CALORIMETRIC MEASUREMENT OF LATENT HEATS OF VAPORIZATION
OF PROPANE AND NORMAL PENTANE AND SOME THERMODYNAMIC PROPERTIES
OF NORMAL PENTANE

Thesis by

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In Partial Fulfillment

of the

Requirements for the Degree of

Master of Science

California Institute of Technology

Pasadena, California

1938

ABSTRACT

Measurements of the latent heat of vaporization of propane and normal pentane were made with an adiabatic bomb calorimeter. The temperature range for propane was from 103.4° F. to 163.2° F. Normal pentane measurements were from 103.7 to 200° Fahrenheit. A description of the apparatus and the method of calculation will be found in Part 1 of this paper.

In the second section of this paper some of the thermodynamic properties of n-pentane in the superheated gas region were calculated. Included in this section are tabulated values of entropy, enthalpy, residual volume, and heat capacity.

I. LATENT HEATS OF VAPORIZATION

Latent heat of vaporization may be defined as the
energy required to convert a unit mass of material from
saturated liquid to saturated gas at the same pressure
and temperature.

The use of latent heats of vaporization is wide-
spread in industries in which materials are distilled or
condensed. The accurate determination of latent heats
of hydrocarbons is particularly important in the pet-
roleum industry. Here the heat required for fractionating
columns and the design of condenser equipment are based
on latent heats.

There are three methods commonly used in the eval-
uation of latent heats. If the P. V. T. relations of a
certain material are known, the latent heat may be cal-
culated from an application of the First and Second Laws
of Thermodynamics known as the Clapeyron equation.

$$L = T\left(\frac{dP}{dT}\right)_b (V_d - V_b) * \qquad (1)$$

This method is particularly accurate for vapor pres-
sure greater than 100 pounds per sq. in. Above this pres-
sure reliable vapor pressures may be obtained whereas, at
lower pressures, adsorption on the walls of the pressure
measuring device often cause errors in the experimental
measurements. It is to be expected, then, that at the lower

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*A definition of symbols will be found at the end of
this thesis.

temperatures the latent heat values determined from the Clapeyron equation will usually be somewhat lower than the actual latent heats.

A second method of relating latent heat of vaporization to temperature involves the heat capacities of saturated gas and liquid, the change in pressure with temperature in the two phase region, and $\left(\frac{\partial H}{\partial P}\right)_T$ for both saturated gas and liquid.

$$L = L_o + \int_{T_o}^{T} \left[C_{P,d} - C_{P,b} + \left\{ \left(\frac{\partial H}{\partial P}\right)_{T,d} - \left(\frac{\partial H}{\partial P}\right)_{T,b} \right\} \left(\frac{dP}{dT}\right)_b \right] dT \qquad (2)$$

If the latent heat of vaporization is known at one temperature it may be calculated for any other temperature by means of this equation. Results are more accurate in the lower temperature range when this method is used because, at lower temperatures, heat capacities vary less with temperature, and lower $\left(\frac{dP}{dT}\right)$ values make the other terms of the equation less important. At higher temperatures all quantities involved change more rapidly with temperature, and the possibility of error will be greater. Since $\left(\frac{\partial H}{\partial P}\right)_T$ is derived from heat capacity, an error in heat capacity may introduce an accumulative error into the evaluation. Therefore, the accuracy of latent heat values determined by this method will be limited by the accuracy of the heat capacity data.

Latent heats may also be determined experimentally. Basically, the method consists of the addition of a known amount of energy to a liquid in a suitable container and of the measurement of the amount of liquid vaporized at constant pressure and temperature. By considering the various energy

losses from the system the latent heat of vaporization can
be evaluated from the following general equation:

$$L = \left(\frac{Q + Q' + Q'' + Q'''}{W'\left(\frac{V_d}{V_d - V_b}\right)}\right) \qquad (3)$$

Q is the known amount of energy added to the system.
Q', Q'' and Q''' are respectively, the thermal leakage loss,
the superheat correction, and the heat capacity correction.
$W'\left(\frac{V_d}{V_d - V_b}\right)$ is the mass of material vaporized. All of these
terms will be discussed further in part (e) of this section.

Latent heats determined experimentally may be expected
to be less accurate at higher temperatures because the volume
correction becomes increasingly important as the critical
temperature is approached.

The best previous work on latent heat of vaporization
has been done by the Linde Laboratory (1)* and the Bureau of
Standards (2).

(a) Theoretical considerations

As a means of extrapolating latent heat curves beyond
the temperature range covered by the experimental points it
is well to under stand the behavior commonly expected through-
out the desired range. This behavior can be predicted to a
certain extent by a consideration of the Clapeyron equation.
At low temperatures the volume of the saturated gas will be
very large in comparison to the volume of the saturated
liquid, and the latter may be neglected with slight error.
Also, at low temperatures it may be expected that the gas
will closely approximate perfect gas behavior. Thus, from

* References to literature cited will be found on page 33.

the Clapeyron equation results the following:

$$L = T\left(\frac{dP}{dT}\right)_b V_d = \frac{bT^2}{dT}\frac{dP}{P} = -b\frac{d\ln P}{d\left(\frac{1}{T}\right)} \tag{4}$$

The slope of the logarithm of vapor pressure against reciprocal temperature has been found experimentally to be approximately constant under these conditions. Therefore L will approach asymptotically to a limiting maximum value.

When the gas approaches the critical temperature, the difference between the volumes of the saturated gas and the saturated liquid grows rapidly smaller and at the critical temperature it is zero. At the critical temperature L is also zero.

(b) Materials

The sample of n-Pentane used in determining latent heats of vaporization was obtained from the Phillips Petroleum Company. Their special analysis showed it to contain 99.3% of n-pentane and 0.7% of isopentane.

The propane used in this study was obtained from the Philgas Company, Bartlesville, Oklahoma. Their analysis showed it to be pure propane, containing neither ethane nor isobutane in appreciable amounts.

