PERFORMANCE OF A/C SPLIT UNITS WORKING BY A DIFFERENT PERCENTAGE MIXTURES OF BUTANE AND PROPANE GASES.

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Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in
Mechanical Engineering

Faculty of Graduate Studies
University of Jordan

December 1996

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DEDICATION

To my Mother and Father

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor, Dr. Mahmoud Hammad, who guided me through my study, and encouraged me to finish my work, and whom I consider to be my second father.

I wish also to thank all those who helped me during my work, naming some of them, Eng. Amer Yassien, Eng. Yousef Moubarak, Dr. Tobji M., Dr.Kahhaleh B., Eng. Fathi Abu-Libdeh, Miss Fathia Shwashreh, and all others who helped me.

Thanks to me Friend Eng. Moudar Zgoul, who really was there when I needed him.

I would also like to thank Eng. Omar Abo_Wishah, Who was very generous with me, and thank all the members of Petra Ind.

And finally, Thanks to my family for their support, love, and care, whom without, this work had never seen the light.

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NOMENCLATURE

100%	Pure Propane
40%	40% Propane , 46% Butane, 14% Isobutane by mass
49%	49% Propane , 39% Butane, 12% Isobutane by mass
60%	60% Propane , 31% Butane, 9% Isobutane by mass
70%	70% Propane , 23% Butane, 7% Isobutane by mass
80%	80% Propane , 15% Butane, 5% Isobutane by mass
90%	90% Propane , 8% Butane, 2% Isobutane by mass
C.O.P.	Coefficient of performance
h	Air enthalpy J/kg
H	Working fluid enthalpy J/mol
LPG	21.39% Propane , 60.23% Butane, 18.38% Isobutane by mass
m	mass (kg)
qe	Evaporator capacity (J/mol)
Q-air	Air enthalpy change, J/s
t	Time (second)
T	Temperature °C
v	Specific volume of air m^3/kg
w	Compressor Work J/mol
ϕ	Relative humidity
ω	moisture content, (g) of water/(kg) Air

ABSTRACT

Performance Of A/C Split Units Working By A Different Percentage
Mixtures Of Butane And Propane Gases.

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Although the thermodynamic properties and performance of pure hydrocarbons as refrigerants has been studied for a long time, not much work have been done on hydrocarbon mixtures. This study will deal with the actual performance of different mixtures of Propane, Butane and Isobutane working in a split A/C unit. A computer algorithm based on the aspen library was used to calculate the properties of the mixtures, and so P-h diagrams of these mixtures were established.

It was found that increasing the Propane ratio in the mixture would enhance its performance as a refrigerant; as example C.O.P. values for 90% Propane mixture was 4.2, while R22 had a 2.8 C.O.P. on the same machine and conditions. Also other performance parameters of the mixtures with high Propane ratios were better than those of R22, such as evaporating pressures and compressor discharge temperatures, both obtained at lower values for the hydrocarbons, "such as 48 psi, and 59 °C for 70% Propane mixture compared with 73.5 psi and 123.6 °C for R22".

The unit which was working on R-22 was evacuated and filled with the mixtures, without any special preparations.

The performance of the split A/C unit was studied as a complete field working unit.

CHAPTER 1

Introduction

In the last 20 years the world started paying attention to the problems that man is causing to the atmosphere. Two main topics were under consideration; the Global Warming and the Ozone Depletion.

1.1- Global Warming

Caused by accumulation of what is known as the green house gases at the earth atmosphere edge.

1.1.1- Emissions Inventories

Greenhouse gas emissions inventories were first prepared in the late 1970s by or for atmospheric scientists, who sought to determine and analyze the human contribution to rising atmospheric concentrations of greenhouse gases. Emissions were assigned to particular countries primarily as a matter of convenience, because underlying energy and industrial production data were organized at the national level. The accuracy of early estimates did not need to be particularly high, nor was there any requirement for detail.

However, as climate change has shifted from being a matter of scientific debate to a topic of policy concern, both the methods of computing inventories and the level of detail that is desirable have changed.

The United Nations' Intergovernmental Panel on Climate Change (IPCC) has been asked to develop a methodology for national inventories that will provide comparable estimates across nations. The IPCC developed an initial draft methodology for preparing national inventories in 1990* .

1.1.2-Global Climate Change and the Greenhouse Effect

The composition of the Earth's atmosphere is a primary determinant of the planet's temperature, which in turn establishes the conditions and limits for all life on Earth. Without the heat-trapping properties of so-called "greenhouse gases," which make up no more than 1 or 2 percent of the Earth's atmosphere, the average surface temperature of the Earth would be similar to that of Mars: -60 degrees Fahrenheit (-16 degrees Celsius).

The main greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons (such as CFC-

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* http://www.uncp.cl/ipcc

11, CFC-12). With the exception of halocarbons, most greenhouse gases occur naturally.

Water vapor is by far the most common, with an atmospheric concentration of nearly 1 percent, compared with less than 0.04 percent for carbon dioxide. Concentrations of other greenhouse gases are a fraction of that for carbon dioxide ,Table (1-1).

Table (1-1): Global Atmospheric Concentrations of Greenhouse Gases, from the IIPC report.

Item	**Carbon Dioxide** parts per million	**Methane** parts per million	**Nitrous Oxide** parts per million	**CFC-11** parts per trillion	**CFC-12** parts per trillion
Preindustrial Atmospheric Concentration	278	0.700	0.275	0.000	0.000
1990 Atmospheric Concentration	356	1.714	0.311	268	503
Average Change (PPM or PPT per year)	1.0	0.007	0.000	72	13

In computer-based simulation models, rising concentrations of greenhouse gases nearly always produce an increase in the average temperature of the Earth. Rising temperatures may, in turn, produce changes in weather and in the level of the oceans that might prove disruptive to current patterns of land use and human settlement, as well as to existing ecosystems. To date, it has proven difficult to detect hard evidence of actual temperature changes, in part, because normal temporal and spatial variations in temperature are far larger than the predicted change in the global average temperature (AASE, 1993).

1.1.3- Global Sources of Greenhouse Gases

Most greenhouse gases have substantial natural sources in addition to human-made sources, and there are powerful natural mechanisms for removing them from the atmosphere. However, the continuing growth in atmospheric concentrations establishes that for each of the major greenhouse gases, more gas is being emitted than is being absorbed each year: that is, the natural absorption mechanisms are lagging behind (Cicerone et al., 1992).

1.1.4- Halocarbons and Other Miscellaneous Chemicals.

In the twentieth century, human ingenuity has produced an array of "engineered" chemicals not normally found in nature, whose special characteristics render them particularly useful. Some engineered chemicals are also greenhouse gases. The best known class of greenhouse chemicals are the chlorofluorocarbons (CFCs), particularly CFC-12, often known by its trade name, "freon". CFCs have many desirable features: they are relatively simple to manufacture, inert, nontoxic, and nonflammable. Because they are chemically stable, once emitted, they remain in the atmosphere for hundreds or thousands of years. Because they are not found in nature, these molecules occupy an infrared "window" that would otherwise be largely unoccupied, and they are potent greenhouse gases, with a direct radiative forcing effect hundreds or thousands of times that of carbon dioxide.

CFCs and hydrochlorofluorocarbons HCFC's can be destroyed by sunlight. This reaction, however, releases free chlorine into the stratosphere, and the free chlorine tends to destroy stratospheric Ozone, which protects the surface of the earth from solar ultraviolet radiation at wavelengths that are potentially damaging to plant and animal life (ultraviolet radiation, for example, is one cause of human and animal skin cancers). The destruction of stratospheric Ozone, not withstanding its potential damage to living organisms, exerts a net cooling effect on the surface of the planet, making the net effects of CFCs and HCFC's on radiative forcing ambiguous. Recent research suggests that the negative indirect effects of CFCs and HCFCs during the 1980s may have been relatively small, and that the positive direct effect may have predominated (Graedel and Crutzen, 1993).

The threat posed by CFCs and HCFCs to the Ozone layer has caused the United States and many other countries to commit themselves to phasing out the production of CFCs and HCFCs pursuant to an international treaty, the 1987 Montreal Protocol. As emissions of CFCs and HCFCs have declined, many related chemicals have emerged as alternatives, including hydrofluorocarbons (HFCs). HFCs have no chlorine, and consequently have no effect on the Ozone layer, but they have potentially powerful direct effects on climate. HFCs were rare before 1990, but in 1994 HFC-134a was adopted as the standard motor vehicle air conditioning refrigerant in virtually all new cars made in America. Consequently, HFC emissions are now rising rapidly, though from a negligible base.

Beyond the halocarbons (CFCs, HCFCs, and HFCs) there are a range of engineered chemicals, produced in relatively small quantities, which also have direct radiative forcing effects.. These include the perfluorocarbons (CF_4 and C_2F_6) emitted as byproducts of aluminum smelting, some industrial solvents such as carbon tetrachloride, methyl chloroform, methylene chloride, and other more obscure chemicals such as sulfur hexafluoride (SF_6) and, possibly, other chemicals not yet identified.

Some of these compounds are regulated in the United States as Ozone depleters, or for toxicity, or both. Recent research suggests that some of the Ozone-depleting solvents with low global warming potentials (such as methyl chloroform) may have had a net cooling effect on the global climate during the 1980s (Penkett et al,. 1989).

1.1.5- Relative Forcing Effects of Various Gases

Some greenhouse gases are more potent at affecting global temperatures than are others. As a result, comparable increases in the concentrations of different greenhouse gases can have vastly different heat-trapping effects. Among those identified, carbon dioxide is least effective as a greenhouse gas. Considering only heat-absorption potential, one molecule of methane can have 24 times the effect on climate that one molecule of carbon dioxide has.

It would be useful to determine the precise relative effectiveness of various greenhouse gases in affecting the Earth's climate. The global warming potential, GWP is intended to demonstrate the relative impacts on global warming of various gases, compared with carbon dioxide. Over the past few years, the IPCC has conducted an extensive research program aimed at summarizing the effects of various greenhouse gases through a set of GWPs.

The IPCC's work has established that the effect of various gases on global warming are too complex to permit them to be easily summarized as a single number. The complexity takes three forms:

•Each gas absorbs radiation in a particular set of wavelengths or "window," in the spectrum. In some cases, where concentrations of the gas are low and no other gases block radiation in the same window, small emissions of the gas will have a disproportionate absorptive effect. However, if concentrations of the gas rise over time, a larger and larger portion of the total light passing through the "window" will already have been captured, and the effects of additional emissions will decline. Therefore, the effect of an additional unit of emissions of a gas that is relatively plentiful in the atmosphere, such as carbon dioxide, tends to be less than that of a rare gas, such as sulfur hexafluoride.

- Various natural processes cause many greenhouse gases to decompose into other gases, or to be absorbed into the ocean or ground. These processes can be summarized in terms of the "atmospheric lifetime" of a particular gas, or the period of time it would take for natural processes to remove a unit of emissions from the atmosphere. Some gases, such as CFCs, have very long atmospheric lifetimes, in the hundreds of years, while others, such as carbon monoxide, have lives measured in hours or days. Methane, which decays into carbon dioxide over a period of a few years, has a much larger short-run effect on global warming than does an equivalent amount of carbon dioxide. However, over longer and longer periods--from 10 years to 100 years to 500 years, for example--the differences between the GWPs of methane and carbon dioxide become less significant.

- Many gases are chemically active, and they may react in the atmosphere in ways that promote or hinder the formation of other greenhouse gases. For example, nitrogen oxides and carbon monoxide combine to promote the formation of Ozone, which is a potent greenhouse gas, while CFCs tend to destroy atmospheric Ozone, thus promoting global cooling. These indirect effects have proven impossible to summarize in terms of global warming potentials. In some cases, such as CFCs, it is unclear whether they contribute to a net warming or cooling of the Earth's atmosphere. In other cases, it is clear that they contribute to a net warming, but the magnitude of the indirect effect is unclear.

Table (1-2) summarizes the consensus results of the most recent studies by scientists working on behalf of the IPCC, showing estimates of atmospheric lifetimes and global warming potentials across various time scales.

Table (1-2) : Numerical Estimates of Global Warming Potentials Relative to Carbon Dioxide
(Carbon Dioxide = 1)

Gas	Lifetime (Years)	Direct Effect for Time Horizons of 20 Years	100 Years	500 Years
Carbon Dioxide	120	1	1	1
Methane	14.5	62	24.5	7.5
Nitrous Oxide	120	290	320	180
Halocarbons				
CFC-11	50	5,000	4,000	1,400
CFC-12	102	7,900	8,500	4,200
CFC-113	85	5,000	5,000	2,300
CFC-114	300	6,900	9,300	8,300
CFC-115	1,700	6,200	9,300	13,700
Halon 1301	65	6,500	5,600	2,200
HCFC-22	13.3	4.300	1,700	520
HCFC-123	1.4	300	93	29
HCFC-124	5.9	1,500	480	150
HCFC-141b	9.4	1,800	630	200
HCFC-142b	19.5	4,200	2,000	630
HCFC-23	250	9,200	12,100	9,900
HFC-125	36	4,800	3,200	11
HFC-134a	14	3,300	1,300	420
HFC-152a	1.5	460	140	44
HFC-227ea	41	4,500	3,300	1,100
Perfluoromethane	50,000	4,100	6,300	9,800
Perfluoroethane	10,000	8,200	12,500	19,100
Other Chemicals				
Carbon Tetrachloride	42	2,000	1,400	500
Methyl Chloroform	5.4	360	110	35
Methylene Chloride	0.41	28	9	3
Chloroform	0.55	15	5	1
Sulfur Hexafluoride	3,200	16,500	24,900	36,500

1.2 What's up

1.2.1- The Nut Shell

The stratosphere extends from about 15 km to 50 km. In the stratosphere temperature increases with altitude, due to the absorption of UV light by oxygen and Ozone. This creates a global "inversion layer" which impedes vertical motion into and within the stratosphere - since warmer air lies above colder air, convection is inhibited. The word "stratosphere" is related to the word "stratification" or layering.

The stratosphere is often compared to the "troposphere", which is the atmosphere below about 15 km. The boundary - called the "tropopause" - between these regions is quite sharp, but its precise location varies between ~9 and ~18 km, depending upon latitude and season. The prefix "tropo" refers to change: the troposphere is the part of the atmosphere in which weather occurs. This results in rapid mixing of tropospheric air.

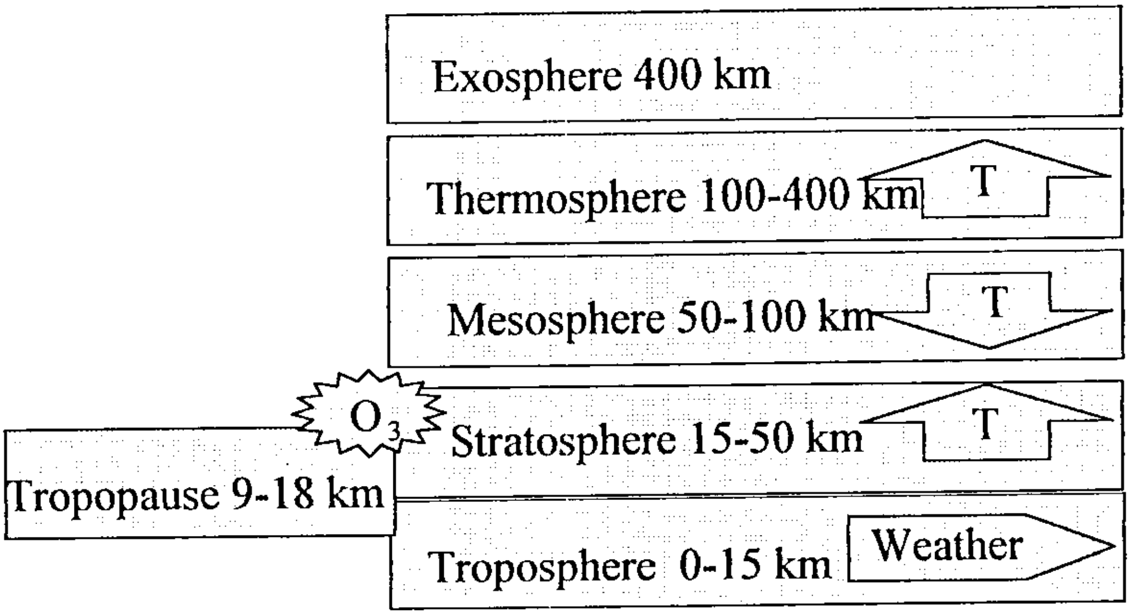

Figure 1.1 The atmosphere

Above the stratosphere lie the "mesosphere", ranging from ~50 to ~100 km, in which temperature decreases with altitude; the "thermosphere", ~100-400 km, in which temperature increases with altitude again, and the "exosphere", beyond ~400 km, which fades into the background of interplanetary space. In the upper mesosphere and thermosphere electrons and ions are abundant, so these regions are also referred to as the "ionosphere". In technical literature the term "lower atmosphere" is synonymous with the troposphere, "middle atmosphere" refers to the stratosphere and mesosphere, while "upper atmosphere" is usually reserved for the thermosphere and exosphere. This usage is not universal, however, and one occasionally sees the term "upper atmosphere" used to describe everything above the troposphere.

The density of the air in the atmosphere depends upon altitude, and in a complicated way because the temperature also varies with altitude. It is therefore awkward to report concentrations of atmospheric species in units like g/cc or molecules/cc. Instead, it is convenient to report the "mole fraction", the relative number of molecules of a given type in an air sample. Atmospheric scientists usually call a mole fraction a "mixing ratio". Typical units for mixing ratios are parts-per-million, billion, or trillion by volume, designated as "ppmv", "ppbv", and "pptv" respectively. (The expression "by volume" reflects Avogadro's Law - for an ideal gas mixture, equal volumes contain equal numbers of molecules - and serves to distinguish mixing ratios from "mass fractions" which are given as parts-per-million by weight.) Thus when someone says the mixing ratio of hydrogen chloride at 3 km is 0.1

ppbv, he means that 1 out of every 10 billion molecules in an air sample collected at that altitude will be an HCl molecule.

1.2.2 CFC's and ground air.

In the earth's troposphere and stratosphere, most stable chemical species are "well-mixed" - their mixing ratios are independent of altitude. If a species' mixing ratio changes with altitude, some kind of physical or chemical transformation is taking place. That last statement may seem surprising - one might expect the heavier molecules to dominate at lower altitudes. The mixing ratio of Krypton (mass 84), then, would decrease with altitude, while that of Helium (mass 4) would increase. In reality, however, molecules do not segregate by weight in the troposphere or stratosphere. The relative proportions of Helium, Nitrogen, and Krypton are unchanged up to about 100 km.

Why is this? Vertical transport in the troposphere takes place by convection and turbulent mixing. In the stratosphere and in the mesosphere, it takes place by "eddy diffusion" - the gradual mechanical mixing of gas by motions on small scales. These mechanisms do not distinguish molecular masses. Only at much higher altitudes do mean free paths become so large that molecular diffusion dominates and gravity is able to separate the different species, bringing hydrogen and helium atoms to the top. The lower and middle atmosphere are thus said to be "well mixed."

1.3- Ozone problem.

Ozone is formed naturally in the upper stratosphere by short wavelength ultraviolet radiation. Wavelengths less than ~240 nanometers are absorbed by oxygen molecules (O_2), which dissociate to give O atoms. The O atoms combine with other oxygen molecules to make Ozone:

$O2 + hv \rightarrow O + O$ (wavelength < 240 nm)

$O + O2 \rightarrow O3$

A Dobson Unit (DU) is a convenient scale for measuring the total amount of Ozone occupying a column overhead. If the Ozone layer over the US were compressed to 0 degrees Celsius and 1 atmosphere pressure, it would be about 3 mm thick. So, 0.01 mm thickness at 0 °C and 1 at is defined to be 1 DU; this makes the average thickness of the Ozone layer over the US come out to be about 300 DU. In absolute terms, 1 DU is about 2.7×10^{16} molecules/cm^2.

The unit is named after G.M.B. Dobson, who carried out pioneering studies of atmospheric Ozone between ~1920-1960. Dobson designed the standard instrument used to measure Ozone from the ground. The Dobson spectrophotometer measures the intensity solar UV radiation at four wavelengths, two of which are absorbed by Ozone and two of which are not (Dobson, 1968a). These instruments are still in use in many places, although they are gradually being replaced by the more elaborate brewer spectrophotometers. Today Ozone is measured in many ways, from aircraft, balloons, satellites, and space shuttle missions, but the worldwide Dobson network is the only source of long-term data. A station at Arosa in Switzerland has been measuring Ozone since the 1920's* and some other stations have records that go back nearly as long, although many were interrupted during World War II. The present worldwide network went into operation in 1956-57.

1.3.1. Ozone cycle.

UV light with wavelengths between 240 and 320 nm is absorbed by Ozone, which then falls apart to give an O atom and an O_2 molecule. The O atom soon encounters another O_2 molecule, however (at all times, the concentration of O_2 far exceeds that of O_3), and recreates O_3:

$$O_3 + h\nu \rightarrow O_2 + O$$

$$O + O_2 \rightarrow O_3 + \text{heat}$$

Thus Ozone absorbs UV radiation without itself being consumed ; the net result is to convert UV light into heat. Indeed, this is what causes the temperature of the stratosphere to increase with altitude, giving rise to the inversion layer that traps molecules in the troposphere. The Ozone layer isn't

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* http://www.epa.gov/docs/Ozone/science/arosa.html

just in the stratosphere; the Ozone layer actually determines the form of the stratosphere.

Ozone is destroyed if an O atom and an O_3 molecule meet:

$O + O_3 \rightarrow 2\ O_2$ ("recombination").

This reaction is slow, however, and if it were the only mechanism for Ozone loss, the Ozone layer would be about twice as thick as it is. Certain trace species, such as the oxides of Nitrogen (NO and NO_2), Hydrogen (H, OH, and HO_2) and chlorine (Cl, ClO and ClO_2) can catalyze the recombination. The present Ozone layer is a result of a competition between photolysis and recombination; increasing the recombination rate, by increasing the concentration of catalysts, results in a thinner Ozone layer.

Putting the pieces together, we have the set of reactions proposed in the 1930's by Sidney Chapman:

$O_2 + hv \rightarrow O + O$	(wavelength < 240 nm)	: creation of oxygen atoms
$O + O_2 \rightarrow O_3$		: formation of Ozone
$O_3 + hv \rightarrow O_2 + O$	(wavelength < 320 nm)	:absorption of UV by Ozone
$O + O_3 \rightarrow 2\ O_2$		: recombination .

Since the photolysis of O_2 requires UV radiation while recombination does not, one might guess that Ozone should increase during the day and decrease at night. This has led some people to suggest that the "Antarctic

Ozone hole" is merely a result of the long Antarctic winter nights. This inference is incorrect, because the recombination reaction requires oxygen atoms which are also produced by photolysis. Throughout the stratosphere the concentration of O atoms is orders of magnitude smaller than the concentration of O_3 molecules, so both the production and the destruction of Ozone by the above mechanisms shut down at night. In fact, the thickness of the Ozone layer varies very little from day to night, and above 70 km Ozone concentrations actually increase at night.

1.3.2 The source of the problem.

CFC's - ChloroFluoroCarbons - are a class of volatile organic compounds that have been used as refrigerants, aerosol propellants, foam blowing agents, and as solvents in the electronic industry. They are chemically very unreactive, and hence safe to work with. In fact, they are so inert that the natural agents that remove most atmospheric pollutants do not react with them, so after many years they drift up to the stratosphere where short-wave UV light dissociates them. CFC's were invented in 1928, but only came into large-scale production after ~1950. Since that year, the total amount of chlorine in the stratosphere has increased by a factor of 4.

The most important CFC's for Ozone depletion are:

1. Trichlorofluoromethane, $CFCl_3$ (usually called CFC-11 or R-11)

2. Dichlorodifluoromethane, CF_2Cl_2 (CFC-12 or R-12)

3. 1,1,2 Trichlorotrifluoroethane, $CF_2ClCFCl_2$ (CFC-113 or R-113).

"R" stands for "refrigerant". One occasionally sees CFC-12 referred to as "F-12", and so forth; the "F" stands for "Freon", DuPont's trade name for these compounds.

In discussing Ozone depletion, "CFC" is occasionally used to describe a somewhat broader class of chlorine-containing organic compounds that have similar properties - unreactive in the troposphere, but readily photolyzed in the stratosphere. These include:

1. HydroChloroFluoroCarbons such as $CHClF_2$ (HCFC-22,R-22)

2. Carbon Tetrachloride (tetrachloromethane), CCl_4

3. Methyl Chloroform (1,1,1 trichloroethane), CH_3CCl_3 (R-140a)

4. Methyl Chloride (chloromethane), CH_3Cl.

Only Methyl Chloride has a large natural source; it is produced biologically in the oceans and chemically from biomass burning. The CFC's and CCl_4 are nearly inert in the troposphere, and have lifetimes of 50-200+ years. Their major "sink" is photolysis by UV radiation. The hydrogen-containing halocarbons are more reactive, and are removed in the troposphere by reactions with OH radicals. This process is slow, however, and they live long enough (1-20 years) for a substantial fraction to reach the stratosphere. (Penkett et al., 1980)

CFC's themselves do not destroy Ozone; certain of their decay products do. After CFC's are photolyzed, most of the chlorine eventually ends up as Hydrogen Chloride, HCl, or Chlorine Nitrate, $ClONO_2$. These are called "reservoir species" - they do not themselves react with Ozone. However, they do decompose to some extent, giving, among other things, a small amount of atomic chlorine, Cl, and Chlorine Monoxide, ClO, which can catalyze the destruction of Ozone by a number of mechanisms. The simplest is:

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

$$\text{Net effect: } O_3 + O \rightarrow 2\ O_2$$

Note that the Cl atom is a catalyst - it is not consumed by the reaction. Each Cl atom introduced into the stratosphere can destroy thousands of Ozone molecules before it is removed. The process is even more dramatic for Bromine - it has no stable "reservoirs", so the Br atom is always available to destroy Ozone. On a per-atom basis, Br is 10-100 times as destructive as Cl. On the other hand, chlorine and bromine concentrations in the stratosphere are very small in absolute terms. The mixing ratio of chlorine from all sources in the stratosphere is about 3 parts per billion, (most of which is in the form of CFC's that have not yet fully decomposed) whereas Ozone mixing ratios are measured in parts per million. Bromine concentrations are about 100 times smaller still.

CHAPTER 2

Work Background.

The Ozone Deplating Components have been studied for many years. Effects, possibilities and replacements have been always a debate points between researchers, moreover the introduction of Natural Refrigerant concept increased the debate.

2.1- Literature Survey:

Work can be divided into main topics. First Hydrocarbons as an alternative, and secondly the behavior of the mixture (binary or multi) of these hydrocarbons.

