VIII. LATENT HEAT OF VAPORIZATION

The data on latent heat of vaporization of petroleum oils, given in Table 15, were calculated from the equation

$$L=\frac{1}{d}(110.9-0.09t) \tag{6}$$

in which L=latent heat of vaporization in Btu./lb., d=specific gravity of liquid at 60°/60° F., and t=temperature in °F. This equation is based on calorimetric measurements found in the literature on latent heat of vaporization of petroleum distillates, all of which are enumerated briefly in the first part of Table 14.

All of these measurements were made at atmospheric pressure, except for those of Rey, which extended to a pressure of 7 atmospheres. In the experiments of Syniewski, Ormandy and Craven, Regnault, and Kuklin, petroleum vapors were condensed in a water calorimeter. Their results yielded, therefore, values of total heat of vaporization from liquid at room temperature to vapor at 1 atmosphere pressure. These observed values were reduced to latent heats of vaporization for the purpose of comparison (Table 14), by means of the data on specific heat of liquid given in the previous section. The values of latent heat so obtained differ somewhat from those reported by the various authors, because, in one case, an arbitrary value for specific heat was used and, in other cases, the increase of specific heat with temperature was neglected.

Equation (6) is fairly consistent with most of the available experimental data on petroleum distillates as shown by the percentage differences between observed and calculated values. The results obtained by Heinlein are obviously inconsistent with the results of other observers. This was probably caused, in part at least, by the fact that there was good opportunity for reflux condensation in Heinlein's experiments.

Equation (6) yields values which differ less than 10 per cent, on the average, from experimental results obtained at 1 atmosphere pressure on the following hydrocarbons: *n*-hexane, 4-methylheptane, cyclohexane, and methylcyclohexane (Mathews, J. Am. Chem. Soc., **48**, p. 562; 1926); *n*-hexane, *n*-heptane, *n*-octane, hexamethylene, dimethylpentamethylene, methylhexamethylene, and dimethylhexamethylene (Mabery and Goldstein, Proc. Amer. Acad. Arts and Sci., **37**, p. 549; 1902); *n*-decane (Louguinine, Ann. Chim. phys., **13**, p. 289; 1898).

In addition to being in general accord with the available experimental results on petroleum distillates and individual petroleum hydrocarbons, equation (6) is in fair agreement with about the only existing evidence on the magnitude of the variation of latent heat with temperature or pressure over a considerable range below the critical point as shown by the second part of Table 14.

There are in the literature numerous values for the latent heat of vaporization of petroleum distillates, some of which were calculated by means of Trouton's rule from measurements of "apparent" molecular weight and "average" boiling point of the distillates, while others were obtained from data on pure substances by means of Trouton's or Hildebrand's rule. The values so obtained are uniformly higher than those found by calorimetric measurements on petroleum distillates, amounting in some cases to nearly 100 per cent. Probably the major reasons for the higher values are (1) that Trouton's and Hildebrand's rules are not applicable to complete vaporization of mixtures with a wide range of boiling points, and (2) that the "apparent" molecular weights of the heavier distillates are too low.

TABLE 14.—*Comparison of observed and calculated values of latent heat of vaporization of petroleum distillates and pure hydrocarbons*

Observer	Method	Range		Number of—		Difference in per cent obs.-calc.		Reference
		Sp. gr. 60°/60° F.	Temp. ° F.	Oils	Observations	Average	Maximum	
Syniewski	Mixtures	0.74–0.83	212–470	7	7	±2	−6	(1)
Gurwitsch	Not stated	.64–.81	104–348	6	6	−4	−9	(2)
Ormandy and Craven	Mixtures	.70–.75	232–250	3	11	±4	−10	(3)
Leslie, Geniesse, Legatski and Jagrawski.	Electric heating	.68–.82	152–576	17	17	±6	+10	(4)
Regnault	Mixtures	.89	536	1	2	+7	+10	(5)
Rey	Not stated	.81	347–527	1	6	+9	+16	(6)
Kuklin	Mixtures	.74–.76	200–235	2	8	+12	+19	(7)
Redwood	Not stated	.64–.81	70–260	4	4	±19	−39	(8)
Heinlein	Electric heating	.74–.91	194–345	5	23	+40	+70	(9)