(c) Apparatus

The adiabatic bomb calorimeter used in carrying out the majority of the determinations of latent heats of vaporization was similiar to that described by Vermeulen (3). Some changes were made, however, that are important enough to justify their description.

All thermocouples used were enclosed in copper tubing to prevent excessive wear and possible physical damage. The tubing

containing these thermocouples led to a central wiring box.
Here the thermocouples were soldered to number 18 B.&S. gage
copper wire. This larger wire was enclosed in conduit and
carried by this means directly to a potentiometer switch board.
Here, the two junctions of any thermocouple could be plug-
ged into any of the three potentiometers installed on the
board. The plugs were also arranged so that any potentiometer
could be used in conjunction with any of the four galvano-
meters on the board. Any potentiometer could be connected to
either of the other two, and this served as a valuable means
of checking each instrument for accuracy of standard cell
setting. The agitator described by Vermeulen was not used
because early experiments showed that agitation was not needed
to secure equilibrium in the bomb.

With the idea of investigating the heat of mixing of
various hydrocarbons at a later date, a new bomb assembly was
designed and installed after a portion of the latent heat
measurements had been completed.

This new bomb was of a steel alloy with a yield point of
120,000 pounds per square inch. The outside overall height of
the bomb was 6 inches and the center diameter was $3\frac{3}{8}$ inches.
It consisted of two hemispherical pieces threaded and sweated
onto a cylindrical center section. The inside volume of the
bomb was approximately 15.2 cubic inches, after allowing for
space occupied by the heater. The heater consisted of in-
sulated no. 36 B.& S. gage constantan wire within 0.06 inch
steel tubing. The heater leads were brought out through two
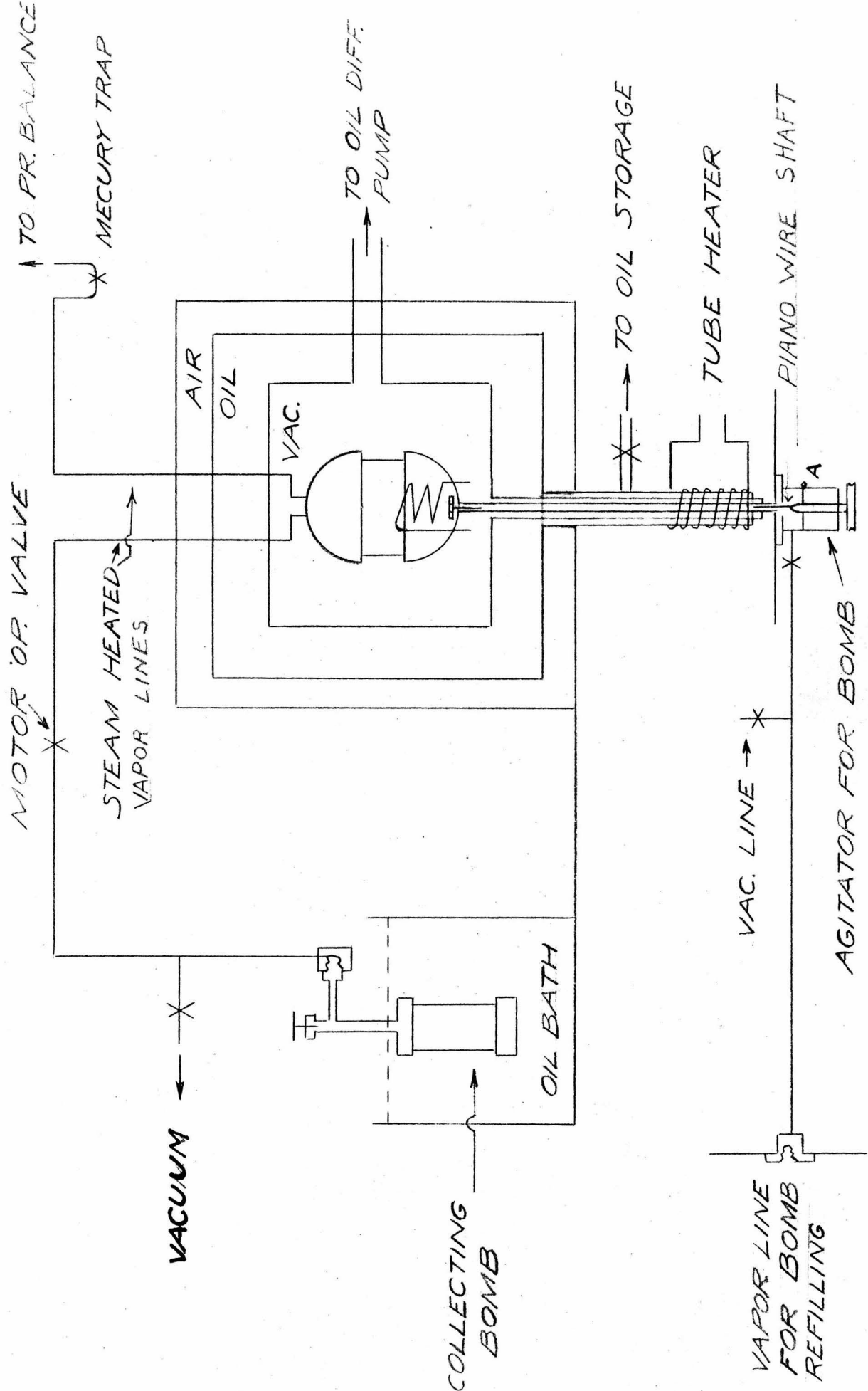openings in the bottom of the bomb, and the steel tubing was

Figure 1. Calorimeter Assembly

soldered to the bomb at this point. The parts of the bomb were machined by the Fred C. Henson Company and heat treated by Dr. D. S. Clark of the California Institute.

