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California Institute of Technology

Pasadena, California

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THE SPECIFIC HEAT CAPACITY
OF
HEAVY PETROLEUM PRODUCTS

Thesis

by

Paul R. Ames

In partial fulfillment of the requirements

for the degree of Bachelor of Science

in Chemical Engineering.

CALIFORNIA INSTITUTE OF TECHNOLOGY

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CONTENTS

THE SPECIFIC HEAT CAPACITY OF HEAVY PETROLEUM PRODUCTS

The Specific Heat Capacity of a substance is defined, in metric units, as the quantity of heat energy necessary to raise the temperature of one gram of the substance one degree centigrade without changing its state. This quantity of heat energy is the same as that transferred to the surroundings when one gram of the substance is cooled thru one degree centigrade. In the English units, this would be the quantity of Heat energy necessary to raise one pound of the substance thru one degree Fahrenheit.

When a substance is heated the energy added is partially utilized in increasing the translatory motion of the molecules and in overcoming the attractive forces between them. When the heating is carried on at constant volume, no external work is done but if constant pressure is maintained, external work will be done due to the change in volume against this pressure , thereby using additional heat. Because of this fact, it is necessary to designate whether the value for the specific heat capacity of the substance is obtained at constant volume or at constant pressure. The two values are distinguished by c_v and c_p respectively and it has been found that the latter can be calculated from the former by the formula

$$c_p = c_v + \frac{T\alpha^2}{BD}$$

where ($\alpha = \frac{1}{v} \quad \frac{(dv)}{(dT)\,p}$ is the coefficient of cubical expansion and

($B = \frac{1}{v} \left(\frac{dv}{dp}\right)_T$ is the coefficient of compressibility and D is the density of the substance in grams per cubic centimeter, all at the absolute temperature T. (1)

For ordinary calorimetry the value c_p is usually taken as it is more easily determined in the calorimeter.

In heating monatomic gases the heat energy would all be utilized as mentioned above, but in the case of substances which will dissociate under the prevailing conditions into simpler molecular or atomic aggregates, there is an added absorption of energy when the dissociation takes place. It has been found that for non-associating liquids, within a comparatively small temperature range in which the system is stable, the curve of the values of c_p plotted against the absolute temperature is a straight line. With associating liquids, however, the dissociation requires some heat energy and it has been found that the value of c_p for these liquids is not a linear function of the temperature T.

Crude petroleum, as it comes from the ground, is composed of a great many hydrocarbons of the saturated, unsaturated, and aromatic series which may be separated by various methods of fractionation into groups that are valuable for different purposes. In all the methods of refining crude oil, proper heating and cooling of the materials used and of those produced are of the highest importance. In order that the separation may be carried out most economically a knowledge of the quantity of heat necessary to cause a given temperature rise in the material under consideration is essential. For instance, when

(1) Washburn, Principles of Physical Chemistry, Chap. 20.

gasoline is fractionated from the other materials in crude oil steam is sometimes used as the source of heat, and in building a plant it would be desirable to know how much steam would be necessary to raise the temperature of the oil being fractionated to the temperature at which the gasoline would be distilled off. Or, in the separation of paraffin from the fractions containing this substance, it would be valuable to know how much heat would be given up by the oil in cooling to the point at which the paraffin may be removed.

A third example in which this knowledge would be of interest is the preheating of crude oil before it eneters the still, with the hot residuum leaving the still. The present investigation was undertaken in order to obtain specific heat data for use in connection with this last problem. The heat exchange is affected by passing the crude oil thru tubes surrounded by a pipe in which the hot residuum from the still is flowing in the opposite direction. In order that as much as possible of the heat which the residuum contains may be utilized, and in order that the crude oil may be heated to the desired temperature, it is necessary, in designing the interchanger, to consider the quantity of heat that can be withdrawn from the residuum as it cools from its original temperature to its outlet temperature.

PREVIOUS WORK

Most of the experimental work which has been done on the determination of the specific heat of mineral oils has been done for the purpose of obtaining data which would be of value in the recovery of paraffin from the heavy fractions of these oils. As a result, the majority of the determinations have been made at low temperatures. The following results, obtained by Bartoli and Stracciati,(1) were among the first data published in regard to the specific heat of the paraffin hydrocarbons obtained from an American crude oil.

SPECIFIC HEAT OF HYDROCARBONS FROM AN AMERICAN CRUDE OIL

	B.P.	Sp.Gr.	Sp.Ht.	at t°C.
C_5H_{12}	30°C.	0.6402	-	-
C_6H_{14}	68	0.6950	0.5042	16-37
C_7H_{16}	92- 94	0.7328	0.4842	17-50
C_7H_{16}	92- 94	0.7303	0.4869	18-51
C_8H_{18}	116-118	0.7463	0.5111	12-19
C_9H_{20}	136-138	0.7624	0.5015	13-18
$C_{10}H_{22}$	158-162	0.7711	0.5058	14-18
$C_{11}H_{24}$	180-182	0.7817	0.5032	14-19
$C_{12}H_{26}$	198-200	0.7915	0.5065	14-20
$C_{13}H_{28}$	218-220	0.8017	0.4987	15-21
$C_{14}H_{30}$	236-240	0.8130	0.4995	14-21
$C_{15}H_{32}$	258-262	0.8224	0.4991	15-22
$C_{16}H_{34}$	278-282	0.8287	0.4964	15-22

---

(1) Das Erdöl - Engler & Höfer Vol.1, p. 90

Similar, but probably more extensive investigations were carried out by Maybery and Goldstein (1) in 1902 with the result that the following data were obtained :

SPECIFIC HEAT OF HYDROCARBONS OF THE PARAFFIN SERIES BETWEEN THE TEMPERATURES OF 0° AND 50°

	B.P.	Sp.Ht.		B.P.	Sp.Ht.
C_6H_{14}	68°C.	0.5272	$C_{11}H_{24}$	195	0.5013
C_7H_{16}	91	0.5005	$C_{12}H_{26}$	214	0.4997
C_7H_{16}	98	0.5074	$C_{13}H_{28}$	226	0.4986
C_8H_{18}	125	0.5052	$C_{14}H_{30}$	242	0.4973
C_9H_{20}	151	0.5034	$C_{15}H_{32}$	260	0.4966
$C_{10}H_{22}$	162	0.4951	$C_{16}H_{34}$	275	0.4957
$C_{10}H_{22}$	172	0.5021	Commercial Gasoline		0.5135

SPECIFIC HEAT OF HYDROCARBONS OF THE METHYLENE SERIES BETWEEN THE TEMPERATURES OF 0° AND 50°

	B.P.	Sp.Ht.		B.P.	Sp.Ht.
C_6H_{12}	68°C	0.5062	$C_{11}H_{22}$	190	0.4819
C_7H_{14}	98	0.4879	$C_{12}H_{24}$	212	0.4570
C_8H_{16}	119	0.4863	$C_{13}H_{26}$	232	0.4573
C_9H_{18}	135	0.4851	$C_{14}H_{28}$	244	0.4531
$C_{10}H_{20}$	160	0.4692	$C_{15}H_{30}$	263	0.4708

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(1) C.F.Maybery and A.H.Goldstein, Am.Chem.J. Vol. 28 (1902) 67 - 74

SPECIFIC HEAT OF HYDROCARBONS OF THE SERIES C_nH_{2n}

	B.P.	Sp.Ht.
$C_{16}H_{32}$	173°C	0.4723
$C_{18}H_{36}$	202	0.4723
$C_{20}H_{40}$	223	0.4706
$C_{23}H_{46}$	260	0.4612
$C_{24}H_{48}$	272	0.4586

The above tables show, to some extent, the relation between the specific heat and the physical properties of the substance. It will be noted that in the same series the specific heat seems to decrease with an increase in the molecular weight. Also, that the more unsaturated hydrocarbons show lower specific heat values than the paraffin series.

The specific heat of the following crude oils from different fields were also obtained by these investigators.

SPECIFIC HEAT OF CRUDE OILS

	Sp.Gr.	Sp.Ht.
Pennsylvania	0.8095	0.5000
Berea Grit	0.7939	0.4690
Japanese	0.8622	0.4532
Texas (Lucas Well)	0.9200	0.4315
Russian	0.9079	0.4355
Wyoming	0.8816	0.4323
California	0.9600	0.3980
Texas	0.9466	0.4009
O hio	---	0.4951

In attempting to determine the value of the specific heat of California Petroleums, H. E. Wales (1) compared the electrical method with the modified Regnault's method. In the former method, the sample was placed in a calorimeter and the specific heat value was determined by noting the temperature rise per calorie of electrical energy put into the system. In the latter method, a metal weight was heated in a condenser by means of steam and the temperature change produced by dropping this weight into a sample of oil was noted.

It was found that the electrical method, the results of which checked within about 2 to 5 per cent, was the less sensitive.

The results of the analysis and the specific heats of twelve samples may be seen in the following table :

Sample Number	H_2O	0-150°C.	150-300°C.	300°C.	Asphalt	Sp.Ht. at 20°C.
			Per Cent Distillate			
1	0.0	-	-	-	-	0.3999
2	0.33	-	-	-	-	0.4143
3	0.52	-	-	-	-	0.4389
4	7.0	5.7	23.14	32.1	31.7	0.5016
5	1.3	0.0	37.4	30.0	30.91	0.4788
6	0.0	35.6	54.1	4.2	6.2	0.4804
7	0.0	8.1	27.3	39.7	23.5	0.4474
8	0.0	25.8	43.3	22.1	7.0	0.4832
9	0.0	0.0	12.3	48.7	36.3	0.4419
10	0.0	0.0	22.5	42.3	34.7	0.4553
11	6.2	0.0	30.9	22.6	39.9	0.4559
12	0.0	0.0	34.1	30.2	35.4	0.4491

---

(1) J.of Ind. & Eng.Chem. Vol. 6, No.9, Sept. 1914, p. 727

Samples 1, 2 and 3 were oils containing only fractions above 300°C. Mr. Wales states that the results seem to indicate that with an increase in asphalt content, the specific heat of the sample decreases and that an increase in the water content causes an increase in the specific heat. From these twelve samples the average specific heat of California crude oils is 0.4500.

The investigations previously referred to have been made at temperatures below 50°C. and are not very valuable for use in connection with interchanger design where the temperature of the oil reaches 250°C. or higher. In 1920, Bailey & Edwards (1) did some experimental work on the specific heat of a sample of mineral oil at temperatures varying from 20° to 250°C. These observers attempted to obtain this data both by using the electrical method, mentioned above, and the method of mixtures. The latter method consists of heating a sample of known specific heat to a predetermined temperature, adding this to the sample of oil and noting the initial and final temperatures of the oil. The electrical method was found to be more satisfactory. The results obtained by Bailey and Edwards are as follows:

SPECIFIC HEAT OF A MINERAL OIL AT DIFFERENT TEMPERATURES

Temperature °C.	Specific Heat
50	0.476
120-140	0.543
140-160	0.565
160-180	0.577
180-200	0.591
215-235	0.630

---

(1) Bailey & Edwards - J.of Ind.Eng.Chem. Vol.12, No.9 (Sept.1920) page 891

The above data, when plotted, give practically a straight line.