Temperature		Pressure atmos.	Latent heat		Difference in per cent obs.-calc.	Pressure atmos.	Latent heat		Difference in per cent obs.-calc.	Temp. ° C.
° C.	° F.		Observations [10]	Calculations			Observations [10]	Calculations		
			(Normal pentane)				(Normal hexane)			
0	32	0.24	168	171	−2	0.06	164	163	+1	0
20	68	.55	160	166	−4	.16	158	158	0	20
40	104	1.12	152	161	−6	.36	152	153	−1	40
60	140	2.11	144	156	−8	.75	145	148	−2	60
80	176	3.60	136	151	−11	1.40	140	143	−2	80
100	212	5.80	126	145	−15	2.42	132	138	−4	100
120	248	8.87	116	140	−21	3.92	125	133	−6	120
140	284	13.0	102	135	−32	6.06	115	129	−12	140
160	320	18.5	85	130	−53	8.94	104	124	−19	160
180	356	25.5	63	125	−98	12.7	92	119	−29	180
			(Normal heptane)				(Normal octane)			
0	32	0.015	162	157	+3	0.004	161	153	+5	0
20	68	.05	158	152	+3	.014	156	148	+5	20
40	104	.12	154	148	+4	.04	150	144	+4	40
60	140	.27	149	143	+4	.10	145	139	+4	60
80	176	.56	143	138	+3	.23	139	134	+4	80
100	212	1.05	136	133	+2	.46	134	130	+3	100
120	248	1.80	129	129	0	.85	129	125	+3	120
140	284	2.92	121	124	−2	1.47	123	121	+2	140
160	320	4.54	113	119	−5	2.38	117	116	+1	160
180	356	6.70	105	115	−9	3.65	110	112	−2	180
200	392	9.56	96	110	−15	5.39	101	107	−6	200
220	428	13.3	84	105	−25	7.73	94	102	−9	220
240	464	18.1	67	100	−49	10.8	83	98	−18	240
260	500	24.3	39	96	−146	14.7	70	93	−33	260
280	536	-------	------	------	--------	19.7	51	89	−75	280

[1] Zeitschrift für Angewante Chemie, **11**, p. 621; 1898.
[2] "Wissenschaftliche Grundlagen der Erdölverarbeitung," 2d ed., p. 144; 1924 (J. Springer, Berlin).
[3] J. Inst. Petroleum Technologists, **9**, p. 368; 1923.
[4] Ind. & Eng. Chem., **18**, p. 45; 1926.
[5] Mémoires de l'Académie Sciences, France, **26**, p. 913; 1862.
[6] Annales des Mines, **8**, p. 53; 1925.
[7] Berichte der Deutschen Chemischen Gesellschaft, **16**, p. 949; 1883.
[8] "Mineral Oils and Their By-Products" p. 200; 1897 (E. and F. N. Spon (Ltd.), London).
[9] Der Motorwagen, p. 395, June 30, 1926.
[10] Observed values in Btu./lb. obtained from experimental data on vapor pressure and specific volume by means of Clapeyron equation. (Young, Proc., Royal Dublin Soc., **12**, p. 374; 1910; also Mills, J. Am. Chem. Soc., **31**, p. 1099; 1909.)

VIII. LATENT HEAT OF VAPORIZATION—Continued

The experimental basis for the data given in Table 15 is described on the preceding pages. The following equation

$$L(\text{Btu./lb.}) = \frac{1}{d}(110.9 - 0.09t)$$

was found to represent satisfactorily most of the experimental results available on petroleum distillates. This equation yields the following convenient relation

$$L(\text{Btu./lb.}) \times \text{density (lbs./gal.)} = 8.33722\ Ld = 925 - 0.75t(\text{Btu./gal.}) \qquad (7)$$

which indicates that the latent heat of vaporization per unit volume of liquid (60° F.) is dependent only on the temperature of vaporization. Thus, the values given in the second column of Table 15 are applicable to any petroleum oil, regardless of gravity. The values given in the other columns are applicable, in general, to all cases of vaporization of petroleum products in which the temperature of vaporization and the gravity of the condensate are known.