A schematic diagram of the apparatus is shown by Figure I. Into the top of the bomb a threaded nut was sweated. This nut had two openings through which the vapors were led to a pressure balance and to the vapor intake by means of steam-heated $\frac{1}{8}$ inch copper tubing. The agitator consisted of a small centrifugal impeller mounted on ball bearings in the bottom of the bomb. The shaft of this impeller was made of 0.020 inch piano-wire enclosed in 0.06 inch steel tubing, one end of which was soldered to the bomb. These two concentric pieces extended from the bottom of the bomb through the oil bath and through the floor of the air thermostat to a flat machined piece (A) mounted on a wooden support directly below the bomb. Here the 0.06 inch tubing was soldered, and the piano-wire extended through a packing gland to a drive pulley. Into the space in the machined piece between the sealed tubing and the packing gland an additional vapor line was sealed. This vapor line was used for filling the bomb with liquid, and it was so arranged that it could be evacuated before the liquid was admitted. The pulley connected to the piano-wire drive shaft was driven by a $\frac{1}{8}$ horsepower motor, connected to the drive pulley by means of a belt and other pulleys which served to reduce the rotating speed of the agitator.

A third tube made of $\frac{3}{8}$ inch brass surrounded the two tubes mentioned above. One end of this was sealed to the calorimeter

vacuum jacket and the other to the 0.06 inch steel tubing about three inches from the machined piece A (Figure I.). This tube was kept evacuated during operations and served to reduce heat loss from the inside tubes. To minimize still further the heat loss, the vacuum tube was surrounded by another tube of $\frac{3}{4}$ inch brass. One end of this tube was soldered to the oil bath container, and the other was sealed off by soldering to the outside of the vacuum tube. There was an outlet from this tube leading to an oil-storage tank. This outer tube was wrapped with a thin layer of asbestos paper over which a heater was placed. The heater was covered with another layer of asbestos paper and, finally, with a layer of asbestos rope. During a determination this tube was kept at the same temperature as the main oil bath by means of the heater, a differential thermocouple indicating any temperature difference between the two. The heater was operated on 110 volt alternating current with suitable re-sistance in series, and the amount of energy added was con-trolled manually.

All other parts of the apparatus were very nearly as described by Vermeulen (I).

(d) Method of Operation

In making a determination of latent heat of vaporization a sample was placed in the bomb, and the space inside the jacket was evacuated. The bomb and the jacket were brought to the desired temperature. As soon as equilibrium between the bomb and the jacket had been reached, this equilibrium

was indicated by a zero reading on the differential thermo-
couple between the two, current was passed through the heat-
er element inside the bomb for a period of from 10 to 20
minutes. During this period the vapor distilled off at
constant temperature was collected in a tared collecting
bomb immersed in an oil bath controlled by a mercury reg-
ulator. The temperature of the distilling vapor was con-
trolled by regulating the amount flowing through a motor-
operated valve in the vapor line and to a certain extent by
adjustment of the temperature of the oil bath, in which the
collecting bomb was immersed, so that the pressure drop from
the main bomb to the collecting bomb was small.

At the end of the vaporization period the heater current
was shut off, and the contents of the bomb were allowed to
come to equilibrium. The equilibrium temperature of the
bomb was recorded. In order to correct for heat loss, read-
ings of the differential thermocouple between the bomb and
the jacket were recorded every 30 seconds. This thermocouple
was also used as a guide in the adjustment of the motor-
operated valve. Temperatures of the bomb, of the vapor line,
and of the oil bath surrounding the vacuum jacket were also
recorded at intervals. At the termination of a run the col-
lecting bomb was again weighed to determine the amount of
liquid evaporated. If the final temperature of the bomb was
not the same as the temperature at the beginning of the run,
a heat capacity determination was made in order to permit
correction for this. Usually the final temperature was within

0.04 ° F. of the initial temperature.

(e) Method of Calculation

To calculate the latent heat of vaporization an energy balance is required. The energy supplied to the bomb by the heater may be dissipated in several ways. The greatest proportion of this supplied energy is, of course, used for the actual vaporization of the liquid. Energy may also be carried out as superheat in the vapor; as heat loss to the jacket by conduction, radiation, and convection; or it may serve to make the final temperature of the bomb different than the initial temperature. These possibilities must be considered if precision results are expected.

Thermocouples in the bomb and on the vapor line just outside the bomb showed that if there was sufficient liquid in the bomb to cover the heating coil, no superheat was apparent. If the liquid did not cover the heater, the superheat was very marked and was indicated by a rapid rise in outlet vapor temperature and a fall in the temperature of the liquid in the bomb. This superheat occurred at infrequent intervals, and it was felt that, rather than correct for superheat with the possibility of error in the correction and in the determination of the average temperature of vaporization, more satisfactory results would be obtained if more liquid were added and the determinations were repeated. Therefore, for all measurements taken superheat was negligible.

Even slight changes in the temperature of the bomb relative to the vacuum jacket gave appreciable heat loss. To

calculate this heat loss a calibration curve was established

by adding a known amount of energy to the bomb with the temper-

ature of the vacuum jacket remaining constant. The rise in

temperature of the bomb as measured by the differential

thermocouple was recorded. As the bomb cooled the reading of

this differential thermocouple was recorded against time.

