.70
979.46	299.92	80.12
1097.06	300.04	96.64
1163.66	300.26	103.80
1263.06	300.45	117.43
1322.06	300.58	126.19

Similarly, the high temperature heat content and heat capacity of Alumel may be represented by the following equations:

$$H_T - H_{298} = 0.1081\,T + 8.981 \times 10^{-6} T^2 - 33.03 \text{ cal./gram}$$

$$(\pm 0.7 \text{ cal./gram}; 398° < T° < 1322° \text{K.})$$

$$C_p = 0.1081 + 1.796 \times 10^{-5} T \text{ cal./gram/° K.}$$

These equations have been used to calculate thermodynamic properties at 100° K. intervals, and the results are presented in Tables III and IV.

Table III. High Temperature Thermodynamic Functions for Chromel-P

Temp., ° K.	$H_T - H_{298}$, Cal./Gram	C_p, Cal./Gram/° K.	$S_T - S_{298}$, Cal./Gram/° K.
298.15	0	0.1023	0
300	0.19	0.1024	0.0006
400	10.64	0.1066	0.0307
500	21.52	0.1109	0.0549
600	32.82	0.1152	0.0755
700	44.55	0.1195	0.0936
800	56.71	0.1237	0.1098
900	69.30	0.1280	0.1246
1000	82.31	0.1323	0.1384
1100	95.75	0.1366	0.1512
1200	109.62	0.1408	0.1632
1300	123.92	0.1451	0.1747
1400	(139)	(0.149)	(0.186)
1600	(169)	(0.158)	(0.206)

Table IV. High Temperature Thermodynamic Functions for Alumel

Temp., ° K.	$H_T - H_{298}$, Cal./Gram	C_p, Cal./Gram/° K.	$S_T - S_{298}$, Cal./Gram/° K.
298.15	0	0.1134	0
300	0.21	0.1135	0.0007
400	11.65	0.1153	0.0336
500	23.26	0.1171	0.0595
600	35.06	0.1189	0.0810
700	47.04	0.1207	0.0995
800	59.19	0.1225	0.1157
900	71.53	0.1243	0.1302
1000	84.05	0.1261	0.1434
1100	96.74	0.1279	0.1555
1200	109.62	0.1296	0.1667
1300	122.67	0.1314	0.1772
1400	(136)	(0.133)	(0.187)
1600	(163)	(0.137)	(0.205)

DISCUSSION

The only value available for the heat capacity of Chromel-P (90% Ni-10% Cr) is 0.107 cal./gram/° K. at 293.15° K. (*4*). This is close to the extrapolated value, 0.1023 cal./gram/° K. at 298.15° K. from this work. The specific heat of an 80% Ni-20% Cr alloy has been measured by Douglas and Dever (*1*) from 293° to 1173° K. and found to vary from 0.1033 to 0.1563 cal./gram/° K. The specific heat of Chromel-P varies from 0.1023 to 0.1408 cal./gram/° K. between 298° and 1200° K. as shown in Table III. The specific heats of the elements Ni and Cr vary from 0.1055 to 0.1415 cal./gram/° K. and 0.1059 to 0.1440 cal./gram/° K., respectively. Thus, the experimental values for Chromel-P and for 80% Ni-20% show that one can calculate the heat contents for the alloys to ±5–10% by using the data for the pure elements.

The only value for the specific heat of Alumel (*4*) is 0.125 cal./gram/° K. at 293.15° K. The specific heat extrapolated from the experimental data is found to be 0.1134 cal./gram/° K. at 298.15° K. and increases to 0.1296 cal./gram/° K. at 1200° K. Since the composition of Alumels may vary, it is difficult to compare the extrapolated value with that given, but the difference could arise, in part, from a C_p equation which does not fit well at $T < 400°$ K.

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LITERATURE CITED

(1) Douglas, T.B., Dever, J.L., *J. Research Natl. Bur. Standards* **54**, 15 (1955).
(2) Grimley, R.T., Ph.D. Thesis, University of Wisconsin, 1958.
(3) Grimley, R.T., Margrave, J.L., *J. Phys. Chem.* **64**, 1763 (1960).
(4) Hoskins Mf. Co., Detroit, Mich., Catalog M-56C-A-2500, 1962.
(5) Margrave, J.L., Grimley, R.T., *J. Phys. Chem.* **62**, 1436 (1958).
(6) Mezaki, R., Margrave, J.L., *Ibid.*, **66**, 1713 (1962).
(7) Mezaki, R., Tilleux, E.W., Barnes, D.W., Margrave, J.L., Paper SM-26/48, Proc. Conf. Thermodynamics Nuclear Materials, Vienna, Austria, May 1962.
(8) Tilleux, E.W., M.S. thesis, University of Wisconsin, 1963.

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