The estimated accuracy of the data in Table 15 is 10 per cent, when vaporization occurs at sensibly constant temperature and at pressures below 50 lbs./in.^{2}, without chemical change. The tabulated values are probably too low by more than this amount for petroleum products containing large quantities of the lower members of the aromatic series and too high for vaporization at high pressures, as is illustrated in Table 14.

Example 1.—What is the difference between the latent heats of vaporization of a 50° and a 70° A. P. I. gasoline, assuming complete vaporization occurs at 140° F. in the intake system of an internal-combustion engine? According to Table 15, on a weight basis the difference in latent heats amounts to 140−126=14 Btu./lb. or about 10 per cent, while on a volume basis both gasolines require 820 Btu./gal.

Example 2.—How much latent heat is required to vaporize or condense various petroleum products at the average temperatures indicated below?

Product	Gravity, °A. P. I.	Average temperature °F.	Latent heat from Table 15	
			Btu./lb.	Btu./gal.
Gasoline	60	280	116	715
Naphtha	50	340	103	670
Kerosene	40	440	86	595
Fuel oil	30	580	67	490

TABLE 15.—*Latent heat of vaporization of petroleum oils*

Temp. ° F.	Latent heat 10°–80° A. P. I. oils Btu./gal.	Latent heat of oils of various gravities in Btu./lb.							Temp. ° F.
		Degrees A. P. I. at 60° F.							
		20	30	40	50	60	70	80	
		Specific gravity at 60°/60° F.							
		0.9340	0.8762	0.8251	0.7796	0.7389	0.7022	0.6690	
0	925	--------	--------	--------	142	150	158	166	**0**
20	910	--------	--------	--------	140	148	155	163	20
40	895	--------	--------	--------	138	145	153	160	40
60	880	--------	--------	--------	135	143	150	158	60
80	865	--------	--------	--------	133	140	148	155	80
100	850	--------	--------	123	131	138	145	152	**100**
120	835	--------	--------	121	128	135	143	150	120
140	820	--------	--------	119	126	133	140	147	140
160	805	--------	--------	117	124	131	137	144	160
180	790	--------	--------	115	121	128	135	142	180
200	775	--------	106	113	119	126	132	139	**200**
220	760	--------	104	110	117	123	130	--------	220
240	745	--------	102	108	115	121	127	--------	240
260	730	--------	100	106	112	118	125	--------	260
280	715	--------	98	104	110	116	122	--------	280
300	700	90	96	102	108	113	119	--------	**300**
320	685	88	94	99	105	111	--------	--------	320
340	670	86	92	97	103	109	--------	--------	340
360	655	84	90	95	101	106	--------	--------	360
380	640	82	88	93	98	104	--------	--------	380
400	625	80	85	91	96	101	--------	--------	**400**
420	610	78	83	89	94	--------	--------	--------	420
440	595	76	81	86	91	--------	--------	--------	440
460	580	74	79	84	89	--------	--------	--------	460
480	565	73	77	82	87	--------	--------	--------	480
500	550	71	75	80	85	--------	--------	--------	--------
520	535	69	73	78	--------	--------	--------	--------	--------
540	520	67	71	75	--------	--------	--------	--------	--------
560	505	65	69	73	--------	--------	--------	--------	--------
580	490	63	67	71	--------	--------	--------	--------	--------
600	475	61	65	69	--------	--------	--------	--------	--------
620	460	59	63	--------	--------	--------	--------	--------	--------
640	445	57	61	--------	--------	--------	--------	--------	--------
660	430	55	59	--------	--------	--------	--------	--------	--------
680	415	53	57	--------	--------	--------	--------	--------	--------
700	400	51	55	--------	--------	--------	--------	--------	--------
720	385	49	53	--------	--------	--------	--------	--------	--------
740	370	47	51	--------	--------	--------	--------	--------	--------
760	355	45	48	--------	--------	--------	--------	--------	--------
780	340	44	46	--------	--------	--------	--------	--------	--------
800	325	42	44	--------	--------	--------	--------	--------	--------