From this record of time vs. temperature difference the cool-

ing curve shown as Figure 2 was plotted. It was found that

the rate of cooling was approximately proportional to the

temperature difference between the bomb and jacket.

$$\left(\frac{dM}{d\theta}\right) = KM \tag{5}$$

The constant, K, was found from the slope of the cooling curve

to be 0.000299 seconds^{-1}. Energy added to the bomb per

microvolt change in potentiometer reading $= \frac{E}{M'}$

$$Q' = \text{Heat loss per pound} = \frac{EKM\theta}{M'W'} \text{ B. T. U.} \tag{6}$$

M = Microvolt bomb-jacket differential reading
M' = Rise in temp. of bomb upon addition of energy
       as measured in microvolts by the potentiometer
E = Energy added to the bomb in B. T. U.
W' = Pounds of liquid collected in the receiving bomb
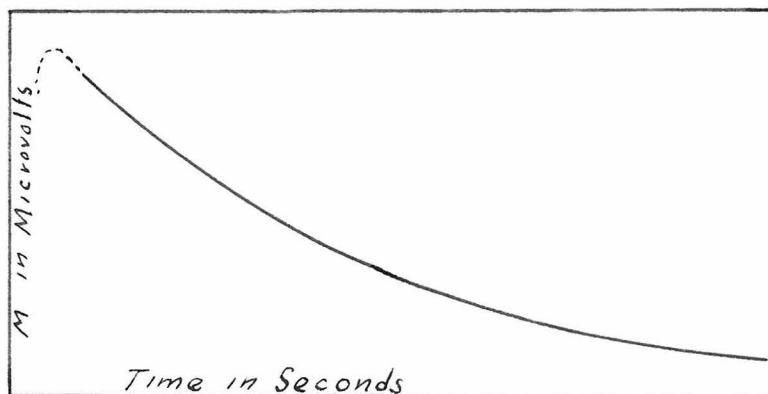θ = Total time of a determination in seconds.

Figure 2. Calibration cooling curve

If the bomb temperature at the end of the determination was different than at the beginning, an additional correction was necessary. This correction will be called the heat capacity correction in further discussion. To calculate it, a known amount of electrical energy was added to the bomb, and the rise in temperature of the bomb was recorded. After this temperature rise was corrected for heat loss, the energy required per unit increase in temperature could be calculated. This value was multiplied by the difference in temperature between initial and final conditions to give the desired correction.

The accurate determination of energy supplied to the bomb was of utmost importance in determining the latent heat of vaporization. Figure 3 shows the electrical circuit used. The e. m. f. drops across resistances R_1 and R_2 were measured against time during a determination. The integrated averages of these values were used to determine E_H and I_H.
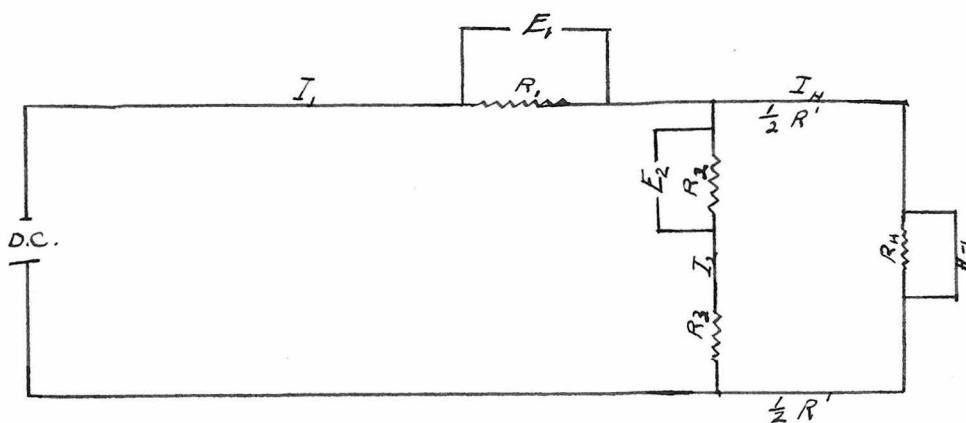

Figure 3. Electrical Circuit for Calorimeter Bomb Heater

Calculation of I_H and E_H:

$R_1 = 2.4287 \; ohms$; $\dfrac{R_3}{R_2} = 10.40156$, $R_2 = 554.208 \; ohms$

$R' = Lead \; wire \; resistance = .335 \; ohms.$

$I_{Heater} = \dfrac{Av. E_1}{R_1} - \dfrac{Av. E_2}{R_2} = .411745 \times \dfrac{1}{\theta}\int_0^\theta E_1 d\theta - .0017883 \times \dfrac{1}{\theta}\int_0^\theta E_2 d\theta$

$E_H = 11.40156 \times \dfrac{1}{\theta}\int_0^\theta E_2 d\theta - \dfrac{.335}{2.4287} \times \dfrac{1}{\theta}\int E_1 d\theta$

$E_H = 11.40156 \times \dfrac{1}{\theta}\int_0^\theta E_2 d\theta - 0.138037 \times \dfrac{1}{\theta}\int_0^\theta E_1 d\theta$

Calculation of Volume Correction:

If the hydrocarbon under investigation is held at constant volume, not all of the material vaporized is removed across the boundary of the system. A volume just equal to that of the liquid vaporized is now filled with an additional quantity of gas. The experimental value must be corrected as shown in the equation:

$$L = \dfrac{Q+Q'+Q''+Q'''}{W} \qquad \dfrac{Q+Q'+Q''+Q'''}{W'\left(\frac{V_d}{V_d - V_b}\right)} \qquad \left(\dfrac{Q+Q'+Q''+Q'''}{W'}\right)\dfrac{V_d - V_b}{V_d} \quad (3)$$

By substitution of the proper values into Equation 3 the final calculation of latent heat of vaporization is as follows:

$$Q = \dfrac{E_H I_H \theta'(0.00094866)}{W'} \; ; \quad Q' = \dfrac{EKM\theta}{M'W'} \; ; \quad Q'' = Superheat = 0$$

$$L = \left(\dfrac{E_H I_H \theta'(0.00094866)}{W'} + EKM\theta \cdot \dfrac{1}{M'} + Q'''\right)\dfrac{V_d - V_b}{V_d} \qquad (7)$$

Symbols defined:

0.00094866	=	Factor to convert from watt seconds to B. T. U.
θ'	=	Time of energy input to the bomb (seconds)
Q	=	Total energy " " " " (B.T.U.)
W	=	Total weight of liquid vaporized (pounds)
W'	=	Weight of vapor collected in the weighing bomb (pounds)
E_H	=	Bomb heater voltage
I_H	=-	" " current