(Paul, 1994) , defined natural refrigeration as: Substances which are part of the natural environment and balance of this planet's household and which can be accommodated in the global ecological system, Non-chemical substance, i.e. no retort substances in a composition and/or with effects which are "unknown" to the global ecological system, substance which are "borrowed" temporarily from the environment and which can be applied in refrigeration plants, substances, which cause no changes and alterations in the environment if these will be emitted.

He also named some -state of the art- refrigeration with natural refrigerants, starting with water (R718), Air(R729), Carbon Dioxide (R744), Ammonia(R717), and Hydrocarbons-especially Propane (R290).

(Vollmer *et al.*, 1994), calculated the thermodynamic and thermophysical properties of the binary mixture Propane/Isobutane (50%/50%), he showed that the mixture is an acceptable substitute for R12, and only minor changes on the refrigerant circuit are necessary to use the mixture in an originally R12 designed refrigerator, their work also showed that both gases enters and leaves the vapor-liquid region at the same time, and so changing the whole procedure of calculation in this thesis.

(Spauschus, *et al.*, 1994), studied the lubricants for hydrocarbon refrigerants, and showed experimentally that at 100°C, dynamic viscosity of propane/lubricant and isobutane/lubricant mixtures is essentially the same for 80 weight percent lubricant/20 weight percent refrigerant mixtures. He showed that saturation pressures of propane/lubricant mixtures are much higher than those of CFC12/mineral oil and HFC-134a/POE while those of isobutane/lubricant mixture are significantly lower. The best match with present working fluids can be achieved with propane/isobutane mixed refrigerants, assuming ideal behavior of the mixtures.

(Hainbach, 1994), concluded that for the range of -15 to 5 °C, R290 would not yield desired success in R134a plants, and concluded that may be a Propane/Butane mixture could work as a better refrigerant. He also developed a dimensionless function for the behavior of compressors.

The tests done by Driessen *et al.*, (1994), showed that with R600a as a substitute for R12, working mass was 36% of the value used for R12. Power consumption was the same for both of them. For a R290/R600a (60/40) mixture the power consumption increased approximately 18%, and needed an evaporator and capillary tube adjustment.

(Habash, 1994), studied the performance of liquefied petroleum gas LPG mixture as a refrigerant for use in domestic refrigerators. He showed that lower evaporating temperatures are reached with LPG than with R12 for the same condensing temperatures, and concluded that no design changes are needed. Long term power consumption monitoring indicated that power consumption of LPG is similar to R12.

(Lavrechenko *et al.*, 1994) examined the thermodynamical aspect of using mixtures of substances in refrigerating machines. They gave a good explanation of the geotropic mixtures and how to handle them. They also showed the T-s diagrams general behavior for such mixtures.

(Rivis *et al.* 1994) studied the Isobutane-Propane mixtures and compared them with traditional refrigerants, but could not compare them through the evaporating temperature since it did not have any meaning. So they used the superheat as a basis of comparison.

(Ruvinsky *et al.*,1994) made a paper, describing binary mixtures, including oil-refrigerant mixtures, by means of virial equation of state.

(Higashi *et al.*, 1994) made a study on the vapor-liquid equilibrium for Propane/Isobutane mixture. The vapor-liquid equilibrium was measured at temperatures of 283.15 K, 293.15 K, and 303.15 K. Although this mixture is expected as the natural refrigerant for refrigerators, no experimental data of thermodynamic properties could be found in their work. They drew a pressure - enthalpy diagram for a 50/50% mass ratio.

2.2- A considerable note

Some researchers used the evaporating temperature as a reference for their work on natural gases mixtures, while others tried to avoid this temperature. (Habbash, 1994), used both evaporator and condenser temperatures as a reference, acting as an x-axis for most of his results.

(Richardson, 1995), studied a mixture of Propane and Isobutane - 56/44% -, and 43/57%. He also used the evaporating temperature as an x axis. No other work was found, using the evaporating temperatures as the x-axis.

The reason is that for a mixture of gases , there exist a due point, a bubble point, but no evaporating temperature. For more information on this subject see Appendix C which has some details on the matter.

2.3- *Importance of this work*

Lots of work has been done on hydrocarbons as a considerable replacement of CFC's and HCFC's, as would be seen in section 2.1, but most of the work, did not consider the mixture choice, that is they preferred to work on pure components. Binary working fluids are much more difficult to handle and even calculating the properties for them is extremely complicated. Researchers who worked on mixtures either simplified the work by taking a super position calculation of each component for more than three components, or just restricted their work with a binary component for more simplified calculations.

This work should have studied Propane and Butane binary mixture, but since no pure Butane was found, a three component mixture had to be used; Propane, Butane and Iso-butane. The three component working fluid was studied and the properties of the mixtures were calculated in a more accurate way. Moreover, P-h diagrams of the mixtures are calculated. No previous work has tried to calculate the P-h diagram for more than a binary system.

Another point is the percentage range for the mixtures. The few literature works that dealt with mixtures staked with a single percent, a very few studied 2 different cases but non studied the full range of percentage for the mixture. In this work, the percentage of propane was changed from

100% down to 21.39%, by mixing the pure propane with a standard LPG mixture (mass based : 21.39% Propane, 60.23% Butane and 18.38% Isobutane).

The rest of this thesis contains experimental procedures, results, analysis, conclusions and recommendations.

2.4 *Comparison table.*

Table 2-1 : Comparison between used gases

	R12	Propane	Butane	Isobutane
Boiling Point[a] (°C)	-29.79	-42.07	-0.5	-11.73
Freezing Point[a] (°C)	-158	-187.7	-138.5	-160
Critical temperature (°C)	112	96.8	152	135
Critical pressure (bar)	41.4	42.54	37.94	36.45
Latent heat of vapor[a] (kJ/kg)	165.2	423.3	386	364.4
Explosive lower limit in air (vol.)	-	2.3	1.6	1.8
Explosive lower limit in air (vol.)	-	7.3	6.5	8.4
Underwriter Group Class	6	5b	5b	5b
Costs (JD/kg)	3	5	12	N.A.

(a) Atmosphere pressure

LPG mixture costs 0.14 JD a kilo.

Chapter 3

Experimental Rig and Procedure

3.1- Introduction

An A/C. split unit locally manufactured specially for this work, was used. The work is aimed to investigate the performance of the Propane, LPG mixtures in such a unit, and compare it with the performance of the R22. The machine was manufactured at Petra Industries, a leading Jordanian company in the field of refrigeration and air conditioning.

3.2-Unit Specifications:

The Unit in general is a simple room split A/C unit, with some modifications. It has an advanced programmable controller, that worked as a programming tool, monitoring device, control center, timer, and a thermostat (Appendix D). The compressor assembled in the unit is usually Copland, but due to Copland Company restrictions on using refrigerants other than R22, and R12, a Hitachi compressor was installed instead.

The specifications of the unit used are as follows:

- Trade mark : Petra
- Manufactured by : Petra Ind. 1994
- Compressor type : Hitachi MD224AX
- Cond. Coil type : DX-10 F/I-3 row. Aluminum Fined copper tube.
- Evap. Coil Type : DX-12 F/I-2row. Aluminume Fined Copper tube.
- Gross Capacity : 2.5 Tons
- Collector type : Refrigeration Research, INC.
- 4 Way valve : Sporland
- FD20 Flow control: Aeroquip
- Additions :
  - Suction Accumulator, Refrigeration Research.
  - Strainer, Hitachi LTD.
  - Filter dryer, Sporland.
  - High pressure gage.
  - Low pressure gage.
  - High pressure limit switch.
  - Low pressure limit switch.
  - Sight glass on liquid line.
  - Moisture indicator.
  - Six Charge and check points.
  - Two Manual control valves

3.3-Air Conditioning Split Units Components and their Functions

The unit in general is used to control the temperature in a room at a certain level, that is either by heating or cooling. It has three main functions.

1.Cooling, with a three speed indoor fan, and with a lower limit of 15°C.

2.Heating, also with a three speed indoor fan control, and with a high limit of 30 °C.

3.Automatic, That is switching between cooling and heating to maintain a room at a certain condition for special purposes, like computer rooms or hospital rooms.

Each Component in the refrigeration system, its function and how it works will be described in brief, as follows:

3.3-1 Evaporator:

The used coil type is DX that is direct expansion coil. In this type coils the pressure loss is minimum, and can be assumed to be negligible. In the DX the designer tries to have as much passes as possible throughout the coil. The whole process takes place in the low pressure region. The coil type in this study is corrugated, 12 FPI, DX coil. The coil is build up from Copper tubes and Aluminum fins.

3.3-2- *Compressor.*

The compressor in the machine used was HITACHI MD224AX, with the following specifications:

- Compressor cooling : Forced Air.
- Capacity : 6400Kcal/Hr(25400 BTU/Hr)
- Watts : 3030
- Amps : 15.1
    - Evap. temp : 7.2 °C Return gas temp 35 °C
    - Cond. Temp : 54.4 °C Amb. Temp 35 °C
    - Liquid Temp : 46.1 °C
- Design : Reciprocating connection Rod, 2 cylinders
- Bore, Stroke : 44.5 mm, 17.5 mm
- Displacement : 54.4 cm^3/rev
- Overload protection : Internal
- Oil Charge : 1600 cm^3

The motor is permanent split capacitor type, runs on 220-240 V, 50 Hz, and have a locked rotor amps of 58A.

3.3-3 Condenser :

Like the evaporator, the condenser is a heat transfer surface. The high pressure vapor (gas) is routed to the condenser where, as it starts to lose energy, and starts to change to high pressure liquid.

3.3-4. Flow control:

Aeroquip FD20, is a state of the art control device, it is a primary expansion mechanism designed to replace traditional capillary tubes and thermostatic expansion valves as a means of metering refrigerant flow through air conditioning and heat pump systems. Its unique design combines a special restrictor with a field connector and distributor housing assembly. This results in fewer components than conventional units. When installed, the field connector attaches to the liquid line. The heart of the FD20 flow control is the field-replaceable restrictor. As liquid refrigerant flows through the device, the restrictor orifice meters the flow into the distributor housing Figure (3.1) This movement results in pressure drop of the proper proportion to vaporize the refrigerant as it travels through the coils. The rate at which refrigerant is vaporized is determined by restrictor orifice size. The restrictor can be quickly replaced with another different size and flow rate, allowing a system to be fine tuned in the field.

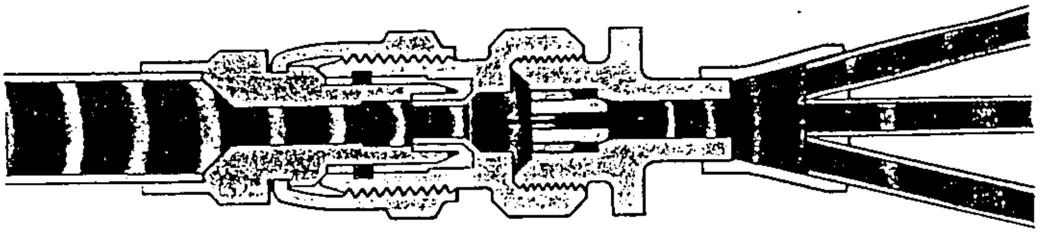


Fig. (3.1) : Flow during air conditioning cycle

The design also permits reverse flow of refrigerant during the heating cycle in the heat pump run. As the liquid refrigerant flows in reverse through the device, the restrictor moves back to free-flow position. This reverse flow capability eliminates the need to check valves and related plumbing (Fig.3.2).

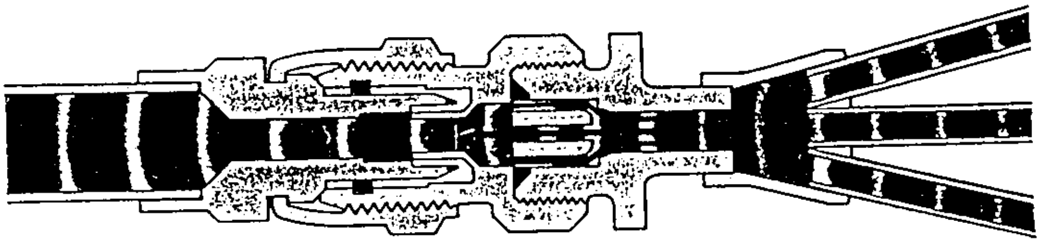


Fig (3-2) : Flow during heatpump cycle

Two valves where installed back to back, and a sight glass was installed in between so the sight glass would always be on the liquid line. This features the heat pump function of the unit.

3.3-5 Suction Accumulator :

The purpose is to prevent damage due to sudden return of liquid through the suction line. Compressors on many air-conditioning units such as truck, heat pump and other refrigeration systems are often subjected to sudden liquid return, resulting in broken valves, pistons, connecting rods, crank-shafts, blown gaskets or bearing failure. Compressors on low superheat applications such as liquid chillers, low temperature display cases and truck refrigeration are specially susceptible to damage from liquid refrigerant. The liquid refrigerant is temporarily held in the suction accumulator and metered back to the compressor at a controlled rate, through the metering orifice.

In most cases it will be found that the suction accumulator also reduces transmission of noise to the low side since it tends to act as a suction muffler.

3.3-6- Filter drier and strainer.

The presence of water and high temperature with R22 will decompose the R22 into slugs, and acids. The presence of acid in the system is very dangerous, since it will destroy almost all components of the system. The presence of water is also very dangerous since it could plug the expansion device while throttling, as it changes to ice at low temperatures and pressures. The slugs also closes the expansions devices, and distroy the flexibility of the 4 way valve. So a filter drier was introduced to the system, so most of the moisture and the slugs would be collected in it. The strainer also holds some slugs and any traces of the small particles in the system present from the initial work (brazing and drilling).

3.4- Measuring Devices and Procedures:

The variables that were measured during the experiments where:

- Temperature
- Pressure
- Time
- Power consumption.

3.4-1 Temperature measurement

Three devices were used to take the measurements of temperature, the 6600 Microprocessor, the DataLogger, and an Elweil logger.

The first two equipments used a T type thermocouples, while the last used a K type Sensor. The temperature readings where as follows:

1. Indoor coil outlet.
2. Compressor suction.
3. Liquid line.
4. Outdoor coil inlet.
5. Four-way valve.
6. Condensing unit outlet.
7. Compressor discharge.
8. Outdoor coil outlet.
9. Indoor coil Inlet.
10. Mid point on outdoor coil.
11. Wet air into indoor coil
12. Dry air into indoor coil.
13. Wet air out from indoor coil.
14. Dry air out from indoor coil.
15. Air temperature leaving the condenser in the outside.
16. Room ambient 1.
17. Room ambient 2.
18. Ambient temperature outside, around the condenser.
19. Room ambient 3.

A 6600 Comark microprocessor and an Eliwel processor were used to take the first ten temperatures for about 3 months tell the DataLogger was obtained. The connection for 6600 machine is as follows.

Table 3-1 660 Comark microprocessor connection.

Function			Pin	Function		Pin
reading data	10000	8	26	input connection number	8	17
		4	8		4	35
		2	27		2	16
		1	9		1	34
	1000	8	28	Decimal Point		25
		4	10	Print Command		23
		2	29	Bust/Data Hold		24
		1	11	Alarm		6
	100	8	30	Remote Scan		5
		4	12			
		2	31	Ground		2
		1	13			3
	10	8	32			4
		4	14			22
		2	33	No connection		20
		1	15			21
	1	8	19	Not to be used		1
		4	37			
		2	18	Serial Output		7
		1	36			

The connection needs a data acquisition card, and the matlab program, but since the data acquisition card was not available, data had to be taken from the LCD display of the 6600 Comark processor.

For the data Logger, a simple connection between the logger serial interface and Com2 in a PC was done and direct reading through com2 port was enough to get the data.

3.4-2 Pressure measurement.

Pressure was measured using a Hi and Low pressure gages mounted on the condensing unit, and on the suction and discharge lines of the compressor. The gauges were calibrated by Petra industries, which in turn has its calibration equipment calibrated by the Royal Air Force, according to ISO9001. The low pressure gage reads from -30 to 250 psi, while the high pressure gage reads from 0 to 500 psi.

Also, a pressure gauge manifold was used for charging and evacuating the system. Both gauges on the manifold where low, but in all cases, no need arise to use a high pressure gauge.

3.4-3 power consumption measurement:

To measure the actual power consumed by the machine, a single-phase watt-hour meter was used. The meter was calibrated at the Royal Air Force, through Petra Ind. The lowest reading on the meter was 0.01 KW.hr.

3.4-4 Time measurement:

The intervals between each FULL READING on the same run was 2 hours, while for the compressor start up was a 5 seconds interval. The start up period was determined from the experiment as will be shown in the procedures section. A (Heaer Trackstor model) stop watch, with a 1/100 min. It was used to take readings for the first three months, then, the Orion

DataLogger was used, and it had its internal clock. So it was possible to program it to take the readings on a regular bases or specific intervals of time.

The Orion had an accuracy of 0.01 second and all the readings where taken exactly on the same time.

3.5- Gases used.

The proposal required the use of Propane and Butane Mixture in the experiment, but due to lack of pure butane, LPG was used instead. The LPG contained more than 20 different gases, but the main were, Butane, Isobutane, and Propane. The mass percentage was as follows

•Propane	21.39%
•Butane	60.23%
•Isobutane	18.38%

And the computer simulation had to be done for the mixture of the above three gases, which meant almost a 20 time computer-simulation-time increase.

3.6- System Design.

The system was designed according to the BS 1608, BSEN378-1, and ISO9001, where these Standards stands for Specification for Electrically driven refrigerant condensing units, Specification for Refrigerating systems and heat pumps - Safety and environmental requirements - part 1, and Quality Control standard .

3.7- *Procedures.*

3.7-1 *Evacuation*

Any time the compressor or the system is exposed to prolonged periods to atmospheric air, or if the system becomes contaminated and removal of the refrigerant charge is necessary, or if the charge to be changed for any reason, the system should be evacuated in the same manner as at the original installation.

Blowing out the lines with refrigerant or purging from the top of the condenser will remove a major part of the air from the system, but it will not remove air from trapped areas. Liquid line filter-dryers will effectively remove small amounts of moisture from the system, but the amount of moisture in an open system may be greater than a dryers capacity. In both cases, evacuation is the only means of insuring a contaminant free system.

Start the vacuum pump and gradually open the gauge manifold valves. It may be necessary to restrict the vacuum pump suction pressure by means of the gauge manifold valves to avoid overloading the pump motor. Continue evacuation until the desired vacuum reading is obtained on both gauges.

When evacuation is complete, close the gauge manifold valves tightly, remove the line from the vacuum pump, and connect to a refrigerant cylinder of the required type. Loosen the common hose connection at the gauge manifold, crack the refrigerant drum valve to purge the hose, and retighten the hose connection. Crack the valves on the gauge manifold until the system pressure rises to 2 psig. Close the refrigerant drum valve and the gauge manifold valves.

For triple evacuation the above procedure should be repeated three times.

One more addition to the procedure is to keep the vacuum on the system each time for 2 hours, with the vacuum pump on, since a normal 1/4 hours power compressor pump was used instead of a standard vacuum pump.

3.7-2 Determining the proper charge.

Two ways were used to check for determining the proper charge of a system.

1.Using a sight glass.

The most common method of determining the proper system charge is by means of a sight glass in the liquid line. Since a solid head of liquid refrigerant is essential for proper expansion valve control, the system can be considered properly charged when a clean stream of liquid refrigerant is visible. Bubbles or flushing usually indicate a shortage of refrigerant. Bear in mind that if there is vapor in the sight glass and no liquid, it will also appear clear.

However, the sight glass may show bubbles or flush gas even when the system is fully charged. A restriction in the liquid line ahead of the sight glass may cause sufficient pressure drop to cause flashing of the refrigerant.

2.The formation of ice on the indoor coil.

The formation of ice on the indoor coil is completely prohibited, due to the enclosure of the coil and the low air temperature discharge from the evaporator. So care must be taken not to stop charging when ice starts forming on the coil. This method is used when there is no procedure to calculate the amount of refrigerant needed in the system and the sight glass is not giving any clear identification of subcooling.

3.7-3 Charging procedure.

The main problem is maintaining a well known amount of mixture ratio. So the first charge was all Propane, since the amount of propane was limited to 2 kilograms, and any further charging and discharging would only result in the loss of the available quantity. When the charge quantity is reached. The system is tested as given in section 3.7.4. Then an amount of

LPG is added, so that the required mass ratio for the propane reaches 90%. As given in the following equation:

$$\frac{\Pr opane\_mass + propan\%\_in\_lpg * (new\_lpg\_mass)}{\Pr opane\_mass + lpg\_mass} = 90\%$$

and the new_lpg_mass can be found to have a 90% mass of propane. Then the system is tested again for performance.

For low values of propane mass percentage the need of LPG is so high, that it would be needed to add 4 or 5 times the required charge of the system. So some of the charge in the system should be removed and then the LPG can be added. Doing this will help reduce the amount of propane in the system and then reduce the amount of LPG needed to reduce the percentage of propane, but then it is very tricky to find out the amount of charge to be removed from the system. It needs lots of trials, and experience.

3.7-4 Experimental work procedure.

When the system is charged and ready to be run, the work is divided into two main steps. Start up, and steady run.

1.Start up of the system

The most significant readings on the start up is the compressor discharge temperature and the current. Both should be measured against time. But due to lack of equipment the staring current could not be measured. The temperature of the compressor discharge is a very good indicator of the steadiness of the system, so it would be taken every 5 seconds for the start up until steady state, that is when reached the system is in dynamic equilibrium. The compressor discharge temperature , T7, is recorded and analyzed.

2.The steady run.

In order to study the performance of the system, conditions had to be changed in each run, in order to get the most of the experiment. First trial was to control the evaporator and condenser temperatures using water spray on the coils, but since the evaporator and the condenser where a forced air heat exchangers, the amount of water would be evaporated before the system would have a chance to get to a steady state, and reading any data before that was not meaningful; since the system was not in a dynamic equilibrium.

So, the second choice was to change the evaporator and condenser areas by covering parts of them. This way, it was possible to have dynamic equilibrium but, no performance change; since the expansion device started to change the mass flow rate and hence reducing the effect of the change in the coil area. Also changing the area means changing the system itself, hence the experiment would not be done (actually) on the same machine.

The last choice was to change the indoor (evaporator) fan speed, which was possible, using the programmable controller of the unit. It was possible to have three different speeds for the indoor coil. Readings were taken every two to three hours.

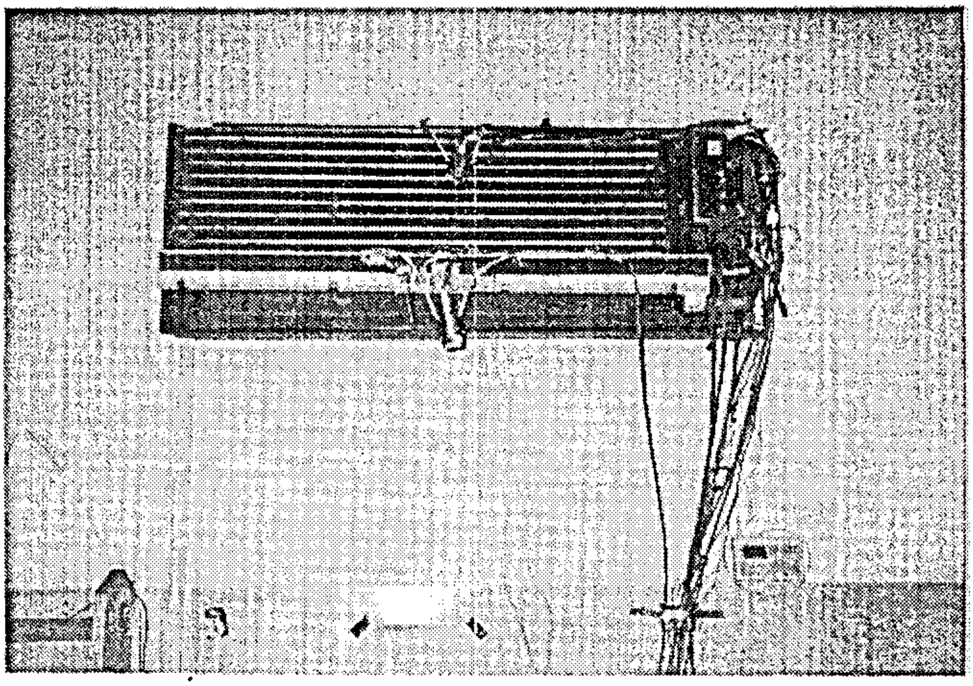


Fig 3.3 Indoor Unit.

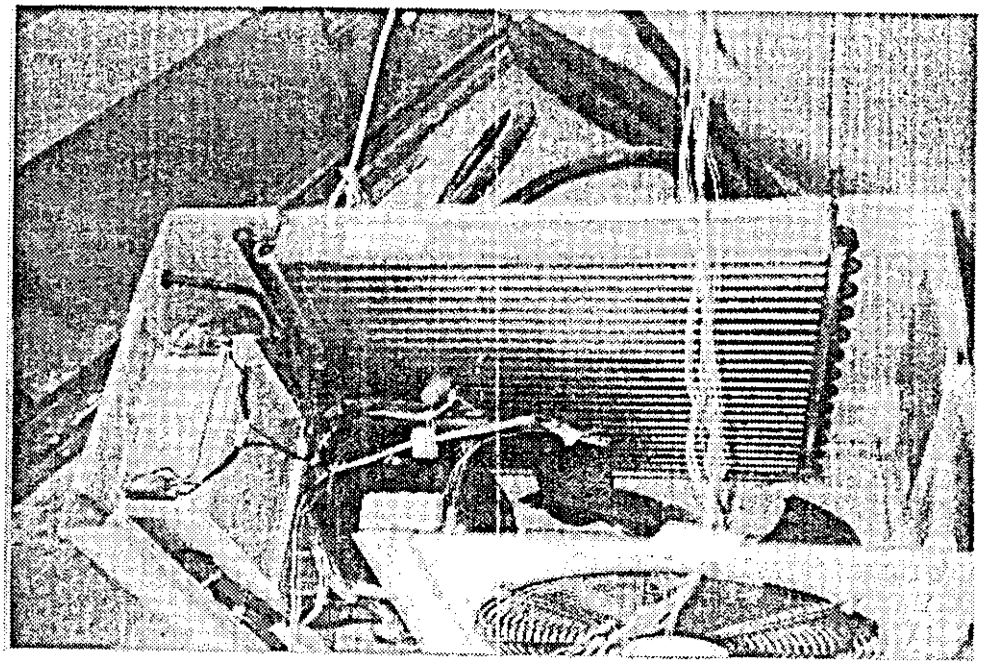


Fig 3.4 Outdoor unit

CHAPTER 4

Mathematical Analysis

4.1 Data Reading

The readings that where taken were temperature, pressure, power, and time; as was discussed in chapter three. These data are usually enough to make most of the required calculations, in a single component working fluid. But in our case there are three main components and some other components that are negligible.

