DEVELOPMENT OF APPARATUS TO

MEASURE VAPOR PRESSURES

OF LIQUIDS

By

SULEIMAN YOUSEF DIAB

Bachelor of Science

Texas A & M University

College Station, Texas

1973

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1980

DEVELOPMENT OF APPARATUS TO

MEASURE VAPOR PRESSURES

OF LIQUIDS

Thesis Approved:

_____
Thesis Adviser

_____

_____

_____

_____
Dean of Graduate College

1057809

ii

PREFACE

An apparatus for measurement of vapor pressure of liquids was designed and constructed. It was used in measuring the vapor pressure of n-pentane, n-octane, methytertiary butyl ether and tertiary butyl alcohol. n-Pentane and n-octane experimental results were compared with literature values and an average difference of about 4% was found.

TABLE OF CONTENTS

LIST OF TABLES

Table   Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The thermophysical properties of liquids constitute the cornerstone in design of most processes in the chemical industries. They are particularly important to vapor-liquid equilibrium processes such as distillation and condensation.

At first glance there appears to be an abundance of vapor-liquid equilibrium data in the literature. Closer examination, however, shows data for most materials to be incomplete and, in many cases, there are no data. If data are available, many are decades old and of questionable value. If data are missing, there are no reliable techniques for estimating most of the properties.

The data that do exist were primarily taken at low temperatures and pressures and extrapolated to ranges of practical interest. The precision was high (7) for both temperatures and pressure measurements. Such measurements are expensive in both time and money to collect.

The purpose of this work was to design and construct an apparatus that could be used to measure the vapor pressure of pure components and mixtures. The apparatus was to be made of inexpensive components, easy to assemble, simple to operate and capable of operating over a wide range of temperatures and pressures. The results were expected to be of reasonable accuracy sufficient for use in engineering design calculations.

CHAPTER II

LITERATURE REVIEW

Investigations of vapor-pressure data form an important segement of the chemical literature. The techniques for such investigations as well as their classifications differ from one country to another and even from one writer to another. Researchers from West Germany and most western European countries tend to classify the employed method into six (18). While Americans and Japanese tend to classify them into two. However, a quick survey for both will be stated with some examples.

The Western European Classifications

Static Methods

In both direct and indirect static methods, the vapor pressure is measured at various temperature. The temperature is varied in a controlled way and is held constant for a certain time to permit equilibrium between liquid phase and vapor phase to be established.

Direct Static Method. In this method direct readings are obtained from manometers of various types. Examples are the mercury liquid manometers of Raleigh (20), the Sharder and Ryder liver manometer (24), and Winfrey (31). Other examples of manomenters are spiral and membrane manometers. Such as the Grigorowicis (6) glass membraine manometer and Quartz or glass spiral manometers (14, 8). The viscosity mano-

2

meter which was based on the visosity of gases like Langmiur's damping

manometer (15). Radiation (29) and ionization manometers have also been

used.

Indirect Statice Method. The pressure here is not read directly

from a manometer or a gauge but is found indirectly by finding the vol-

ume of the vapor and relating it to the vapor pressure. The volume is

found by different methods such as the optical method (4) and the radio

active method (2).

Boiling Point Method. This method made use of the fact that a

liquid boils when the pressure of its saturated vapor is equal to the

external pressure. There are two versions for this method: in the

first version, the temperature is slowly changed; in the second version,

the pressure is changed. In each case, the point when boiling begins is

determined. Blackford and York (3) in determining the vapor-liquid

equilibria of the acrylonitrile-acetonitrile-water system and Greenwood

(5) are examples of the boiling point method.

Flow Method. In this method the vapor is transferred by a current

of inert gas. The inert gas is passed over a sample heated to a given

temperature. The gas carries the vapor of the sample into a condenser.

By applying the perfect gas law and Henry's Law, the vapor pressure of

the sample can be known.

Evaporation Method. Evaporation here is carried from an open sur-

face in a vacuum then the rate of evaporation is determined. An example

of this method is the Langmiur method (10).

The <u>Knudsen</u> <u>Effusion</u> <u>Method</u>. This method is based on measurements of the flow rate of vapor escaping through a small opening from a space saturated with vapor. Large number of studies were carried out using the effusion method, consequently large number of versions of the method were introduced. Some of them are:

Determination of vapor pressure from loss weight of the effusion chamber.

Determination of vapor pressure from the quantity of condensed vapor.

Determination of vapor pressure from the density of the molecular beam which leaves the effusion orifice.

<u>Isotopic</u> <u>Exchange</u> <u>Method</u>. The principle of this method requires measurement of the rate of isotopic exchange between two samples of the substance under study. The changes in the isotopic composition can be related to the changes in the specific activity of the surface of the opposite sample. By forming a set of equations and solving for the rate of evaporation it is possible to determine the pressure of the saturated vapor as the specific activity of the opposite surface changes with time at constant temperature.

American Classification

The above six methods can be fundamentally categorized into two methods (30) namely dynamic and static or a combination of both. Such classification has been followed in the United States and Japan. The following works exemplify this classification.

Dynamic Method

This method is based on measuring the boiling point at controlled changable pressures. As examples on this method are Colburn and Co-workers (9) in their equilibrium still for miscible liquid, Katayama, et al. (12) in determining isothermal vapor-liquid equilibria of acetone-carbon dioxide system and Ramalko, et al. (21) in their method for obtaining vapor-pressure equilibrium data for multicomponent systems.

Static Method

Here the vapor pressure is measured at changable controlled temperatures. Examples of this are Kaminishi, Arai, Saito and Maeda (11) in their work for determining vapor-liquid equilibria for binary and ternary systems containing carbon dioxide; Noda, Morisue and Ishida (19) in determining vapor-liquid equilibria for benzene-cyclohexane-ammonia system; and Sagar, Arai and Saito (23) in measuring vapor-liquid equilibria of binary and ternary systems containing hydrogen and light hydrocarbon.

A combination of both methods can be featured in the experiment of Lodle and Scheller (17) for determining the isothermal vapor-liquid equilibrium data for the system n-pentane-n-valeric acid at 50°, 75° and 100°C.

So according to this classification the method of this study can be categorized as a static method.

CHAPTER III

EXPERIMENTAL APPARATUS

An apparatus was designed and constructed for the measurement of
vapor pressure. The overall schematic diagram of the apparatus is shown
in Figure 1 and its major parts are the following:

Constant Temperature Bath

It is composed of a bath and thermal fluid. The bath was made by
Colora Company of West Germany, Model No. 1 NB-3329. It has a circula-
ting system and it is equipped with an electric stirrer, with a thermo
regulator and with a 500, 1000, and 1500 watt immersion type electric
heater. It has a capacity of 3.5 gallon. The bath set-point tempera-
ture could be tapped continuously by adjusting the set point on the
thermo regulator. The thermal fluid is silicon oil SF-96 which is a
General Electric Company product.

Potentiometer

The potentiometer used was "Volt Potentiometer" made by Leeds &
Northup, Model No. 8687. Its' limits of error are 0.04% of +3 reading.
It has a range of 0.0 to 0.1601 volts with the smallest division 5 v
adjustable to 0.1 v (16).
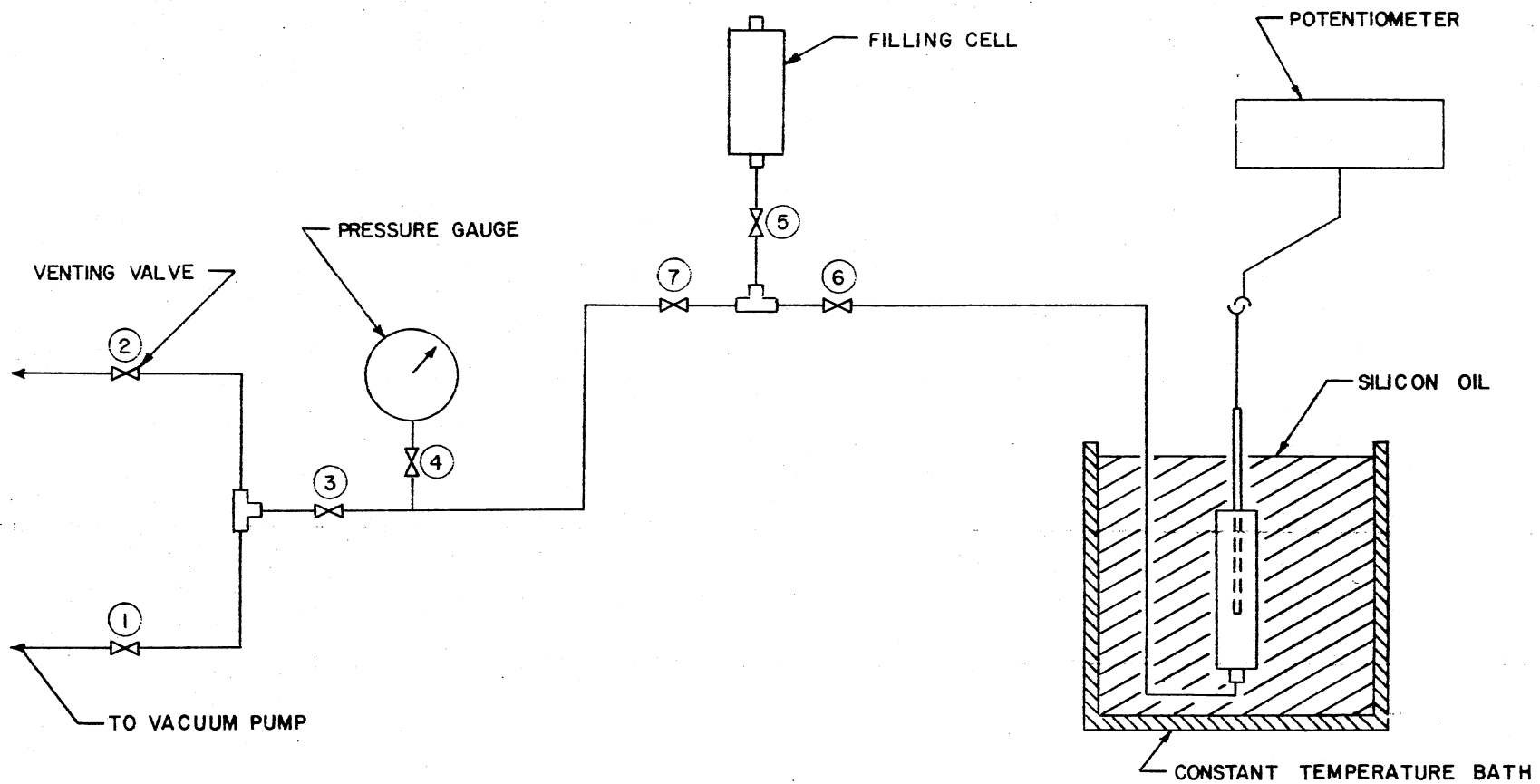
Figure 1. Overall Schematic Diagram of Apparatus for Vapor Pressure Measurements

Vacuum Pump

Duo-Seal Vacuum Pump, Model No. 60482-0 was used. It was made by W. M. Welch Scientific Company of Chicago.