(f) Correlation of the Data

Fourteen measurements of L were made for normal pentane.
Of these values thirteen did not vary from the mean by more
than 0.5% and in most instances by much less than this. The
other value differed by nearly 2% and it was discarded.
Values of L for pentane are shown in Table I. Figure (4)
shows a comparison of experimental data with values reported
by Young (4) and with values calculated in this laboratory
from pressure-volume-temperature data by means of the Clapeyron
equation. Young's values are intermediate between the experi-
mental and the calculated values although, even at the lower
temperatures, the maximum variation is not more than 1.5%.
It is believed that the experimental latent heat values are more trust-
worthy at these lower temperatures. Experimental P-V-T rel-
ations are difficult to obtain accurately in this temperature
range, while experimental latent heats of vaporization are
obtained with greater precision because the lower vapor pres-
sures encountered permit more favorable operating conditions
and because volume corrections are not so important. Using
heat capacity and Joule-Thomson data Equation (2) on page 3
was evaluated taking for L_O the experimental value at 104° F.
This value was used because of the general consistency of ex-
perimental measurements in this temperature range. The values
of L calculated from this equation throughout the entire experi-
mental temperature range were within 0.5% of the curve based
upon the directly measured values. To avoid confusion in in-
terpreting the other curves these results were not shown in
Figure 4. The good agreement of experimental data with latent
heats obtained from other sources indicates

an absolute accuracy of nearly 0.3%.

Figure (5) shows a plot of L as a function of temperature
for propane. The agreement here is not all that could be
desired. On the same figure are values from the Clapeyron
equation, from the experiments of the Linde Laboratories (1),
and from the integrated equation mentioned above. The experi-
mental values seem to fit the points reported by Dana much
better than do the values from the Clapeyron equation.
However, the values calculated from the Clapeyron equation
are almost the same as previously reported values (5) cal-
culated using entirely independent P-V-T data. The results
obtained by integration of Equation (2), taking for L_o a
value derived from the Clapeyron equation, agree very well
with the Clapeyron equation values, but these would agree
equally well if a value of L_o had been taken from the experi-
mental curve. Until additional measurements can be made, it
will be difficult to ascertain which values are correct.
Experimental values for propane are tabulated in Table 2.

Table 1.

Latent Heat of Vaporization of Normal Pentane

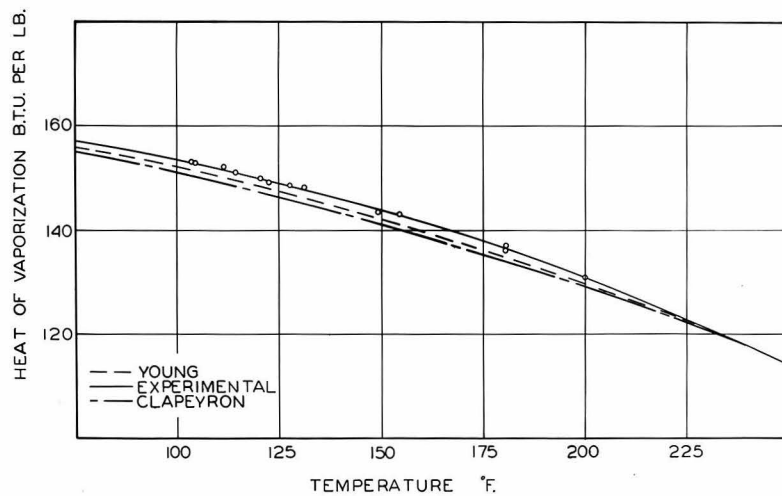| Temperature F	Calculated Energy B.T.U. #	Heat Capacity Correction B.T.U. #	Heat Loss Correction B.T.U. #	Calculated Energy Plus Correction	$\frac{V_d - V_b}{V_d}$	Heat of Vaporization B.T.U. #
104.3	154.38	-.2432	-.1460	153.99	.9944	153.14
103.7	153.69	-.0630	.2376	153.86	.9945	153.03
111.5	152.93	.0891	.0590	153.08	.9936	152.10
114.4	151.43	.7678	-.2297	151.97	.9933	150.96
120.5	150.96	.4785	-.2862	151.15	.9925	150.03
122.4	150.37	-.0330	-.1798	150.29	.9923	149.14
127.8	148.34	3.2798	-1.1842	150.43	.9916	149.17
131.0	151.10	-1.4355	-.1409	149.53		148.15
149.0	146.38	-.1070	-1.2030	145.07	.9882	143.36
154.3	144.07	.4950	.2340	144.80	.9872	142.94
179.5	140.34	.8360	.4750	141.65	.9810	138.97
180.4	137.10	.9734	.6940	138.77	.9807	136.10
180.5	138.43	1.0440	.2650	139.74	.9807	137.06
200.0	128.18	4.3180	1.6360	134.13	.9753	130.82

Figure 4. Latent heat of vaporization of n-pentane

Table II
Latent Heat of Vaporization of Propane

Temperature °F.	Calculated Energy* B.T.U./#	Heat Loss Correction B.T.U./#	Calculated Energy Plus Correction	$\frac{V_d - V_b}{V_d}$	Heat of Vaporization B.T.U./#
103.4	140.47	1.7756	142.24	0.9346	1.3294
103.7	141.44	1.0996	142.54	0.9342	133.16
109.5	138.49	1.9663	140.45	0.9281	130.34
109.8	143.62	-1.1385	142.48	0.9278	132.20
110.0	142.53	-0.2594	142.27	0.9276	132.20
110.1	141.10	-1.4084	139.69	0.9276	129.58
110.6	145.33	-1.2562	144.08	0.9270	133.56
114.4	139.66	-0.3975	139.27	0.9227	128.50
130.7	132.94	0.2064	133.14	0.9000	119.84
130.9	133.89	-1.3886	132.50	0.9000	119.26
144.4	125.93	-0.0916	125.84	0.8758	110.21
144.5	126.55	-0.1900	126.36	0.8758	110.67
161.6	108.85	4.0540	112.90	0.8310	93.82
162.0	120.11	-0.1951	119.92	0.8302	99.56
163.2	119.57	0.1823	119.75	0.8299	99.386