4.2 Calculation

The original work was to be made on a binary mixture of Propane and Butane, but pure butane was hard to find; causing the use of LPG. The compositions of the mixtures were as follows:

Table (4-1): Components of mixtures used in the system.

Mass				Persentage		
Propane	Butane	Iso-Butane	Total	Propane%	butane%	Isobutane%
715.00	0.00	0.00	715.00	100.00	0.00	0.00
738.53	66.25	20.22	825.00	90.00	8.00	2.00
767.62	148.17	45.21	961.00	80.00	15.00	5.00
809.76	266.82	81.42	1158.00	70.00	23.00	7.00
798.44	408.81	124.75	1332.00	60.00	31.00	9.00
737.35	582.03	177.62	1497.00	49.00	39.00	12.00
599.09	691.80	216.16	1507.05	40.00	46.00	14.00

These mixtures do not have ready tables or P-h diagrams, so finding out the mixture enthalpy or liquid percentage, would be some how tricky.

(Habash, 1994) used the following equation to get the enthalpy of the mixture

$$h_{\text{mixture}} = X_{\text{propane}}\, h_{\text{propane}} + X_{\text{butane}}\, h_{\text{butane}} + X_{\text{Isobutane}}\, h_{\text{Isobutane}}$$

This equation is applicable for ideal gases, and gases only, and the gases in our case are as far as possible from being ideal, and most of the time are not in the vapor phase at all.

To give a clearer picture of the problem, lets see Fig. (4-1),

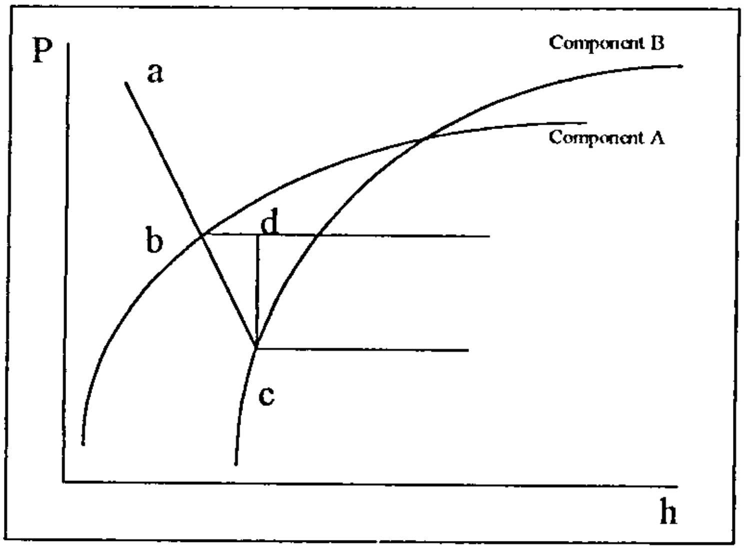


Fig (4-1) : Hypothetical P-h diagram

This figure gives the imaginary case that was used in the previous work at the University of Jordan, in which, there were two gases in a mixture, that were kept at a constant temperature and the pressure is being reduced, starting form point **a**, the solution would reach point **b** in which component **A** would supposedly starts boiling, while component **B** is far away from its boiling point **c**, which have a different temperature. If it to be assumed that **B** would keep on going to point **c**; so it would begin to evaporate, then three large errors will be encountered;

First, just after leaving point **b** we would have two pressures for the same system, and that is physically impossible (points C, and D), and we can not say that these are partial pressures; because just after point b the pressure sum is double the total pressure, and then starts to change tell point **c**, although the composition is constant.

Secondly, we would have two curves for the constant temperature line, which is also extremely unlikely.

Thirdly even if the Bell curve are on the same P-h diagram the temperature curves for each component dose not match; line a-b can not be the constant temperature curve for both components

What really happens in our case is that the mixtures start behaving as a single component with new properties. These properties are different from the those of the original gases that makes the mixture. The mixture starts to boil at the same point and condenses at the same point. They will also have a single line for constant temperature, that is almost like a single gas, but the main difference is inside the dome. The temperature lines are no longer parallel to the pressure lines, but slightly inclined with some curvature. The slope and curvature of the temperature lines depend on the components, ratio, and temperature.

To solve the problem of calculating such extremely complicated problem, Aspen Library had to be used. This library is mainly used by Chemical Engineers to simulate the chemical processes in large plans. It is a library like the NAG library, but needs much programming work.

Luckily, the Aspen library was found on the Labs of the Faculty of Engineering at the University, expired and refusing to work. A new definition file was given to the Library to overcome the expiration problem, the definition file can be found in Appendix B. With Aspen it was possible to calculate both the enthalpy and the liquid fraction, of the mixtures, but with an approximate time of half a minute to each point. The time was a limiting factor at this work, so the iteration had to be cut down. Drawings of P-h diagrams are found in the next chapter.

To give an idea on the time needed to make these drawings; temperatures from -10 to 100°C in a 10 degrees step where calculated and in 1psi pressure step staring from 10 to 300 psi. For each point, enthalpy of liquid and vapor, mass and mole fractions of propane butane and isoutane, both in liquid and vapor phases where calculated, that is 11 data types by 291 different pressure by 11 different temperature by 6 different compositions by half a minute would give us two months and 13 days of a 24 hour computer run time.

4-3 *Performance of the system*

The performance of the system shall be defined by calculating the COP, capacity, power, and the startup-settling behavior of the compressor.

A Diagram of the system is shown bellow

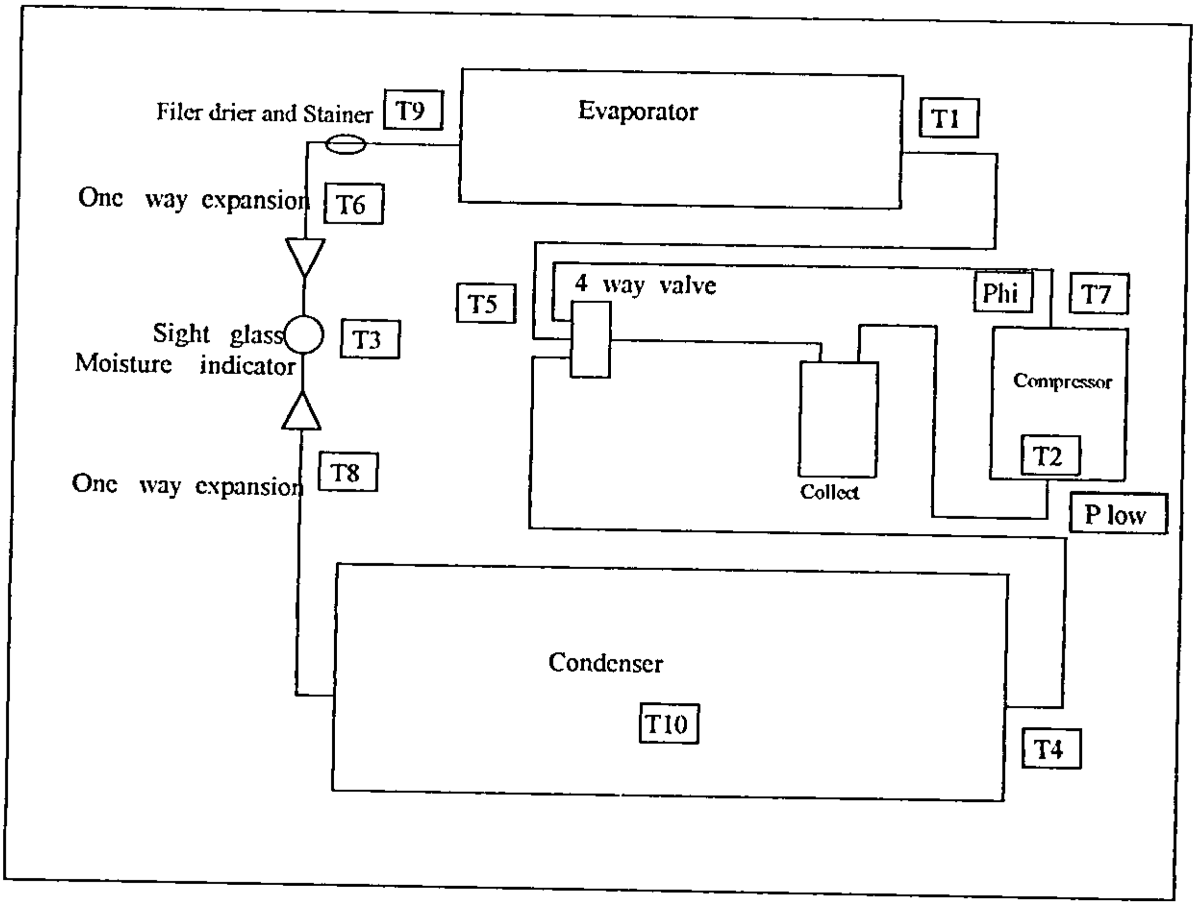


Figure (4-2): The Temperature and pressure measuring points.

All the calculation will be based on the Aspen calculations.

CHAPTER 5

Results and Discussion

5.1- Introduction

In this chapter the experimental results are shown on curves and analyzed. For the refrigerants like R12 or R22, the temperature is constant through the constant pressure line in the saturation region. For the case of Propane-Butane-Isobutane mixtures, the temperature lines are not parallel to the pressure lines - in the two phase region - as will be shown later on. This made the calculations more exact and easier.

5.2- Results

5.2-1- Enthalpy Results.

All the enthalpy values were obtained using the aspen library. The data given in Tables (5.1) to (5.7) show values of enthalpy for the evaporator, compressor, condenser inlet and outlet.

5.2-2- Performance Results

Tables (5.9) to (5-24) show the values of evaporator capacity, compressor work, C.O.P., and ideal C.O.P. They also show the air enthalpy, humidity ratio, specific volume, and relative humidity, calculated for 900m above sea level, which is the height of the unit location. The tables also show the working fluid mole flow rate, the condensate mass, and the change in air energy.

5.3- Discussion

The results are given in graphical form from Figure (5.1) to Figure (5.44).

5.3-1 Refrigerant mass

Figure (5-1) shows the masses of the components Propane, Butane, and Isobutane of the mixture. Propane mass increases as its ratio increases up to 70%, and then starts to decrease against the increase of the butane and Isobutane masses, which increase all the time. The reason is the limit on the total mass of the working fluid in the system. At the start there is only pure propane, then gradually some part of the propane is leaked out, and an amount of LPG is introduced to the system tell the mass limit is reached. The LPG contains propane, that will compensate for the missing part. After a few change in the percentage the propane entering with the LPG will not be enough to cover for the leaving Propane, and so the Propane mass in the system will be reduced.

Figure (5.2) shows the percentages of the gases versus the total mass of the system. Requiring a certain percentage of one gas would give the total mass needed and the percentages of the other two gases. The figure also shows a sudden change in percentage at the total working fluid mass of 1500, where propane falls and butane and Isobutane increase very fast.

5.3-2 The compressor discharge temperature.

The higher the compressor temperature the more problems to be expected from the system, Burned Oil and Refrigerant, acid and slugs forming, overheating, etc.

Figure (5-3) shows the compressor discharge temperature versus time. It is clearly seen that R22 have the highest temperature.

Figure (5-4) shows the rate of change of the compressor discharge temperature with time. The rate of change in compressor discharge temperature is used to measure the steadiness of the system. This figure shows that for the first 10 minutes from starting the compressor, no data can reflect the actual performance of the system.

For hydrodynamics after the first 1000 seconds the system becomes thermodynamically stable. While for R22 it takes much longer to become thermodynamically stable. This means that the respond time for hydrocarbon is much shorter than that of R22, which is obviously an advantage. But time is not the only important point here. The moment the compressor is started, its current runs up very high (startup current) and then decreases to the normal (running) current as the compressor reaches a steady state. Longer respond time means longer time before reaching steady state, in tern means longer exposure to higher currents. And this means a well known fact; shorter compressor life.

5.3-3- The P-h diagrams.

Figures (5.5) to (5-11) show the P-h diagrams for the different mixtures. These diagrams shows the usual P-h diagram features and some other new ones.

The temperature lines in the two phase region are not parallel to the pressure line, they are inclined to the gas side, because the saturation temperatures of the different gases are not equal for the same saturation pressure.. This inclination increases as the temperature increases. This means for constant temperature the pressure change from the boiling point to the dew point becomes much higher.

The temperature lines also have another interesting behavior at lower values of pressure. They tend to get closer, and this means that for the same pressure the temperature range between the boiling and dew point is very high.

One detail is the curvature of the temperature lines inside the saturation dome. In the case of 90% propane mass mixture, the lines are curved downward. Once the propane is reduced from the mixture, the lines begins to straighten up tell the 49% curves and then begins to curve upwards.

Another very interesting point is the fact that lower propane mass percentage in the mixture leads to lower pressures for the same temperatures. This is because of the fact that for the same temperatures Propane has a much higher saturation pressure, and hence reducing its percentage means getting closer to the pressures of the other two gases which are very near, and lower than Propane's.

Also it can be seen that for the liquid region, enthalpy is only a function of temperature. Also the whole body of the dome is moved to the left when ever the propane mass percentage is reduced.

5.3.4 Temperatures of the system.

Figures (5-12) to (5-19) show the inlet and outlet temperatures of the compressor, evaporator and condenser. It can be seen that generally reducing the propane ratio will reduce the compressor discharge temperature.

The temperatures are drawn against the time, showing constant values; indicating the steady state condition at the time of experimenting, with average values show in Table (5-25).

5.3-5 Evaporator capacity and compressor work.

Figures (5.20) to (5.27) show the evaporator capacity and the compressor work against the evaporator pressure. Increasing the evaporator pressure leads to increase in evaporator capacity, and decrease in compressor work. Generally speaking the evaporator capacity is almost in the same range for the hydrocarbon mixtures. Over all capacity for the hydrocarbons are much higher than that of R22, but R22 has higher mole flow rate.

5.3-6 Coefficient of performance

Figures (5.28) to (5.35), show the C.O.P versus the evaporator pressure. As shown in section 5.3.5 the range between evaporator capacity and compressor work gets larger through the increase of evaporator capacity or reduction of compressor work or both, and hence the C.O.P. must eventually increase with the evaporator pressure.

Figure (5-36) shows the values of C.O.P. for all the mixtures used against the evaporator pressure. One clear point that can be seen is that each mixture covers a certain range of the evaporator pressure, and not the full range. This is due to the fact that the temperature of the room in which the experiment was done was kept in a range between 13-19 °C, this is the normal temperature for cooling the rooms. A higher or lower values of temperature means changing the purpose of the machine, and its normal function. Now reaching back to the P-h diagrams, for the same temperature range the saturation pressure is reduced when reducing the Propane percentage. The numerical values shows that reducing the propane percentage means reducing the C.O.P., the reduction between 100% propane up to 70% is not significant. But for Propane percentage lower than 70%, the C.O.P. goes very low. It is very clear that for 100% propane, 90%, 70% the C.O.P. is much higher than for R22.

5.3-7 Mole flow rate inside the machine.

Figures (5.37) to (5.43) shows the mole flow rate for the different mixtures of hydrocarbons. No clear pattern was obtained for the mole flow rate, but it was very clear that the overall mole flow rate had a clear pattern with the propane percentage in the mixture. Having the FD20 flow control device means that having moving parts in the system, which would be affected by the viscosity of the working fluid. Hence changing its position according to the viscosity and the drag force on it. Nevertheless the overall mole flow rate range is reduced while reducing the propane mixture till the 50%, and in witch after the reduction of propane mass will start increasing the mole flow rate range. The hydrocarbons had a much lower mole flow rate that that of R22,due to their lower total mass in the system.

Table (5-1) : Enthalpy values for 100% propane, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
90.5	9.30	-105690000	27.5	-104310000	0.97	-122860000
89.4	9.10	-105710000	27.9	-104280000	1.73	-122520000
88.7	8.90	-105720000	28.3	-104250000	1.59	-122660000
90.0	8.62	-105740000	28.05	-104270000	1.3	-122820000
88.0	8.34	-105760000	28.27	-104250000	1.83	-122480000
87.6	8.18	-105780000	28.33	-104250000	1.47	-106270000
84.7	7.05	-105860000	28.33	-104250000	1.51	-106270000
84.3	6.90	-105870000	28.29	-104250000	1.47	-106270000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
168.7	73.8	-101200000	85.7	-100110000	37	-104460000
168.7	75.5	-101050000	87.6	-99937000	37.4	-104430000
171.7	76.8	-100950000	88.9	-99837000	38.2	-104390000
171.7	75.55	-101070000	88.25	-99897000	37.54	-104450000
171.7	75.46	-101070000	88.3	-99893000	37.99	-104410000
173.7	75.95	-101050000	88.45	-99893000	38.26	-104400000
173.7	76.13	-101030000	88.68	-99871000	38.34	-104400000
173.7	76.19	-101020000	88.75	-99865000	38.55	-104380000

Table (5.2) : Enthalpy values for 90% propane, Temperature in oC, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
76.8	9.47	-107600000	26.12	-106310000	2.77	-124950000
78.8	10.35	-107540000	26.67	-106270000	2.94	-124930000
78.3	10.15	-107560000	26.78	-106260000	2.68	-124960000
75.4	8.85	-107660000	26.45	-106290000	2.07	-125030000
74.0	8.25	-108119302.3	26.14	-106310000	1.76	-125060000
70.7	6.82	-110982250	25.98	-106330000	1.42	-125100000
68.2	5.74	-114191147	25.59	-106360000	1.35	-125110000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
152.7	70.81	-103170000	81.57	-102180000	34.46	-108420000
157.7	72.6	-103050000	83.47	-102040000	35.48	-109060000
157.7	72.86	-103030000	83.87	-102000000	35.65	-108620000
157.7	72.74	-103040000	83.55	-102030000	35.57	-108829514
157.7	72.58	-103050000	83.66	-102020000	35.59	-108773216
157.7	72.49	-103060000	83.43	-102040000	35.75	-108374820
157.7	72.27	-103080000	83.01	-102080000	35.89	-108040500

Table (5-3) : Enthalpy values for 70% propane, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
47.0	5.82	-111887360	14.51	-113830000	-0.28	-130280000
45.5	5.73	-111892040	14.19	-114260000	-0.35	-130290000
46.5	5.48	-111905040	14.27	-114160000	-0.53	-130310000
48.3	5.59	-111899320	15.38	-112670000	-0.23	-130280000
47.9	5	-111930000	14.93	-113270000	-0.4	-130300000
48.2	4.71	-111945080	15.03	-113130000	-0.12	-130270000
47.8	4.05	-111979400	14.35	-114050000	0.27	-130220000
46.0	3.95	-111984600	14.04	-114470000	0.61	-130180000
45.3	4.38	-111962240	14.01	-114510000	0.59	-130180000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
127	49.9	-108920000	58.5	-108120000	28.6	-126790000
127	49.87	-108920000	58.4	-108130000	28.71	-126780000
127	49.78	-108930000	58.32	-108140000	28.75	-126770000
127	50.81	-108830000	59.08	-108060000	30.64	-125000000
127	49.49	-108960000	57.75	-108190000	30.72	-124790000
127	48.55	-109040000	56.97	-108260000	30.85	-124440000
127	46.78	-109200000	55.55	-108390000	30.01	-126610000
127	46.2	-109260000	55.28	-108420000	30.01	-126610000
127	46.87	-109200000	55.81	-108370000	31.22	-123480000

Table (5-4) : Enthalpy values for 60% propane, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
40.5	5.35	-114027600	14.81	-119880000	0.7	-132840000
40.2	5.17	-114039120	14.78	-119920000	0.53	-132860000
40.2	5.13	-114041680	14.66	-120090000	0.49	-132860000
40.0	5.02	-114048720	14.58	-120200000	0.33	-132880000
40.0	5	-114050000	14	-121040000	0.28	-132890000
40.0	5.03	-114048080	13.97	-121090000	0.37	-132880000
39.5	4.62	-114074320	13.58	-121660000	-0.02	-132920000
39.4	4.54	-114079440	13.67	-121530000	-0.04	-132920000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
120.7	42.3	-111740000	45.62	-111430000	31	-129100000
120.7	42.5	-111720000	45.6	-111430000	31.2	-129070000
120.7	42.5	-111730000	45.55	-111440000	31.2	-129080000
120.7	42.4	-111730000	45.66	-111430000	31.2	-129080000
120.7	42.4	-111730000	45.66	-111430000	31.2	-129080000
120.7	42.4	-111730000	45.58	-111440000	31.3	-129070000
120.7	42.2	-111750000	45.25	-111470000	31.1	-129090000
120.7	42.2	-111750000	45.31	-111460000	31.1	-129090000

Table (5-5) : Enthalpy values for 49% propane, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

PRES.	T1	H1	T2	H2	T9	H9
38.2	7.69	-116467080	15.6	-123420000	1.63	-135870000
38.0	7.47	-116482040	15.4	-123710000	1.36	-135900000
37.4	7.02	-116512640	15.44	-123660000	1.41	-135900000
37.0	6.65	-116537800	15.06	-124200000	1.09	-135940000
36.7	6.42	-116553440	15	-124290000	0.94	-135950000
36.7	6.41	-116554120	14.9	-124430000	0.79	-135970000
36.1	5.93	-116586760	14.67	-124760000	0.44	-136010000
36.0	5.81	-116594920	14.49	-125020000	0.62	-135990000
35.9	5.78	-116596960	14.55	-124940000	0.55	-136000000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
91.7	41.11	-114140000	43.61	-113900000	29.09	-126200000
91.7	41.12	-114130000	43.68	-113890000	28.94	-126420000
91.7	41.17	-114130000	43.71	-113890000	29.17	-126080000
91.7	40.94	-114150000	43.22	-113940000	29.12	-126150000
91.7	40.88	-114160000	43.13	-113950000	29.07	-126230000
91.7	40.96	-114150000	43.24	-113940000	29.19	-126050000
91.7	40.85	-114160000	43.03	-113950000	29.25	-125960000
91.7	40.72	-114170000	42.89	-113970000	29.15	-126110000
91.7	40.9	-114150000	43.01	-113960000	29.48	-125610000

Table (5-6) : Enthalpy values for 40% propane, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
33.9	7.88	-118668640	14.78	-125000000	1.82	-138540000
33.9	7.94	-118658320	15.06	-124560000	1.93	-138520000
33.7	7.68	-118677040	15.56	-123740000	1.92	-138530000
33.5	7.47	-118692160	15.1	-124490000	1.87	-138530000
33.4	7.44	-118694320	15.31	-124150000	1.76	-138540000
33.5	7.53	-118687840	15.38	-124030000	1.88	-138530000
33.5	7.52	-118688560	14.84	-124910000	1.58	-138570000
33.2	7.17	-118713760	14.57	-125330000	1.39	-138590000
32.7	6.72	-118746160	14.18	-125940000	0.89	-138650000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
76.7	38.61	-116410000	41.08	-116180000	26.11	-129930000
76.7	39.2	-116360000	41.52	-116140000	26.84	-128860000
76.7	39.7	-116310000	41.94	-116100000	27.48	-127910000
76.7	39.32	-116350000	41.51	-116140000	27.07	-128520000
76.7	39.49	-116330000	41.69	-116120000	27.34	-128120000
76.7	39.46	-116330000	41.7	-116120000	27.15	-128400000
76.7	38.65	-116410000	40.86	-116200000	26.33	-129610000
76.7	38.59	-116410000	40.66	-116220000	26.26	-129710000
76.7	38.08	-116460000	40.29	-116250000	25.85	-130310000

Table (5-7) : Enthalpy values for LPG, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
40.8	19.8	-122260000	22.5	-131900000	6	-144030000
40.5	19.6	-131930000	22.3	-141930000	5.9	-144040000
40.2	19.3	-142320000	22.2	-141940000	5.7	-144070000
40.2	19.3	-142320000	22.2	-141940000	5.4	-144110000
40.0	19.2	-142340000	22.2	-141940000	5.5	-144090000
40.3	19.4	-142310000	22.4	-141910000	5.9	-144040000
40.3	19.4	-142310000	22.2	-141940000	5.3	-144120000
39.6	18.8	-142390000	21.7	-142000000	5.5	-144090000
39.8	19	-142360000	21.6	-142020000	5.2	-144130000

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
138.7	51.4	-117330000	56.6	-117040000	35.5	-140120000
138.7	51.3	-117340000	56.6	-117040000	35.5	-140120000
138.7	51.2	-137860000	56.5	-137060000	35.5	-140120000
138.7	51.2	-137860000	56.3	-137090000	35.5	-140120000
138.7	51.3	-137840000	56.4	-137070000	35.7	-140090000
138.7	51.5	-137810000	56.6	-137040000	35.6	-140100000
138.7	51.5	-137810000	56.5	-137060000	35.7	-140090000
138.7	50.9	-137900000	55.8	-137160000	35.5	-140120000
138.7	50.5	-137960000	55.5	-137210000	35	-140190000

Table (5-8) : Enthalpy values for R22, Temperature in °C, Pressure in Psi, and Enthalpy in J/mole

LOW PRESSURE SIDE						
PRES.	T1	H1	T2	H2	T9	H9
73.5	6.4	410000	35	430000	0.7	252500
72.8	6.4	410000	35.5	430250	0.7	253000
73	6.3	410000	35.3	430250	0.7	252750
72	6	409750	34.7	429750	0.5	255500
72.8	6.1	409750	34.9	430000	0.8	253750
72.2	6	409750	35	430000	0.8	253750
72.5	5.6	409500	34.3	429750	0.4	253500
72	5.8	409750	34.3	429750	0.6	253750
72	5.8	409750	34.9	430000	0.6	253750

HIGH PRESSURE SIDE						
PRES.	T4	H4	T7	H7	T8	H8
226	98.9	466250	120.9	486250	49.6	274460
230	99.8	467500	122.2	489000	50.4	273910
230	100.1	468000	122.2	489000	50.3	274710
233	100	467800	122.5	489000	50.9	273740
233	100.7	469500	122.9	490000	51.2	276000
234	101	469750	123.3	491500	51.1	274390
236	100.7	469250	123.2	491250	51.5	274140
237	100.7	469250	123.2	491250	51.8	273330
237	101	469000	123.6	491250	51.7	273490

Table (5-9) : Values of qe, w, and C.O.P.'s, Energy in J/mol for 100% Propane.