PROCEDURE

A sample of the residuum resulting from a distillation up to 271°C., was obtained from the crude oil stills at the Los Angeles Refinery of the Union Oil Co. of California, on October 10th, 1921. About 300 grams of this sample was placed in an insulated apparatus in which it could be stirred by a constant speed stirrer, and a known amount of heat energy was added by means of an electrical resistance coil. The resulting temperature change at various temperatures was noted and the specific heat of the sample was calculated from these data. By making a series of these determinations at various temperatures it was hoped that a relation between the temperature and the specific heat of the sample might be obtained.

The apparatus shown in the accompanying figure (Fig.1, page 10) was used in the determinations of the specific heat of the sample under consideration. It consisted of a Dewar flask (a), with a wooden cover thru which the stirring rod (b), the thermometer (c) and the lead wires (d) to the heating coil (e) pass. The stirrer (b) was a piece of glass rod so bent that when it was rotated it stirrred the liquid both above and below the heating coil. The stirrer was run at a constant rate from a belt attached to a motor. The sample was heated by means of the resistance coil (e) wound on an annular glass core and thru which a direct current from a storage battery passed. The wiring diagram is shown in Fig. 2, page 10. The resistance coil was connected to the voltmeter (v) by means of heavy copper wires, in order that the voltage drop between

Electrically Heated Calorimeter for use in the Determination of the Specific Heat of Residuum

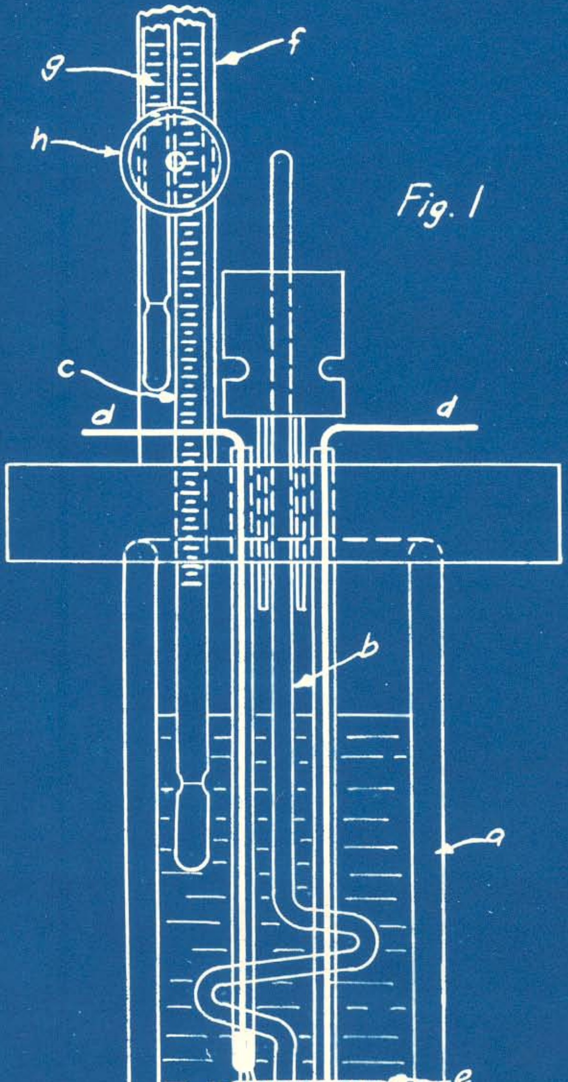


Fig. 1

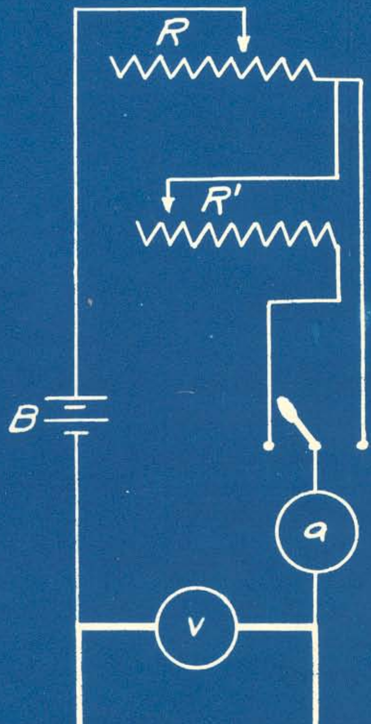


Fig. 2

the coil and the voltmeter might be negligible. The current passing thru the circuit could be varied by adjusting the resistances R and R' and could be read by means of the ammeter (a). The temperature was read thru a magnifying reading glass on the thermometer (c), the bulb of which dipped beneath the surface of the liquid. The stem of the thermometer was surrounded by a piece of glass tubing (f) in which a second thermometer (g) was hung in order to determine the average temperature of the exposed mercury thread. The readings of the latter thermometer were for use in calculating the stem correction for the former thermometer at high temperatures.

In order to obtain the specific heat of the residuum, it was first necessary to determine the water equivalent of the apparatus, or the quantity of heat necessary to raise the temperature of the apparatus thru one degree centigrade. This value was obtained by placing a weighed quantity of distilled water in the apparatus, heating this water and the apparatus thru a known temperature change and noting the quantity of electrical energy necessary to produce this change. Since the apparatus was at a higher temperature than its surroundings, during the experiments, it was also necessary to determine the quantity of heat energy transferred from the apparatus to the surroundings. Two methods were used to determine this correction for heat dissipation during the runs. The first was the electrical method, in which the temperature of the apparatus and its contents were held constant at the average temperature of the run by passing a steady current thru the coil; the electrical energy required for this purpose being noted. In using this method, the apparatus and oil were heated thru from three to five degrees centigrade, the dissipation correction was determined, and the apparatus was again heated thru an equal increment of temperature.

The second method was to shut off the current and to note the rate at which the temperature of the apparatus fell. In determining the dissipation loss by this method the apparatus and its contents were allowed to cool after each of the heating periods until they reached the initial temperature of that period and the average of the rates of change of the temperature during the two cooling periods was taken, or else they were allowed to cool from the final temperature of the run to the initial temperature of the run and the rate of change over this period was noted. In all cases the stirring was continued at the same rate thruout the complete runs. By using these methods of determination of the dissipation loss, the heat of vaporization of the sample was partially accounted for since the sample was vaporizing at practically the same rate while the correction was being determined as it was during the heating period.

Since the specific heat of distilled water has been accurately determined at different temperatures, it is possible to calculate the energy necessary to raise the water thru a given temperature range. By subtracting this quantity and the dissipation loss from the total amount of energy added to the system, the energy necessary to raise the temperature of the apparatus thru that temperature range or thru one degree could be calculated.

In the first attempt to determine the water equivalent of the apparatus, a piece of No. 26 "Advance" resistance wire was used as the heating element. It was found, however, that there was appreciable electrolysis between the alloy and the water, and a light colored precipitate was formed after the current had been turned on a short time. It was found necessary, therefore, to replace the "Advance" resistance wire by a three foot length of No. 36 platinum wire. The ends of the latter were sealed into the ends of two pieces of glass tubing which were used as conduits for the copper leads. The electrical contact between the copper and the platinum was made by means of a small amount of mercury in the bottom of each tube.

After determining the water equivalent of the apparatus, the distilled water was replaced by weighed quantities of residuum and the specific heat capacities of the latter were determined by similar procedures at temperatures between 20° and 160°C.

TABLE - 1

WATER EQUIVALENT OF APPARATUS

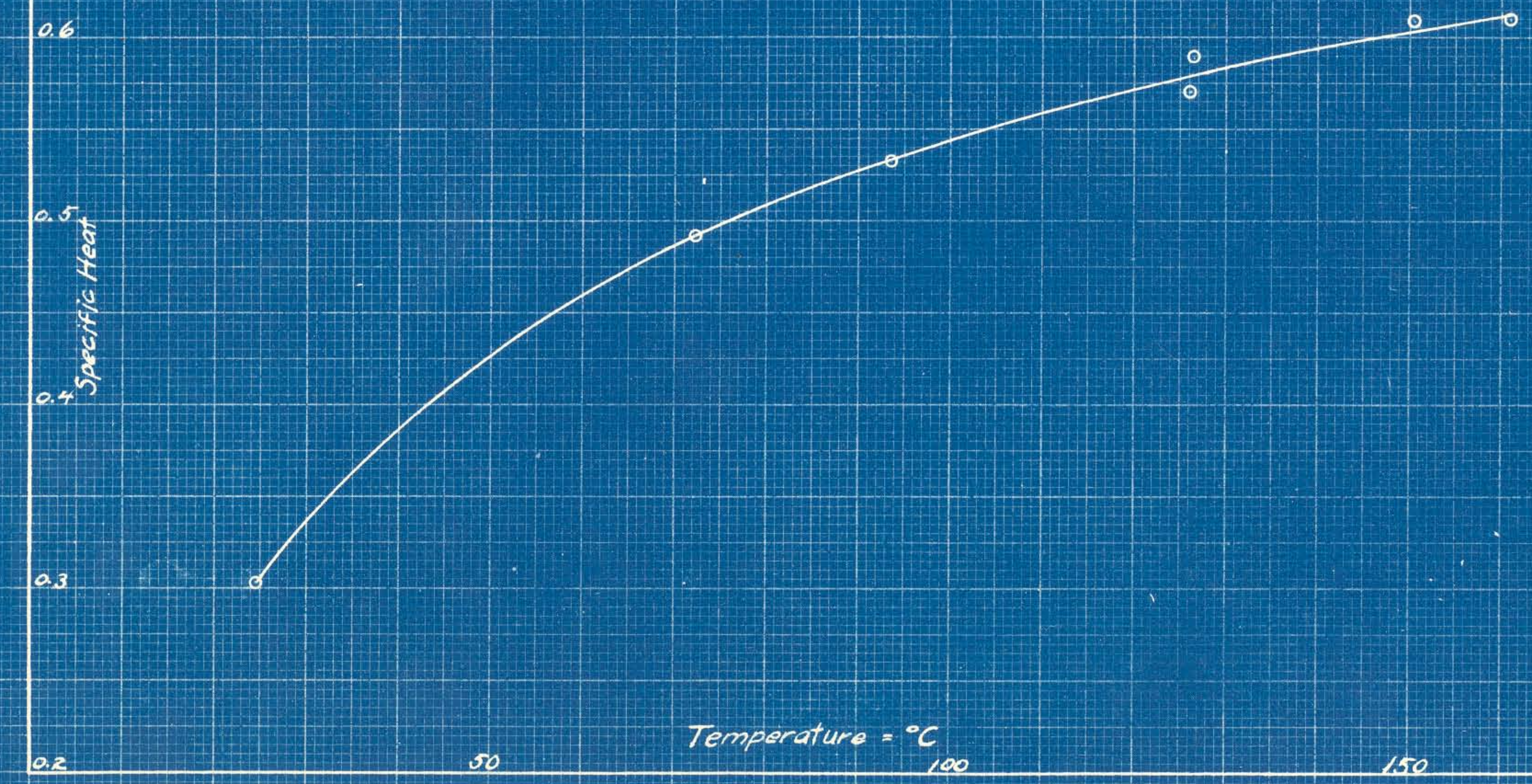
Run No.	Room Temp.	During Heating			Dissipation Correction			Wt. of Water	ΔT	Aver. Temp.	Water Equiv. of Apparatus E.
		Aver. Volts	Average Amperes	Time	Volts	Amperes	Time				
	°C.			Min.			Min.	Grams	°C.	°C.	Grams
1	24.2	9.27	1.424	24	1.35	0.202	25.5	301.9	13.91	29.3	20.0
2	22.5	8.45	1.408	24	1.10	0.183	25.5	304.6	12.37	25.9	20.6
3	21.5	8.34	1.396	24	1.02	0.175	25.5	305.5	12.10	24.3	20.3
4	21.5	8.75	1.381	24	1.75	0.261	25.5	302.4	12.35	30.6	20.7
							Average				20.4