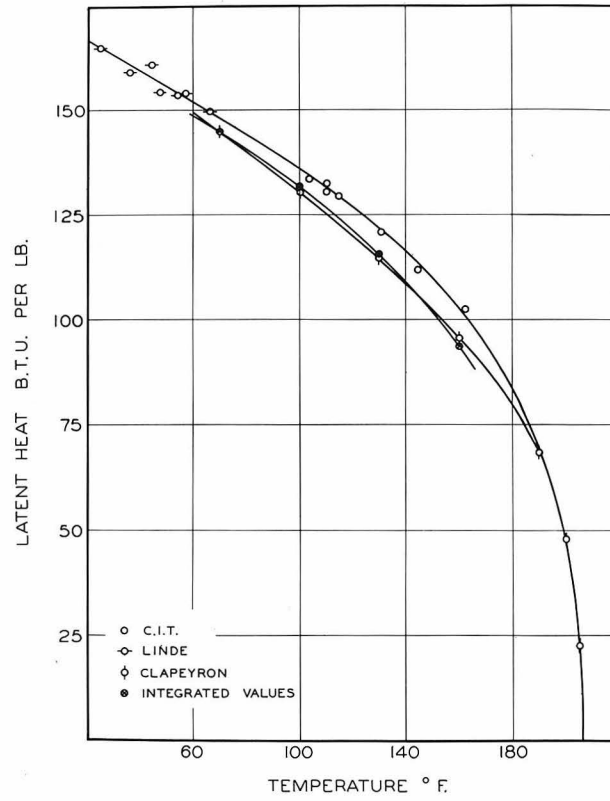* The heat capacity correction is included in the calculated energy term.

Figure 5. Latent heat of vaporization of propane

II. SOME THERMOCYNAMIC CALCULATIONS FOR n-PENTANE

A knowledge of the Joule-Thomson coefficient as a function of state and of the isobaric heat capacity as a function of temperature for a single pressure is sufficient to determine completely the heat capacity throughout the pressure range for which Joule-Thomson data are available. The method employed in such calculations is based upon the progressive graphical integration of the following general thermodynamic relation.

$$-\left(\frac{\partial C_P}{\partial P}\right)_T = \mu \left(\frac{\partial C_P}{\partial T}\right)_P + C_P \left(\frac{\partial \mu}{\partial T}\right)_P \tag{8}$$

Data for the isobaric heat capacity of n-pentane have recently been published (6). These values together with Joule-Thomson data (7) have been used to calculate the heat capacity throughoutthe superheated region. The heat capacity as a function of pressure and temperature is shown in Table 3 and is graphically recorded in Figure 5. Previous values of heat capacity have been reported (7) based upon estimated values of C_p at atmospheric pressure. Later experimental work (6) showed that these values were about 1% in error. Using the latest atmospheric heat capacity data, the values of heat capacity in the superheated gas region are slightly greater than those previously reported. It is believed that the accuracy of the present values is 0.5%.

From the isobaric heat capacity and the Joule-Thomson coefficient, the isothermal change in enthalpy with pressure
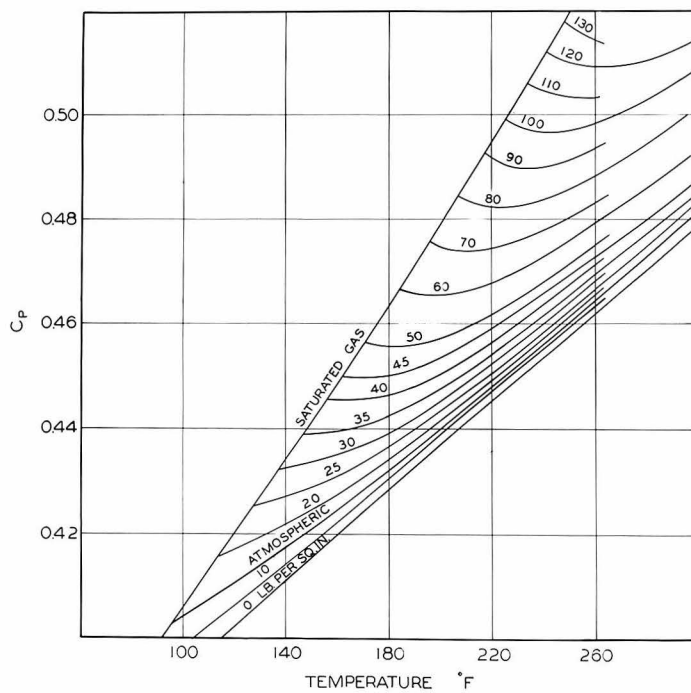
Figure 6. Heat Capacity at constant pressure
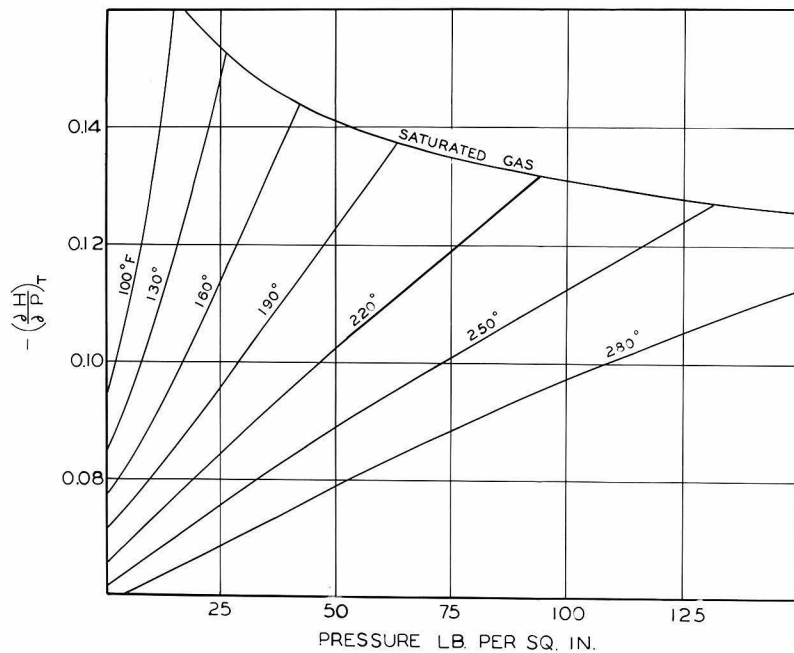for n-Pentane (C_p is expressed in B.T.U.
per pound.)