Pressure	qe	w	C.O.P.	C.O.P. Ideal
90.5	17170000	4200000	4.08	5.52
89.4	16810000	4343000	3.87	5.20
88.7	16940000	4413000	3.83	5.13
90.0	17080000	4373000	3.90	5.34
88.0	16720000	4357000	3.83	5.26

Table (5-10) Calculation of Air Properties, and propane mole flow rate, energy in J/mol

Cooling					
Evap. P	90.5	89.4	88.7	90.0	88.0
Air in					
h J/mol	49.16	48.22	47.27	50.43	49.79
ϕ	96.51	98.36	95.54	96.54	96.53
ω	12.86	12.69	12.32	13.2	13.03
v m /Kg	0.93	0.93	0.93	0.94	0.93
Air out					
h J/mol	26.21	25.53	25.3	26.67	26.21
ϕ	77.17	77.95	79.94	77.31	78.17
ω	6.52	6.42	6.45	6.63	6.57
v m /Kg	0.9	0.9	0.9	0.9	0.9
Calculation					
Air d(h) kJ/kg	22.95	22.69	21.97	23.76	23.58
lost water g/kg	6.34	6.27	5.87	6.57	6.46
Q-air J/s	96186	95096.31	92078.71	96333.6	95603.8
qe J/mol	17170000	16810000	16940000	17080000	16720000
Mole/s	0.00560	0.00566	0.00544	0.00564	0.00572

Table (5.11) : Values of qe, w, and C.O.P.'s for 90% propane, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
68.2	10918853	4280000	2.55	3.33
70.7	14117750	4290000	3.29	4.32
74.0	16940698	4290000	3.95	5.20
75.4	17370000	4260000	4.08	5.34
76.8	17350000	4130000	4.20	5.53
78.3	17400000	4260000	4.08	5.39
78.8	17390000	4230000	4.11	5.40

Table (5-12) Calculation of Air Properties, and mole flow rate for 90% propane, energy in J/mol

Cooling							
Evap. Pres. Psi	76.8	78.8	78.3	75.4	74.0	70.7	68.2
Air in							
h J/mol	48.45	46.27	46.78	46.15	44.19	44.025	43.25
ϕ	95.74	87.24	98.93	98.43	97.03	95.86	96.51
ω	12.15	11.2	11.85	11.67	11.11	11.02	10.85
v m /Kg	0.84	0.84	0.84	0.84	0.83	0.83	0.83
Air out							
h J/mol	24.09	24.4	24.41	20.23	19.31	16.12	16.01
ϕ	80.49	90.4	83.76	75.01	80.94	69.93	73.71
ω	5.87	6.27	5.86	4.94	4.98	4.05	4.16
v m /Kg	0.8	0.81	0.81	0.8	0.8	0.8	0.8
Calculation							
Air d(h) kJ/kg	24.36	21.87	22.37	25.92	24.88	27.905	27.24
lost water g/kg	6.28	4.93	5.99	6.73	6.13	6.97	6.69
Q-air J/s	11485.74	10184.4	10417.23951	11822.76	11348.39	11262.28359	10993.89375
qe J/mol	10918853	14117750	16940698	17370000	17350000	17400000	17390000
Mole/s	0.00105	0.00072	0.00061	0.00068	0.00065	0.00065	0.00063

Table (5-13) : Values of qe, w, and C.O.P.'s for 70% propane, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
47.0	18392640	5710000	3.22	3.75
45.5	18397960	6130000	3.00	3.45
46.5	18404960	6020000	3.06	3.52
48.3	18380680	4610000	3.99	4.79
47.9	18370000	5080000	3.62	4.26
48.2	18324920	4870000	3.76	4.48
47.8	18240600	5660000	3.22	3.76
46.0	18195400	6050000	3.01	3.49
45.3	18217760	6140000	2.97	3.43

Table (5-14) Calculation of Air Properties, and mole flow rate for 70% propane, energy in J/mol

Cooling									
Evap. Pres. Psi	47.0	45.5	46.5	48.3	47.9	48.2	47.8	46.0	45.3
Air in									
h J/mol	33.95	33.3	33.05	34.05	32.68	32.31	33.01	32.72	33.08
ϕ	81.89	89.29	89.77	92.07	88.48	84.86	84.21	84.74	91.13
ω	8.01	8.17	8.13	8.45	8	7.77	7.9	7.86	8.19
v m /Kg	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Air out									
h J/mol	16.66	16.1	16.2	15.88	14.81	14.42	13.18	12.78	13.11
ϕ	77.88	77.75	81.14	79.44	78.3	76.8	76.13	72.96	76.09
ω	4.41	4.31	4.43	4.32	4.11	4	3.77	3.62	3.76
v m /Kg	0.81	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Calculation									
Air d(h) kJ/kg	17.29	17.2	16.85	18.17	17.87	17.89	19.83	19.94	19.97
lost water g/kg	3.6	3.86	3.7	4.13	3.89	3.77	4.13	4.24	4.43
Q-air J/s	8051.590123	8212.455696	8045.341772	8392.7	8254.13038	8263.368354	8104.571203	8149.528481	8161.789557
qe J/mol	18392640	18397960	18404960	18380680	18370000	18324920	18240600	18195400	18217760
Mole/s	0.000437762	0.000446379	0.000437129	0.000456604	0.000449327	0.000450936	0.000444315	0.000447889	0.000448013

Table (5-15) : Values of qe, w, and C.O.P.'s for 60% propane, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
40.5	18812400	8450000	2.23	2.31
40.2	18820880	8490000	2.22	2.30
40.2	18818320	8650000	2.18	2.25
40.0	18831280	8770000	2.15	2.22
40.0	18840000	9610000	1.96	2.02
40.0	18831920	9650000	1.95	2.01
39.5	18845680	10190000	1.85	1.90
39.4	18840560	10070000	1.87	1.93

Table (5.16) Calculation of Air Properties, and mole flow rate for 60% propane, energy in J/mol

Cooling								
Evap. P	40.5	40.2	40.2	40.0	40.0	40.0	39.5	39.4
Air in								
h J/mol	37.03	35.29	35.31	35.49	35.7	36	36.31	36.27
ϕ	91.61	88.57	83.98	83.64	82.38	58.78	83.04	86.3
ω	9.56	9.02	8.83	8.86	8.85	9.07	9.02	9.15
v m /Kg	0.92	0.91	0.92	0.92	0.92	0.92	0.92	0.92
Air out								
h J/mol	19.16	18.91	18.95	18.26	18.12	18.36	17.13	16.96
ϕ	88.48	82.61	85.18	81.8	82.85	85.78	79.82	81.11
ω	5.51	5.27	5.37	5.12	5.13	5.27	4.85	4.86
v m /Kg	0.89	0.89	0.89	0.89	0.89	0.89	0.88	0.88
Calculation								
Air d(h) kJ/kg	17.87	16.38	16.36	17.23	17.58	17.64	19.18	19.31
lost water g/kg	4.05	8.13	3.46	3.74	3.72	3.8	4.17	4.29
Q-air J/s	7573.667416	6942.175281	6933.698876	7064.3	7207.8	7232.4	7037.207386	7084.90483
qe J/mol	18812400	18820880	18818320	18831280	18840000	18831920	18845680	18840560
Mole/s	0.000403	0.000369	0.000368	0.000375	0.000383	0.000384	0.000373	0.000376

Table (5-17) : Values of qe, w, and C.O.P.'s for 49% propane, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
35.9	19403040	10980000	1.77	1.798
36.0	19395080	11050000	1.76	1.787
36.1	19423240	10810000	1.79	1.832
36.7	19415880	10490000	1.85	1.888
36.7	19396560	10340000	1.87	1.915
37.0	19402200	10260000	1.89	1.931
37.4	19387360	9770000	1.98	2.034
38.0	19417960	9820000	1.98	2.027
38.2	19402920	9520000	2.04	2.091

Table (5.18) Calculation of Air Properties, and mole flow rate for 49% propane, energy in J/mol

Cooling									
Evap. P	38.2	38.0	37.4	37.0	36.7	36.7	36.1	36.0	35.9
Air in									
h J/mol	38.13	38.21	37.84	37.79	37.44	37.32	37.56	37.5	37.47
ϕ	86.18	85.73	82.59	9.38	84.7	78.2	88.65	86.94	84.25
ω	9.59	9.59	9.37	9.38	9.36	9.04	9.57	9.48	9.35
v m /Kg	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Air out									
h J/mol	23.09	22.85	22.72	21.71	21.3	21.34	20.12	19.94	20.1
ϕ	86.16	84.51	84.93	82.27	81.81	83.43	81.45	82.8	84.52
ω	6.22	6.11	6.1	5.8	5.71	5.77	5.47	5.48	5.57
v m /Kg	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Calculation									
Air d(h) kJ/kg	15.04	15.36	15.12	16.08	16.14	15.98	17.44	17.56	17.37
lost water g/kg	3.37	3.48	3.27	3.58	3.65	3.27	4.1	4	3.78
Q-air J/s	6374.256	6509.879	6408.162	6592.8	6617.4	6551.8	6326.899	6370.433	6301.504
qe J/mol	19403040	19395080	19423240	19415880	19396560	19402200	19387360	19417960	19402920
Mole/s	0.000329	0.000336	0.00033	0.00034	0.000341	0.000338	0.000326	0.000328	0.000325

Table (5-19) : Values of qe, w, and C.O.P.'s for 40% propane, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
32.7	19903840	9690000	2.05	2.10
33.2	19876240	9110000	2.18	2.23
33.4	19845680	8030000	2.47	2.54
33.5	19837840	8350000	2.38	2.44
33.5	19881440	8710000	2.28	2.34
33.5	19842160	7910000	2.51	2.58
33.7	19852960	7640000	2.60	2.67
33.9	19871360	8820000	2.25	2.31
33.9	19861680	8420000	2.36	2.42

Table (5-20) Calculation of Air Properties, and mole flow rate for 40% propane, energy in J/mol

Cooling									
Evap. P	33.9	33.9	33.7	33.5	33.4	33.5	33.5	33.2	32.7
Air in									
h J/mol	37.67	37.28	37.12	37.18	37.18	37.17	38.88	39.07	37.24
ϕ	88.85	82.94	83.73	88.32	86.33	81.22	78.87	89.1	78.35
ω	9.6	9.25	9.24	9.46	9.37	9.14	9.44	9.95	9.03
v m /Kg	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Air out									
h J/mol	24.57	24.82	24.57	23.71	23.71	24.04	23.89	22.85	22.27
ϕ	88.85	90.86	90.59	88.13	88.94	89.81	92.16	85.08	88.34
ω	6.63	6.75	6.69	6.42	6.45	6.55	6.6	6.13	6.13
v m /Kg	0.9	0.9	0.9	0.9	0.9	0.9	0.89	0.89	0.89
Calculation									
Air d(h) kJ/kg	13.1	12.46	12.55	13.47	13.47	13.13	14.99	16.22	14.97
lost water g/kg	2.97	2.5	2.55	3.04	2.92	2.59	2.84	3.82	2.9
Q-air J/s	54903.56	52221.24	52598.44	54613.37	54613.37	53234.86	54380.86	58843.06	54308.3
qe J/mol	19903840	19876240	19845680	19837840	19881440	19842160	19852960	19871360	19861680
Mole/s	0.00276	0.00263	0.00265	0.00275	0.00275	0.00268	0.00274	0.00296	0.00273

Table (5-21) : Values of qe, w, and C.O.P.'s for LPG, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
39.6	21700000	14840000	1.46	1.49
39.8	21770000	14810000	1.47	1.50
40.0	21750000	14870000	1.46	1.49
40.2	21750000	14880000	1.46	1.49
40.2	21790000	14850000	1.47	1.49
40.3	21730000	14870000	1.46	1.49
40.3	21810000	14880000	1.47	1.49
40.5	21760000	14890000	1.46	1.49
40.8	21770000	14860000	1.47	1.49

Table (5-22) Calculation of Air Properties, and mole flow rate for LPG, energy in J/mol

Cooling									
Evap. P	40.8	40.5	40.2	40.2	40.0	40.3	40.3	39.6	39.8
Air in									
h J/mol	57.14	56.44	55.41	55.76	55.76	56.45	55.06	54.74	54.39
ϕ	94.11	94.94	94.04	96.65	97.53	97.54	92.33	98.41	96.62
ω	14.91	14.76	14.43	14.65	14.69	14.88	14.25	14.45	14.27
v m /Kg	0.95	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
Air out									
h J/mol	35.28	34.49	33.97	33.72	33.46	34.23	33.46	32.69	31.92
ϕ	79.58	77.62	78.38	79.23	78.26	79.35	77.36	71.07	66.68
ω	8.62	8.35	8.27	8.25	8.15	8.37	8.11	7.64	7.26
v m /Kg	0.92	0.92	0.92	0.91	0.91	0.92	0.91	0.92	0.92
Calculation									
Air d(h) kJ/kg	21.86	21.95	21.44	22.04	22.3	22.22	21.6	22.05	22.47
lost water g/kg	6.29	6.41	6.16	6.4	6.54	6.51	6.14	6.81	7.01
Q-air J/s	89626	89995	87904	88377.97802	89420.54945	88131.28261	76638.46154	77384.71467	78858.70924
qe J/mol	21770000	21760000	21750000	21790000	21750000	21730000	21810000	21700000	21770000
Mole/s	0.00411695	0.0041358	0.004041563	0.004055896	0.00411129	0.004055742	0.003513914	0.003566116	0.003622357

Table (5.23) : Values of qe, w, and C.O.P.'s for R22, Energy in J/mol

PRES.	qe	w	C.O.P.	C.O.P. Ideal
72	144250	59250	2.43	3.79
72	156000	61500	2.54	3.95
72	156000	61250	2.55	4.00
72.2	156000	61500	2.54	3.92
72.5	156000	61500	2.54	3.95
72.8	157000	58750	2.67	4.21
72.8	156000	60000	2.60	3.95
73	157250	58750	2.68	4.17
73.5	157500	56250	2.80	4.34

Table (5-24) Calculation of Air Properties, and mole flow rate for R22, energy in J/mol

Cooling									
Evap. P	73.5	72.8	73	72	72.8	72.2	72.5	72	72
Air in									
h J/mol	59.95	58.52	58.53	59.24	59.24	60.68	61.04	61.04	61.04
ϕ	87.79	88.47	89.26	8.52	8.52	87.07	86.34	86.34	86.34
ω	15.37	15.01	15.05	15.21	15.21	15.53	15.59	15.59	15.59
v m /Kg	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Air out									
h J/mol	28.57	28.33	27.16	25.55	26.23	22.87	23.09	23.53	23.31
ϕ	95.81	96.96	96.92	94.46	98.09	82.49	84.79	90.68	8.29
ω	7.74	7.73	7.47	7.03	7.3	6.05	6.17	6.47	6.34
v m /Kg	0.9	0.9	0.9	0.9	0.9	0.9	0.89	0.89	0.89
Calculation									
Air d(h) kJ/kg	31.38	30.19	31.37	33.69	33.01	37.81	37.95	37.51	37.73
lost water g/kg	7.63	7.28	7.58	8.18	7.91	9.48	9.42	9.12	9.25
Q-air J/s	131517.0667	126529.6444	131475.1556	136594.2333	133837.2111	153298.5444	137675.3511	136079.1152	136877.2331
qe J/kg	144250000	156000000	156000000	156000000	156000000	157000000	156000000	157250000	157500000
kg/s	0.000912	0.000811	0.000843	0.000876	0.000858	0.000976	0.000883	0.000865	0.000869

Table (5-25) Average values of properties for the different mixtures.

Mixture	qe J/mol	w J/mol	COP	COP ideal	h1 J/mol	h2 J/mol	h9 J/mol	h7 J/mol
100%	16944000	4337200	3.91	5.2907	-105766250	-104263750	-116518750	-99912875
90%	15927000	4248571	3.75	4.93	-109093243	-106304286	-125020000	-102055714
70%	18324991	5585555	3.317	3.881	-111931676	-113816667	-130256667	-108231111
60%	18830130	9235000	2.013	2.12	-114051119	-120676250	-132881250	-111441250
49%	19404915	10337777	1.882	1.923	-116542862	-124270000	-135947778	-113932222
40%	19863688	8520000	2.342	2.4033	-118691867	-124683333	-138555556	-116163333
LPG	21758889	14861111	1.464	1.491	-138948889	-140835556	-144080000	-132641111
R22	155111 *	59861 *	2.59	4.03	409806*	429972*	253583*	489833*

* J/kg (different reference point)