Sample Cell and Thermocouple

A 33.3 ml stainless steel cell, Hoke, Model No. 2HD30, was used with a chromel-alumel type K thermocouple. The thermocouple, made by Omega Engineering Inc. of Connecticut, was connected to one end of the cell for temperature measurements.

Pressure Gauge

The pressure was measured by four different types of pressure gauges. The first and the second were Roylyn 60 psi pressure gauges with and without diaphram, respectively. Both have a 0.1 psi division and an accuracy of 0.5% of 1%.

The third and the fourth types were 30 and 100 psi Dura compound gauges. Both made by Ascroft U.S.A. and have 1.0 psi division.

Valves

All valves used in the apparatus are Parker AI valves.

All data of this study were taken on fluids furnished by "Fluids Properties Research Laboratory, Inc." n-Pentane and n-heptane were from Phillips, methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol were from Shell Chemical and Dow Chemical Companies, respectively.

CHAPTER IV

EXPERIMENTAL PROCEDURE

This chapter is subdivided into three sections: (1) Calibration
Procedure; (2) Operating Procedure; and (3) Data Gathering Procedure.

Calibration Procedure

Pressure Gauges Calibration

The calibration of the 60 psig Roylyn gauge with diaphgram using
a mercury manometer was conducted. Results are stated in Appendix A
in Table VIII, plotted in Figure 7. Another calibration had two checks
for the same gauge were made using dead weight load tester, 2400 HL
Ruska Pressure System (22). The results are given in Tables IX, X,
and XI, and plotted in Figures 8, 9, and 10 in Appendix A.

For the compound gauge, three calibration checks were made using
the same dead weight tester system used above. No changes were noted
in the second and the third checks. Results are tabulated in Table XII
and Appendix A.

Thermocouple Calibration

The three chromel-alumel thermocouples used in this study were
calibrated using N.B.S. calibrated Leeds and Northrup platinum resist-
ance thermometer, Serial No. 1761202; Leeds and Northrup bridge; and

9

Leeds and Northrup volt potentiometer. The temperature range covered was from 27.035°C to 211.109°C. The data obtained from this procedure are given in Table VII. A plot, such as Figure 6, was used to correct temperature readings. (Figure and plot are in Appendix A)

However, fitting the experimental data points obtained from the calibration into a quadratic equation, and evaluating the quadratic equation constants by using the Texas Instrument (26) quadratic regression program gave the following:

$$T_{co} = T_p + DT \tag{1}$$

$$T = a_0 + a_1 T_p + a_2 T_{p2} \tag{2}$$

where

T_{co} = corrected temperature

T_p = temperature read from the potentiometer tables.

a_0, a_1, a_2 = quadratic equation constants. When,

T_p is in ^{o}F then

$T = 0.3454 - 0.00591 T_p + 0.000032 T^2_p$.

Operating Procedure

The system as shown in Figure 1 was evacuated and purged three times with the test sample by applying the following step by step procedure:

1. Valves 1, 3, 4, 6 and 7 were opened.

2. Valves 2 and 5 were closed.

3. Valve 1 was connected to a vacuum pump line and the whole

apparatus was vacuumed.

4. Valve 6 was closed and valve 5 was opened until some of the sample was seen running through the transparent tube connecting the apparatus with vacuum pump; then valves 1, 3 and 7 were closed.

5. Valve 6 was opened and the sample was charged into the test cell, then 5 was closed. After flashing the samples three times, the test cell was charged with about 10-20 ml of the sample.

6. The temperature regulator of the constant temperature bath was set to the desired temperature and the electric heater and stirrer were turned on.

CHAPTER V

EXPERIMENTAL RESULTS

The apparatus was used in determining the vapor pressure of n-pentane, methyl tertiary butyl ether and tertiary butyl alcohol.

The experimental vapor pressure data for n-pentane were compared with API (25), Timmermans (27) and Vargaftik (28) data and are tabulated in Tables I, II, III and in Figure 2. The normal boiling point of methyl tertiary butyl ether and tertiary butyl alcohol was determined first, then their vapor pressures were measured and shown in Tables IV and V, and in Figures 3 and 4. The vapor pressure of methyl tertiary butyl ether was compared with Townsend and Coworkers (1), Table VI.

Supplementary details for experiment using the apparatus with different variations and other materials such as n-octane are found in Appendix A.

TABLE I

n-PENTANE VAPOR PRESSURE MEASUREMENTS
USING THE APPARATUS

Temp. ^{o}F	Exp. Vapor Pr. PSIA	API Corresp. Data PSIA
103.727	17.308	16.697
119.696	23.104	22.267
128.435	26.904	25.851
142.348	33.328	32.498
153.217	40.269	38.516

*Experimental data were reproduced by repeating the experiment three times. The results were within 2-4% of the reported data.

TABLE II

n-PENTANE VAPOR-PRESSURE MEASUREMENTS
REPORTED BY TIMMERMANS (29)

T Temp $^\circ F$	P PSIA	T $^\circ R$	$\dfrac{10^4}{T_R - 1}$	Log P
104	16.881	563.67	17.741	1.227
122	23.069	581.67	17.192	1.363
140	31.036	599.67	16.676	1.492
158	40.975	617.67	16.190	1.613
176	52.881	635.67	15.731	1.723

Slope = -0.247358

$Y_{Intercept}$ = 5.615969

TABLE III

n-PENTANE VAPOR-PRESSURE MEASUREMENTS
REPORTED BY VARGAFTIK (30)

T Temp $^\circ F$	P PSIA	T $^\circ R$	$\dfrac{10^4}{T_R-1}$	Log P
104	16.767	563.67	17.741	1.225
122	23.076	581.67	17.192	1.363
140	31.111	599.67	16.676	1.493
158	41.832	617.67	16.170	1.622
176	53.317	635.67	15.731	1.727

Slope = 0.241327

$Y_{Intercept}$ = 5.527606
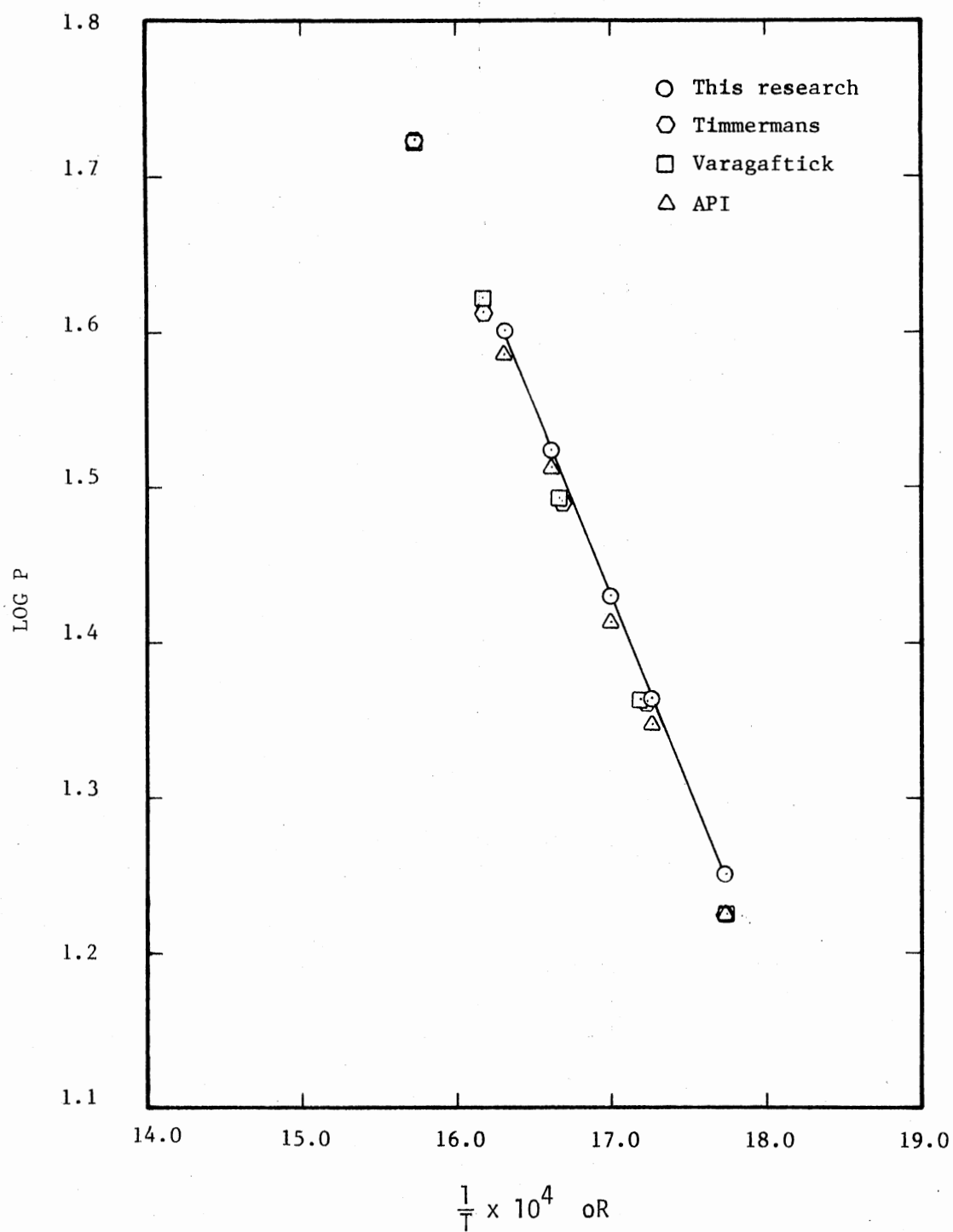
Figure 2. n-Pentane Vapor Pressure