Figure 7. Isothermal change in enthalpy with pressure.

n-Pentane

may be calculated by means of the general thermodynamic
relation: $\left(\frac{dH}{dP}\right)_T = -\mu C_P$ (9)

These values are shown in Figure 7.

The compressibility factor z may be defined as the
ratio $\frac{PV}{bT}$. The isobaric change in this quantity with
temperature may be calculated from the following equation:

$$\left(\frac{dz}{dT}\right)_P = -\left(\frac{dH}{dP}\right)_T \frac{P}{bT^2}$$ (10)

Values of z were determined from the above expression by
graphical integration using values of z at 220° F. (8) as
reference points.

Residual volume may be defined as the difference be-
tween the perfect gas volume and the actual gas volume for
any given pressure and temperature. Residual volumes were
calculated from the simple relation:

$$\underline{v} = \frac{(1-z)bT}{P}$$ (11)

The results are shown in Figure 8 and Table 4. It was found
that these values were slightly lower than those previously
reported (8). This would be expected since the heat capacity
data from which $\left(\frac{dH}{dP}\right)_T$ was calculated were found to be slightly
higher than the earlier ones.

From these primary data the variations in enthalpy and
entropy with pressure and temperature have been calculated for
the superheated gas. Both entropy and enthalpy were arbi-
trarily taken as zero for the saturated liquid at 60° F. The
method of calculating these values has already been described
(9,10). Calculated values of entropy differ from previous

values (8) by as much as 7% at the higher temperatures. The improved experimental data on latent heat of vaporization and atmospheric heat capacity are believed to be sufficient to account for the difference.

Tabulated and graphical values of entropy are shown by Table 6 and Figure 10. Values for enthalpy are shown by Table 5 and Figure 9.
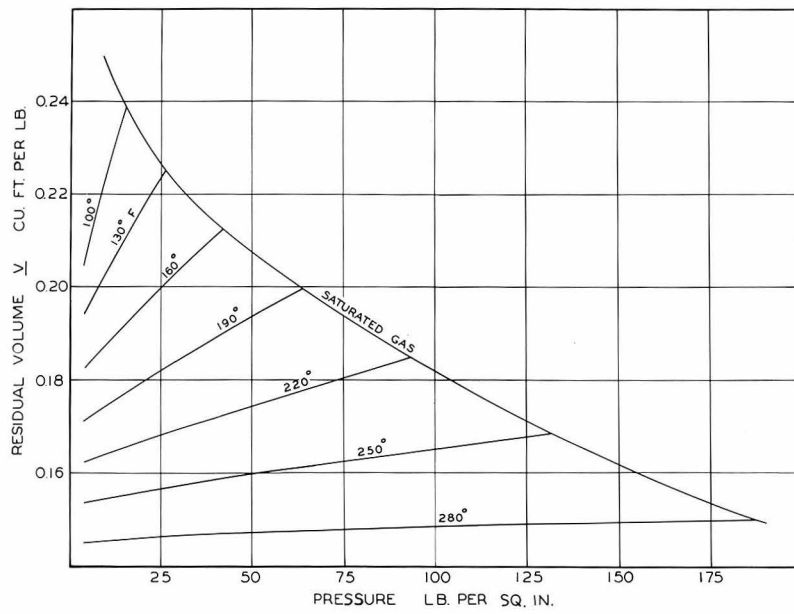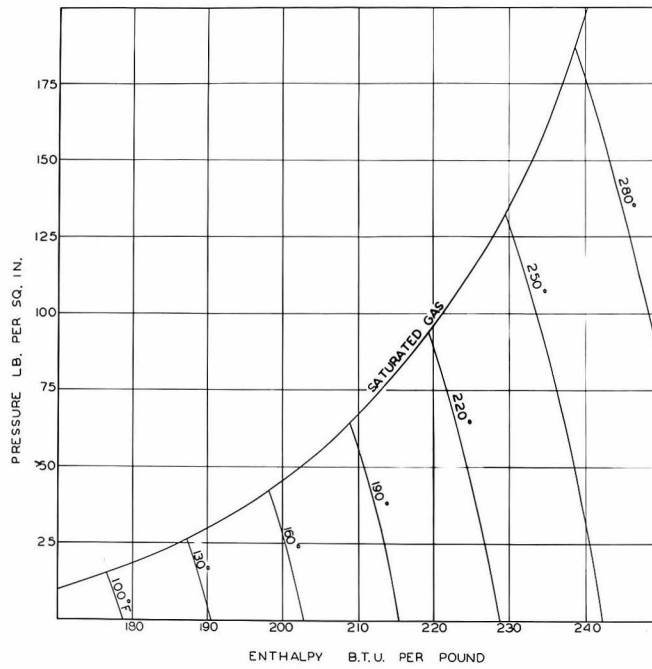
Figure 8. Residual Volume