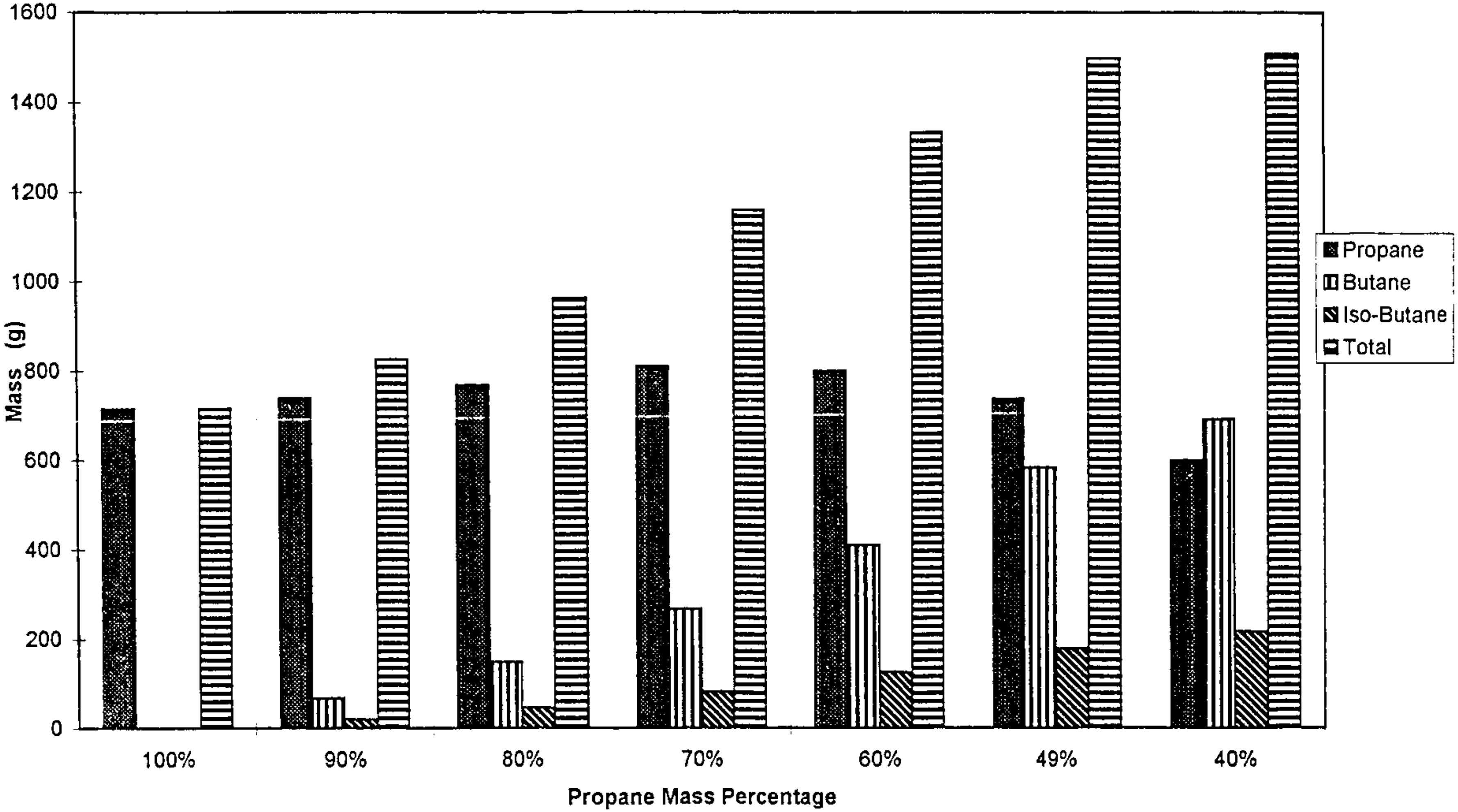


Figure (5.1) Components masses vs. Propane mass Percentage

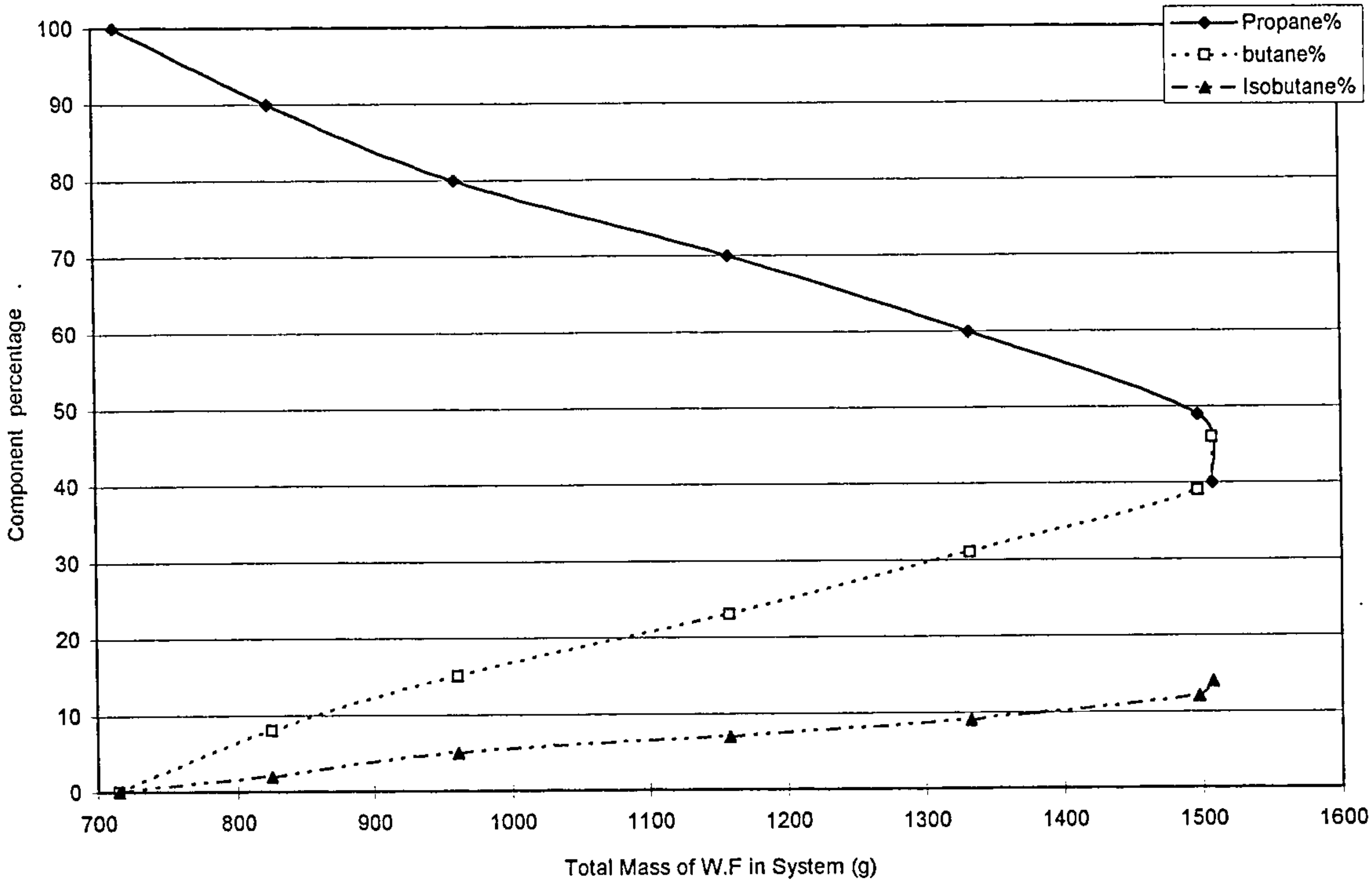


Figure (5-2) Component percentage vs. Total Mass

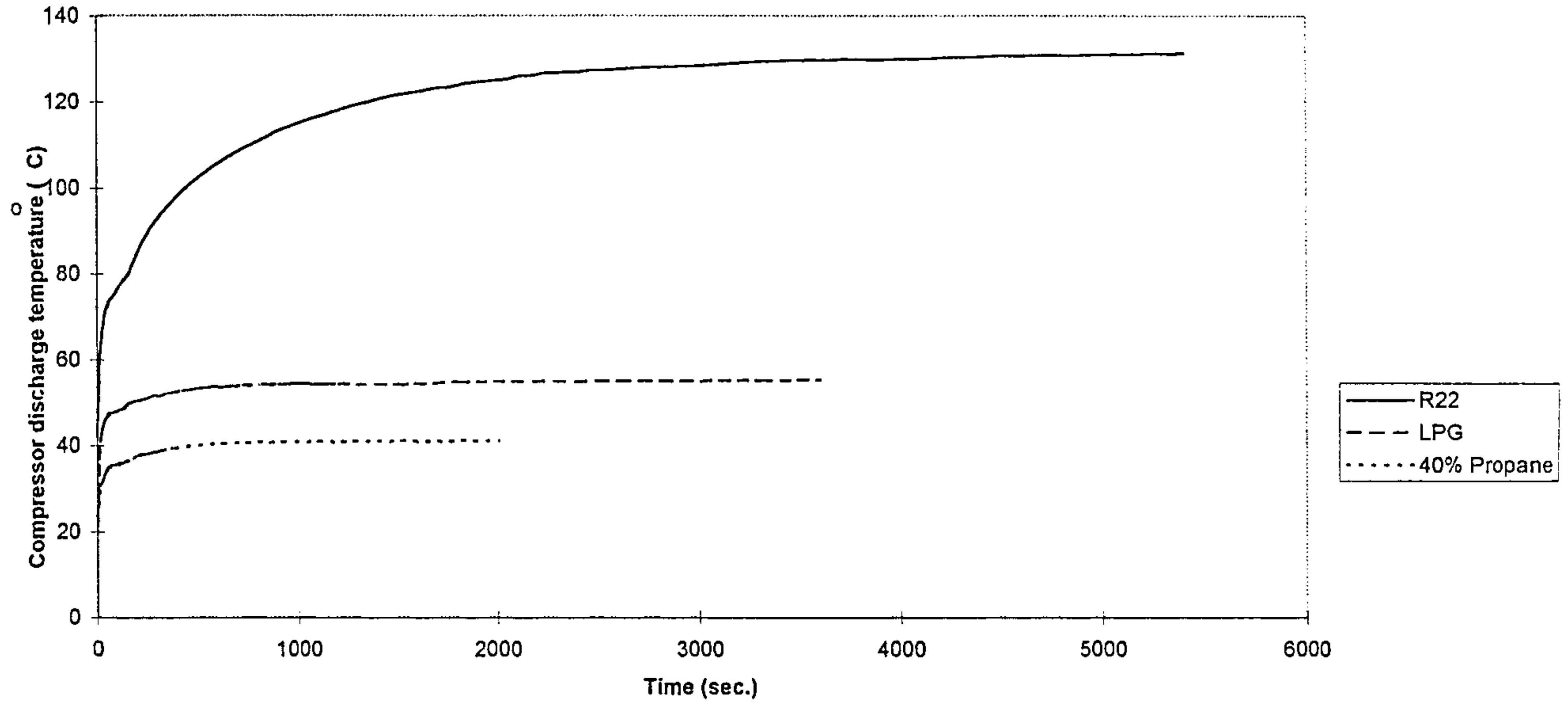


Figure (5.3) Compressor Discharge Tempeature vs. time

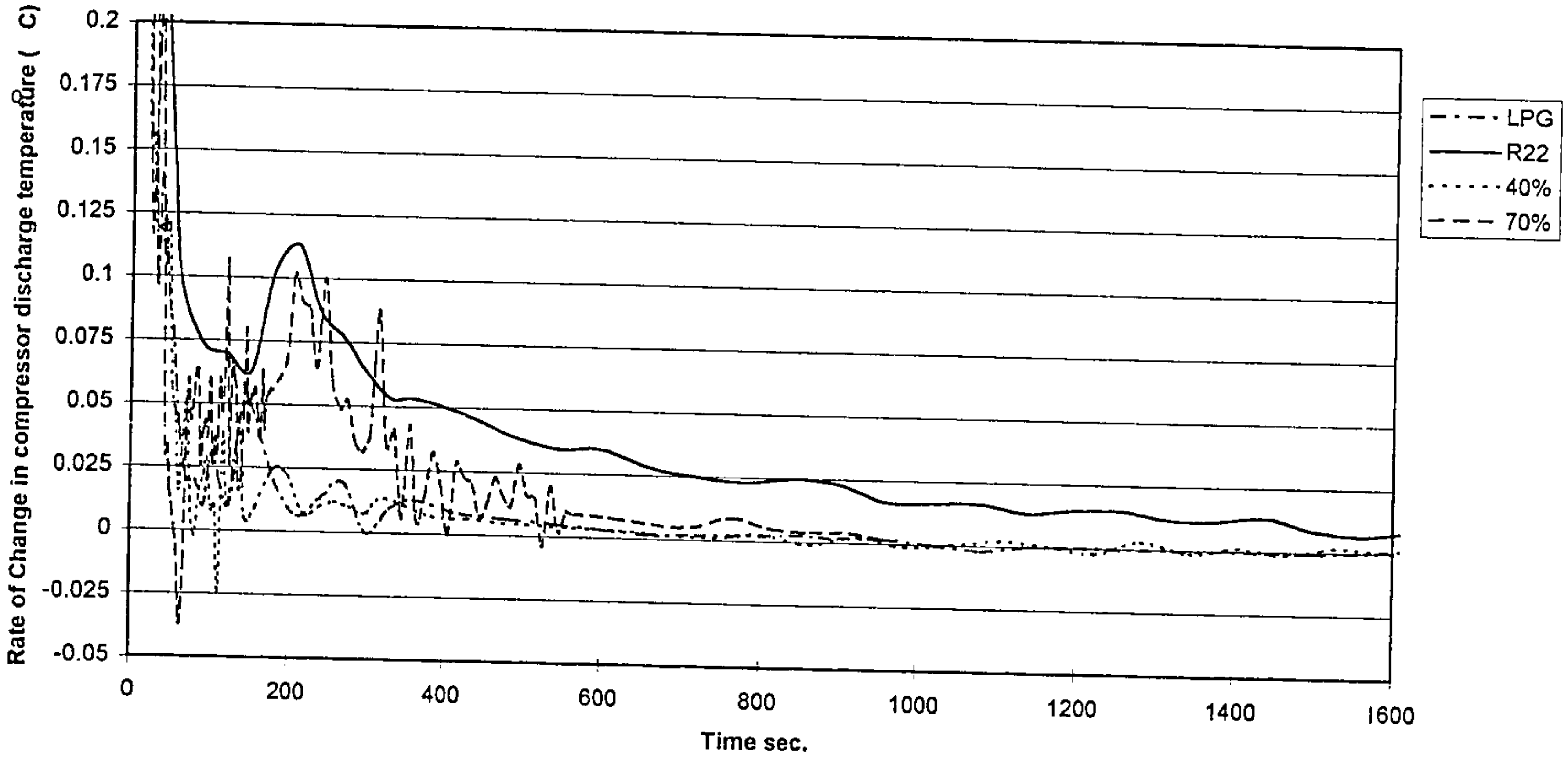


Figure 5.4 Rate of change in compressor discharge temperature vs. time

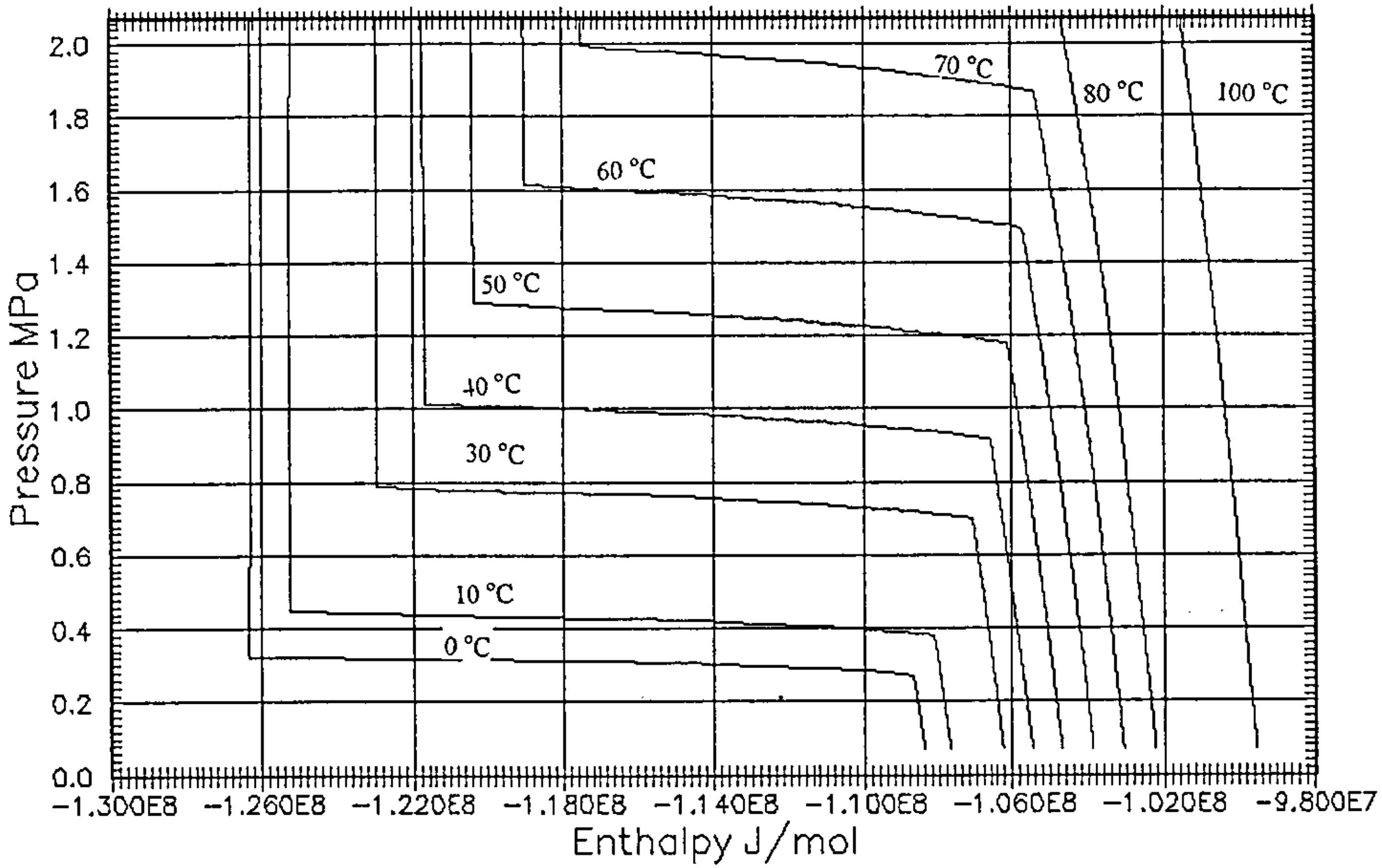


Figure (5.5): p-h diagrams for 90% Propane, 8% Butane, 2% Isobutane

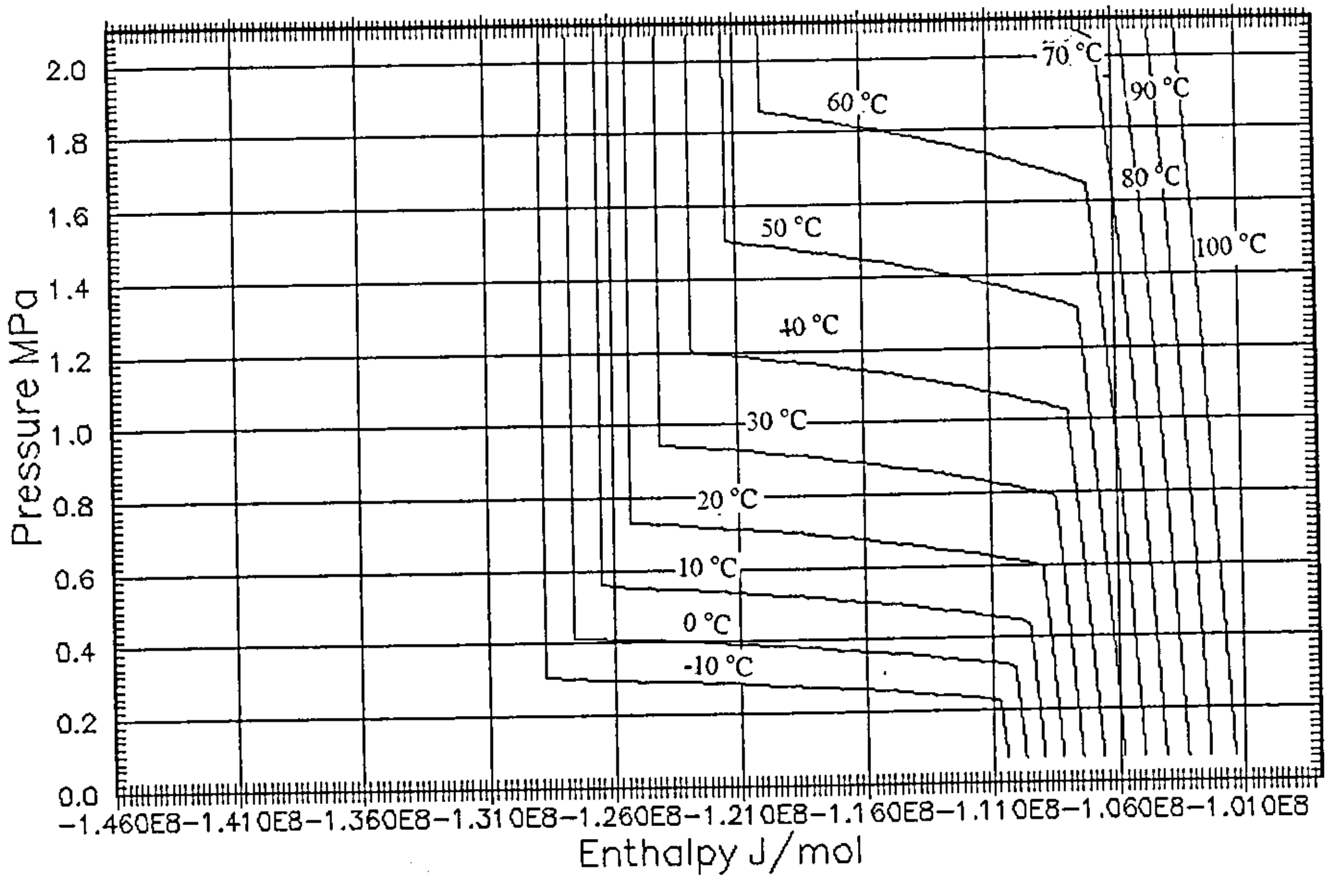


Figure (5.6): p-h diagrams for 80% Propane, 15% Butane, 5% Isobutane

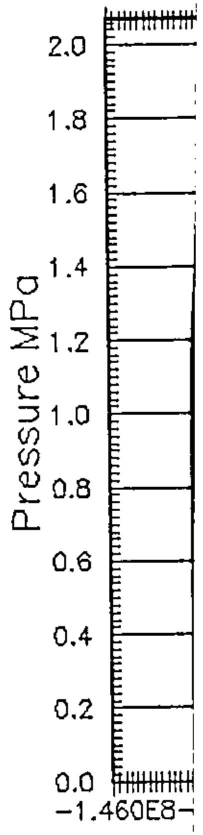


Figure (5.