TABLE IV

METHYL TERTIARY BUTYL ETHER
VAPOR-PRESSURE

100 (Potenti-ometer Reading) Mu	Temp. ^{o}F	Experimental Vapor Pressure
2.535	144.304	23.303
3.110	169.261	33.283
3.675	193.652	46.798
4.33	222.217	67.593
4.88	246.304	90.503
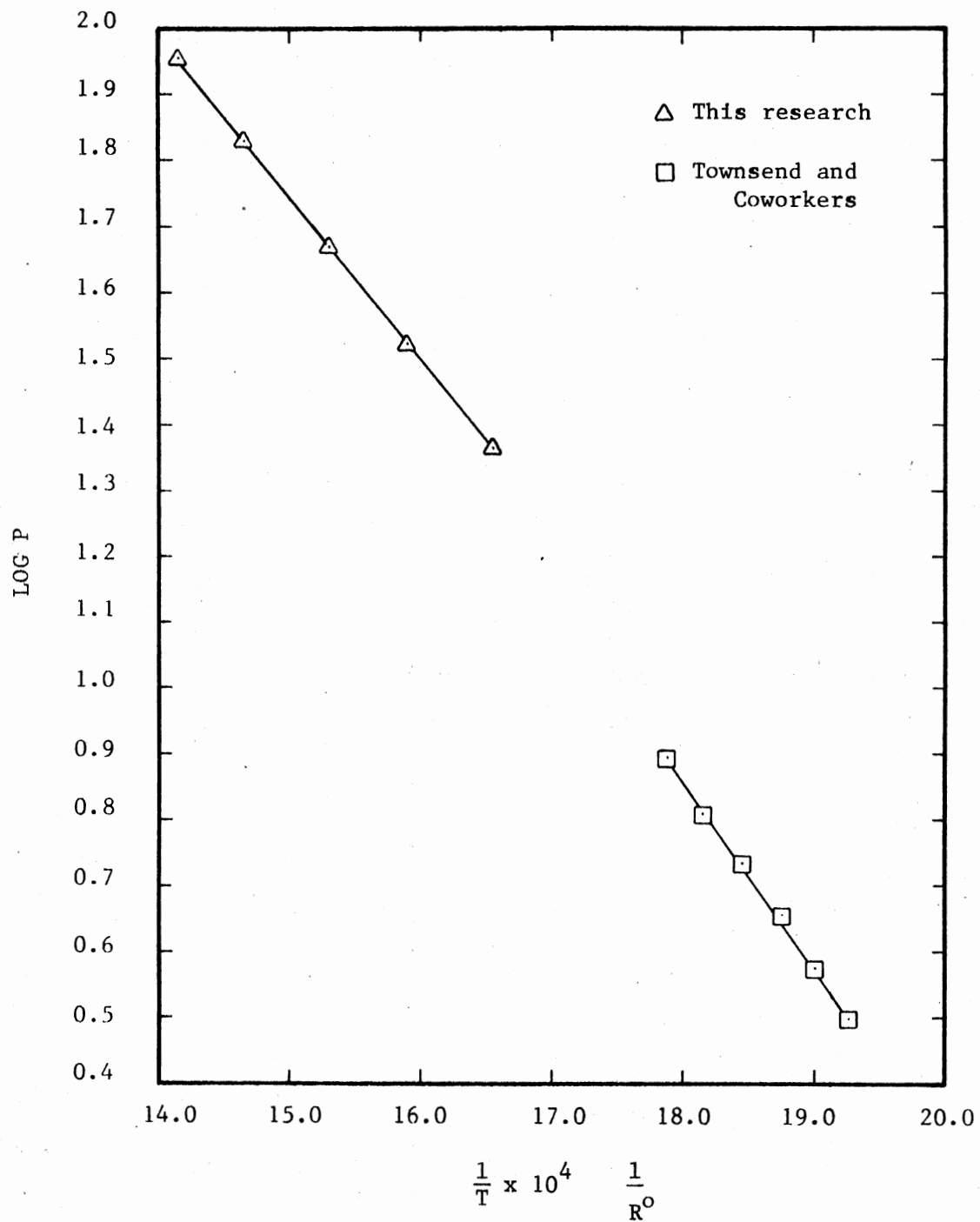
Figure 3.   t-Methyl Butyl Ether Vapor Pressure

TABLE V

TERTIARY BUTYL ALCOHOL VAPOR-PRESSURE

100 (Potenti-ometer Reading) Mv	Temp. $^{\circ}$F	Experimental Vapor Pressure PSIA
3.700	194.826	22.171
4.210	217.000	34.161
4.670	237.087	45.842
5.270	263.455	69.332
5.790	286.522	96.366
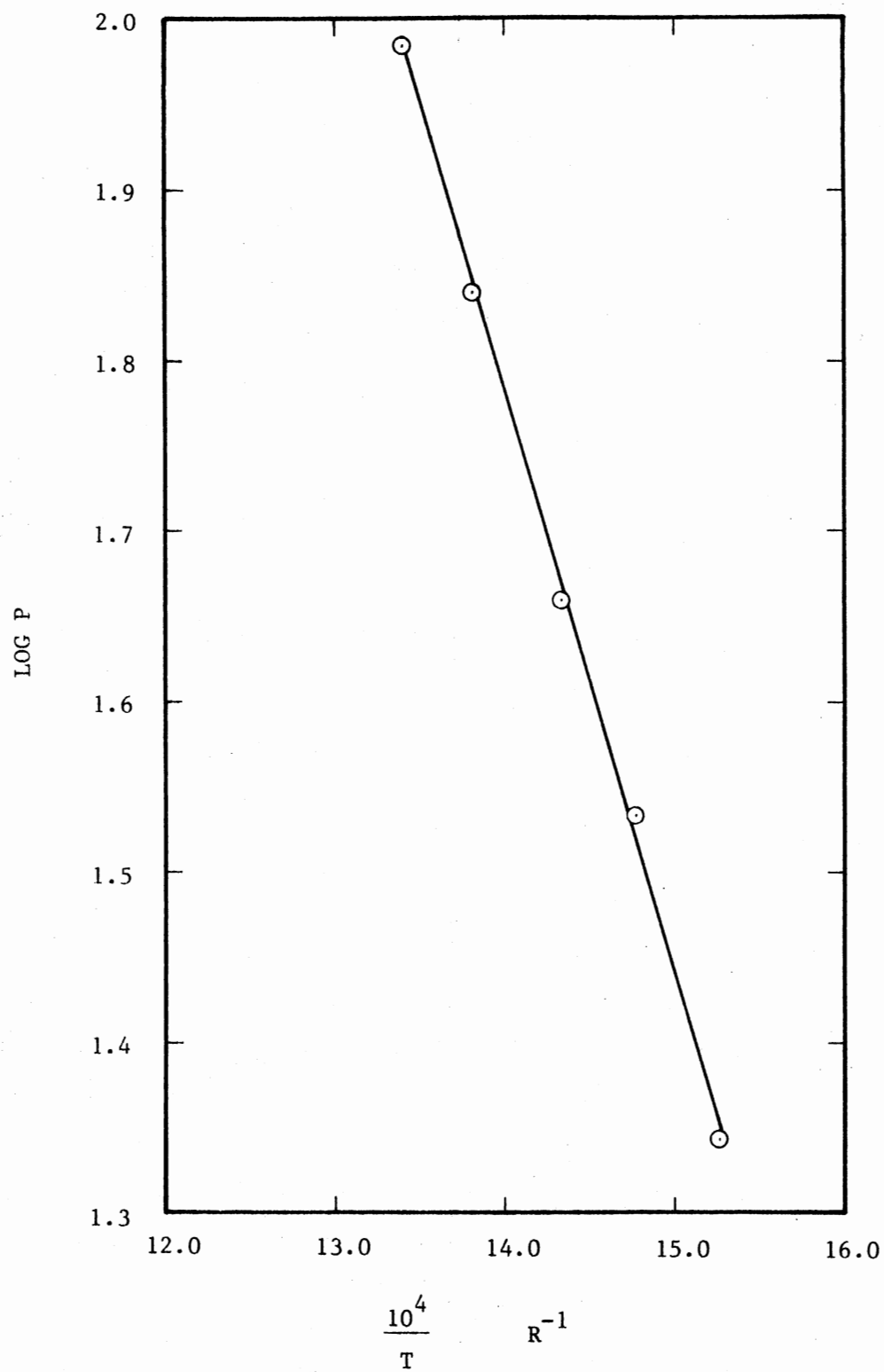
Figure 4.   t-Butyl Alcohol Vapor Pressure

TABLE VI

DATA REPORTED BY TOWNSEND AND COWORKERS (31)
t-BUTYL METHYL ETHER

$T_{^\circ R}$	P PSIA	$^\circ R$	$\frac{1}{T} \times 10^4$	Log P
58.995	3.16	518.665	19.28	0.4997
66.164	3.75	525.834	19.017	0.57403
74.107	4.52	533.077	18.734	0.6552
81.802	5.4	541.472	18.468	0.7324
90.127	6.47	549.797	18.189	0.8107
99.158	7.83	558.828	17.895	0.8938

$Y_{Intercept}$ = 5.9949

Slope = -0.28502

CHAPTER VI

DISCUSSION OF RESULTS

The purpose of this study was to design and construct an apparatus capable of measuring vapor pressure of liquids, pure and mixtures, with about 99% precision. Through a series of experiments, the apparatus which was shown in Figure 1 was developed and then, was used in measuring the vapor presure of n-pentane, methyl tertiary butyl ether and tertiary butyl alcohol. The experimental results of n-pentane were compared with API (25). Timmermans (29) and Vargaftik (30) as shown in Figure 2. This comparison showed about 4% average difference between the experimental values and what was reported by API, Timmermans or Vargaftik; a difference which is higher than 1% that the study aimed to achieve.