T A B L E - 2

SPECIFIC HEAT OF PETROLEUM RESIDUUM

Run No.	Room Temp. °C.	During Heating Aver. Volts	During Heating Aver. Amperes	During Heating Temp. increase per minute °C.	During Cooling Temp. decrease per minute °C.	Wt. of Sample Grams	Aver. Temp. °C.	Sp.Ht. Cal/g°C.
10	21.5	4.01	0.608	0.276	0.036	303.8	24.5	0.302
9	20.6	6.52	0.901	0.316	0.194	293.9	72.3	0.493
10-A	24.2	7.51	0.969	0.304	0.269	303.8	93.4	0.533
11	24.2	9.52	1.193	0.450	0.389	305.3	126.1	0.570
11-A	25.2	9.71	1.200	0.437	0.397	305.3	126.7	0.589
12	-	10.15	1.142	0.390	0.525	265.3	150.5	0.609
12-A	-	10.23	1.142	0.324	0.605	265.3	161.0	0.604

Curves Showing the Relation Between the Specific Heat and the Temperature of a Sample of Residuum.



DATA

The tables shown on Pages 15 and 16 give the results obtained for the water equivalent of the apparatus (E) and the specific heat of the sample of residuum at the temperatures shown. The total data obtained thruout the test and an explanation of the method of calculation are shown in the appendix.

The curve shown on Page 17 shows the relation which was found to exist between the specific heat and the temperature of the sample of residuum.

The residuum was analyzed in the laboratory of the Union Oil Company and the following results obtained :

Sp. Gr. = .9490

H_2O = 0.10 %

Flash (Cleveland Open-Cup Fire-Tester) = 225°F.

Fire (" ") = 335°F.

Furol Viscosity

Temperature	Viscosity
100°F.	182 seconds
122°F.	84 seconds
150°F.	36 seconds
210°F.	15 seconds

Because of the fact that there was not sufficient time for further research on this subject, it was impossible to check the results shown above. Their applicability to engineering problems can only be determined by comparing the actual heat exchange in an operating unit with the heat exchange calculated for that unit from the specific heat as herein determined.

POSSIBILITIES OF FUTURE EXPERIMENTATION

The work covered in this report is merely a start in a field of investigation which offers a big opportunity for work of an original and valuable nature. The first consideration would, of course, be the means of obtaining greater accuracy than has been possible in the time available for this investigation. This would mean the development and calibration of a calorimeter which would overcome some of the difficulties encountered in the present work. For instance, the dissipation losses could be cut down considerably by surrounding the calorimeter with insulating material or with a second Dewar flask; the lag in the apparatus might be reduced by improving the stirring device and changing the heating element; the accuracy of the temperature readings might be increased by using a different type of thermometer, possibly of the electrical resistance or thermocouple types. A further consideration of, and possibly an improvement in, the means of accounting for the energy used in vaporizing a portion of the liquid at the temperature of the experiment would also be valuable. This would be particularly so if the temperatures were extended to higher values.

Upon consideration of the complexity of the material used in these experiments and the variation in the composition of samples from different sources it will be seen that extreme accuracy is not of paramount importance. It is desirable, however, to obtain, with fair accuracy, the specific heat of samples of petroleum products of different nature and produced under different conditions and to compare these data thruout the range of temperatures used in the refining of petroleum. If, for example, the specific heat of two samples, which were produced under very similar operating conditions, could be compared at various temperatures, it would be possible to ascertain the accuracy with which the curve shown on Page 17 could be applied to different samples of the material. It would be interesting also to ascertain the applicability of these data to samples from different fields and to samples of varying composition from the same field. By such comparisons, it might be possible to determine an approximate relation between the specific heat and the other physical properties of petroleum products.

SUMMARY

An electrically heated calorimeter was developed for the purpose of measuring the specific heat of petroleum products at different temperatures.

The specific heat of a sample from a heavy fraction of a California petroleum was found to increase from 0.3 to 0.6 with a temperature change from 25°C. to 150°C. The rate of this increase was more rapid at low temperatures than at higher temperatures.

APPENDIX

The following pages contain the data obtained in the determination of the water equivalent of the apparatus and the specific heat of the sample of petroleum residuum. The different means used in calculating the results from the data obtained are discussed for the purpose of showing the dependability of the results chosen.

RUN - 1

Nov. 30, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
3:20	22.62	9.10	1.415 (1)
:20.5		9.10	1.405
:21		9.05	1.403
:21.5		9.05	1.403
:22.		9.05	1.403
:22.5		9.04	1.402
:23.		9.02	1.401
:23.5		9.02	1.401
:24.		9.02	1.401
:24.5		9.02	1.401
:25.		9.02	1.401
:25.5		9.02	1.400
:26.		9.02	1.400
:26.5		9.02	1.399
:27.		9.02	1.399
:27.5		9.02	1.398
:28.		9.02	1.398
:28.5		9.02	1.398
:29.		9.02	1.398
:29.5		9.02	1.397
:30.		9.02	1.397
:30.5		9.02	1.395
:31.		9.02	1.394
:31.5		9.02	1.393
:32.			
:32.5	29.38		
:33.	29.39		
:34.	29.38		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
4:25.	29.25	9.55	1.459 (1)
:25.5		9.53	1.459
:26.		9.53	1.458
:26.5		9.52	1.457
:27.		9.52	1.456
:27.5		9.51	1.455
:28.		9.51	1.453
:28.5		9.51	1.452
:29.		9.51	1.451
:29.5		9.51	1.449
:30.		9.51	1.448
:30.5		9.51	1.447
:31.		9.51	1.445
:31.5		9.51	1.444
:32.		9.51	1.443
:32.5		9.51	1.442
:33.		9.51	1.442
:33.5		9.50	1.442
:34.		9.51	1.442
:34.5		9.51	1.441
:35.		9.51	1.441
:35.5		9.51	1.440
:36.		9.51	1.440
:36.5		9.51	1.440
:37.0			
:37.5	36.39		
:38.	36.38		
:38.5	36.37		
:39.	36.36		

---

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of water = 301.85 grams
Speed of stirrer = 183 R.P.M.
Average Room Temp. = 24.2°C.
Dissipation Loss = The temperature was held constant at 29.25°C. for 14 minutes with a voltage of 1.35 volts and a current of 0.202 amperes.

RUN - 2

Dec. 1, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
2:30.	19.61	8.49	1.425 (1)
:30.5		8.47	1.421
:31.		8.48	1.422
:31.5		8.48	1.421
:32.		8.47	1.420
:32.5		8.47	1.419
:33.		8.47	1.419
:33.5		8.45	1.418
:34.		8.43	1.415
:34.5		8.45	1.419
:35.		8.45	1.415
:35.5		8.43	1.419
:36.		8.45	1.419
:36.5		8.45	1.419
:37.		8.45	1.418
:37.5		8.45	1.417
:38.		8.43	1.410
:38.5		8.40	1.410
:39.		8.40	1.410
:39.5		8.42	1.410
:40.		8.45	1.415
:40.5		8.45	1.410
:41.		8.45	1.408
:41.5		8.45	1.407
:42.			
:42.5	25.82		
:43.	25.83		
:43.5	25.82		
:44.	25.82		
:45.	25.81		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
4:15.	25.85	8.45	1.401 (I)
:15.5		8.48	1.402
:16.		8.47	1.402
:16.5		8.47	1.401
:17.		8.48	1.401
:17.5		8.48	1.401
:18.		8.45	1.401
:18.5		8.45	1.401
:19.		8.45	1.401
:19.5		8.45	1.401
:20.		8.45	1.401
:20.5		8.45	1.401
:21.		8.45	1.399
:21.5		8.45	1.399
:22.		8.47	1.399
:22.5		8.45	1.399
:23.		8.45	1.399
:23.5		8.45	1.399
:24.		8.45	1.399
:24.5		8.45	1.399
:25.		8.45	1.398
:25.5		8.45	1.397
:26.		8.45	1.397
:26.5		8.45	1.397
:27.			
:27.5	32.00		
:28.	32.00		
:29.	31.98		

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(1) Current readings were taken 15 seconds after the voltage readings.

Weight of water = 304.61 grams

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 22.5°C.

Dissipation Loss - The temperature was held constant at 25.85°C. for 13 minutes using a voltage of 1.10 volts and a current of 0.183 amperes.

R U N - 3

Dec. 2, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
9:10.	18.20	8.45	1.419 (1)
:10.5		8.35	1.410
:11.		8.38	1.415
:11.5		8.38	1.408
:12.		8.38	1.408
:12.5		8.35	1.405
:13.		8.35	1.405
:13.5		8.30	1.402
:14.		8.30	1.402
:14.5		8.30	1.402
:15.		8.30	1.402
:15.5		8.35	1.402
:16.		8.35	1.402
:16.5		8.35	1.402
:17.		8.35	1.401
:17.5		8.30	1.401
:18.		8.30	1.401
:18.5		8.30	1.400
:19.		8.35	1.400
:19.5		8.35	1.399
:20.		8.30	1.399
:20.5		8.30	1.398
:21.0		8.30	1.398
:21.5		8.28	1.385
:22.			
:22.5	24.30		
:23.	24.32		
:23.5	24.30		
:24.	24.29		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
10:40.	24.30	8.40	1.400 (1)
:40.5		8.38	1.399
:41.		8.37	1.399
:41.5		8.35	1.397
:42.		8.35	1.397
:42.5		8.35	1.395
:43.		8.35	1.395
:43.5		8.35	1.395
:44.		8.35	1.390
:44.5		8.35	1.385
:45.		8.35	1.395
:45.5		8.35	1.395
:46.		8.35	1.390
:46.5		8.35	1.385
:47.		8.35	1.383
:47.5		8.35	1.385
:48.		8.35	1.382
:48.5		8.35	1.382
:49.		8.35	1.381
:49.5		8.33	1.381
:50.		8.33	1.381
:50.5		8.30	1.380
:51.		8.30	1.380
:51.5		8.35	1.379
:52.			
:52.5	30.28		
:53.	30.27		
:53.5	30.25		
:54.	30.23		

---

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of water = 305.48 grams

Speed of Stirrer - 180 R.P.M.