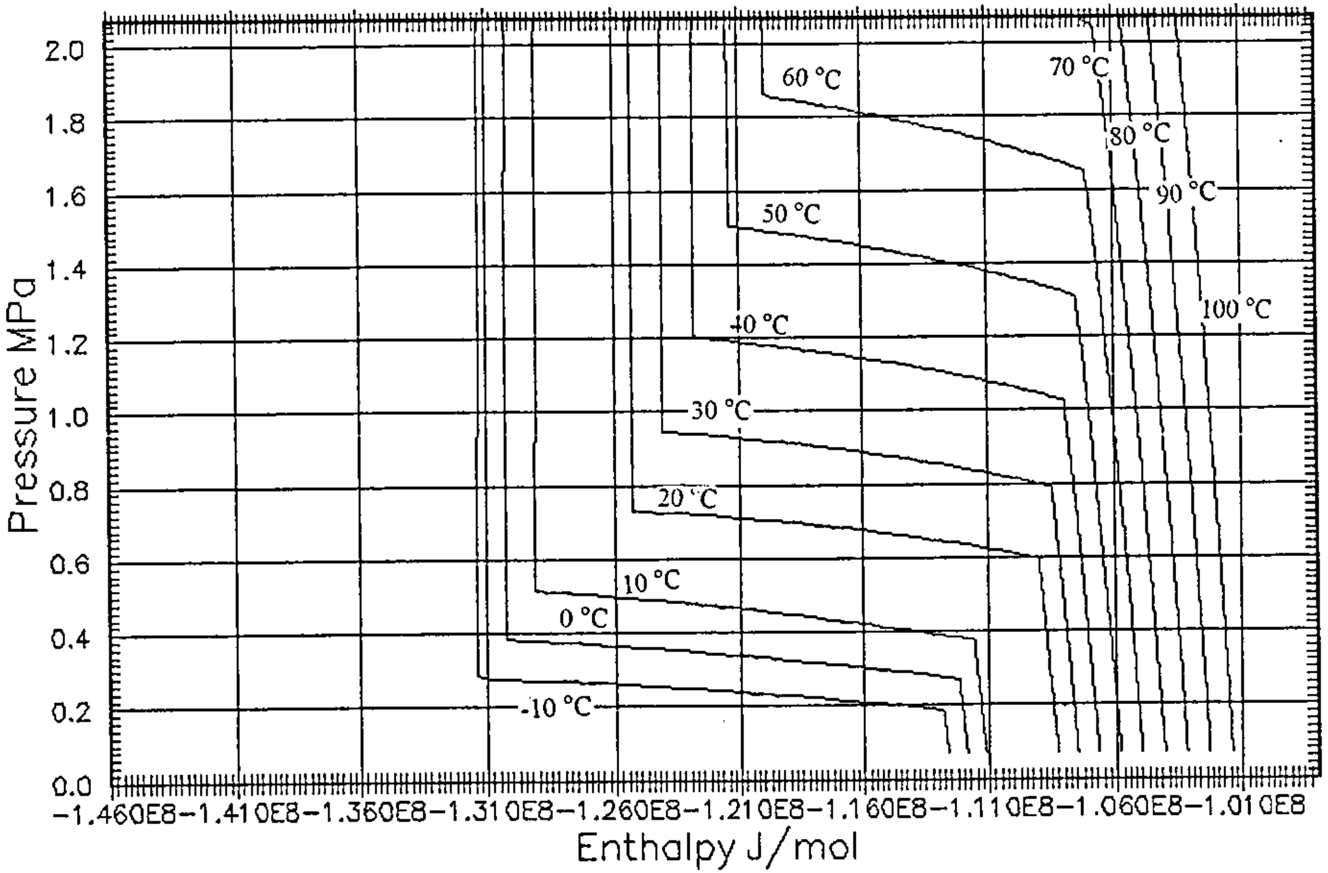


Figure (5.7): p-h diagrams for 70% Propane, 23% Butane, 7% Isobutane

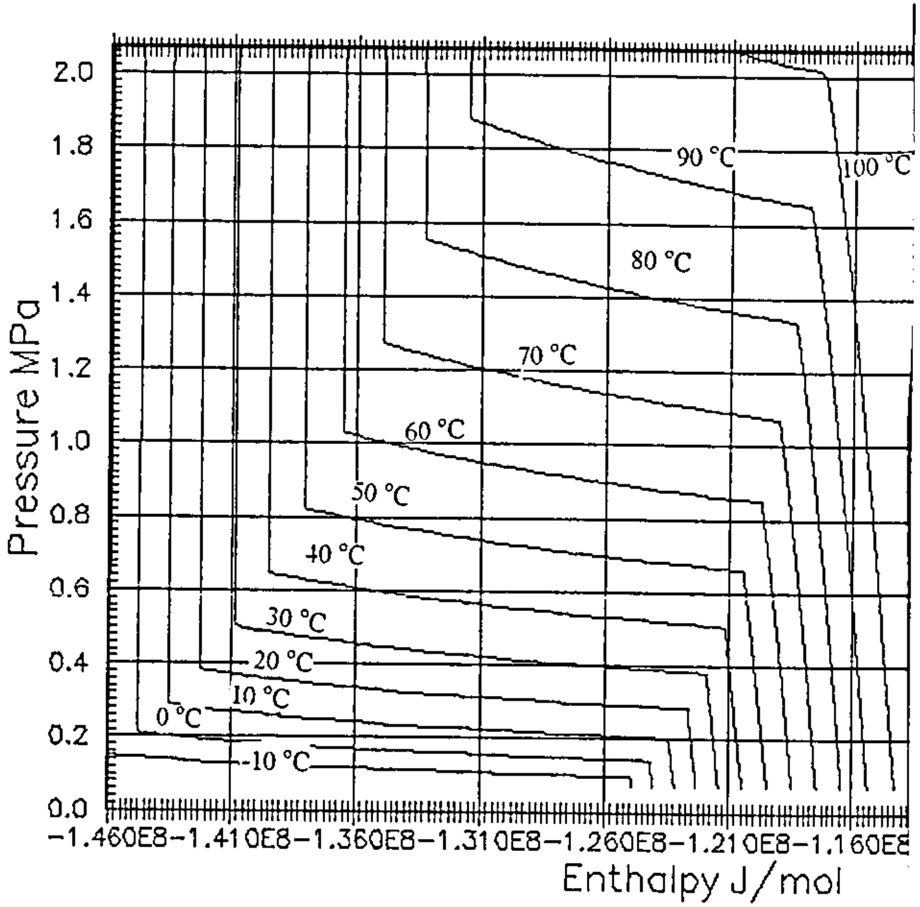


Figure (5.11): p-h diagrams for 21.39% Propane, 60.23% B

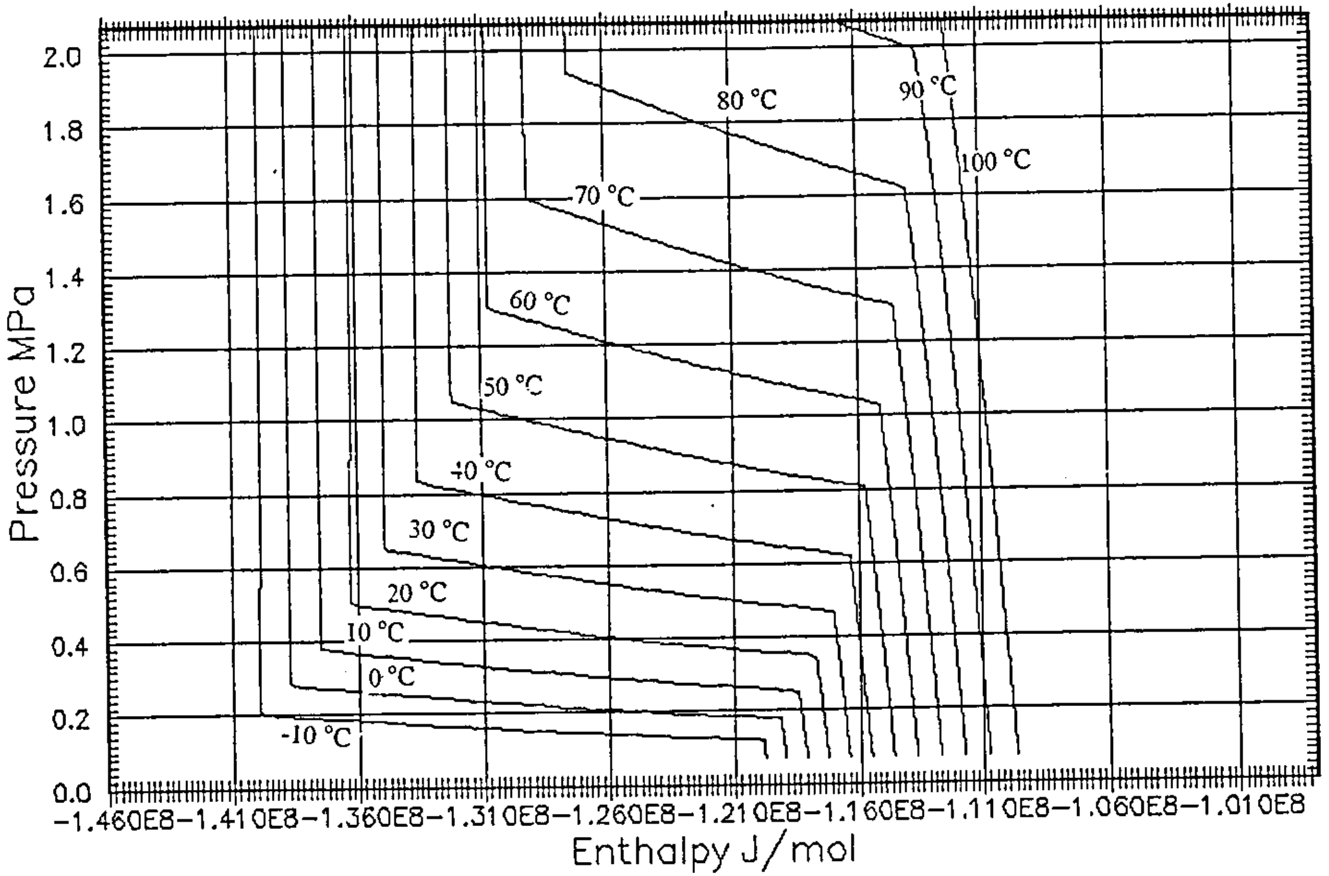


Figure (5.10): p-h diagrams for 40% Propane, 46% Butane, 14% Isobutane

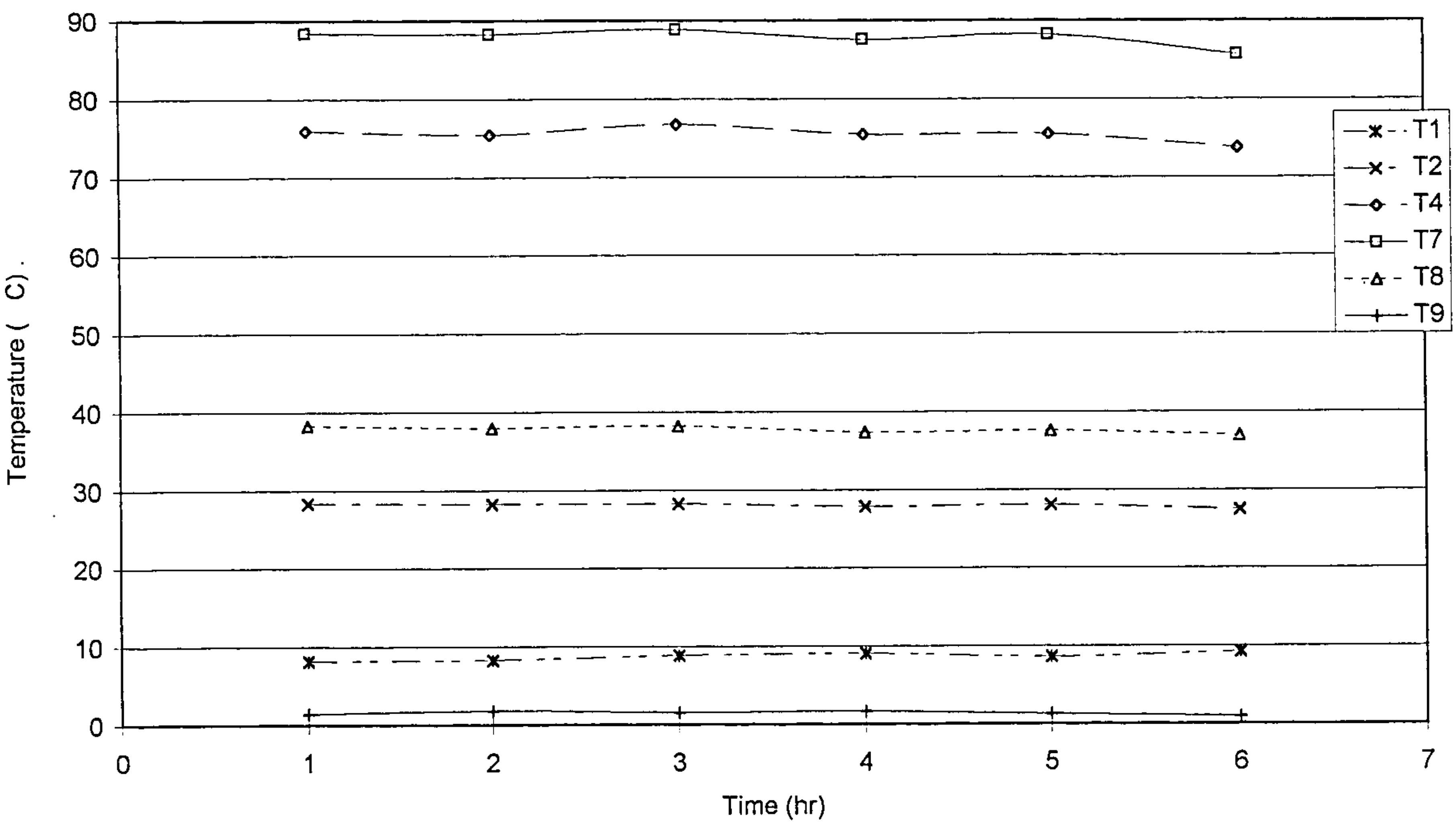


Figure (5.12) : System Temperatures vs. time for 100% propane

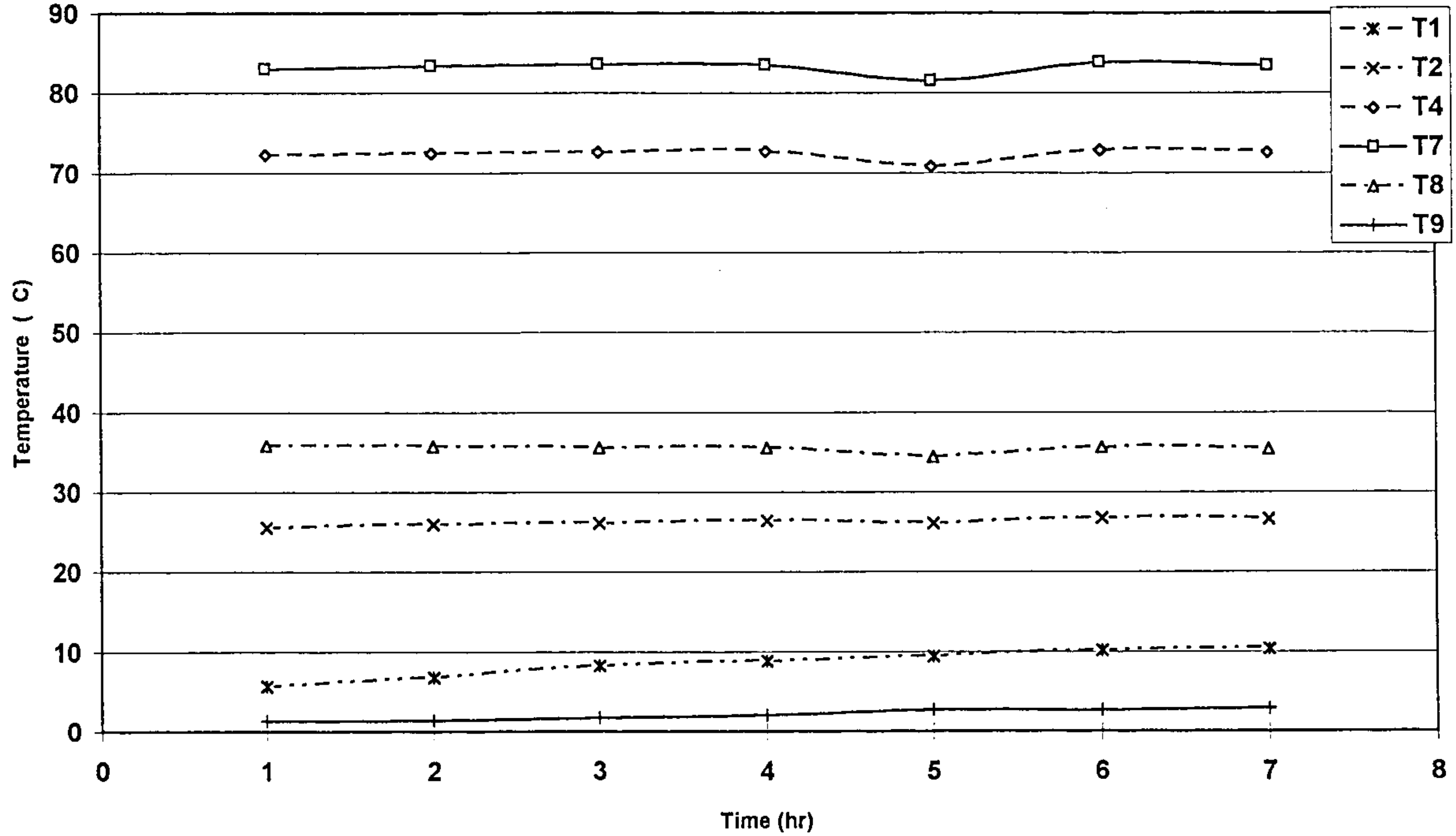
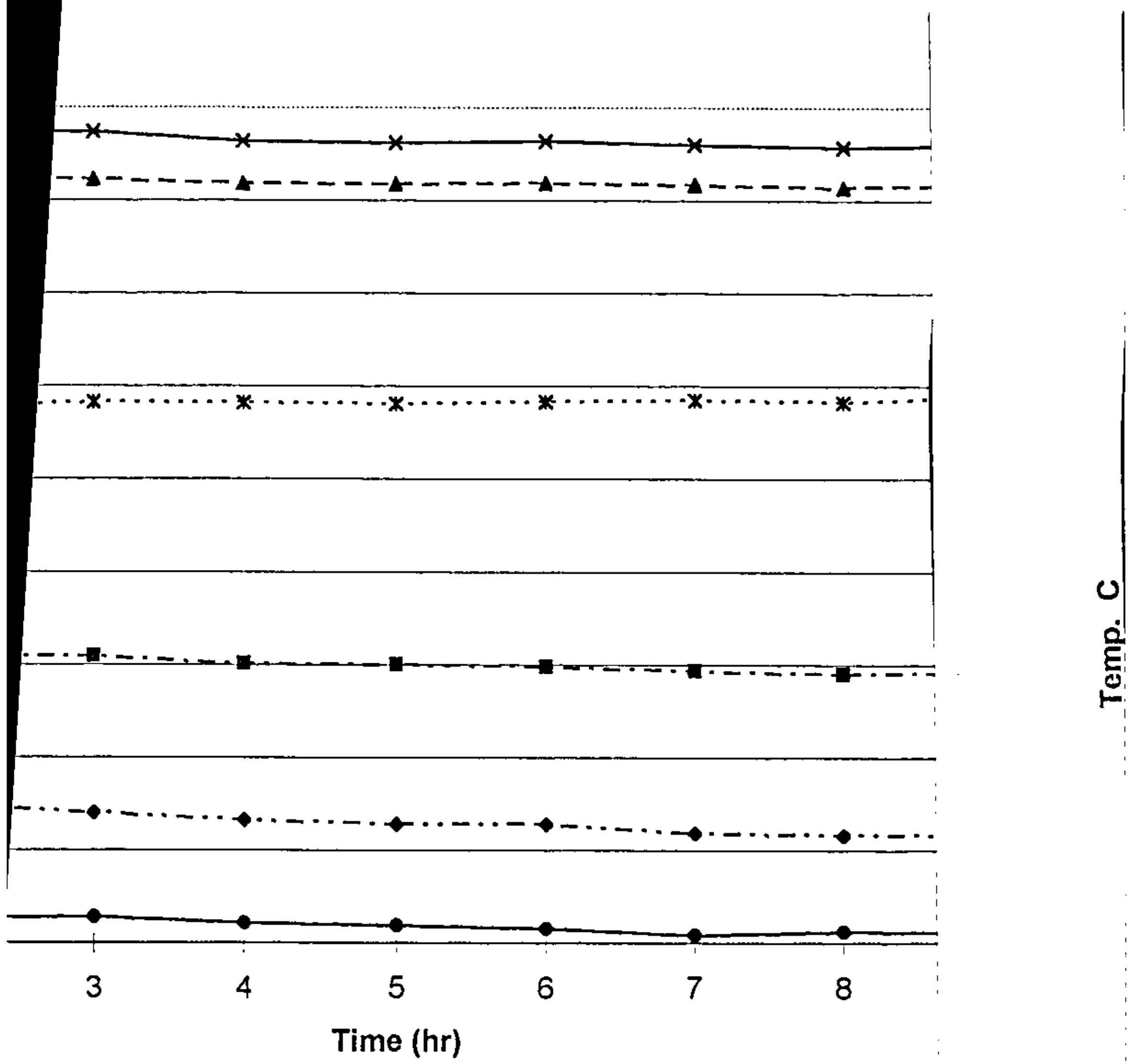


Figure (5.13): System Temperatures vs. time for 90% mass Propane



) : System Temperatures vs. time for 49% mass Propane.

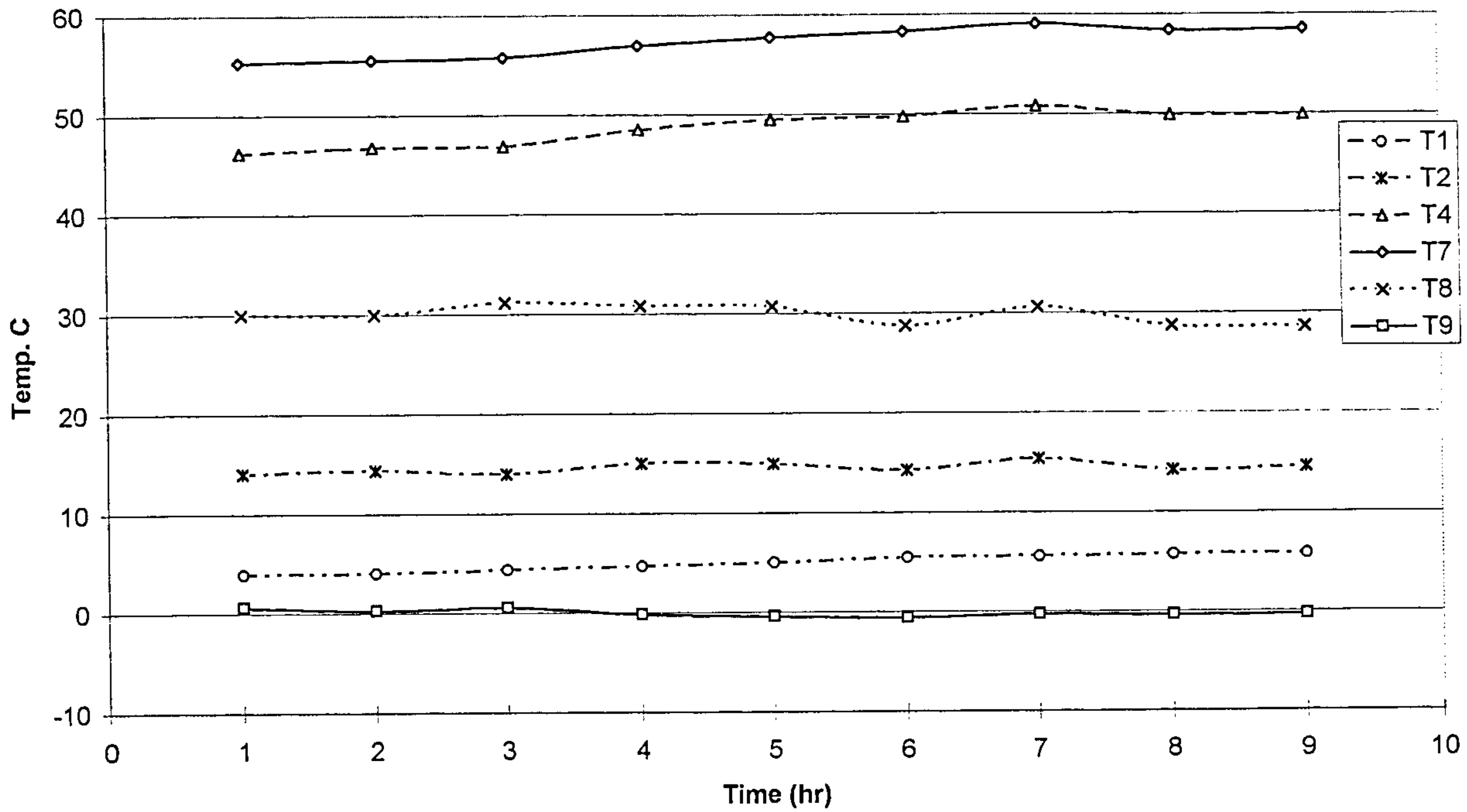


Figure (5.14) : System Temperature vs. time for 70% mass Propane.

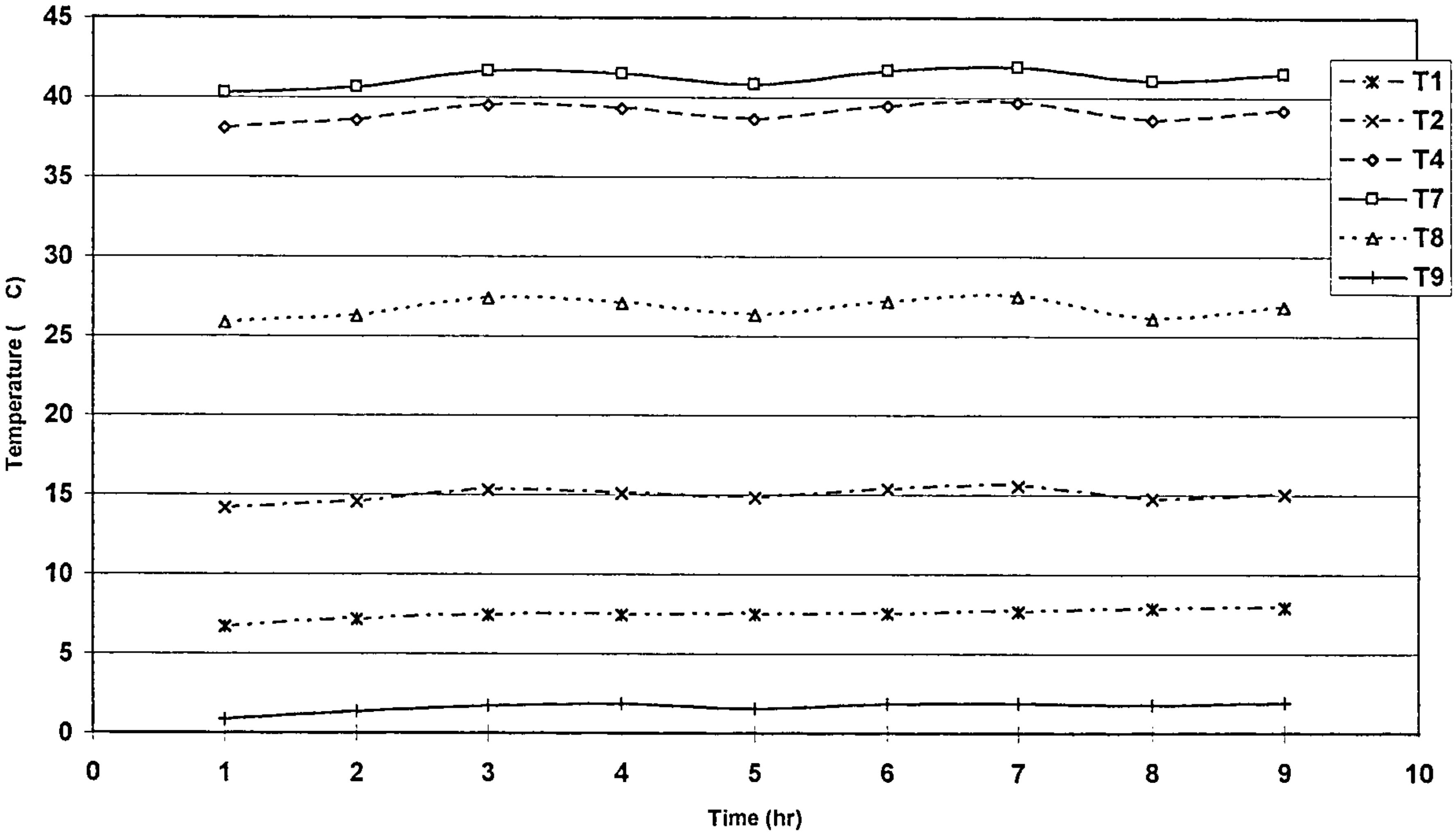


Figure (5.17) : System Temperature vs. time for 40% mass Propane.

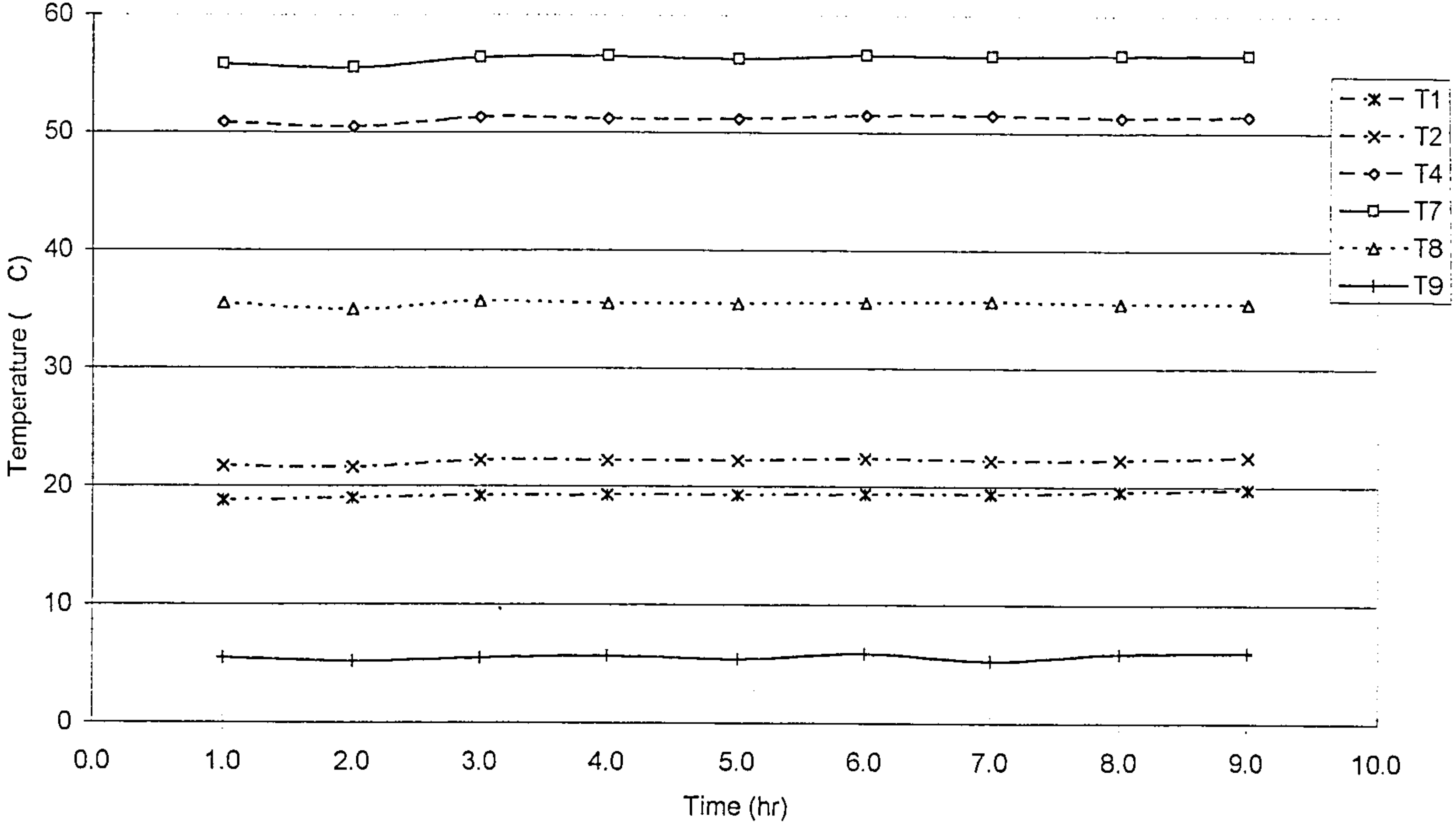


Figure (5.18) : System Temperatures vs. time for LPG

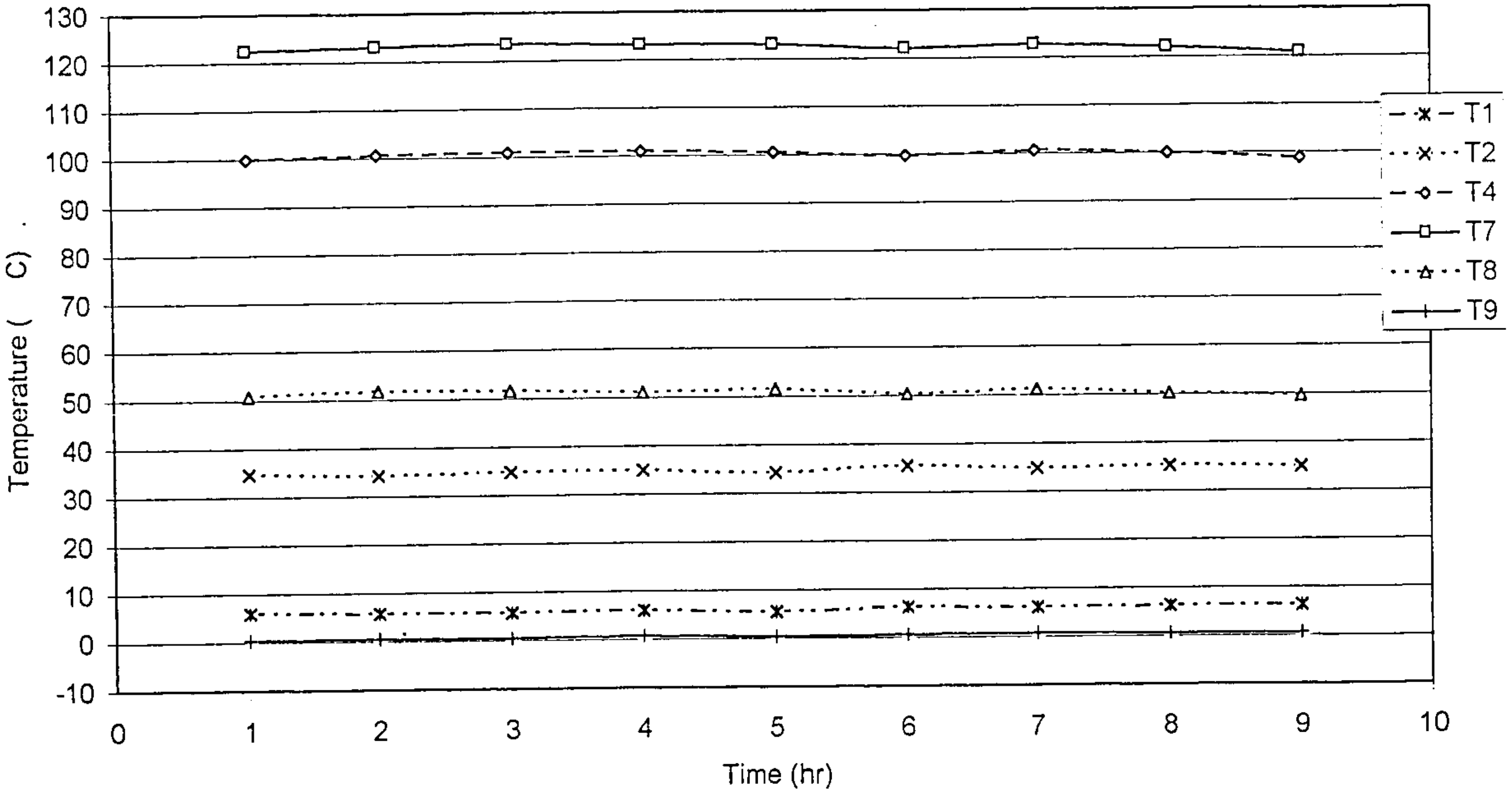


Figure (5.19) : System Temperatures vs. time for R22

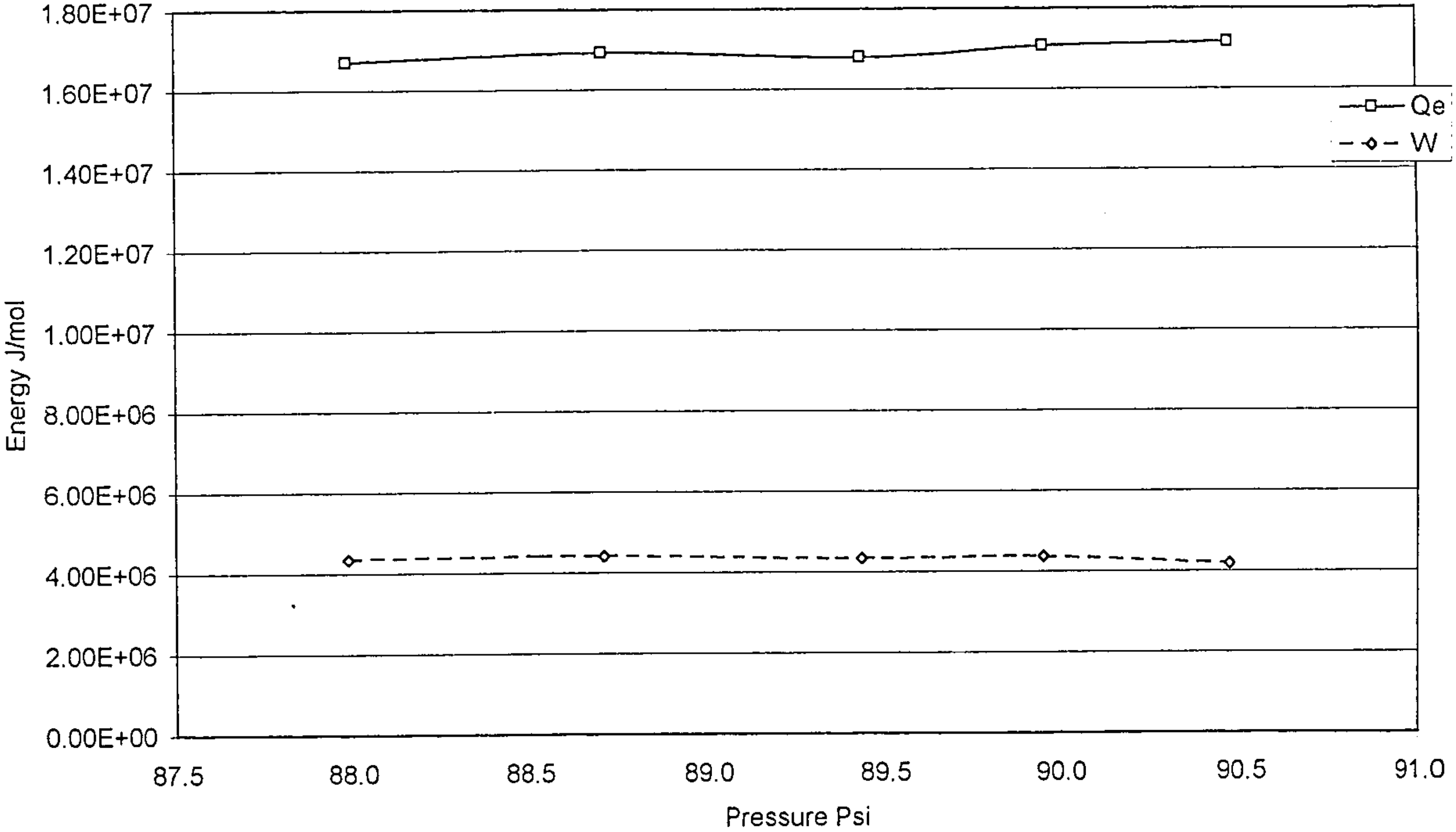


Figure (5.20) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for 100% Propane