However, following the recommendations that are stated in Chapter VII (degasifying the liquid by boiling it, flush it two or three times). Repeating the experiments three or four times in order to reproduce the data which were obtained the first time gave some confidence in the results. The reproduced data were within 2% of the data obtained during the first runs.

The normal boiling points of methyl tertiary butyl ether and bytyl tertiary alcohol were determined and they were found to be about $137^{o}F$ and $190^{o}F$, respectively. Their vapor pressures were measured and are shown in Tables IV and V, and Figures 3 and 4.

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

Conclusion

Apparatus

The purpose of this study was achieved by designing an apparatus for measuring vapor pressure of liquids pure and mixtures, over a wide range of pressures.

This apparatus, Figure 1, was shown to have an average deviation of 4% from the data reported by API (4), Timmermans (29), Vargaftik (3).

Material

The normal boiling point of methyl tertiary butyl ether and tertiary butyl alcohol were determined and found to be about 137^oF and 190^oF, respectively.

The vapor pressure of n-pentane, tertiary butyl ether and tertiary butyl alcohol were measured and tabulated in Table I, IV and V, and were shown in Figures 2, 3 and 4.

Recommendations

The following recommendations are suggested to achieve the stated goal of the study and to improve its results:

1. Degasify the liquid to be measured before charging it to the

apparatus to minimize the effect of the dissolved gases in the tested liquid vapor pressure.

2. For pure components only flash and vacuum part of the sample to be measured two or three time to dilute any contaminents in the apparatus after vacuuming.

3. Fill the sample cell to about one-third of its volume when measuring the vapor pressure of pure liquids; and fill it to about 80-90% of its volume when measuring the vapor pressure of mixtures so as to avoid changes in composition of the mixtures while being tested.

4. A 1000 psi compound gauge is recommended to be used with this apparatus to get high pressure measurements.

5. If the apparatus is used to measure vapor pressure below 100 psig, then it is recommended to have a compound pressure gauge with 0.1 lb. divisions for more accurate reading.

6. The filling technique is important in minimizing the amount of air left in the apparatus after vacuuming so carefullness and attention are required.

7. The higher the degree of vacumming is achieved the less deviation in the results are reported.

A SELECTED BIBLIOGRAPHY

1. Ambrose, D., J. H. Ellender, C. H. S. Sprake and R. Townsend.
    "Thermodynamic Properties of Oxygen Compounds. XLIIII
    Vapor-Pressure of Some Ethers." J. Chem. Thermodynamics,
    Vol. 8 (1976), pp 165-178.

2. Auslander, J. S. and J. J. Georgescu. Determination of Vapor
    Pressure by Radioactivity. Geneva: International Conference
    on Peaceful Uses of Atomic Energy, Report No. 1090, (1955).

3. Blackford, D. S. and R. York. "Vapor Liquid Equilibria of the
    System Acrylonitrile-Acetonitrile-Water." J. Chem. Eng.
    Data, Vol. 10 (1965), p 313.

4. Fuchtbauer, C. and H. Barties. "Vapor Pressure by Optical Method."
    Z. Physik, Vol. 4 (1921), p 337.

5. Greenwood, H. C. "Vapor Pressure by Boiling Point Method." Z.
    Electrochem., Vol. 18 (1912), p 319.

6. Grigorowici, R. "Glass Membranine Manometer." Z. Tech. Physik,
    Vol. 20 (1939), p 102.

7. Herington, E. F. and J. F. Martin. "Vapor Pressure of Pyridine
    and Its Homologues." Trans. Farady Soc., Vol. 49 (Feb. 1953),
    pp 154-162.

8. Johnson F. M. G. and D. McIntosh. "Liquid Chlorine." J. Am. Chem.
    Soc., Vol. 31 (1909), p 1138.

9. Jones, C. A., E. M. Schoenborn and A. P. Colburn. "Equilibrium
    Still for Miscible Liquids." Ind. Eng. Chem., Vol. 35 (1943),
    p 660.

10. Jones, H. A., I. Langmuir and G. M. J. Mackay. "The Rates of
    Evaporation and the Vapor Pressures of Tungsten, Molybolenum,
    Platinum, Nickle, Iron, Copper and Silver." Phys. Rev.,
    Vol. 30 (1927), p 201.

11. Kaminishi, G., Y. Arai, S. Saito and S. Maeda. "Vapor-Liquid
    Equilibria for Binary and Ternary Systems Containing Carbon
    Dioxide." J. Chem. Eng. Japan, Vol. 1 (1968), p 109.

12. Katayama, T., K. Ohgaki, G. Mackawa, M. Goto and T. Nagans.
    "Isothermal Vapor-Liquid Equilibria of Acetone-Carbon Dioxide
    and Methanol-Darbon Dioxide System at High Pressure." J.

Chem. Eng. Japan, Vol. 8 (1975), p 89.

13. Knudsen, M. "Vapor-Pressure by Effusion Method." Am. Physik, Vol. 35 (1911), p 389.

14. Ladenburg, A. and E. Lehman. "Quartz Membrane Manometer." Ver-handle Deut. Phys. Ges., Vol. 8 (1906), p 20.

15. Langmiur. I. "Chemical Reactions at Very Low Pressures. The Clean Up of Oxygen in Tungsten Lamp." J. Am. Chem. Soc., Vol. 35 (1913). p 105.

16. Potentiometer Instruction Manual. Leeds and Northrup Corporation, Philadelphia, Penn., 1966.

17. Lodle, S. J. and W. A. Scheller. "Isothermal Vapor-Pressure Equilibrium Data for the System n-Heptane-n-Valeric Acid at 50°, 75°, and 100°C." J. Chem. Eng. Data, Vol. 12 (1967), p 485.

18. Nesmeyanov, A. N. Vapor Pressure of the Chemical Elements. 1st Ed. New York: Elsevier Publishing Company, 1963.

19. Noda, K., T. Morisue and K. Ishida. "Vapor-Liquid Equilibria for Beuzene-Cyclohexane-Ammonia System." J. Chem. Eng. Japan, Vol. 8 (1975), p 104.

20. Raleigh, _. "Mercury Liquid Manometer." Phil. Trans., Vol. 196 (August 1901), p 208.

21. Ramalho, R. S., F. M. Tiller, W. J. James and D. W. Bunch. "Arapid Method for Obtaining Vapor-Liquid Equilibrium Data, Theoretical Aspect." Ind. Eng. Chem., Vol. 35 (1961), p 895.

22. Ruska Dead Weight Gauge Manual. Ruska Instrument Corporation, Houston, Texas, 1966.

23. Sagara, H., Y. Arai and S. Saito. "Vapor-Liquid Equilibria of Bi-nary and Ternary Systems Containing Hydrogen and Light Hydro-carbons." J. Chem. Eng. Japan, Vol. 5 (1972), p 13.

24. Sharader, J. E. and H. M. Ryder. "An Optical Lever Manometer." Phys. Rev., Vol. 13 (1919), p 321.

25. Technical Data Book-Petroleum Refining. Vol. 1, 2nd Ed., American Petroleum Institute, 1970.

26. TI 52 Calculator Manual. Texas Instruments Inc., Dallas, Texas, 1975.

27. Timmermans, J. Physco-Chemical Constants of Pure Organic Compounds. Vol. 2, New York: Elsevier Publishing Company, 1965.

28. Vargaftik, N. B. Tables on the Thermophysical Properties of Liquids. 2nd Ed. New York: John Wiley and Sons, 1975.

29. Voege, W. "Radiation Manometer." Phys. Z., Vol. 7 (1906), p 498.

30. Verver, C. G. Handbook of Laboratory Distillation. 1st Ed. New York: Elsevier Publishing Company, 1963.

31. Winfrey, J. C. "New Method for the Vapor Pressure for the Hexanes-Plus Fraction of Natural Gasoline." Petroleum Refiner, Vol. 35 (1956), p 205.

APPENDIX A

SUPPLEMENTARY MATERIAL

DISCUSSION

In the course of developing the apparatus, a number of variations were tried. The first attempt was to place the pressure gauge in the vapor phase from the vapor pressure cell. Condensation of the vapor in the cool portion of the pressure gauge line appeared to be the cause of erratic vapor pressure readings.