Average Room Temperature = 21.5°C.

Dissipation Loss - The temperature was held constant at 24.30°C. for 10 minutes using a voltage of 1.02 volts and a current of 0.175 amperes.

RUN - 3 A

Dec. 2, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
1:15	32.05	8.40	1.378 (1)
:15.5		8.39	1.377
:16.		8.39	1.375
:16.5		8.37	1.370
:17.		8.37	1.365
:17.5		8.35	1.363
:18.		8.35	1.362
:18.5		8.35	1.362
:19.		8.30	1.362
:19.5		8.30	1.370
:20.		8.35	1.362
:20.5		8.35	1.362
:21.		8.35	1.370
:21.5		8.35	1.370
:22.		8.40	1.365
:22.5		8.38	1.365
:23.		8.38	1.363
:23.5		8.35	1.362
:24.		8.35	1.361
:24.5		8.35	1.361
:25.		8.35	1.360
:25.5		8.35	1.361
:26.		8.35	1.361
:26.5		8.35	1.360
:27.			
:27.5	37.61		
:28.	37.61		
:28.5	37.60		
:29.	37.59		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
2:45.	37.53	8.45	1.350 (1)
:45.5		8.45	1.350
:46.		8.43	1.345
:46.5		8.40	1.345
:47.		8.40	1.345
:47.5		8.40	1.342
:48.		8.40	1.341
:48.5		8.40	1.342
:49.		8.40	1.342
:49.5		8.35	1.341
:50.		8.38	1.341
:50.5		8.40	1.340
:51.		8.37	1.340
:51.5		8.39	1.340
:52.		8.38	1.339
:52.5		8.37	1.339
:53.		8.38	1.339
:53.5		8.35	1.339
:54.		8.38	1.339
:54.5		8.38	1.338
:55.		8.37	1.338
:55.5		8.35	1.337
:56.		8.35	1.335
:56.5		8.35	1.330
:57.			
:57.5	42.86		
:58.	42.84		
:58.5	42.82		
:59.	42.80		

---

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of water = 305.48 grams (Same sample as in Run 3)

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 23.5°C.

Dissipation Loss - The temperature was held constant at 37.54°C. for 10 minutes using a voltage of 2.15 volts and a current of 0.355 amperes.

R U N - 4

Dec. 5, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
1:10	24.25	8.80	1.401 (1)
:10.5		8.75	1.400
:11.		8.72	1.399
:11.5		8.80	1.399
:12.		8.78	1.399
:12.5		8.75	1.400
:13.		6.75	1.399
:13.5		8.80	1.398
:14.		8.75	1.400
:14.5		8.80	1.400
:15.		8.75	1.399
:15.5		8.75	1.399
:16.		8.75	1.400
:16.5		8.80	1.399
:17.		8.80	1.399
:17.5		8.75	1.399
:18.		8.80	1.395
:18.5		8.80	1.395
:19.		8.82	1.395
:19.5		8.82	1.397
:20.		8.82	1.395
:20.5		8.83	1.395
:21.		8.80	1.390
:21.5		8.80	1.390
:22.			
:22.5	30.61		
:23.	30.60		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
2:15	30.61	8.82	1.380 (1)
:15.5		8.80	1.378
:16.		8.80	1.379
:16.5		8.80	1.379
:17.		8.80	1.381
:17.5		8.82	1.380
:18.		8.78	1.380
:18.5		8.80	1.375
:19.		8.80	1.374
:19.5		8.82	1.365
:20.		8.80	1.350
:20.5		8.50	1.342
:21.		8.70	1.380
:21.5		8.70	1.350
:22.		8.50	1.342
:22.5		8.50	1.340
:23.		8.60	1.345
:23.5		8.68	1.360
:24.		8.70	1.380
:24.5		8.70	1.360
:25.		8.70	1.360
:25.5		8.72	1.355
:26.		8.70	1.350
:26.5		8.65	1.360
:27.			
:27.5	36.60		
:28.	36.60		
:28.5	36.59		

---

(1) The current readings were taken 15 seconds after the voltage readings.
Weight of water = 302.39 grams
Speed of Stirrer = 180 R.P.M.
Average of Room Temperature = 21.5°C.
Dissipation Loss - The temperature was held constant at 30.61°C. for 11 minutes using a voltage of 1.75 volts and a current of 0.261 amperes.

R U N - 4 A

Dec. 5, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
2:55.	36.22	8.58	1.350 (1)
:55.5		8.60	1.347
:56.		8.60	1.345
:56.5		8.58	1.347
:57.		8.58	1.345
:57.5		8.55	1.345
:58.		8.57	1.344
:58.5		8.55	1.325
:59.		8.50	1.332
:59.5		8.50	1.335
3:00.		8.52	1.338
:00.5		8.52	1.338
:01.		8.52	1.337
:01.5		8.53	1.338
:02.		8.52	1.338
:02.5		8.55	1.337
:03.		8.55	1.338
:03.5		8.55	1.338
:04.		8.55	1.337
:04.5		8.54	1.337
:05.		8.55	1.338
:05.5		8.55	1.339
:06.		8.55	1.353
:06.5		8.65	1.355
:07.			
:07.5	41.80		
:08.	41.80		
:08.5	41.78		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
4:00.	41.63	8.99	1.375 (1)
:00.5		8.90	1.378
:01.		8.85	1.377
:01.5		8.85	1.375
:02.		8.85	1.375
:02.5		8.85	1.375
:03.		8.80	1.372
:03.5		8.80	1.375
:04.		8.80	1.375
:04.5		8.80	1.375
:05.		8.80	1.375
:05.5		8.80	1.372
:06.		8.80	1.375
:06.5		8.80	1.375
:07.		8.80	1.372
:07.5		8.80	1.369
:08.		8.80	1.370
:08.5		8.80	1.370
:09.		8.80	1.367
:09.5		8.80	1.367
:10.		8.80	1.365
:10.5		8.80	1.367
:11.		8.80	1.365
:11.5		8.80	1.365
:12.			
:12.5	47.39		
:13.	47.38		
:13.5	47.33		

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(1) The current readings were taken 15 seconds after the voltage readings.

Weight of water = 302.39 grams (Same sample as in Run 4)

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 23.0°C.

Dissipation Loss - The temperature was held constant at 41.63°C. for 15 minutes, using a voltage of 2.48 volts and a current of 0.380 amperes.

R U N - 5

Dec. 6, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period				Second Heating Period			
Time	Temp. °C.	Volts	Amperes	Time	Temp. °C.	Volts	Amperes
1:20.	24.33	9.40	1.440 (1)	2:15.	31.75	9.28	1.458 (1)
:20.5		9.35	1.439	:15.5		9.25	1.458
:21.		9.33	1.439	:16.		9.24	1.457
:21.5		9.33	1.436	:16.5		9.21	1.457
:22.		9.28	1.435	:17.		9.20	1.457
:22.5		9.28	1.430	:17.5		9.20	1.455
:23.		9.25	1.430	:18.		9.15	1.453
:23.5		9.25	1.425	:18.5		9.15	1.455
:24.		9.25	1.428	:19.		9.20	1.455
:24.5		9.25	1.427	:19.5		9.20	1.455
:25.		9.30	1.428	:20.		9.20	1.450
:25.5		9.28	1.425	:20.5		9.20	1.450
:26.		9.25	1.424	:21.		9.20	1.450
:26.5		9.25	1.422	:21.5		9.20	1.448
:27.		9.25	1.422	:22.		9.20	1.447
:27.5		9.25	1.422	:22.5		9.20	1.448
:28.		9.25	1.421	:23.		9.20	1.448
:28.5		9.25	1.421	:23.5		9.20	1.445
:29.		9.25	1.421	:24.		9.20	1.445
:29.5		9.25	1.421	:24.5		9.20	1.445
:30.		9.25	1.420	:25.		9.20	1.445
:30.5		9.25	1.420	:25.5		9.20	1.445
:31.		9.25	1.420	:26.		9.20	1.445
:31.5		9.25	1.420	:26.5		9.20	1.443
:32.		9.25	1.440	:27.		9.20	1.443
:32.5		9.10	1.440	:27.5		9.20	1.442
:33.				:28.			
:33.5	31.79			:28.5	39.01		
:34.	31.79			:29.	39.02		
:34.5	31.78			:29.5	39.00		

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(1) The current readings were taken 15 seconds after the voltage readings.
Weight of water = 302.03 grams
Speed of Stirrer = 180 R.P.M.
Average Room Temperature = 22.8°C.
Dissipation Loss - The temperature was held constant at 31.75°C. for 13 minutes using a voltage of 1.60 volts and a current of 0.261 amperes.

RUN - 5 A

Dec. 6, 1921

WATER EQUIVALENT OF APPARATUS

First Heating Period

Time	Temp. °C.	Volts	Amperes
2:40.	39.15	9.35	1.453 (1)
:40.5		9.35	1.452
:41.		9.35	1.448
:41.5		9.35	1.448
:42.		9.30	1.445
:42.5		9.30	1.445
:43.		9.30	1.442
:43.5		9.27	1.442
:44.		9.25	1.441
:44.5		9.25	1.441
:45.		9.25	1.441
:45.5		9.25	1.440
:46.		9.25	1.441
:46.5		9.25	1.440
:47.		9.25	1.440
:47.5		9.25	1.440
:48.		9.25	1.440
:48.5		9.25	1.440
:49.		9.25	1.440
:49.5		9.27	1.440
:50.		9.27	1.440
:50.5		9.27	1.440
:51.		9.30	1.440
:51.5		9.28	1.439
:52.			
:52.5	45.59		
:53.	45.58		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
4:16.	45.45	9.35	1.458 (1)
:16.5		9.30	1.458
:17.		9.27	1.457
:17.5		9.25	1.456
:18.		9.25	1.455
:18.5		9.25	1.450
:19.		9.23	1.450
:19.5		9.23	1.450
:20.		9.20	1.447
:20.5		9.20	1.448
:21.		9.22	1.445
:21.5		9.25	1.445
:22.		9.25	1.445
:22.5		9.25	1.445
:23.		9.25	1.445
:23.5		9.25	1.445
:24.		9.25	1.445
:24.5		9.25	1.445
:25.		9.25	1.442
:25.5		9.25	1.442
:26.		9.25	1.441
:26.5		9.25	1.441
:27.		9.25	1.441
:27.5		9.26	1.441
:28.			
:28.4	51.75		
:29.	51.70		

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(1) The current readings were taken 15 seconds after the voltage readings.