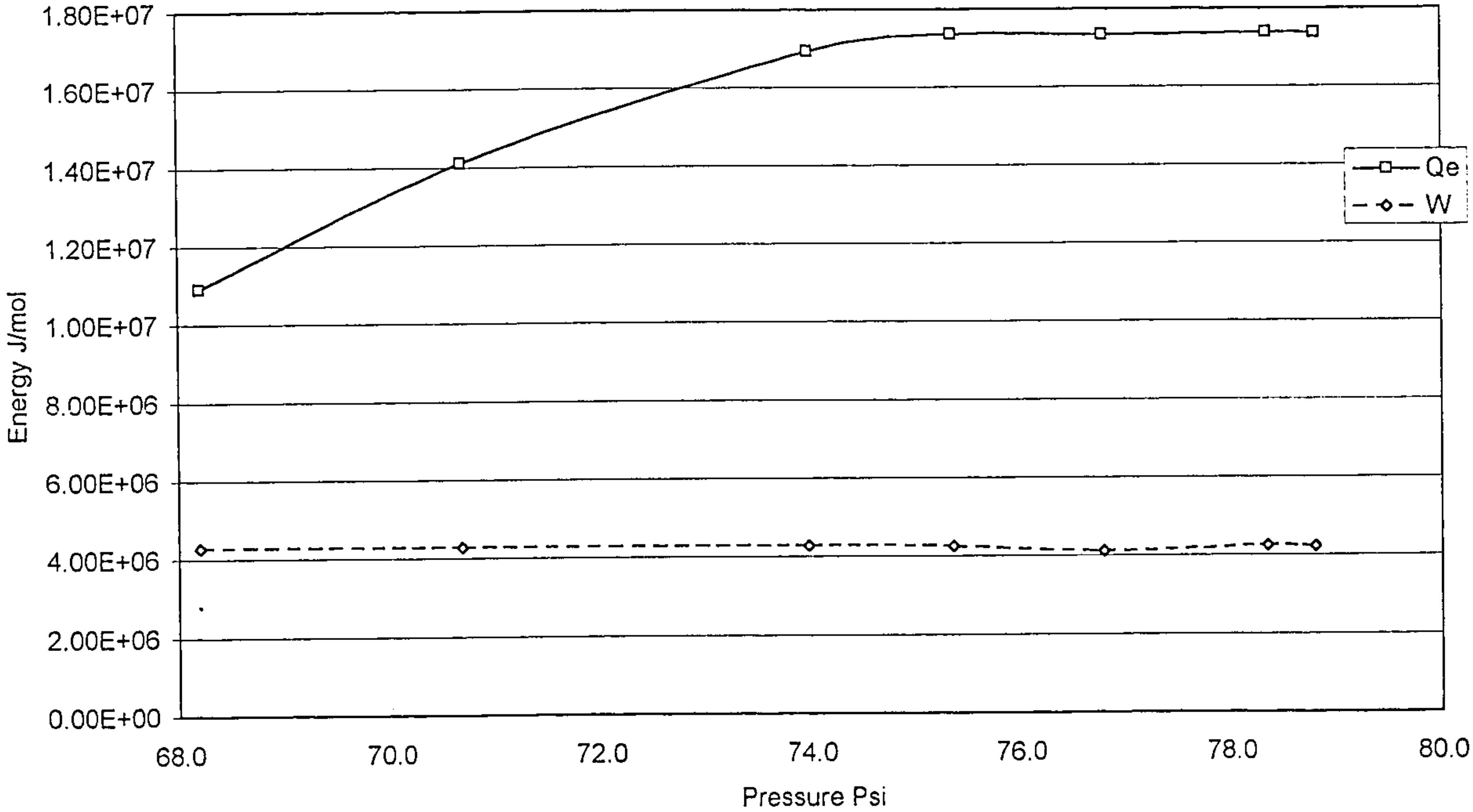


Figure (5.21) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure fir 90% mass propane mixture

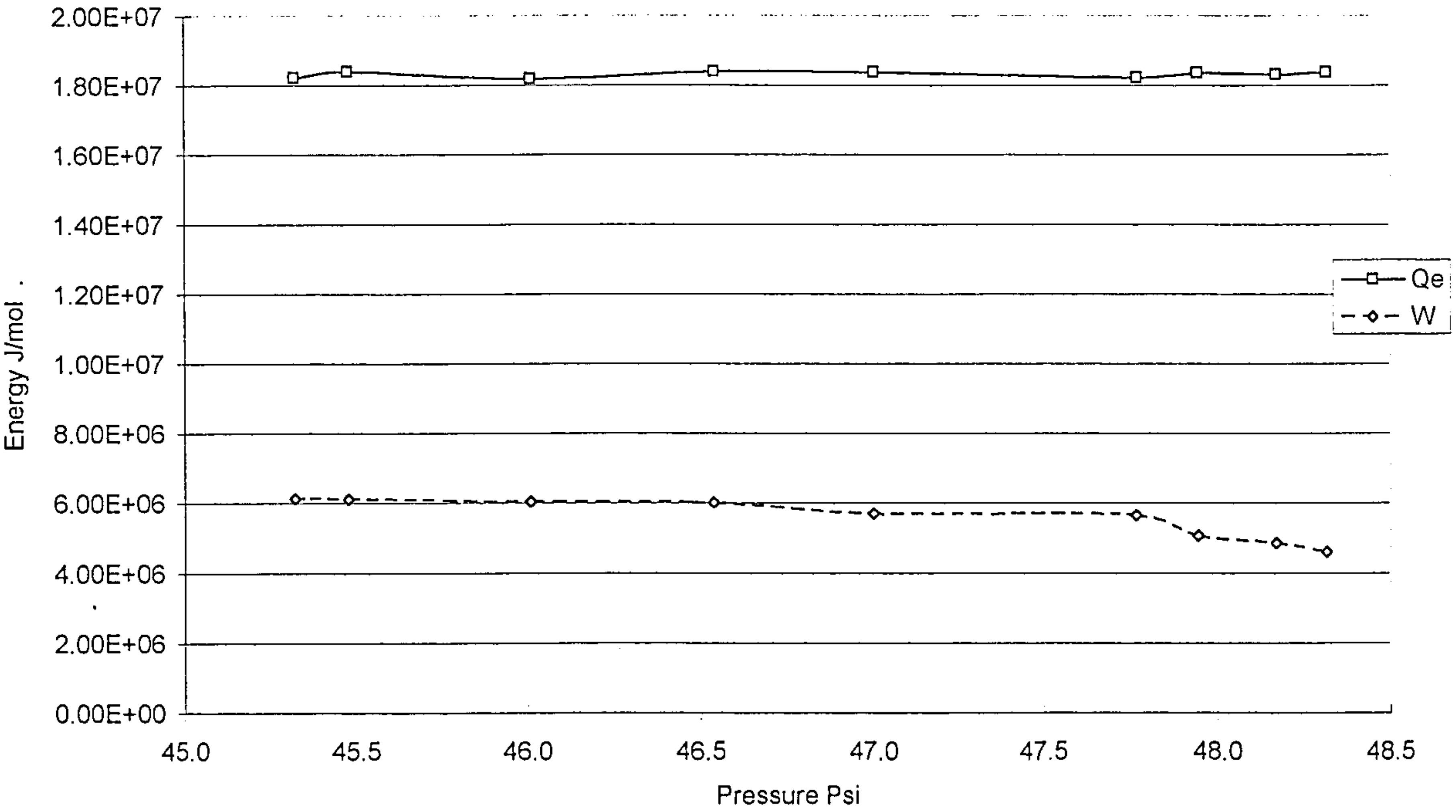


Figure (5.22) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for 90% mass propane mixture

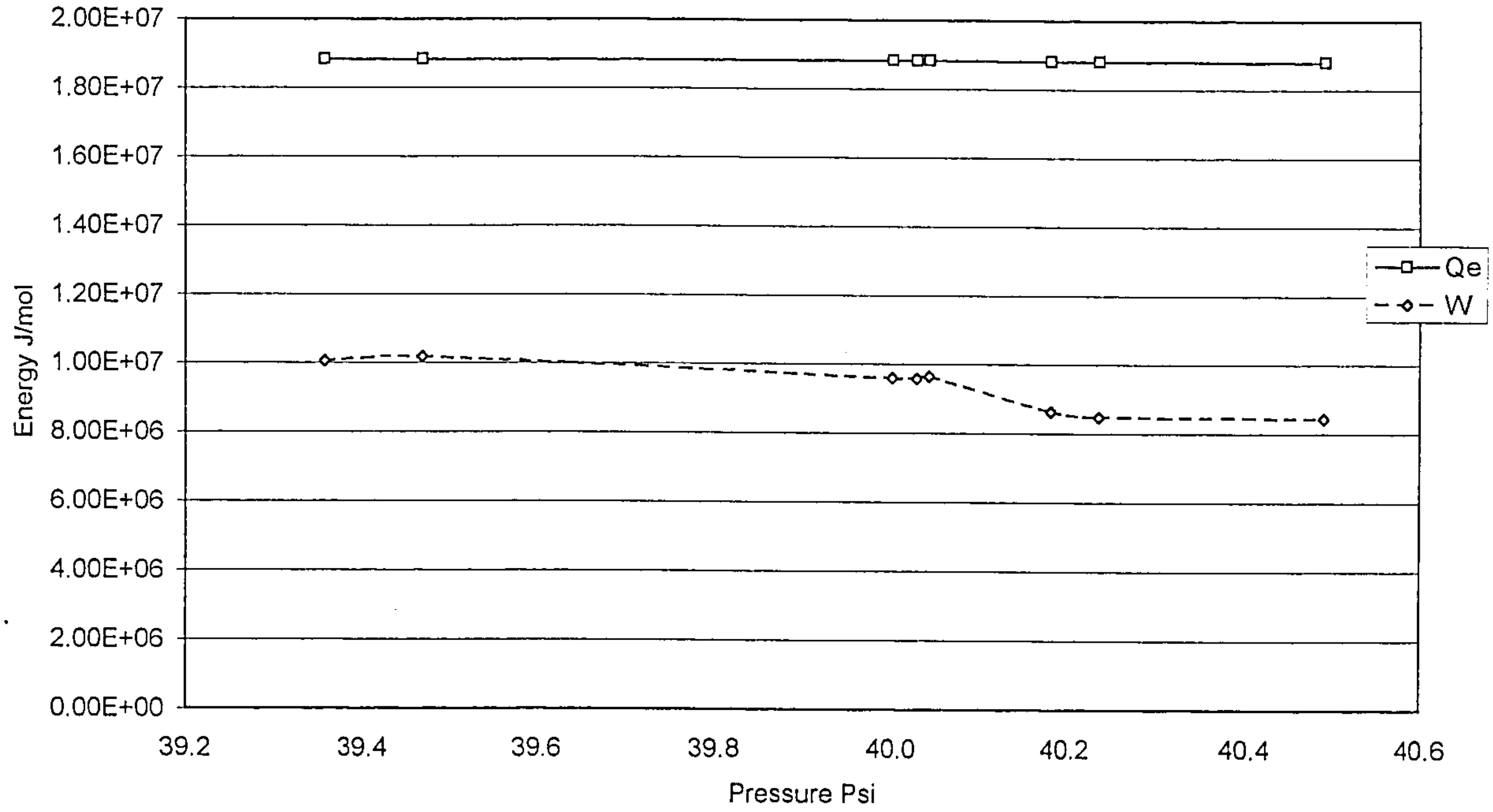


Figure (5.23) Evaporator Capacity, Compressor Work vs. Evaporator Pressure for 60% mass propane mixture

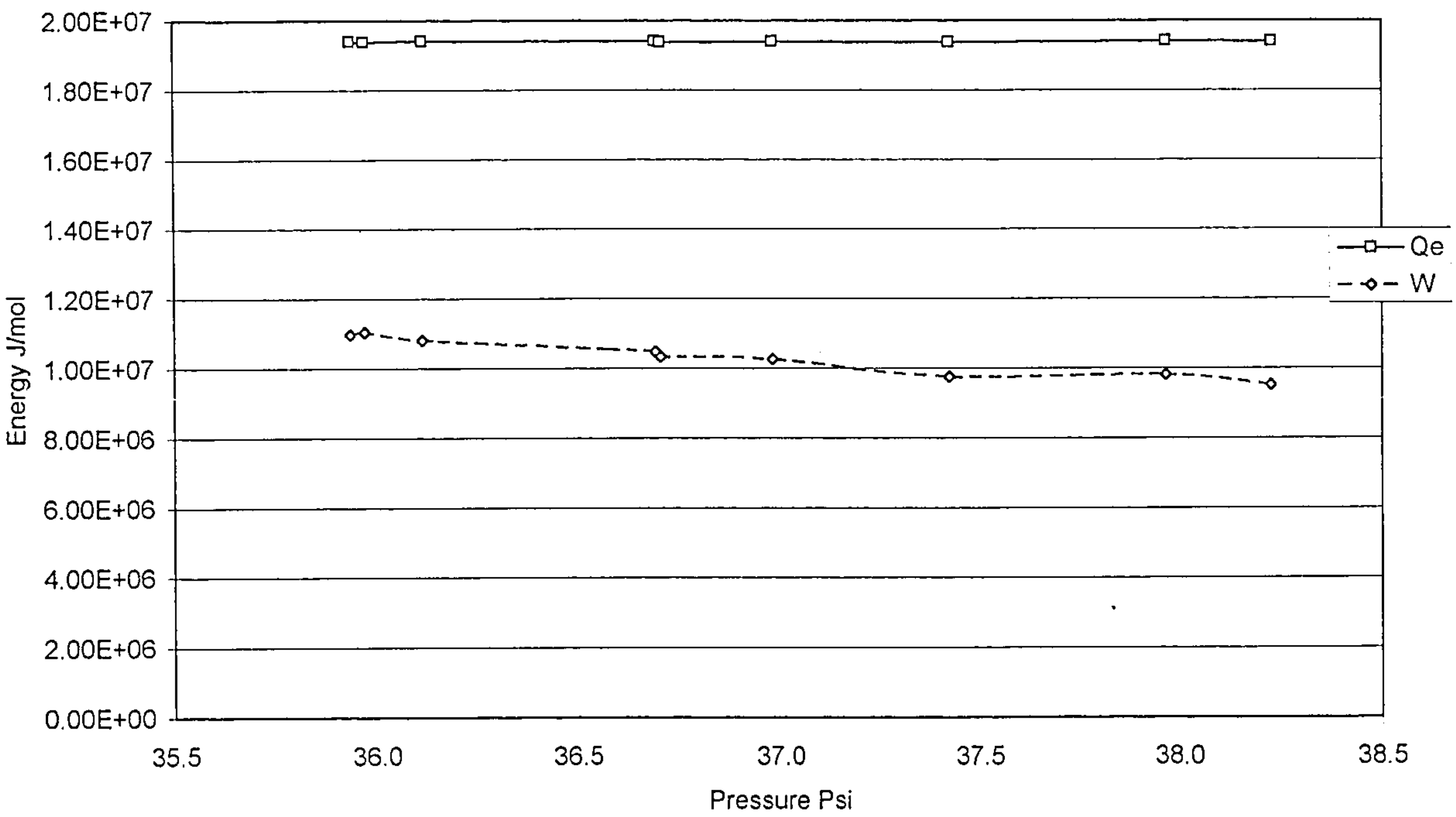


Figure (5.24) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for a 49% mass Propane mixture

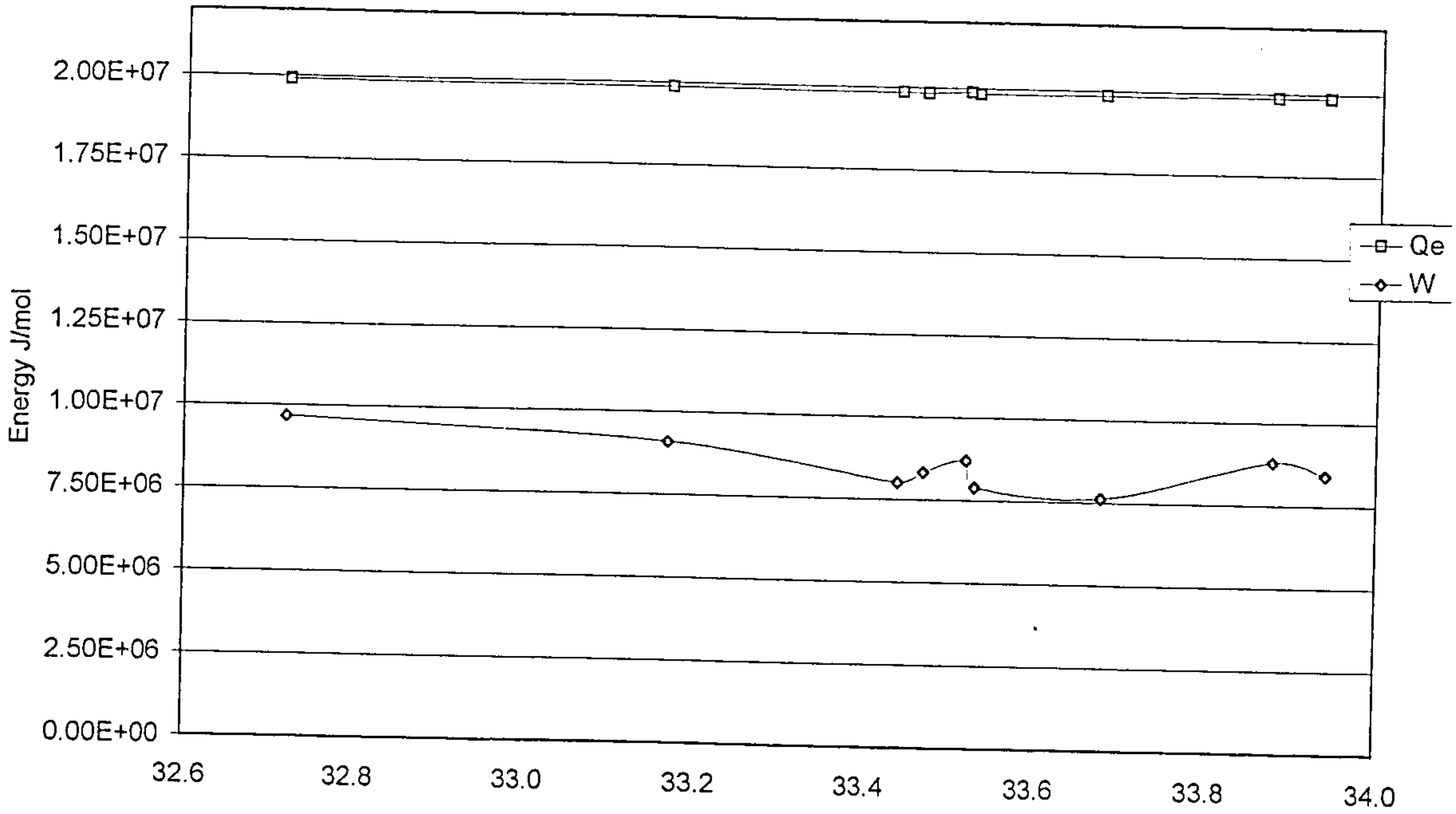


Figure (5.25) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for 40% mass propane mixture

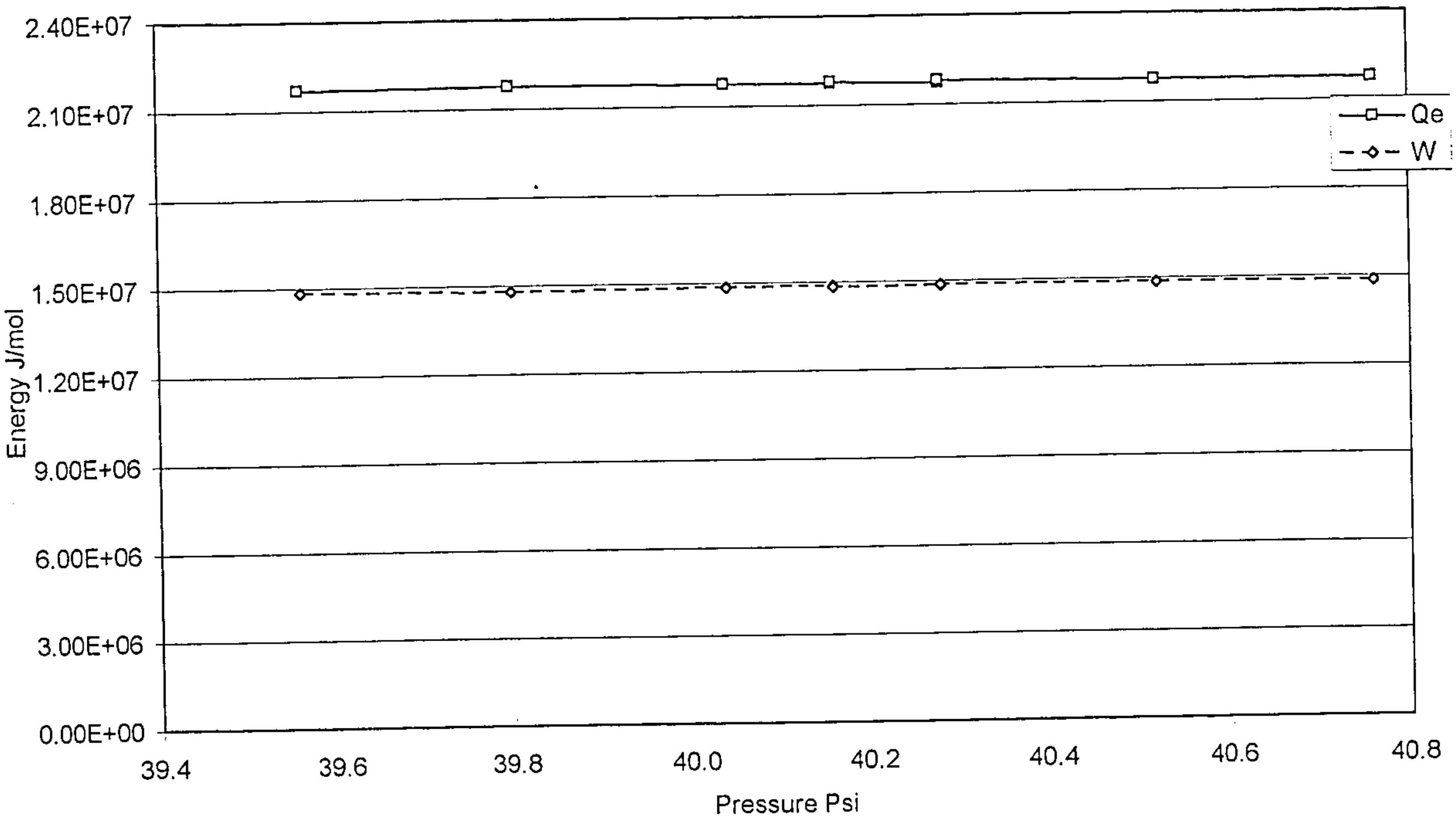


Figure (5.26) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for LPG

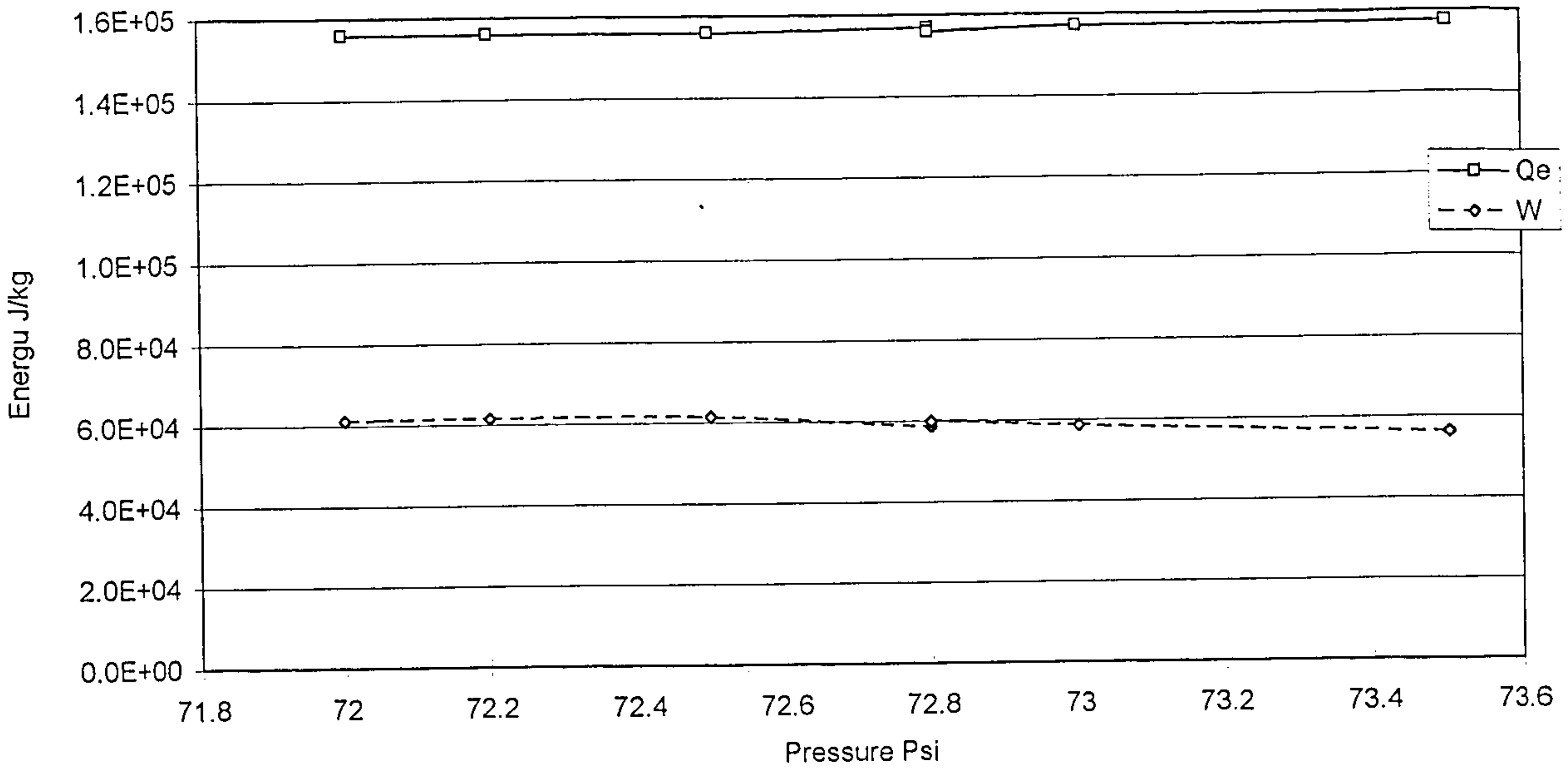


Figure (5.27) : Evaporator Capacity, Compressor Work vs. Evaporator Pressure for R22