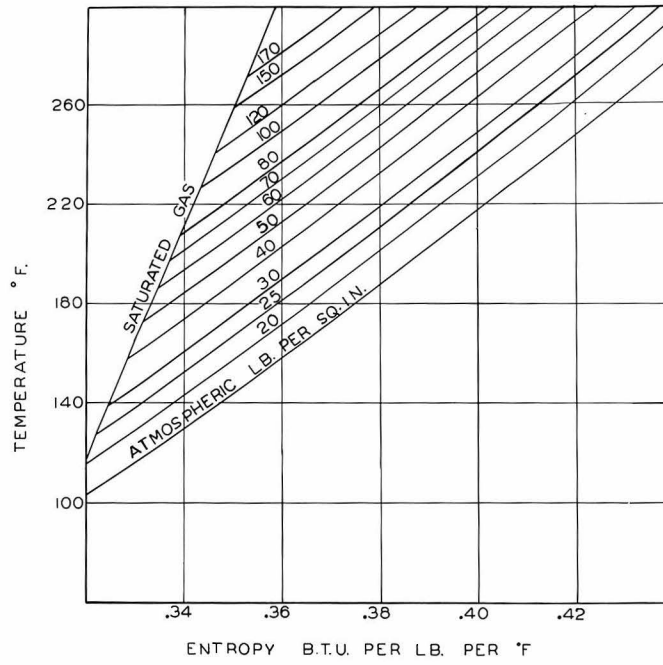Figure 9. Effect of pressure on Enthalpy at constant
temperature

Figure 10. Effect of Temperature on Entropy

Table III
Values of C_p from Smoothed Curves (B.T.U. per pound)

Pressure #/sq. in.	Saturated Gas	130	160	190	220	250*
0		.4065	.4196	.4325	.4455	.4578
10	.3900	.4100	.4221	.4344	.4470	.4593
14.696	.4033	.4138	.4245	.4360	.4479	.4603
20	.4150	.4192	.4274	.4378	.4491	.4614
25	.4242	.4256	.4308	.4398	.4506	.4627
30	.4321		.4350	.4419	.4523	.4641
35	.4392		.4394	.4447	.4543	.4657
40	.4456		.4456	.4479	.4566	.4674
45	.4512			.4514	.4590	.4693
50	.4568			.4559	.4618	.4713
60	.4668			.4658	.4678	.4756
70	.4762				.4744	.4805
80	.4846				.4824	.4857
90	.4924				.4914	.4913
100	.4993					.4972
110	.5060					.5036
120	.5120					.5103
130	.5180					.5174
Saturation		.4268	.4484	.4750	.4950	.5194

* Extrapolated values.

Table IV
Residual Volume
Cu. ft./#

Pressure #/sq. in.	Saturated Gas	130	160	190	220	250	280
10	.247	.203	.187	.174	.163	.155	.147
14.696		.210	.192	.177	.165	.155	.146
20	.232	.217	.195	.179	.166	.156	.146
25		.223	.199	.181	.167	.156	.146
30	.221		.202	.184	.169	.157	.146
35			.207	.186	.170	.158	.146
40	.214		.211	.188	.172	.158	.147
45				.191	.173	.159	.147
50	.208			.193	.174	.160	.147
60	.201			.197	.176	.160	.147
70	.196				.179	.162	.148
80	.191				.181	.163	.148
90	.186				.184	.164	.148
100	.182					.164	.148
110						.165	.149
120						.166	.149
130						.168	.149
150							.149
170							.149
Saturation		.225	.213	.199	.185	.168	.150

Table V
Enthalpy
B.T.U./#

Pressure #/sq. in.	130	160	190	220	250	280
14.696	188.8	201.4	214.3	227.6	241.2	255.2
20	188.2	200.9	213.9	227.2	240.8	254.9
25	187.5	200.4	213.4	226.8	240.5	254.5
30		199.8	212.9	226.3	240.1	254.2
35		199.1	212.4	225.9	239.7	253.8
40		198.5	211.8	225.4	239.3	253.5
45			211.3	224.9	238.9	253.1
50			210.7	224.4	238.4	252.7
60			209.4	223.4	237.5	251.9
70				222.2	236.5	251.0
80				221.1	235.5	250.2
90				219.8	234.5	249.2
100					233.4	248.3
110					232.2	247.3
120					231.0	246.3
130					229.8	245.2
150						243.0
170						240.7
Saturation	187.3	198.1	208.8	219.3	229.5	238.6

Table VI
Entropy
B.T.U./#/F

Pressure #/sq. in.	130	160	190	220	250	280
14.696	.3403	.3611	.3815	.4014	.4210	.4403
25	.3241	.3453	.3660	.3860	.4057	.4251
30		.3397	.3605	.3806	.4004	.4198
40		.3302	.3514	.3718	.3917	.4113
50			.3440	.3647	.3848	.4045
60			.3376	.3587	.3789	.3987
70				.3532	.3737	.3937
80				.3484	.3691	.3893
90				.3438	.3648	.3851
100					.3607	.3813
110					.3569	.3777
120					.3532	.3743
130					.3495	.3711
150						.3650
170						.3592
Saturation	.3226	.3287	.3353	.3419	.3484	.3546

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A definition of symbols not previously defined:

b = Gas constant = 10.715 cubic feet/square in. $\times$ $^{\circ}$R.

b (when used as a subscript) refers to bubble point conditions

C_p= Heat Capacity (B.T.U. per pound)

d (when used as a subscript) refers to dew point conditions

H = Enthalpy (B.T.U. per pound)

L = Latent heat of vaporization (B.T.U. per pound)

P = Pressure (pounds per square inch)

$\mathcal{M}$ = Joule-Thomson coefficient = $\left(\dfrac{dT}{dP}\right)$

T = Absolute temperature (degrees Rankin)

V = Volume (cubic feet per pound)

$\underline{V}$ = Residual volume (cubic feet per pound)

z = Compressibility factor = $\dfrac{bT}{PV}$

ACKNOWLEDGEMENT