Weight of water = 302.03 grams (Same sample as in Run 5)

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 23.4°C.

Dissipation Loss - The temperature was held constant at 45.46°C. for 15 minutes by using a voltage of 2.60 volts and a current of 0.419 amperes.

R U N - 6

Dec. 9, 1921

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
8:05.	20.39	3.99	0.602 (1)
:05.5		3.99	0.600
:06.		3.99	0.600
:06.5		3.99	0.600
:07.		3.99	0.600
:07.5		3.99	0.600
:08.		3.98	0.600
:08.5		3.98	0.600
:09.		3.99	0.600
:09.5		3.99	0.599
:10.		3.98	0.599
:10.5		3.99	0.599
:11.		3.98	0.599
:11.5		3.98	0.599
:12.		3.98	0.599
:12.5		3.98	0.599
:13.		3.99	0.599
:13.5		3.97	0.598
:14.		3.98	0.598
:14.5		3.98	0.599
:15.		3.99	0.599
:15.5		3.99	0.599
:16.		3.98	0.599
:16.5		3.99	0.598
:17.			
:17.5	23.81		
:18.	24.00		
:18.5	24.00		
:19.	24.00		
:19.5	23.98		
:20.	23.90		
:20.5	23.85		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
10:35.	24.38	3.97	0.600 (1)
:35.5		3.97	0.600
:36.		3.97	0.599
:36.5		3.97	0.599
:37.		3.97	0.599
:37.5		3.97	0.598
:38.		3.97	0.598
:38.5		3.97	0.598
:39.		3.97	0.598
:39.5		3.97	0.598
:40.		3.97	0.598
:40.5		3.97	0.598
:41.		3.97	0.598
:41.5		3.97	0.598
:42.		3.97	0.597
:42.5		3.98	0.597
:43.		3.98	0.596
:43.5		3.98	0.596
:44.		3.98	0.595
:44.5		3.97	0.595
:45.		3.97	0.597
:45.5		3.97	0.595
:46.		3.97	0.595
:46.5		3.97	0.595
:47.			
:47.5	27.42		
:48.0	27.53		
:48.5	27.57		
:49.	27.57		
:49.5	27.45		
:50.	27.41		

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(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 301.67 grams

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 22.5°C.

Dissipation Loss - The temperature was held constant at 24.35°C. for 28 minutes by using a voltage of 0.65 volts and a current of 0.100 amperes.

R U N - 7

Dec. 10, 1921.

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
8:30.	20.69	3.95	0.603 (1)
:30.5		3.95	0.602
:31.		3.95	0.602
:31.5		3.94	0.601
:32.	20.99		
:32.5		3.94	0.600
:33.		3.94	0.600
:33.5		3.94	0.600
:34.		3.93	0.600
:34.5		3.94	0.600
:35.		3.93	0.599
:35.5		3.93	0.600
:36.		3.93	0.599
:36.5		3.92	0.600
:37.		3.92	0.600
:37.5		3.92	0.599
:38.		3.92	0.599
:38.5		3.92	0.599
:39.		3.93	0.599
:39.5		3.93	0.599
:40.	23.41		
:40.5		3.93	0.598
:41.		3.94	0.599
:41.5		3.94	0.599
:42.			
:42.5	24.05		
:43.	24.19		
:43.5	24.22		
:44.	24.23		
:44.5	24.22		
:45.	24.21		
:45.5	24.18		
:46.	24.15		
:46.5	24.12		
:47.	24.08		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
10:40.	23.87	3.93	0.602 (1)
:40.5		3.94	0.600
:41.		3.94	0.600
:41.5		3.93	0.600
:42.	24.05		
:42.5		3.93	0.599
:43.		3.92	0.599
:43.5		3.92	0.599
:44.		3.93	0.598
:44.5		3.93	0.599
:45.		3.93	0.599
:45.5		3.93	0.599
:46.		3.94	0.599
:46.5		3.94	0.598
:47.		3.94	0.598
:47.5		3.94	0.598
:48.		3.94	0.598
:48.5		3.94	0.598
:49.		3.94	0.597
:49.5		3.93	0.597
:50.	26.30		
:50.5		3.93	0.597
:51.		3.93	0.597
:51.5		3.93	0.597
:52.			
:52.5	26.92		
:53.	27.01		
:53.5	27.04		
:54.	27.05		
:54.5	27.03		
:55.	27.01		
:55.5	26.99		
:56.	26.97		
:56.5	26.92		
:57.	26.84		
:57.5	26.80		
:58.0	26.79		
:58.5	26.77		
:59.	26.75		

RUN - 7 Dec. 10, 1921

(Continued)

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 301.67 grams (Same Sample as in Run 6)

Speed of Stirrer = 177 R.P.M.

Average Room Temperature = 22.8°C.

Dissipation Loss - The temperature was held constant at 23.87°C. for 7 minutes by using a voltage of 0.35 volts and a current of 0.055 amperes.

RUN - 8

Dec. 17, 1921.

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
9:31.	69.25	6.35	0.905 (1)
:31.5		6.30	0.901
:32.		6.30	0.901
:32.5		6.30	0.900
:33.	69.38		
:33.5		6.30	0.900
:34.		6.30	0.900
:34.5		6.30	0.900
:35.		6.30	0.900
:35.5		6.30	0.900
:36.		6.30	0.899
:36.5		6.30	0.899
:37.		6.30	0.899
:37.5		6.30	0.899
:38.		6.30	0.899
:38.5		6.30	0.899
:39.		6.30	0.899
:39.5		6.30	0.899
:40.		6.30	0.899
:40.5		6.30	0.899
:41.	71.50		
:41.5		6.30	0.899
:42.		6.30	0.899
:42.5		6.30	0.899
:43.	72.15		
:43.5	72.23		
:44.	72.35		
:44.5	72.38		
:45.	72.38		
:45.5	72.35		
:46.	72.22		
:46.5	72.20		
:47.	72.15		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
11:15.	72.18	6.30	0.901 (1)
:15.5		6.30	0.899
:16.		6.30	0.899
:16.5		6.30	0.899
:17.	72.22		
:17.5		6.30	0.899
:18.		6.30	0.898
:18.5		6.30	0.898
:19.		6.30	0.898
:19.5		6.30	0.898
:20.		6.30	0.897
:20.5		6.30	0.897
:21.		6.30	0.897
:21.5		6.30	0.897
:22.		6.30	0.897
:22.5		6.30	0.897
:23.		6.30	0.897
:23.5		6.30	0.896
:24.		6.30	0.896
:24.5		6.30	0.896
:25.	74.35		
:25.5		6.30	0.896
:26.		6.30	0.896
:26.5		6.30	0.896
:27.	74.85		
:27.5	75.00		
:28.	75.00		
:28.5	75.02		
:29.	75.03		
:29.5	75.01		
:30.	74.98		
:30.5	74.88		
:31.	74.79		
:31.5	74.70		
:32.	74.60		
:32.5	74.50		
:33.	74.40		

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(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 301.67 grams (Same Sample as in Run 6)

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 26.0°C.

Dissipation Loss = The temperature was held constant at 72.21°C. for 15 minutes, using a voltage of 4.00 volts and a current of 0.578 amperes.

RUN - 9

Dec. 19, 1921

SPECIFIC HEAT OF RESIDUUM

First Heating Period				Second Heating Period			
Time	Temp. °C.	Volts	Amperes	Time	Temp. °C.	Volts	Amperes
12:50.	69.22	6.52	0.915 (1)	4:10.	71.79	6.51	0.901 (1)
:50.5		6.52	0.910	:10.5		6.51	0.900
:51.		6.52	0.905	:11.		6.51	0.900
:51.5		6.52	0.905	:11.5		6.51	0.900
:52.	69.37			:12.	71.93		
:52.5		6.52	0.905	:12.5		6.51	0.900
:53.		6.52	0.905	:13.		6.51	0.899
:53.5		6.52	0.904	:13.5		6.51	0.899
:54.	69.83			:14.	72.42		
:54.5		6.52	0.903	:14.5		6.51	0.899
:55.		6.52	0.903	:15.		6.51	0.899
:55.5		6.52	0.903	:15.5		6.51	0.899
:56.	70.51			:16.	73.02		
:56.5		6.52	0.903	:16.5		6.51	0.899
:57.		6.52	0.902	:17.		6.51	0.899
:57.5		6.52	0.902	:17.5		6.51	0.899
:58.	71.18			:18.	73.62		
:58.5		6.52	0.902	:18.5		6.51	0.899
:59.		6.52	0.902	:19.		6.51	0.899
:59.5		6.52	0.902	:19.5		6.51	0.899
1:00	71.80			:20.	74.25		
:00.5		6.52	0.902	:20.5		6.51	0.898
:01.		6.52	0.902	:21.		6.52	0.898
:01.5		6.52	0.902	:21.5		6.51	0.898
:02.	72.45			:22.	74.85		
:02.5	72.58			:22.5	75.01		
:03.	72.62			:23.	75.04		
:03.5	72.65			:23.5	75.06		
:04	72.65			:24.	75.08		
:04.5	72.63			:24.5	75.03		
:05.	72.60			:25.	74.99		
:06.	72.47			:26.	74.83		
:07.	72.35			:27.	74.68		
:08.	72.15			:28.	74.50		
:09.	71.98			:29.	74.30		
:10.	71.79			:30.	74.10		
:11.	71.59			:31.	73.90		
:12.	71.40						

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 293.89 grams

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 20.6°C.

Dissipation Loss- The temperature was held constant at 71.79°C. for 12 min. using a voltage of 3.99 volts and a current of

RUN - 10

Dec. 21, 1921.

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
10:15.	20.19	4.00	0.615 (1)
:15.5		4.00	0.614
:16.		4.01	0.615
:16.5		4.01	0.615
:17.	20.51		
:17.5		4.01	0.615
:18.		4.01	0.615
:18.5		4.01	0.615
:19.	21.25		
:19.5		4.01	0.612
:20.		4.00	0.612
:20.5		4.00	0.610
:21.	22.01		
:21.5		4.00	0.611
:22.		4.00	0.610
:22.5		4.00	0.611
:23.	22.61		
:23.5		4.01	0.609
:24.		4.01	0.609
:24.5		4.01	0.608
:25.	23.20		
:25.5		4.00	0.608
:26.		4.01	0.608
:26.5		4.01	0.608
:27.	23.73		
:27.5	23.82		
:28.	23.90		
:28.5	23.95		
:29.	23.93		
:30.	23.80		
:31.	23.74		
:32.	23.62		
:33.	23.57		
:34.	23.47		
:35.	23.41		
:36.	23.38		
:37.	23.35		
:38.	23.31		
:39.	23.24		
:40.	23.22		
:41.	23.20		
:42.	23.19		
:43.	23.18		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
11:25.	23.81	4.01	0.615 (1)
:25.5		4.01	0.612
:26.		4.01	0.610
:26.5		4.01	0.609
:27.	24.04		
:27.5		4.01	0.608
:28.		4.00	0.607
:28.5		4.00	0.607
:29.	24.78		
:29.5		4.00	0.607
:30.		4.01	0.607
:30.5		4.01	0.606
:31.	25.41		
:31.5		4.00	0.606
:32.		4.00	0.606
:32.5		4.00	0.605
:33.	25.98		
:33.5		4.00	0.605
:34.		4.00	0.605
:34.5		4.00	0.605
:35.	26.46		
:35.5		4.00	0.605
:36.		4.00	0.604
:36.5		4.00	0.605
:37.	27.00		
:37.5	27.03		
:38.	27.17		
:38.5	27.18		
:39.	27.14		
:40.	27.00		
:41.	26.88		
:42.	26.76		
:43.	26.64		
:44.	26.60		
:45.	26.55		
:46.	26.45		
:47.	26.41		
:48.	26.39		
:49.	26.37		
:50.	26.35		
:51.	26.25		
:52.	26.22		
:53.	26.20		

RUN - 10

(Continued)

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 303.75 grams

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 21.5°C.