A Rolyn gauge manufactured by 3D Instruments and equipped with an isolator was used in attempts to overcome the vapor condensation problem. The isolator is simply a liquid filled tube which transmits pressure to the gauge. However, when the isolator was physically close enough to the cell to overcome the vapor condensation problem, there was enough heat transmitted to the vapor isolator to cause the liquid to expand and produce incorrect pressure readings.

A sketch of the apparatus with the pressure gauge in the vapor line is shown in Figure 5.
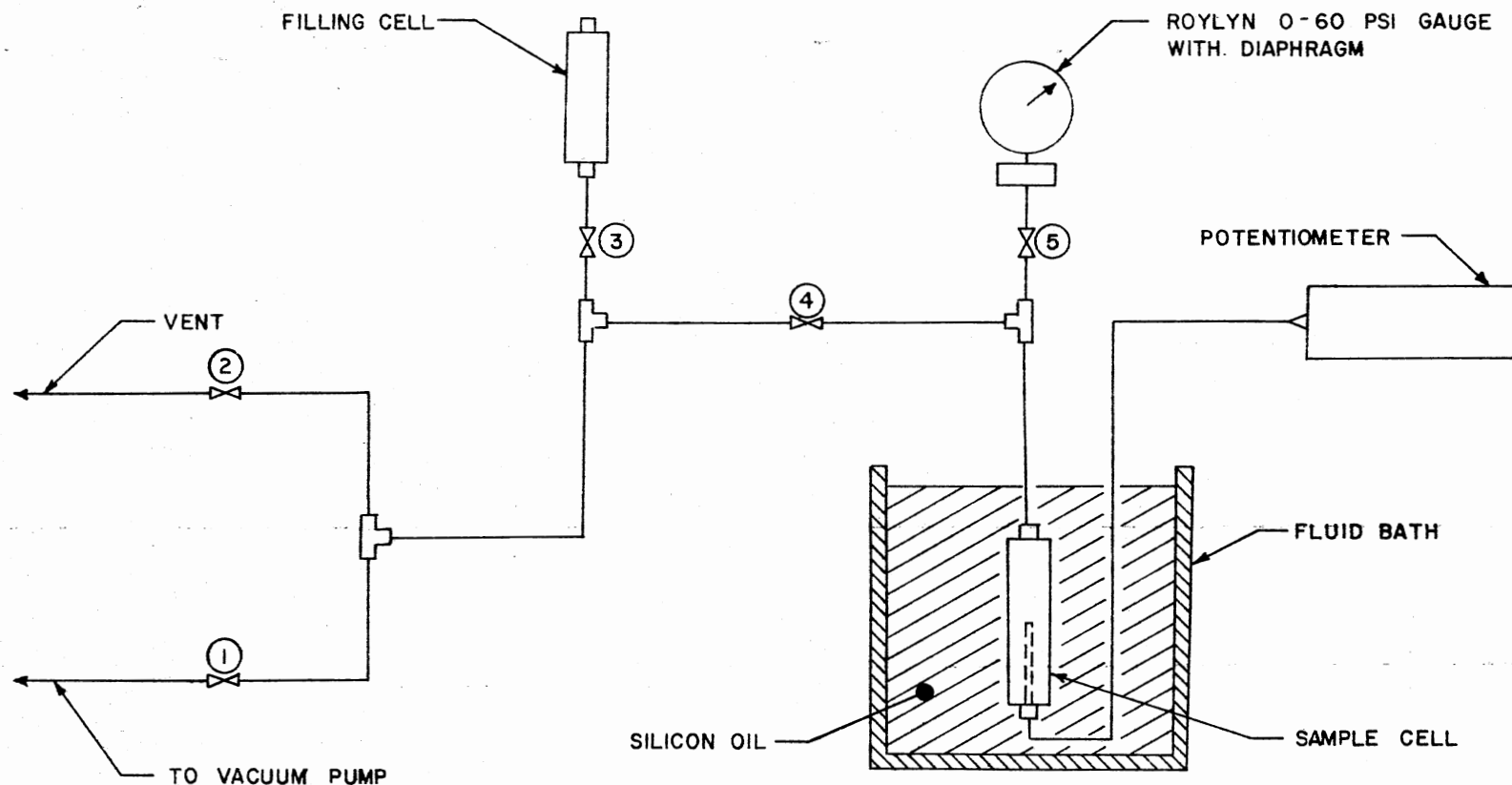
Figure 5. Overall Schematic Diagram of the Appartus
(Pressure Gauge in the Vapor Line)

APPENDIX A

EXPERIMENTAL DATA

TABLE VII

CALIBRATION OF CHROMEL-ALUMEL THERMOCOUPLES. USING N.B.S.
CALIBRATION LEED AND NORTHRUP CORPORATION PLATINUM
RESISTANCE THERMOMETER (Serial No. 1761202)

Thermo-couple No.	Temp. Read from Potenti-onmeter Table $T_e\,^oC$	Temp. Resis. (Calib.) $T_{co}\,^oC$	DT	$T_p(^oF)$	$T_{co}(^oF)$	T
1	26.894	27.035	0.141	80.409	80.663	0.254
2	26.875	27.035	0.160	80.375	80.663	0.288
3	26.875	27.035	0.160	80.375	80.663	0.288
1	53.33	53.563	0.230	127.999	128.413	0.414
2	53.333	53.564	0.231	127.999	128.415	0.416
3	53.333	53.561	0.228	127.999	128.410	0.410
1	112.714	112.792	0.078	234.885	235.026	0.140
2	112.714	112.790	0.076	234.885	235.022	0.137
3	112.708	112.789	0.081	234.874	235.020	0.146
1	145.250	145.318	0.068	293.450	293.572	0.122
2	145.250	145.317	0.067	293.450	293.571	0.121

TABLE VII (Continued)

Thermo-couple No.	Temp. Read from Potenti-onmeter Table $T_e{}^oC$	Temp. Resis. (Calib.) $T_{co}{}^oC$	DT	$T_p({}^oF)$	$T_{co}({}^oF)$	T
3	145.250	145.320	0.070	293.450	293.576	0.126
1	162.575	162.866	0.291	324.635	325.159	0.524
2	162.575	162.867	0.291	324.635	325.161	0.526
3	162.575	162.867	0.292	324.635	325.161	0.526
1	210.575	211.109	0.534	411.035	411.996	0.961
2	210.575	211.109	0.534	411.035	411.996	0.961
3	210.575	211.108	0.533	411.035	411.994	0.959

$$T = 0.859662 - 0.007263\ T_p + 0.000018\ T_p{}^2 \quad \text{where } T_p \text{ in } {}^oF$$
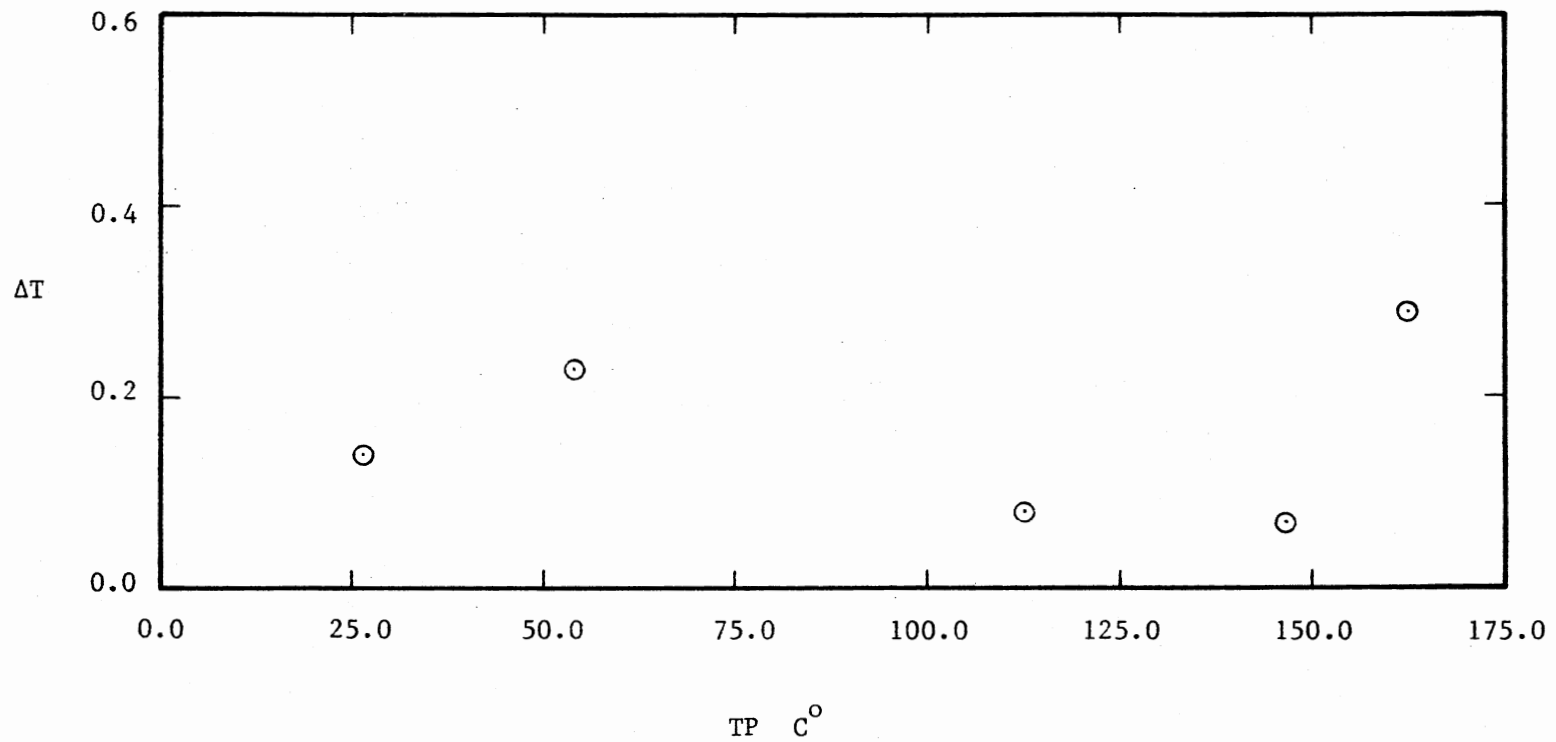
Figure 6.   Calibration of Chromel-Alumel Thermocouples