Dissipation Loss - The temperature was held constant at 23.15°C. for 15 minutes by using a voltage of 0.70 volts and a current of 0.110 amperes.

RUN - 10-A

Dec. 21, 1921.

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
1:15.	90.24	7.52	0.977 (1)
:15.5		7.52	0.975
:16.		7.52	0.974
:16.5		7.51	0.973
:17.	90.30		
:17.5		7.51	0.973
:18.		7.51	0.972
:18.5		7.51	0.972
:19.	90.78		
:19.5		7.50	0.970
:20.		7.51	0.969
:20.5		7.51	0.970
:21.	91.38		
:21.5		7.51	0.970
:22.		7.51	0.969
:22.5		7.51	0.969
:23.	91.99		
:23.5		7.51	0.969
:24.		7.50	0.968
:24.5		7.50	0.967
:25.	92.59		
:25.5		7.51	0.967
:26.		7.51	0.967
:26.5		7.51	0.967
:27.	93.21		
:27.5	93.35		
:28.	93.37		
:28.5	93.37		
:29.	93.28		
:30.	93.10		
:31.	92.85		
:32.	92.60		
:33.	92.38		
:34.	92.06		
:35.	91.79		
:36.	91.55		
:37.	91.25		
:38.	91.00		
:39.	90.75		
:40.	90.49		
:41.	90.21		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
4:27.	93.00	7.52	0.967 (1)
:27.5		7.52	0.965
:28.		7.52	0.964
:28.5		7.52	0.962
:29.	93.05		
:29.5		7.52	0.962
:30.		7.52	0.963
:30.5		7.52	0.963
:31.	93.57		
:31.5		7.52	0.963
:32.		7.52	0.962
:32.5		7.52	0.962
:33.	94.15		
:33.5		7.52	0.962
:34.		7.52	0.961
:34.5		7.52	0.961
:35.	94.77		
:35.5		7.52	0.961
:36.		7.52	0.961
:36.5		7.52	0.961
:37.0	95.35		
:37.5		7.52	0.961
:38.		7.52	0.960
:38.5		7.51	0.961
:39.	96.00		
:39.5	96.05		
:40.	96.13		
:40.5	96.03		
:41.	96.00		
:42.	95.81		
:43.	95.59		
:44.	95.35		
:45.	95.04		
:46.	94.79		
:47.	94.53		
:48.	94.21		
:49.	94.00		
:50.	93.65		
:51.	93.40		
:52.	93.15		
:53.	92.85		

RUN - 10-A

(Continued)

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 303.75 grams (Same Sample as in Run 10)

Speed of Stirrer = 180 R.P.M.

Average Room Temperature = 24.2°C.

Dissipation Loss - The temperature was held constant at 93.19°C. for 8 minutes using a voltage of 5.15 volts and a current of 0.676 amperes.

R U N - 11

Dec. 22, 1921.

SPECIFIC HEAT OF RESIDUUM

Time	Temp. °C.	Volts	Amperes
12:30.	121.5	9.55	1.200
:30.5		9.55	1.199
:31.		9.55	1.199
:31.5		9.55	1.198
:32.	122.6		
:32.5		9.55	1.198
:33.		9.54	1.197
:33.5		9.54	1.198
:34.	123.6		
:34.5		9.53	1.197
:35.		9.52	1.197
:35.5		9.52	1.197
:36.	124.3		
:36.5		9.52	1.197
:37.		9.52	1.196
:37.5		9.52	1.196
:38.	125.2		
:38.5		9.52	1.195
:39.		9.52	1.195
:39.5		9.52	1.195
:40.	126.1		
:44.	127.9	9.52	1.185
:44.5		9.52	1.184

Time	Temp. °C.
12:45	128.2
:45.5	128.0
:46.	127.9
:47.	127.2
:48.	126.9
:49.	126.3
:50.	126.0
:51.	125.6
:52.	125.1
:53.	124.8
:54.	124.2
:55.	124.0
:56.	123.6
:57.	123.1
:58.	122.8
:59.	122.3
1:00.	122.0
:01.	121.8
:02.	121.2

(1) The current readings were taken 15 seconds after the voltage readings.
Weight of Residuum = 305.28 grams
Speed of Stirrer = 178 R.P.M.
Average Room Temperature = 24.2°C.

The dissipation loss was obtained only by the cooling method.

RUN - 11 - A

Dec. 22, 1921.

SPECIFIC HEAT OF RESIDUUM

First Heating Period

Time	Temp. °C.	Volts	Amperes
1:05.	120.0	9.55	1.199 (1)
:05.5		9.54	1.197
:06.		9.53	1.195
:06.5		9.53	1.195
:07.	121.1		
:07.5		9.52	1.193
:08.		9.52	1.191
:08.5		9.52	1.189
:09.	122.2		
:09.5		9.52	1.187
:10.		9.52	1.185
:10.5		9.51	1.184
:11.	123.1		
:11.5		9.51	1.185
:12.		9.51	1.185
:12.5		9.51	1.186
:13.	124.0		
:13.5		9.51	1.186
:14.		9.51	1.185
:14.5		9.51	1.184
:15.	125.0		
:15.5		9.52	1.183
:16.		9.52	1.181
:16.5		9.52	1.181
:17.	125.8		
:17.5	125.6		
:18.	125.2		

Second Heating Period

Time	Temp. °C.	Volts	Amperes
2:25.	125.8	9.90	1.219 (1)
:25.5		9.90	1.219
:26.		9.90	1.218
:26.5		9.90	1.217
:27.	126.8		
:27.5		9.90	1.215
:28.		9.90	1.213
:28.5		9.90	1.215
:29.	127.8		
:29.5		9.90	1.215
:30.		9.90	1.213
:30.5		9.90	1.213
:31.	128.7		
:31.5		9.90	1.213
:32.		9.90	1.213
:32.5		9.90	1.210
:33.	129.6		
:33.5		9.90	1.205
:34.		9.90	1.205
:34.5		9.90	1.205
:35.	130.4		
:35.5		9.90	1.204
:36.		9.90	1.204
:36.5		9.90	1.204
:37.	131.2		
:37.5	131.1		
:38.	130.9		
:39.	130.3		
:40.	130.0		
:41.	129.5		
:42.	129.0		
:43.	128.7		
:44.	128.2		
:45.	127.9		
:46.	127.4		
:47.	127.0		
:48.	126.7		
:49.	126.1		
:50.	125.9		
:51.	125.3		
:52.	124.9		
:53.	124.6		
:54.	124.1		
:55.	123.8		
:56.	123.4		

RUN - 11-A

(Continued)

Second Heating Period

Time	Temp. °C.
2:57.	123.0
:58.	122.7
:59.	122.1
3:00.	121.9
:01.	121.4
:02.	121.0
:03.	120.8
:04.	120.3
:05.	119.9
:06.	119.7

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(1) The current readings were taken 15 seconds after the voltage reading.

Weight of Residuum = 305.28 grams (Same sample as in Run 11)

Speed of Stirrer = 178 R.P.M.

Average Room Temperature = 25.2°C.

Dissipation Loss - The temperature was held constant at 126.1°C. for 11 minutes, using a voltage of 6.60 volts and a current of 0.845 amperes.

R U N - 12

Dec. 28, 1921

SPECIFIC HEAT OF RESIDUUM

Time	Temp. °C.	Volts	Amperes
10:51.	148.1	10.15	1.149 (1)
:51.5		10.15	1.145
:52.		10.15	1.142
:52.5		10.15	1.142
:53.	148.6		
:53.5		10.15	1.141
:54.		10.15	1.141
:54.5		10.15	1.141
:55.	149.4		
:55.5		10.15	1.140
:56.		10.13	1.140
:56.5		10.15	1.140
:57.	150.0		
:57.5		10.15	1.140
:58.		10.15	1.140
:58.5		10.15	1.140
:59.	150.9		
:59.5		10.15	1.142
11:00.		10.15	1.143
:00.5		10.15	1.143
:01.	151.8		
:01.5		10.15	1.143
:02.		10.15	1.143
:02.5		10.15	1.142
:03.	152.5		
:03.5	152.3		
:04.	152.0		
:04.5	151.8		
:05.	151.5		
:06.	151.0		
:07.	150.3		
:08.	149.9		
:09.	149.4		
:10.	148.9		
:11.	148.3		
:12.	147.8		
:13.	147.4		

(1) The current readings were taken 15 seconds after the voltage readings.

Weight of Residuum = 265.30 grams
Speed of Stirrer = 180 R.P.M.

The dissipation loss was only determined by the method of cooling the apparatus and its contents.

RUN - 12-A

Dec. 28, 1921.

SPECIFIC HEAT OF RESIDUUM

Time	Temp. °C.	Volts	Amperes
11:23.	158.7	10.25	1.147 (1)
:23.5		10.25	1.141
:24.		10.20	1.140
:24.5		10.20	1.141
:25.	159.0		
:25.5		10.20	1.142
:26.		10.23	1.145
:26.5		10.23	1.150
:27.	159.8		
:27.5		10.23	1.142
:28.		10.20	1.140
:28.5		10.23	1.140
:29.	160.3		
:29.5		10.23	1.140
:30.		10.23	1.140
:30.5		10.23	1.140
:31.	161.0		
:31.5		10.23	1.140
:32.		10.23	1.140
:32.5		10.23	1.140
:33.	161.7		
:33.5		10.23	1.140
:34.		10.25	1.139
:34.5		10.26	1.139
:35.	162.2		
:35.5		10.26	1.139
:36.		10.26	1.139
:36.5		10.26	1.139
:37.	162.9		
:37.5	162.8		
:38.	162.4		
:38.5	162.1		
:39.	161.8		
:40.	161.2		
:41.	160.6		
:42.	160.0		
:43.	159.4		
:44.	158.8		
:45.	158.1		
:46.	157.7		
:47.	157.0		
:48.	156.4		

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(1) The current readings were taken 15 seconds after the voltage readings.

RUN - 12-A

(Continued)

Weight of Residuum = 265.30 Grams
(Same Sample as in Run 12)

Speed of Stirrer = 180 R.P.M.

The dissipation loss was only determined by the method of cooling the apparatus and its contents.

TABLE 1 - A

RESULTS OF DETERMINATION OF WATER EQUIVALENT OF THE APPARATUS

		During Heating			Dissipation Correction						
Run No.	Room Temp.	Aver. Volts	Aver. Amp.	Time Min.	Volts	Amp.	Time Min.	Weight of H_2O	ΔT	Aver. Temp.	E Cal./°C.
	°C.	v	a	θ	v'	a'	ϕ	Grams	°C.	°C.	
1	24.2	9.27	1.424	24	1.35	0.202	25.5	301.9	13.91	29.3	20.0
2	22.5	8.45	1.408	24	1.10	0.183	25.5	304.6	12.37	25.9	20.6
3	21.5	8.34	1.396	24	1.02	0.175	25.5	305.5	12.10	24.3	20.3
3-A	23.5	8.37	1.353	24	2.15	0.355	25.5	305.5	10.89	37.5	26.6
4	21.5	8.75	1.381	24	1.75	0.261	25.5	302.4	12.35	30.6	20.7
4-A	23.0	8.69	1.356	24	2.48	0.380	25.5	302.4	11.34	41.6	24.7
5	22.8	9.25	1.439	26	1.60	0.261	28.	302.0	14.73	31.8	22.8
5-A	23.4	9.27	1.445	24	2.60	0.419	24.9	302.0	12.74	45.5	29.5

The condensed table shown above gives the results obtained while determining the water equivalent of the apparatus. The values "v" and "a" are the average values of the voltage and current, respectively, during the heating periods. The values"v'" and "a'" are the voltage and current required to hold the temperature of the apparatus constant at the average temperature of the run. The total time during which the heating current was turned on is given in the column marked θ, while θ' gives the number of minutes from the start of the heating period to the time at which the temperature reaches its maximum value for that period. The latter time interval was somewhat greater at lower temperatures than the former because of the lag in the temperature reading; at higher temperatures these two values were about the same because the dissipation of heat from the sample was then so great that the temperature dropped almost immediately when the current was turned off. The column marked ΔT shows the sum of the temperature differences, initial to maximum values in each case, during the two heating periods. "T" is the mean of the initial temperature of the run and the maximum temperature of the second heating period. "W" is the weight of the distilled water used in the run. "E" is the water equivalent of the apparatus or the number of calories of energy necessary to raise the temperature of the apparatus thru one degree centigrade. This last value was calculated from the data by means of the following formula :

Calories added = calories dissipated + calories used to heat water + calories used to heat apparatus.

since $1 \text{ watt} = \frac{60}{4.18} = 14.34$ calories per minute

$$(V)(a)(\theta)(14.34) = (V')(A')(\theta')(14.34) + (1)(W)(\Delta T) + (E)(\Delta T)$$

or

$$E = \frac{(v)(a)(\theta) - (v')(a')(\theta')\,14.34}{\Delta T} - W\,(1)$$

Where the specific heat of water is taken as 1 calorie per gram per degree centigrade.

Taking Run 3 as an example -

$$E = \frac{(8.34 \times 1.396 \times 24 - 1.02 \times 0.175 \times 25.5)\,14.34}{12.10} - 305.5$$

$$E = 20.3$$

SPECIFIC HEAT OF RESIDUUM

By Method 1

		During Heating			During Cooling			
Run No.	Room Temp.	Aver. Volts	Aver. Amp.	Temp. Increase °C./min.	Temp. Decrease °C./Min.	Weight	Aver. Temp.	Sp. Ht.
	°C.	(v)	(a)	(x)	(y)	Gms.	°C.	
10	21.5	4.01	0.608	0.276	0.036	303.8	24.5	0.302
9	20.6	6.52	0.901	0.316	0.194	293.9	72.3	0.493
10-A	24.2	7.51	0.969	0.304	0.269	303.8	93.4	0.533
11	24.2	9.52	1.193	0.450	0.389	305.3	126.1	0.570
11-A	25.2	9.71	1.200	0.437	0.397	305.3	126.7	0.589
12	-	10.15	1.142	0.390	0.525	265.3	150.5	0.609
12-A	-	10.23	1.142	0.324	0.605	265.3	161.0	0.604

SPECIFIC HEAT OF RESIDUUM

By Method 2

Run No.	Room Temp.	During Heating Aver. Volts	 Aver. Amp.	 Time	Dissipation Correction Aver.V.	 Aver.A.	 Time	ΔT °C.	Weight	Aver.T.	Sp.Ht.
	°C.	(v)	(a)	θ Min.	(v')	(a')	θ' Min.		Grams	°C.	
6	22.5	3.98	0.598	24	0.65	0.100	28	6.80	301.7	24.0	0.318
7	22.8	3.93	0.599	24	0.35	0.055	28	6.72	301.7	23.9	0.328
10	21.5	4.01	0.608	24	0.70	0.110	27	7.13	303.8	23.6	0.306
8	26.0	6.30	0.899	24	4.00	0.578	28	5.98	301.7	72.1	0.498
9	20.6	6.52	0.901	24	3.99	0.561	28	6.72	293.9	72.1	0.500
10-A	24.2	7.51	0.969	24	5.15	0.676	26.5	6.26	303.8	93.2	0.561
11-A	25.2	9.71	1.200	24	6.60	0.845	24	11.2	305.3	125.6	0.545