TABLE VIII

CALIBRATION OF ROYLYN 0-60 PSI GAUGE WITH
DIAPHRAGM USING MERCURY MANOMETER

	Manometer High in Hg	Manometer Low in Hg	Total in Hg	Total PSI	Guage PSI	Dev. 1%
1	0.05	+0.05	0.0	0.0	0.0	0.0
2	2.51	-2.44	4.95	2.43	2.7	1.3
3	4.90	-4.84	9.74	4.79	4.8	0.2
4	7.59	-7.54	15.13	7.43	7.4	0.4
5	10.16	-10.14	20.30	9.97	9.95	0.2
6	12.70	-12.67	25.37	12.46	12.35	0.9
7	15.20	-15.18	30.38	14.73	14.89	0.3
8	17.32	18.42	35.74	17.56	17.48	0.5

ATM = 29.285

$P_{ACT} = 1.0047 (P_{IND}) - 0.0035$

PSI = (0.4913)
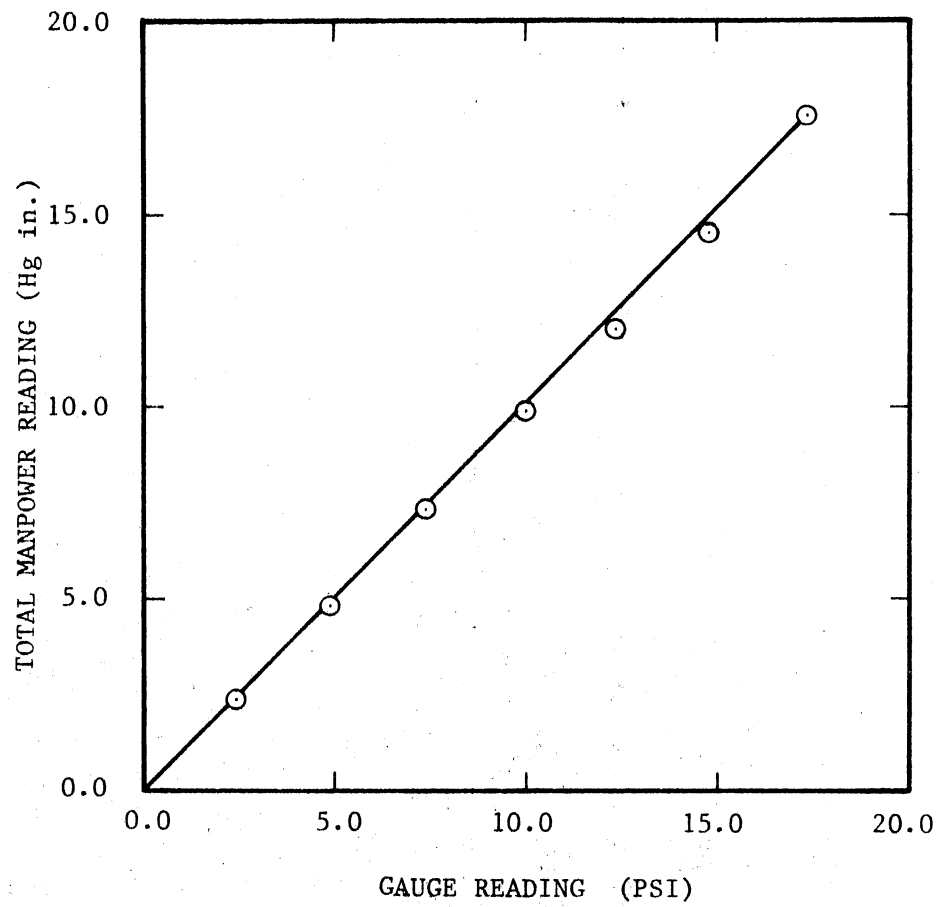
Figure 7. Calibration of Roylyn Pressure Gauge
with Diaphragm Using Mercury
Manometer

TABLE IX

CALIBRATION OF ROYLYN PRESSURE GAUGE WITH DIAPHRAGM USING DEAD WEIGHT TESTER

Dead Wt.	Gauge Reading
6.00	6.15
10.00	10.13
14.00	14.12
20.00	20.09
26.00	26.045
34.00	34.05
40.00	40.05
46.00	46.12
50.00	50.10
54.00	54.12
58.00	58.12

Pact = 1.000288 (Pind) -0.104352
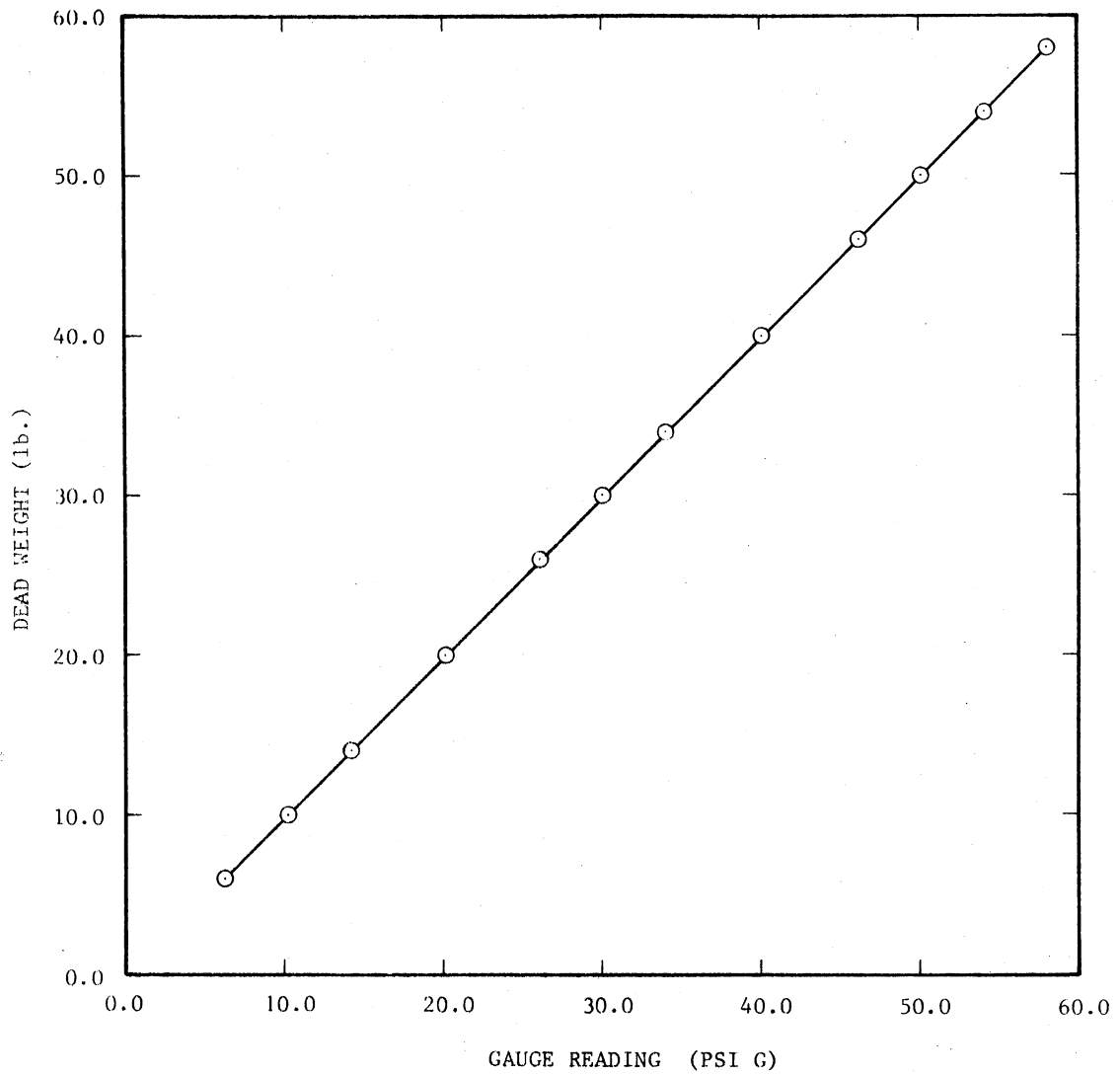
Figure 8. Calibration of Roylyn Pressure Gauge with Diaphragm
Using Dead Weight Tester

TABLE X

FIRST CALIBRATION CHECK OF ROYLYN GAUGE
WITH DIAPHRAGM USING A
DEAD WEIGHT TESTER

Tester Reading	Gauge Reading
6.00	5.95
14.00	13.85
20.00	19.85
26.00	25.85
34.00	33.80
40.00	39.80
46.00	45.75
54.00	53.65