TABLE 4

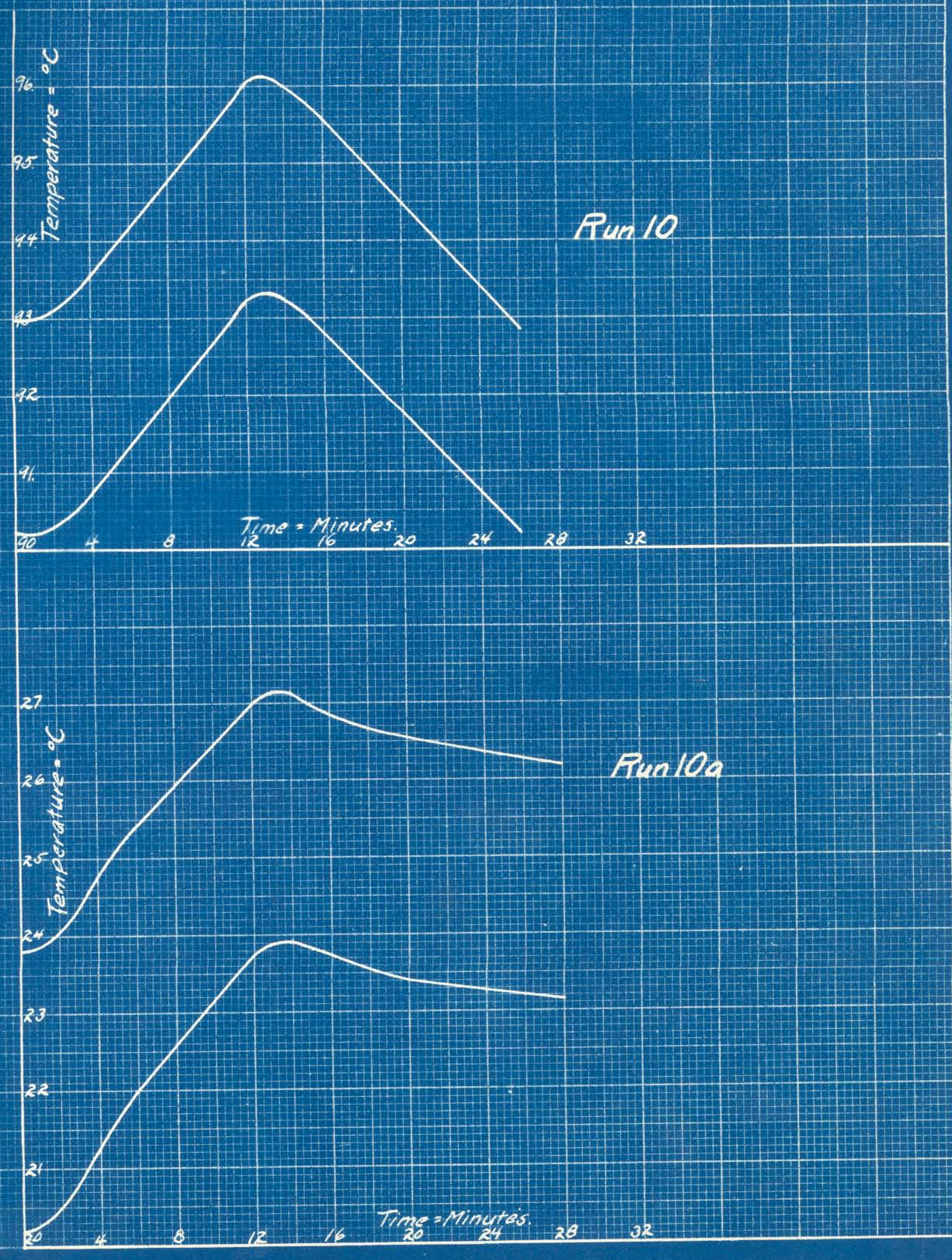
SPECIFIC HEAT OF RESIDUUM

By Method 3

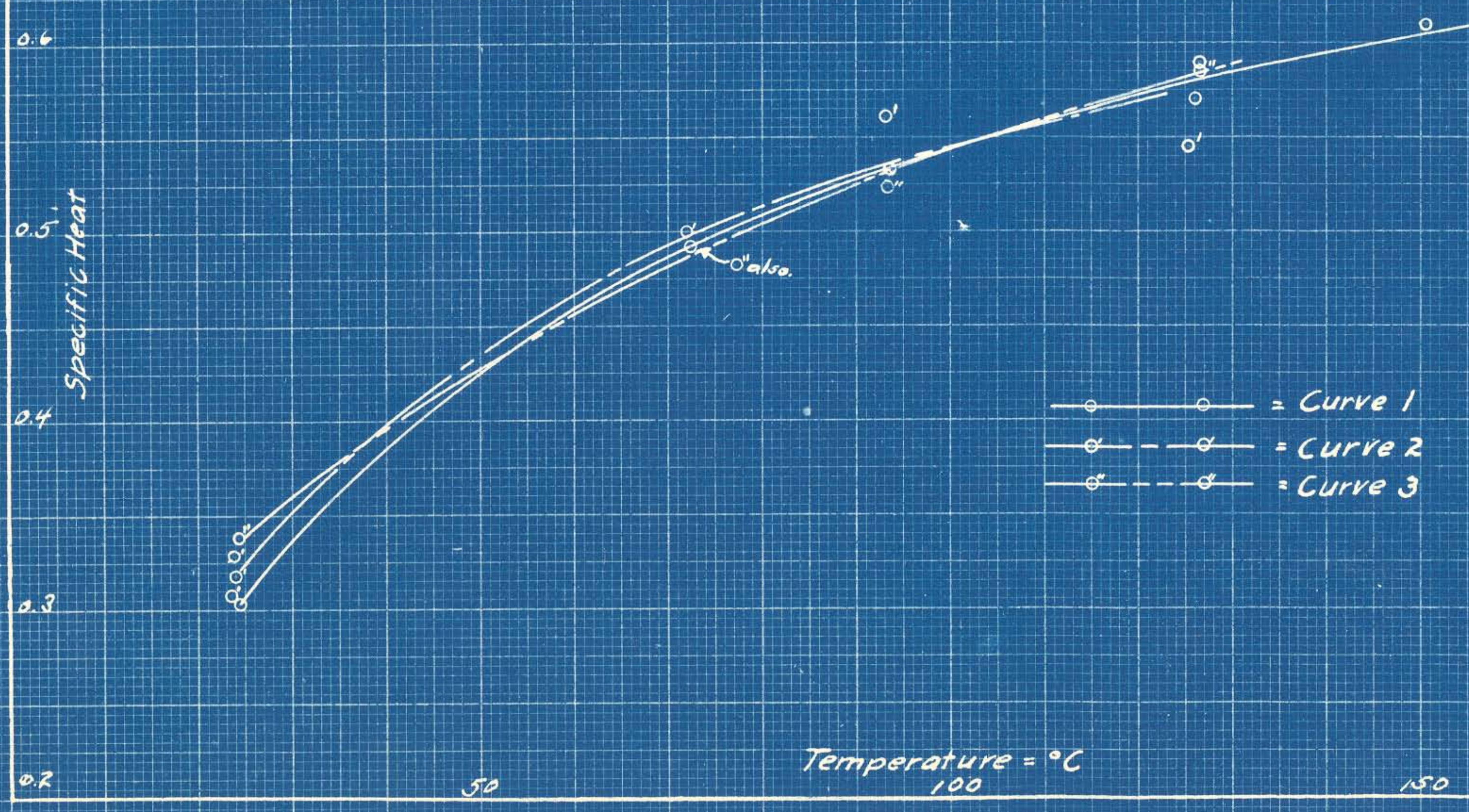
Run No.	Room Temp.	During Heating									
		Aver.V.	Aver.A.	Time	Aver.V.	Aver.A.	Time	ΔT	Weight	Aver.T.	Sp.Ht.
	°C.	(v)	(a)	θ Min.	(v')	(a')	θ' Min.	°C.	Gms.	°C.	
10	21.5	4.01	0.608	12	0.70	0.110	12	3.31	303.8	24.5	0.338
9	20.6	6.52	0.901	16	3.99	0.561	16	5.05	293.9	72.3	0.493
10-A	24.2	7.51	0.969	16	5.15	0.676	16	4.86	303.8	93.4	0.523
1 11-A	25.2	9.71	1.200	16	6.60	0.845	16	7.00	305.3	126.7	0.585

Specific Heat of Residuum

Curves Showing the Rate of Change of the Temperature During the Heating and Cooling Periods



Curves Showing the Comparison of the Results Obtained by Calculating the Specific Heat by three Different Methods



From the results shown in Table 1-A, it will be seen that the values obtained for "E" vary considerably and that they increase with an increase in the temperature at which the run was made. Since the specific heat of the materials from which the apparatus was constructed does not change appreciably with the temperature, this value should be practically a constant, and, in order to determine the specific heat of the oil, it was necessary to choose a value from the above results which would approximate as closely as possible the correct constant for the apparatus. Since the latent heat of vaporization of water is very much greater than its specific heat it is possible that this variation in the value of "E" was due to the vaporization of a part of the water at the higher temperatures attained in some of the runs. This would cause an increase in the amount of heat energy used and an apparent increase in the heat equivalent of the apparatus. Upon this consideration it was decided to take the average of the four values obtained at temperatures between 24°C. and 30°C. for the correct value of this constant. It was found to equal 20.4 calories.

Tables 2, 3 and 4, pages 49, 50 and 51, show the results obtained by calculating the specific heat of the sample of residuum, from the data obtained in Runs 6 to 12, by three different methods. In the first method (Table 2) the values (x) for the temperature increase per minute during the heating period and (y) for the temperature decrease per minute during the cooling period, were taken from curves in which the temperature was plotted as the abscissa and the time as the ordinate.

A sample of these curves from tests 10 and 10-A is shown on page 52. The portions of the curves in which the rates of change were constant during the cooling or heating periods were used to obtain these values. The columns marked (v) and (a) contain the average values of the voltage and current, respectively, during the total heating period. The energy input was calculated from the relation :

$$\text{Calories per minute} = (v)(a)(14.34)$$

The temperature of the run (T) was the mean of the initial temperature and the maximum temperature attained during the run. The specific heat was calculated from the following formula :

$$(14.34)(v)(a) = (E)(x+y) + (\text{Sp.Ht.})(x+y)(W)$$

or

$$\text{Sp. Ht.} = \frac{(v)(a)(14.34)}{(x+y)\ (W)} - \frac{E}{W}$$

Taking Run 10 as an example -

$$\text{Sp. Ht.} = \frac{4.01 \times 0.608 \times 14.34}{(0.276+0.036)\ 303.8} \quad \frac{20.4}{303.8} = 0.369 - 0.067 = 0.302$$

By plotting the values thus obtained as the abscissae and the temperatures of the runs as the ordinates a curve was drawn (Curve 1, pages 17 and 53) showing the relation between the specific heat and the temperature of the sample of residuum.

The results shown in table 3 were obtained by method 2, which is the method used to calculate the heat equivalent of the apparatus. The following equation was used :

$$\text{Sp. Ht.} = \frac{(v)(a)(\theta) - (v')(a')(\theta')14.34}{(W)\ (\Delta T)} - \frac{E}{W}$$

Taking Run 10 as an example :

$$\text{Sp.Ht.} = \frac{(4.01 \times 0.608 \times 24 - 0.70 \times 0.110 \times 27)\ 14.34}{7.13 \times 303.8} - \frac{20.4}{303.8}$$

$$= \frac{(58.5 - 2.1)\ 14.34}{216.6} - 0.067 = 0.375 - 0.67 = 0.306$$

These results when plotted upon the same coordinates as the preceding curve, page 53, gave Curve 2 which approximated Curve 1 very closely, the points however were more irregular, especially at the higher temperatures.

Table 4 shows the values obtained by a combination of these two methods of calculation. The heating period was considered as only that time during which the rates of increase of the time-temperature curves were constant. The temperature was taken at the beginning and ending of these periods so the dissipation correction was effective over the same period of time as the heating. The last formula shown above was used to calculate the specific heat shown in the example from Run 10.

$$\text{Sp.Ht.} = \frac{(4.01 \times 0.608 \times 12 - 0.70 \times 0.110 \times 12)\ 14.34}{3.31 \times 303.8} - \frac{20.4}{303.8}$$

$$= \frac{(29.3 - 0.9)\ 14.34}{3.31 \times 303.8} - 0.067 = 0.405 - 0.067 = 0.338$$

It was found that the results thus obtained, when plotted on the same coordinates, gave Curve 3 which was very similar to Curve 1.

By comparing the results obtained when using Methods 1 and 3, it will be seen that the two methods of calculating the specific heat gave results which checked very closely at higher temperatures. In both methods the rate of temperature change during the heating was taken from the curves, but in Method 3, the dissipation loss was figured from the electrical energy required to hold the temperature of the apparatus and its contents constant, while in Method 1 this value was calculated from that portion of the time-temperature curve in which the temperature was decreasing. Since the same means were used in both methods to determine the rate of change of the temperature upon the addition of electrical energy at a constant rate, it is probable that the difference in the results was due to the difference in the two ways in which the dissipation loss was determined. Because of the difficulties encountered in holding the temperature of the apparatus and its contents at a constant value, it is very likely that the electrical method of determination of the dissipation loss was the least accurate.

In comparing Methods 1 and 2 it will be seen that not only was the dissipation loss calculated differently in the two methods but also the heat energy utilized in changing the temperature of the sample of residuum was figured differently.

In the first method the rate of temperature change, caused by the addition of electrical energy at a definite rate, was taken from the time-temperature curve. By observing the curve on page 52 it will be seen that the rate of change of the temperature with the time was not constant at first. This was due to the fact that the conduction of heat thru the liquid was not instantaneous and that the effect of a change in the heating current was not shown immediately by the thermometer. A constant energy input did, however, result in a constant rate of change in the temperature, as is shown by the straight portion of the curve, and it was this rate of change that was used to determine that part of the energy input which was utilized in raising the temperature of the sample.

In the second method, it was necessary to determine the total temperature change caused by the addition of a definite quantity of electrical energy. In order to do this, observations were made of the length of time during which the temperature was turned on, of the total temperature change from the initial temperature to the maximum temperature and of the length of time during which the dissipation loss was effective. The last value was the difference between the time at which the current was turned on and the time at which the temperature reached its maximum value. The initial time and temperature, and the time at which the current was shut off, could all be determined very accurately but in order to get the maximum temperature and the corresponding time it was necessary to take an instantaneous reading of these two values. The inaccuracy in taking these two simultaneous readings is probably the partial cause of the deviations in the results obtained by Method 2. This inaccuracy might have been reduced by using a chronograph to accurately record the time interval but such an instrument was not available for use in the experiment. It would still remain, however, that the accuracy of this method would be dependent upon the accuracy of two temperature readings, while in Method 1 the average rate of temperature change was used and the total error was the algebraic sum of any positive and negative errors made in the individual temperature and time readings.

In all three methods, the energy input was calculated from the averages of the voltage and current values during the two heating periods.

As a result of the above consideration of the three methods of determination, it was decided that the most accurate calculation was that used in Method 1, in which the rates of temperature change during the heating and cooling periods were taken from the time-temperature curves.

It is very likely that greater accuracy would have been obtained in the calculation of the water equivalent of the apparatus if the temperature readings had been taken more often and the rate of change of the temperature during the test had been taken from a time-temperature curve, as was done in Method 1 for determining the specific heat of the residuum. As is shown by Curve 2, on page 53, the deviations in the second method by which the specific heat was calculated, which was the same method as that used to calculate the water equivalent of the apparatus were greater at higher temperature. For this reason the water equivalent of the apparatus, which was used in the subsequent calculations of the specific heat, was taken as the average of only the values determined at the lower temperatures. The average of all the values obtained for the water equivalent of the apparatus was 23.1 calories per degree. By using this value instead of 20.4 calories per degree, a decrease of about one per cent would have been caused in the specific heat values determined.

The accuracy of the experiments was not great enough to warrant the correction of the thermometer readings for stem exposure, so this correction was omitted. The stirring was kept constant thruout each run and nearly so thruout the series of runs.

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