$Y_{intercept} = 0.037469$

Scope = 1.005033

$P_{(ACT)} = 1.005033\ P_{ind} + 0.037469$
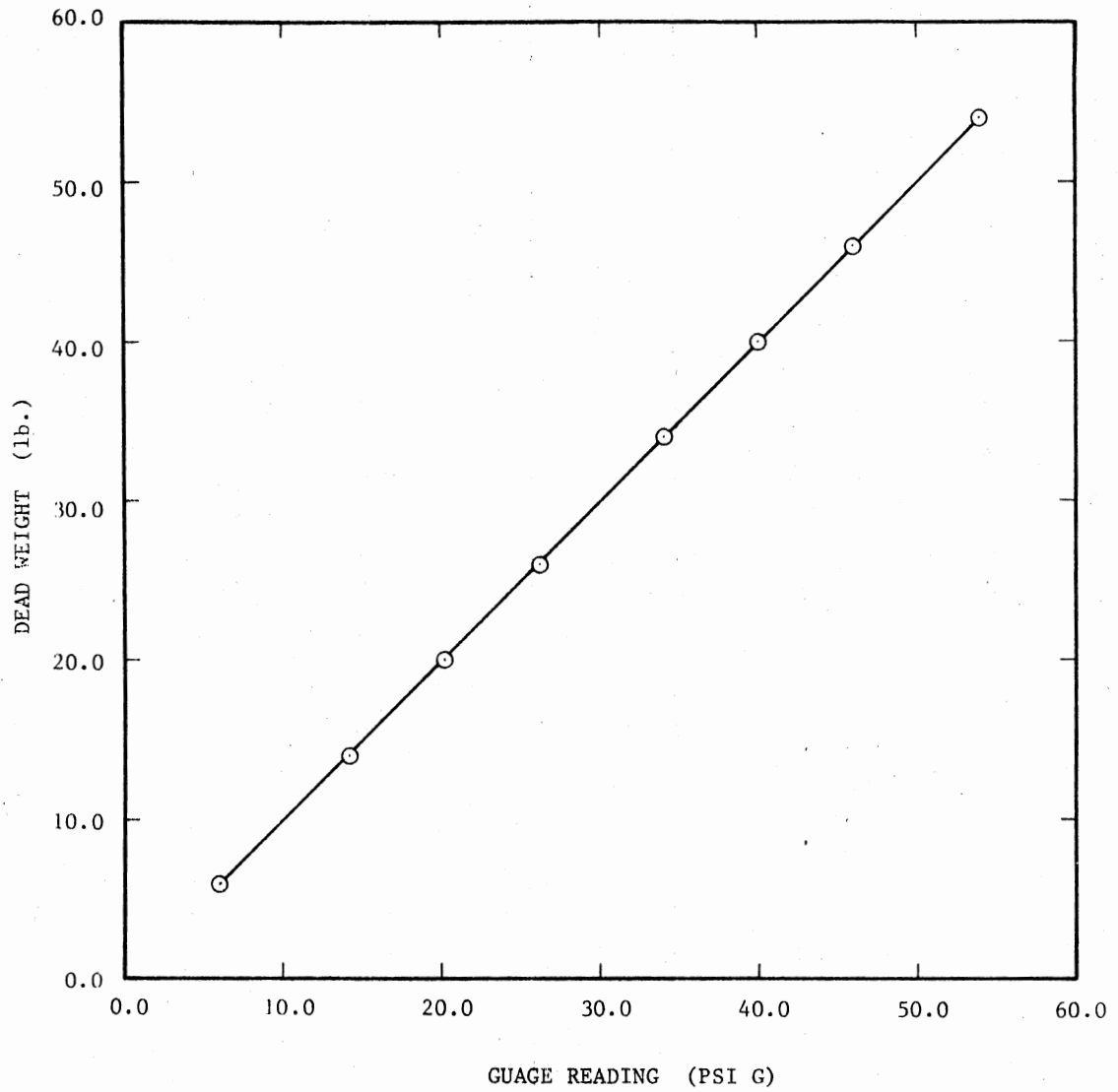
Figure 9. First Calibration Check of Roylyn Pressure Gauge
Using Dead Weight Tester

TABLE XI

SECOND CALIBRATION CHECK OF ROYLYN GAUGE WITH
DIAPHRAGM USING A DEAD WEIGHT TESTER

Tester Reading	Gauge Reading
6.00	6.00
14.00	14.10
20.00	20.10
26.00	26.10
34.00	34.00
40.00	40.00
46.00	46.00
54.00	54.00

$$P_{ACT} = 1.001577 \, (P_{ind}) - 0.084880$$
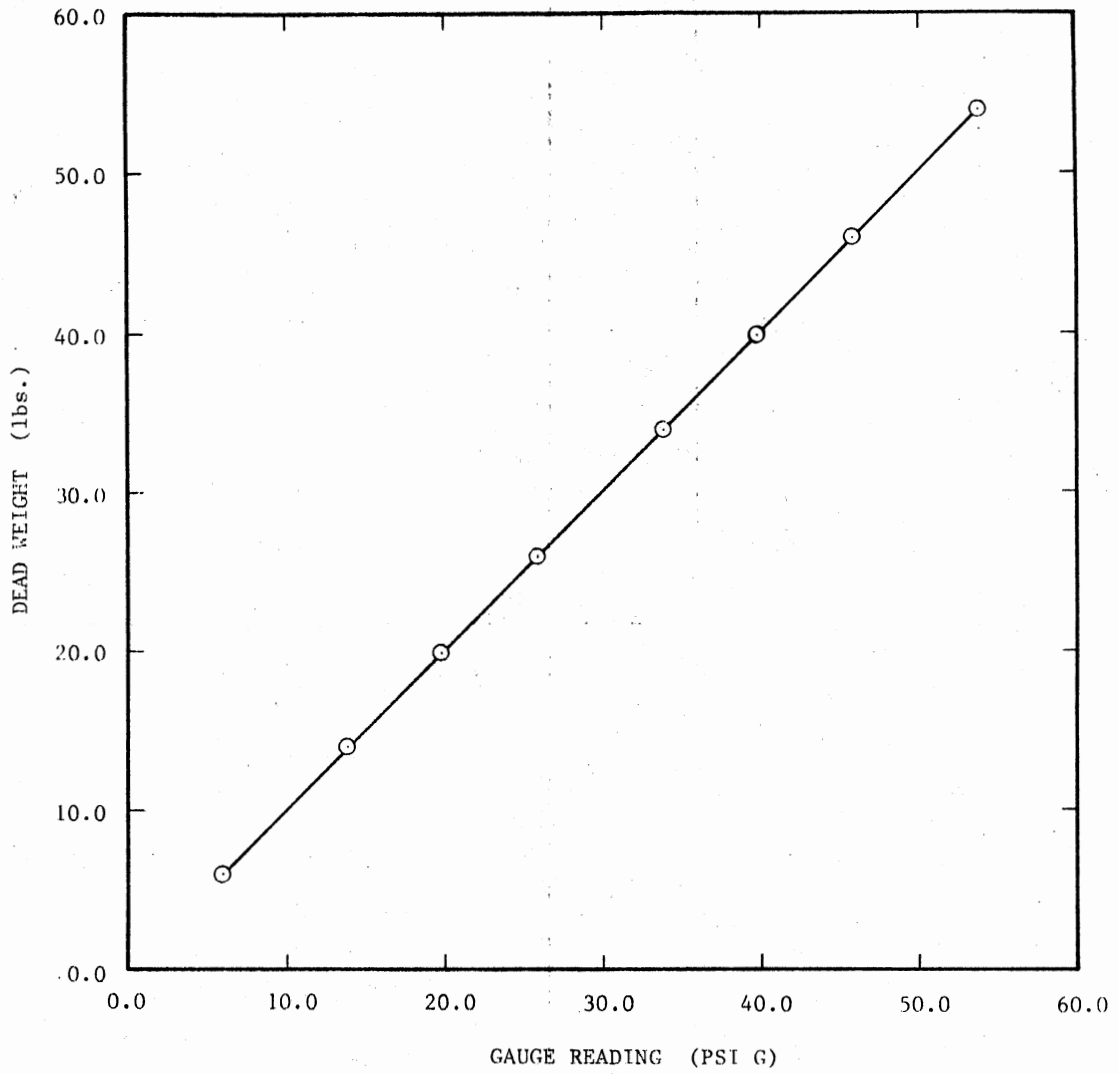
Figure 10.   Second Calibration Check of Roylyn Pressure
Gauge Using Dead Weight Tester

TABLE XII

CALIBRATION OF COMPOUND PRESSURE GAUGE USING
2400 HL RUSKA PRESSURE SYSTEM AS
A DEAD WEIGHT TESTER

Dead Weight Tester Reading	Compound Gauge Diviation from the Tester Reading[*]
6.0	−
14.0	−
20.0	−
26.0	−
34.0	−
40.0	−
46.0	−
50.0	−
54.0	−

[*]Deviation of 0.2 psi or more is recorded whenever it occurs. None was recorded.

TABLE XIII

n-OCTANE VAPOR PRESSURE MEASUREMENTS

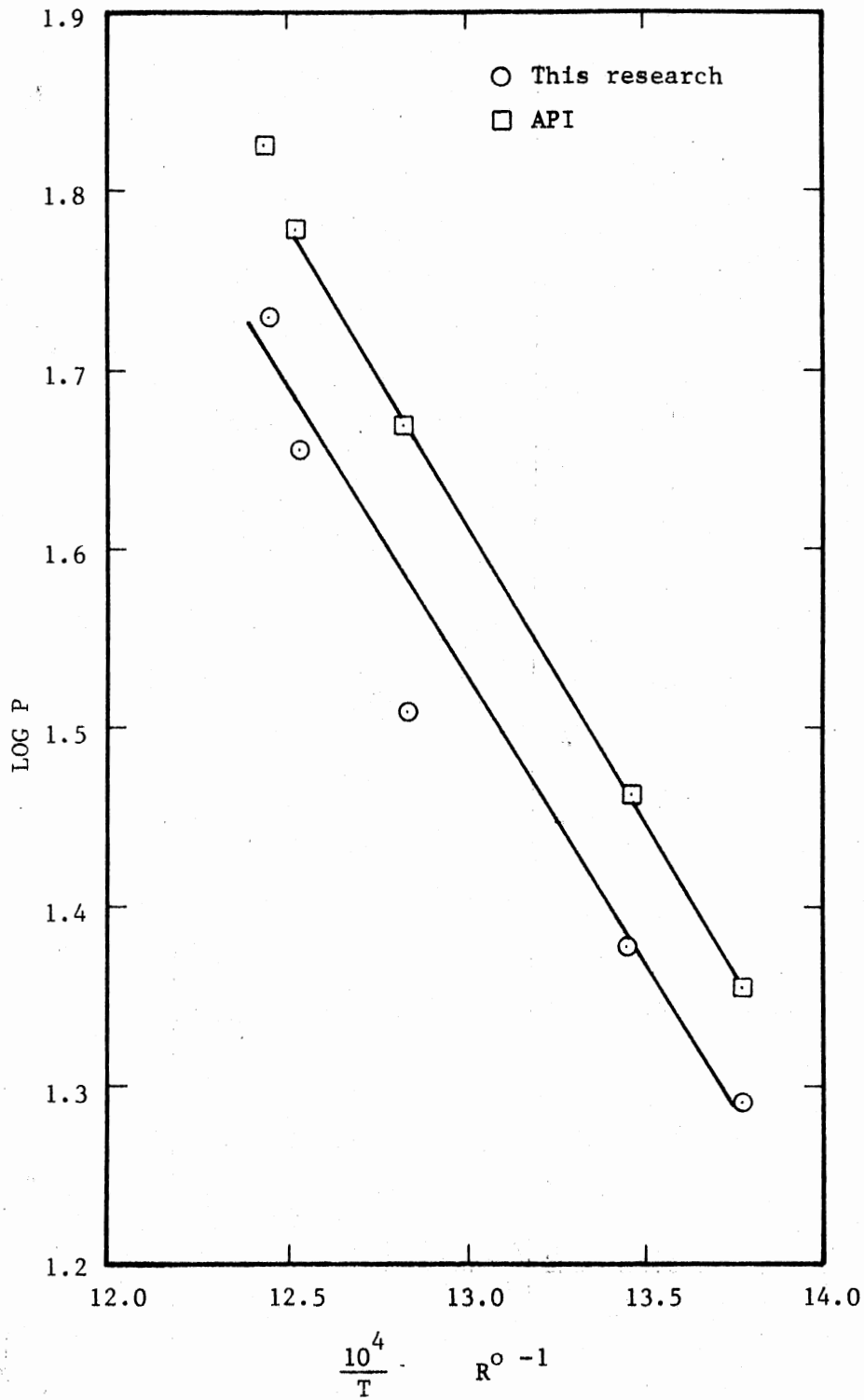| T in °F	T °R	T	P (psia) Exp.	Log P Exp.	P (psia) API	
277.636	737.306	13.563	23.443	1.370	18.725	1.272
282.304	741.974	13.478	27.549	1.440	21.108	1.324
299.681	759.352	13.169	39.202	1.593	26.893	1.430
337.136	796.806	12.550	52.780	1.723	43.444	1.638
357.864	817.534	12.232	64.569	1.810	55.418	1.745

Figure 11. n-Octane Vapor Pressure

TABLE XIV

DATA FROM TABLE I FOR FIGURE (2)
(n-PENTANE VAPOR PRESSURE
MEASUREMENTS)

Temp. ^{o}F	Exp. Pressure P_{exp} PSIA	Cal. Pressure P_{cal} PSIA	Temp. ^{o}R	$\dfrac{10^4}{T}$	Log P_{exp}	Log P_{cal}
103.727	17.608	16.697	563.397	17.749	1.251	1.223
119.676	23.104	22.267	579.366	17.260	1.364	1.343
128.435	26.904	25.851	588.105	17.004	1.430	1.413
142.348	33.328	32.498	602.018	16.611	1.523	1.512
153.217	40.269	38.516	612.887	16.316	1.605	1.586

(Exp.) $\dfrac{10^4}{T}$ v.s log P_{exp} Slope = -0.246042

Y Inter = 5.614354

(API) $\dfrac{10^4}{T}$ v.s log P_{cal} Slope = -0.253272

Y Inter. = 5.718986

TABLE XV

DATA FROM TABLE IV FOR FIGURE (3)
(METHYL TERTIARY BUTYL ETHER
VAPOR PRESSURE MEASUREMENT)

Temp ^oF	Exp. Pressure PSIA	Temp ^oR	$\dfrac{10^4}{T}$	Log P_{exp}
144.304	23.303	603.974	16.557	1.367
169.261	33.283	623.931	15.900	1.522
193.652	46.798	653.322	15.306	1.670
222.217	67.593	681.887	14.665	1.830
246.304	90.503	705.974	14.165	1.957

$Y_{Intercept}$ = 5.454497

Slope = -0.247105

TABLE XVI

DATA FROM TABLE VI FOR FIGURE (4)
(TERTIARY BUTYL ALCOHOL VAPOR
PRESSURE MEASUREMENT)

Temp $°F$	Experimental Pressure P_{exp} PSIA	Temp $°R$	$\dfrac{10^4}{T}$	Log P_{exp}
194.826	22.171	654.496	15.279	1.346
217.000	34.161	676.67	14.778	1.534
237.087	45.842	696.757	14.352	1.661
263.455	69.332	723.125	13.829	1.841
286.522	96.366	746.192	13.401	1.984

$Y_{Intercept}$ = 0.336647

Slope = -0.336647

APPENDIX B

SAMPLE CALCULATIONS

PENTANE SAMPLE CALCULATIONS (4)

$\log P_r^* = (\log P_r^*) + w (\log P_r^*)^{(1)}$ at constant T_r (1)

$(\log P_r^*)^{(o)} = c - 1.192\ B$ (2)

$(\log P_r^*)^{(1)} = 4.92\ B$ (3)

$c = 7 \log (T_r) - 0.118\ A$ (4)

$A = \dfrac{36}{T_r} - 35 - T_r^6 + 96.73 \log T_r$ (5)

$B = \log T_r - 0.364\ A$ (6)

$P^* = (P_r^*) (P_c)$ (7)

Where, P_r^* = reduced vapor pressure P^*/P_c

P^* = vapor pressure psia

W = acentric factor for hydrocarbons

T_r = reduced temperature T/T_c

T_c = crotical temperature in degrees Rankines ^oR

T = temperature in degrees Rankine ^oR

The physical properties needed to calculate the vapor pressure of

n-octane:

$T_c = 564.22\ ^oF$

$P_c = 360.6$ psia

$W = 0.3978$

Vapor pressure of n-octane at $374.13\ ^oF$

$Tr = \dfrac{T}{Tc}$ T & T_c in ^oR

$T_r = \dfrac{374.13 + 459.67}{564.22 + 459.67} = 0.814345$

$$A = \frac{.36}{0.814345} - 35 - (0.814345)^6 + 96.73 \log (0.814345)$$

$$A = 0.2881652 \tag{5}$$

$$B = \log (0.814345) - 0.0364 (0.2881652)$$

$$B = -0.099681 \tag{6}$$

$$C = 7 \log (0.814345) - 0.118 (0.2881652)$$

$$C = -0.6583445 \tag{9}$$

$$(\log P_r^*)^{(o)} = (-0.658345) - 1.192 (-0.099681)$$

$$(\log P_r^*)^{(1)} = 0.539525 \tag{2}$$

$$(\log P_r^*)^{(1)} = 4.92 (-0.099681) \tag{3}$$

$$(\log P_r^*)^{(1)} = 0.490431$$

$$\log P_r^* = (-0.539525) + (0.3978) (-0.490431)$$

$$\log P_r^* = 0.734619$$

$$P_r^* = -0.184239$$

$$P^* = (0.184239) (360.6) \tag{7}$$

$$P^* = 66.437 \text{ psia}$$

APPENDIX C

NOMENCLATURE

NOMENCLATURE

a_0, a_1, a_2	quadratic equation constants
P^*	vapor pressure (psia)
P_c	critical pressure (psia)
P_r^*	reduced vapor pressure P^*/P_c
T	temperature in degrees Rankine $^\circ R$
T_c	critical temperature in degrees Rankines $^\circ R$
T_{co}	corrected temperature ($^\circ F$ or $^\circ C$)
T_p	temperature read from the potentionmeter tables tables $^\circ C$ or $^\circ F$
T_r	reduced temperature T/T_c
W	accentric factor for hydrocarbons

VITA

Suleiman Yousef Diab

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF APPARATUS TO MEASURE VAPOR PRESSURES
         OF LIQUIDS

Major Field: Chemical Engineering

Biographical:

   Personal Data: Born in Annaba, Palestine, December 5, 1943,
       the son of Mr. and Mrs. Y. Diab. Married to Rajiya H.
       Badwan, August 6, 1965.

   Education: Graduated from Al-Hashimieh Secondary School, Birereh,
       West Bank, in June, 1960; from Teacher's Training Center,
       Ramallah, West Bank, in June, 1962; Bachalor of Science
       Degree, Texas A & M University, College Station, Texas, in
       December, 1973; completed requirements for Degree of Master
       of Science at Oklahoma State University in December, 1979.

   Professional Experience: Science teacher with UNARWA from June,
       1962 to August, 1964; Teacher with the Ministrey of Education
       of Kuwait from 1964-1970; Process Chemical Engineer with Ku-
       wait Asphalt Emulsion Company from 1974-1976; Deputy Director
       of the Industrial Section of Dar El Khalerdg (Kuwait from
       1976-1978); Graduate teaching assistant from 1978-1980;
       Graduate research assistant Algae Center from 1979-1980,
       Oklahoma State University.

   Membership in Scholarly or Professional Societies: Omega Chi
       Epsilom, Member of National AIChE., Associate Member of
       Kuwait Society of Engineers.