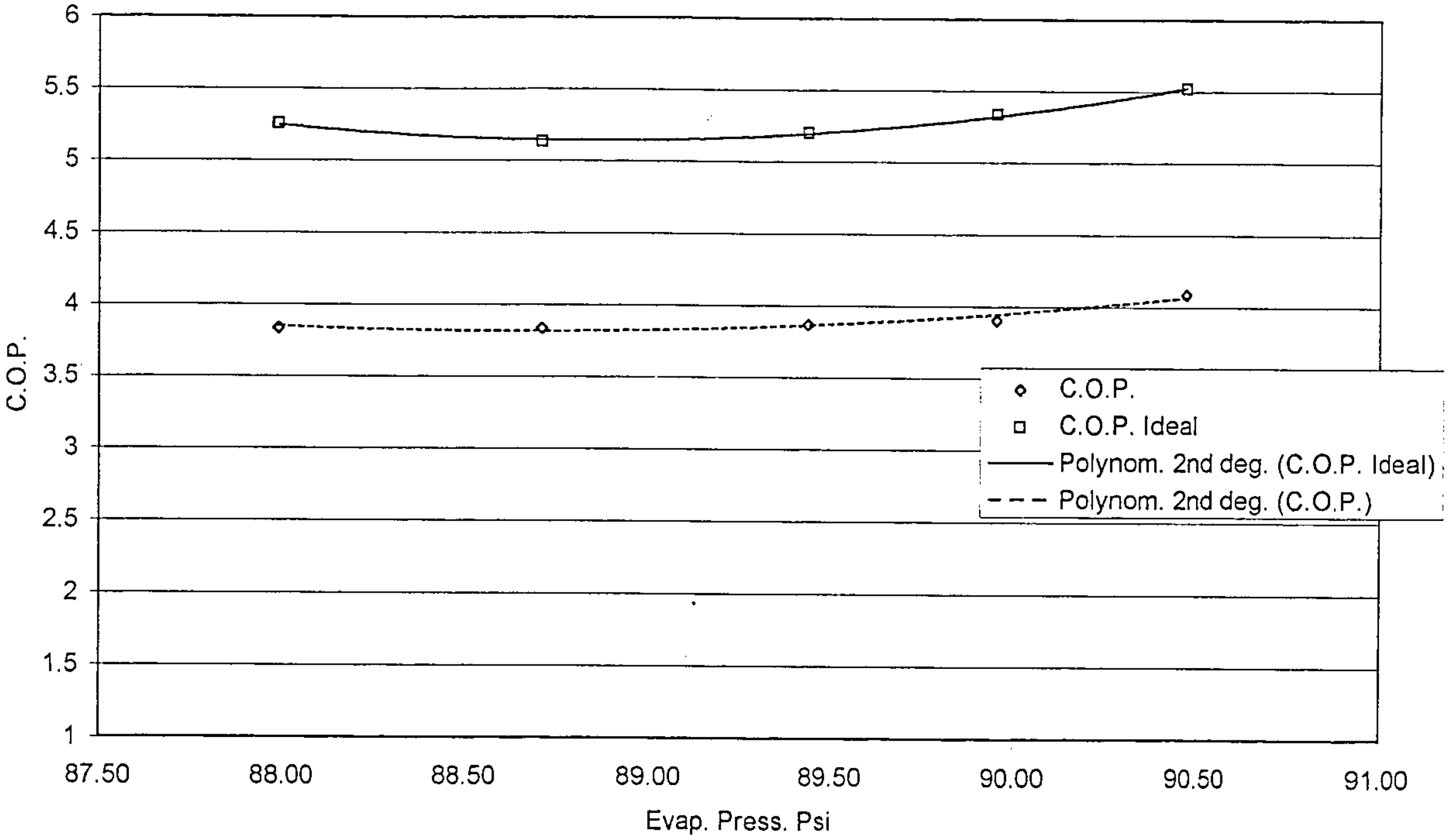


Figure (5.28) : C.O.P. vs. Evaporator Pressure for 100% Propane

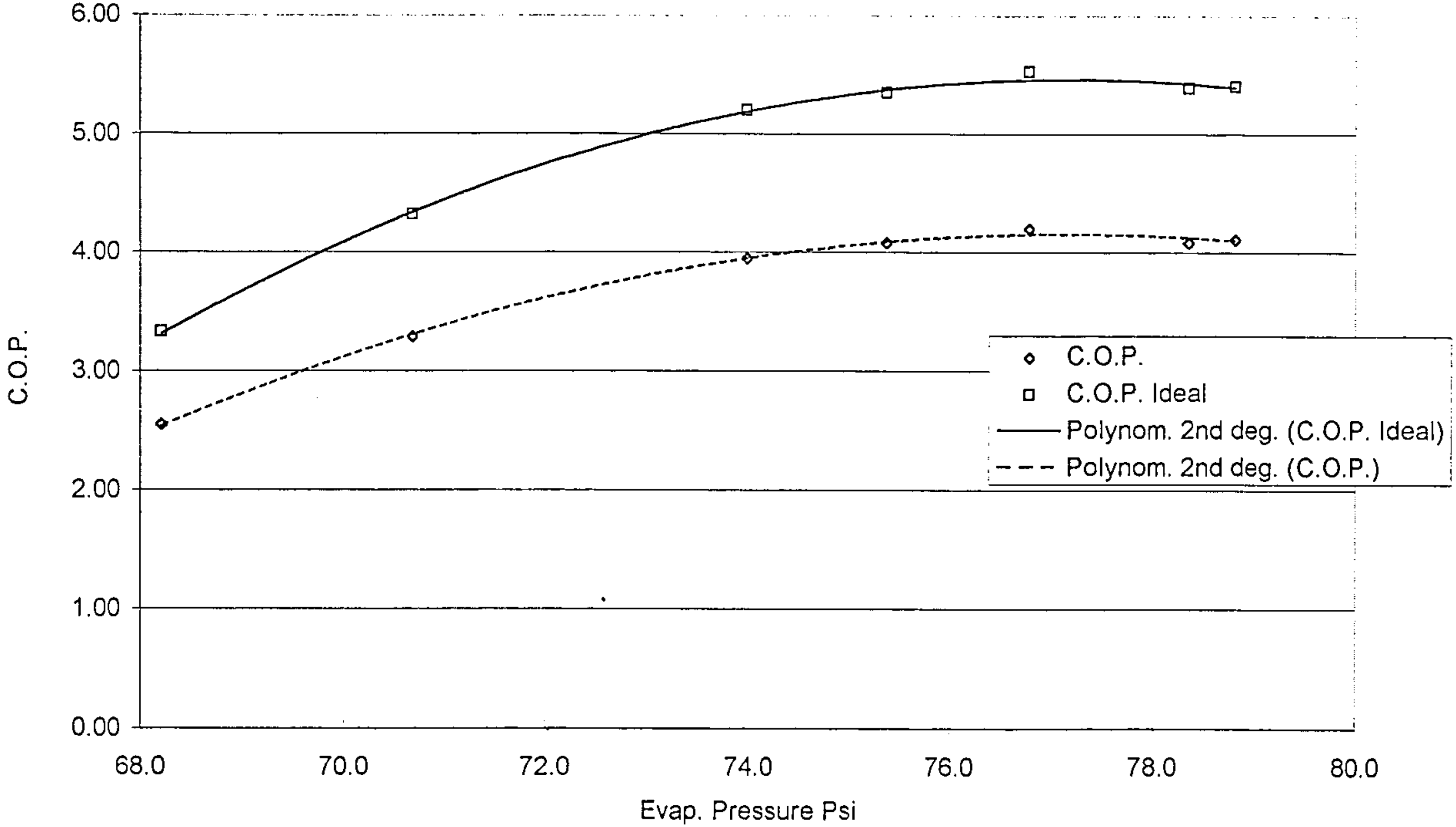


Figure (5.29) : C.O.P. vs. Evaporater Pressure for 90% mass Propane.

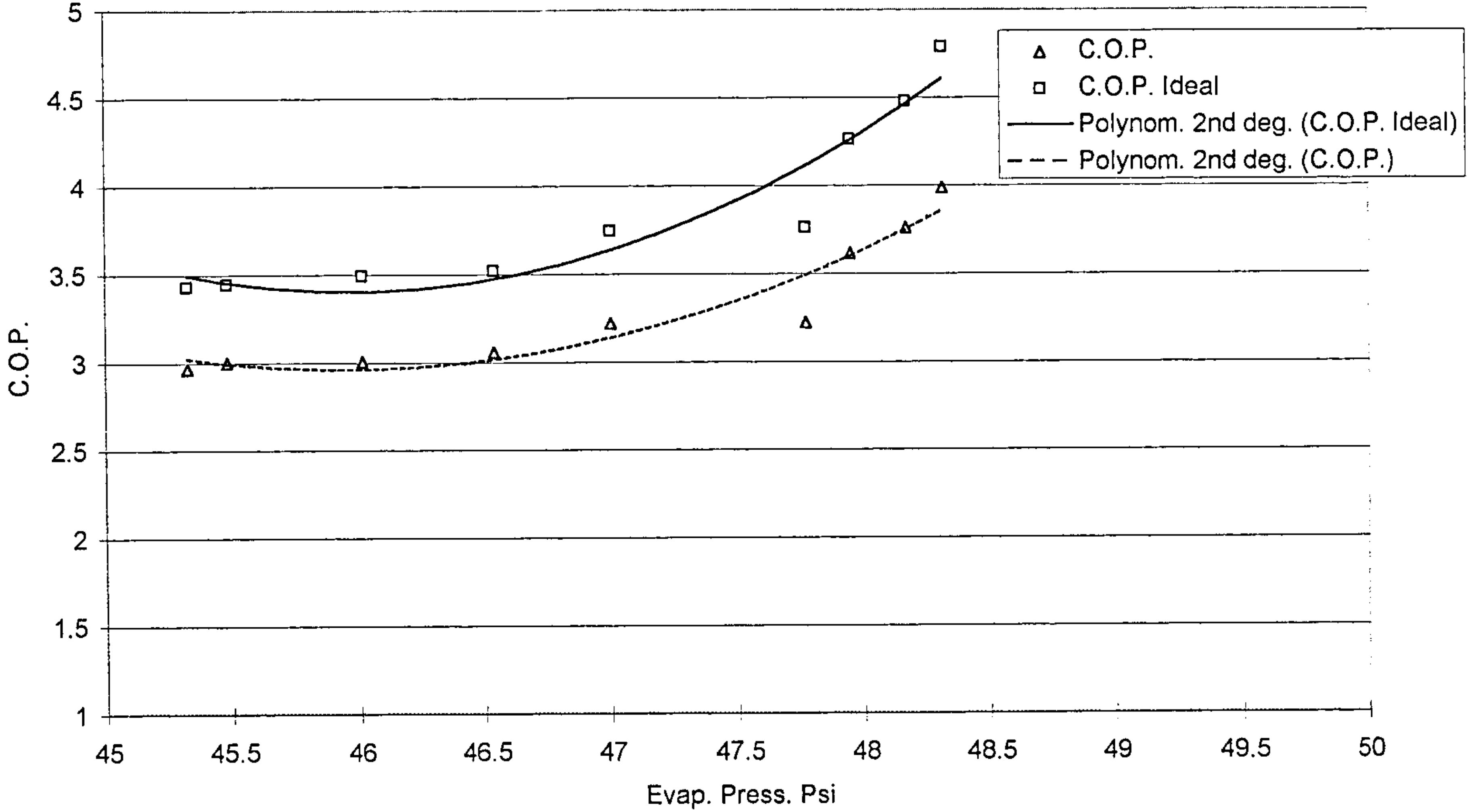


Figure (5.30) : C.O.P. vs. Evaporator Pressure for 70% mass Propane.

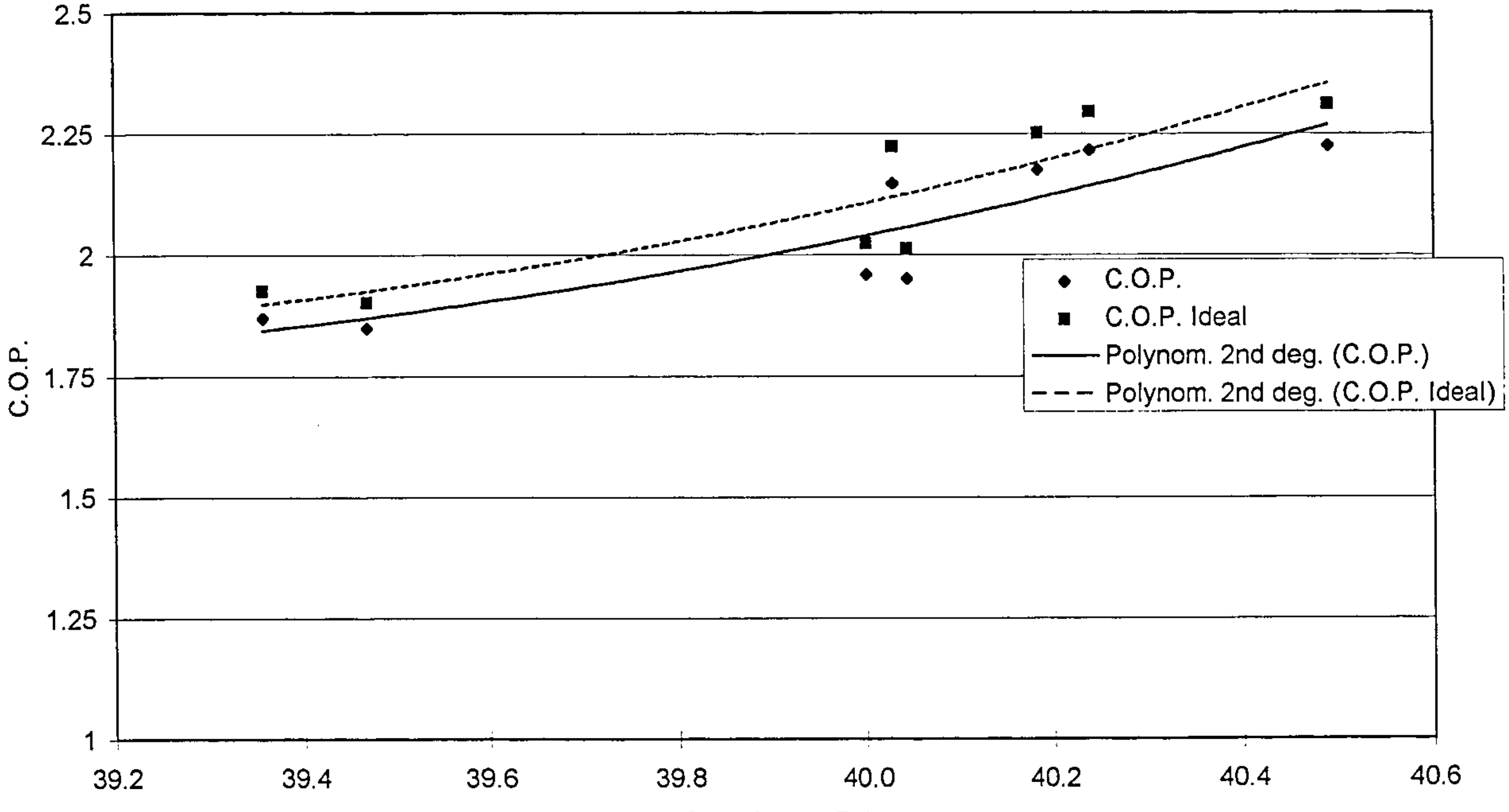


Figure (5.31) : C.O.P. vs. Evaporator Pressure for 60% mass Propane.

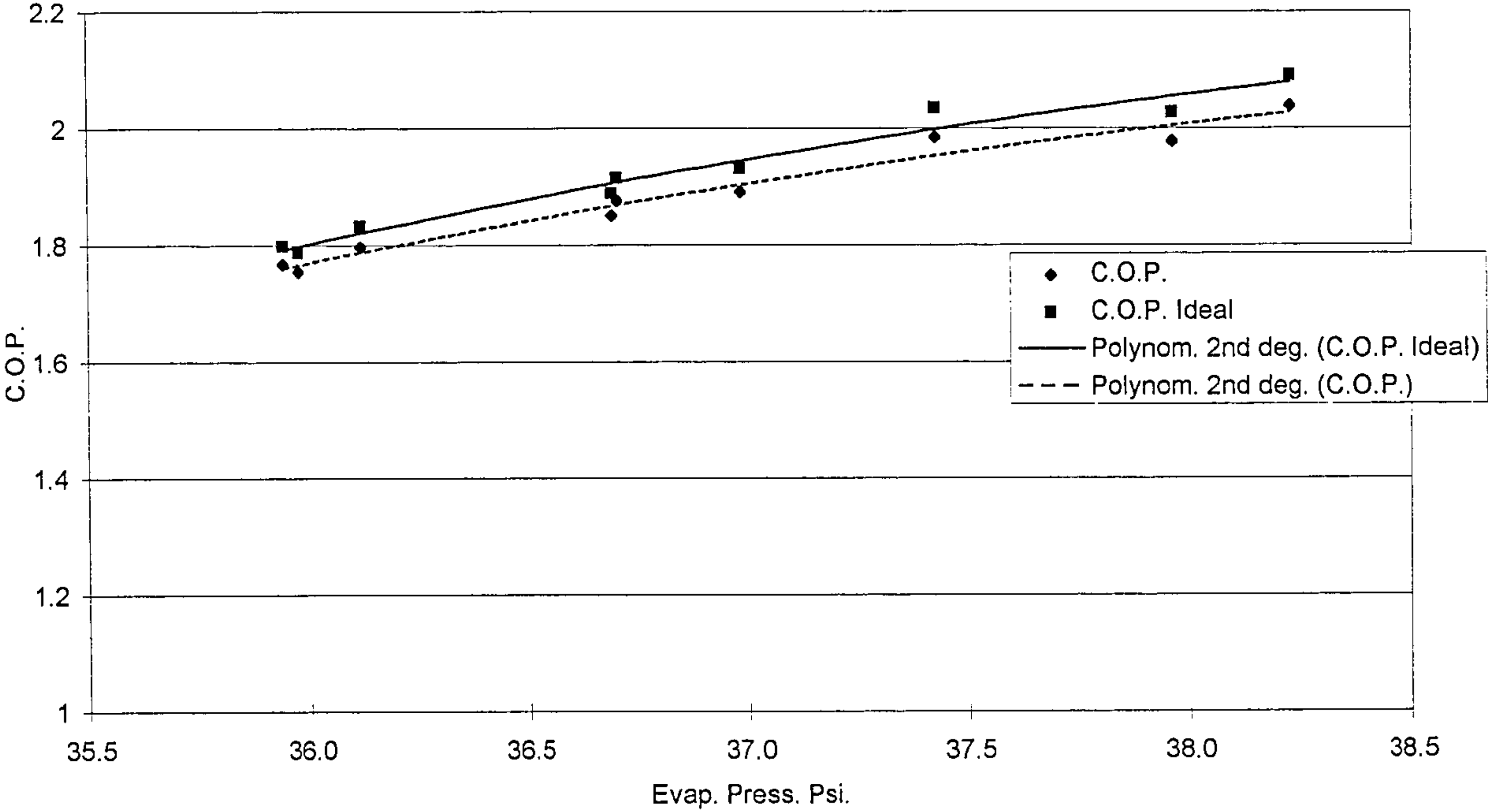


Figure (5.32) : C.O.P. vs. Evaporator Pressure for 49% mass Propane.

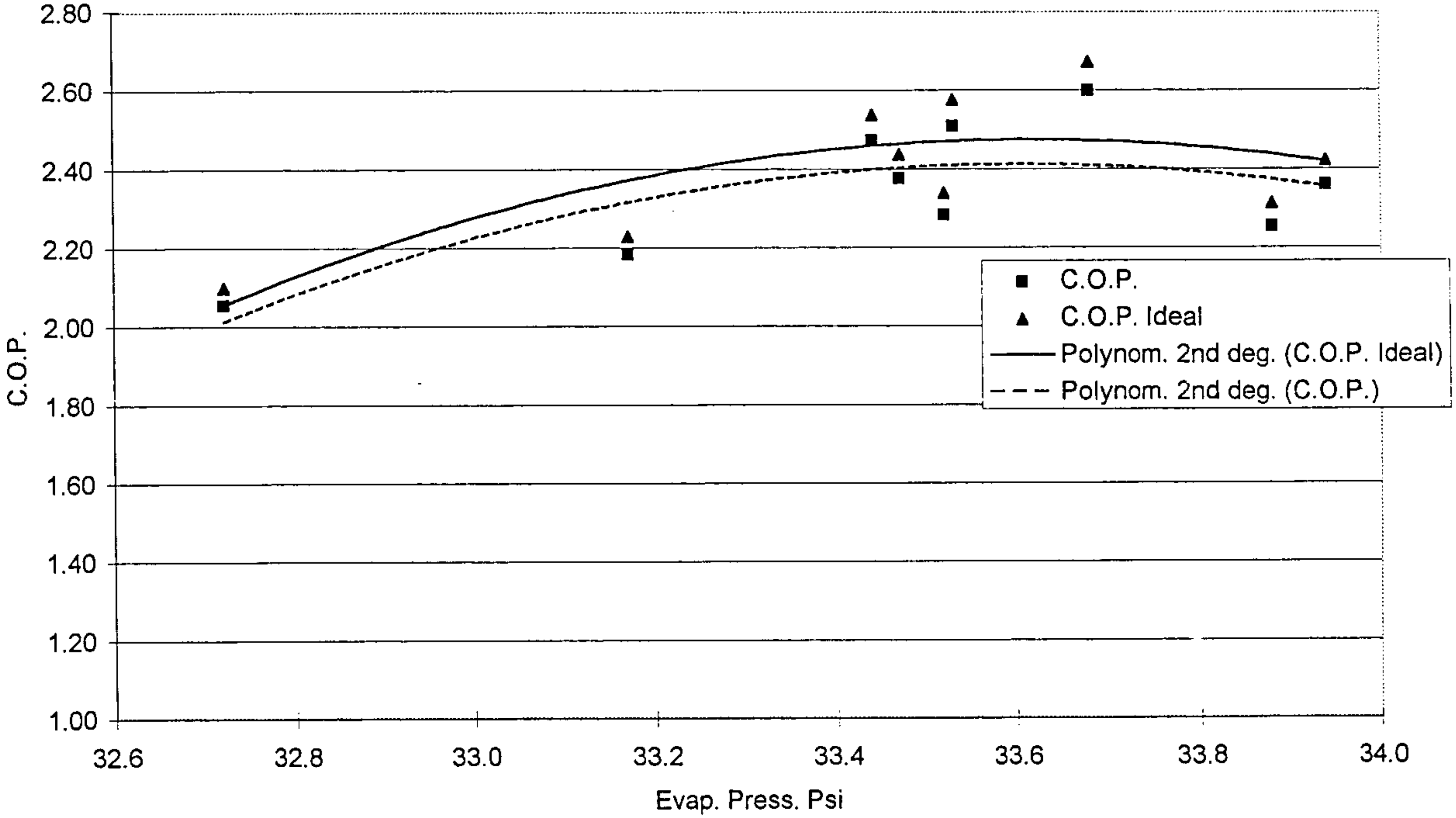


Figure (5.33) : C.O.P. vs. Evaporator Pressure for 40% mass Propane.

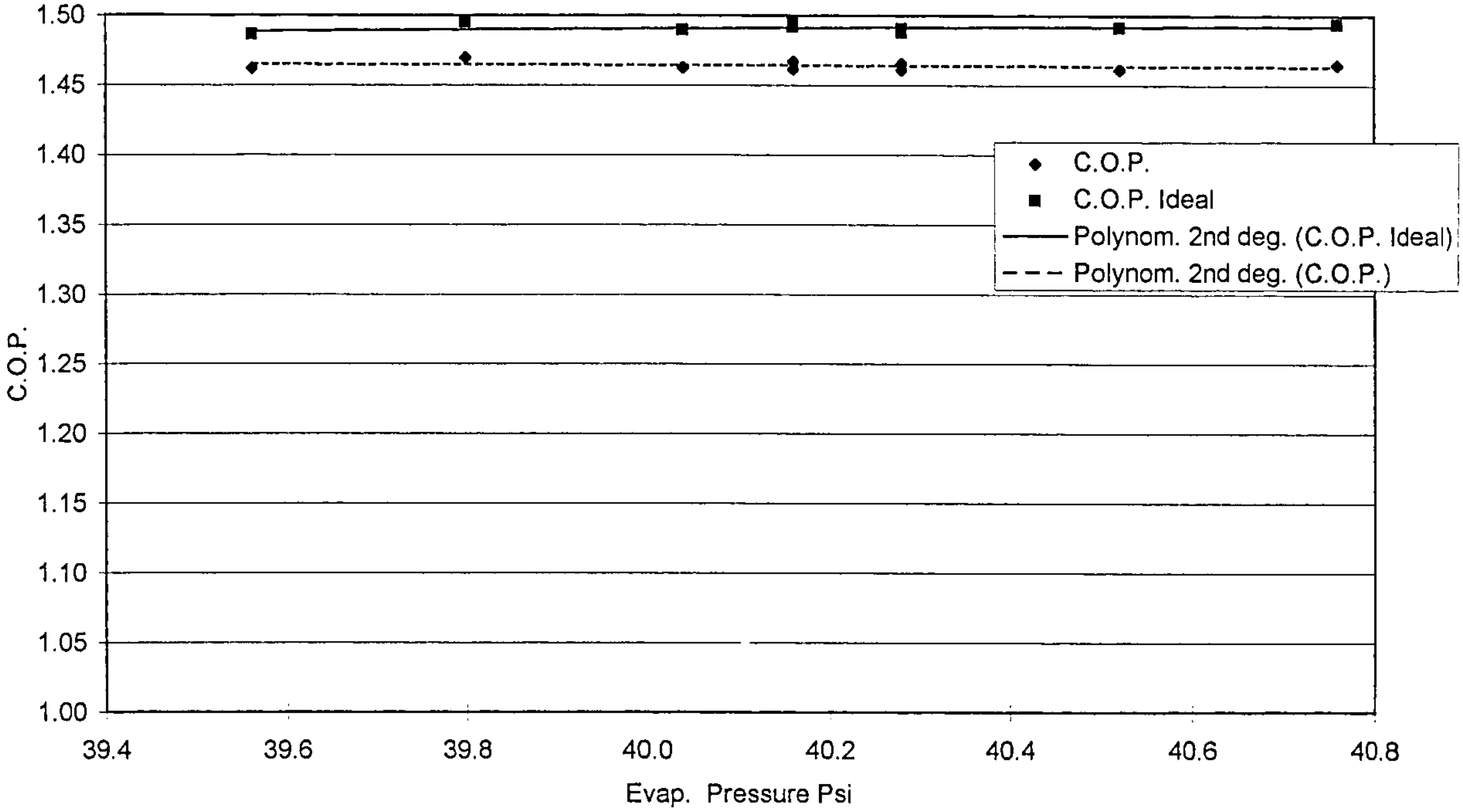


Figure (5.34) : C.O.P. vs. Evaporator Pressure for LPG

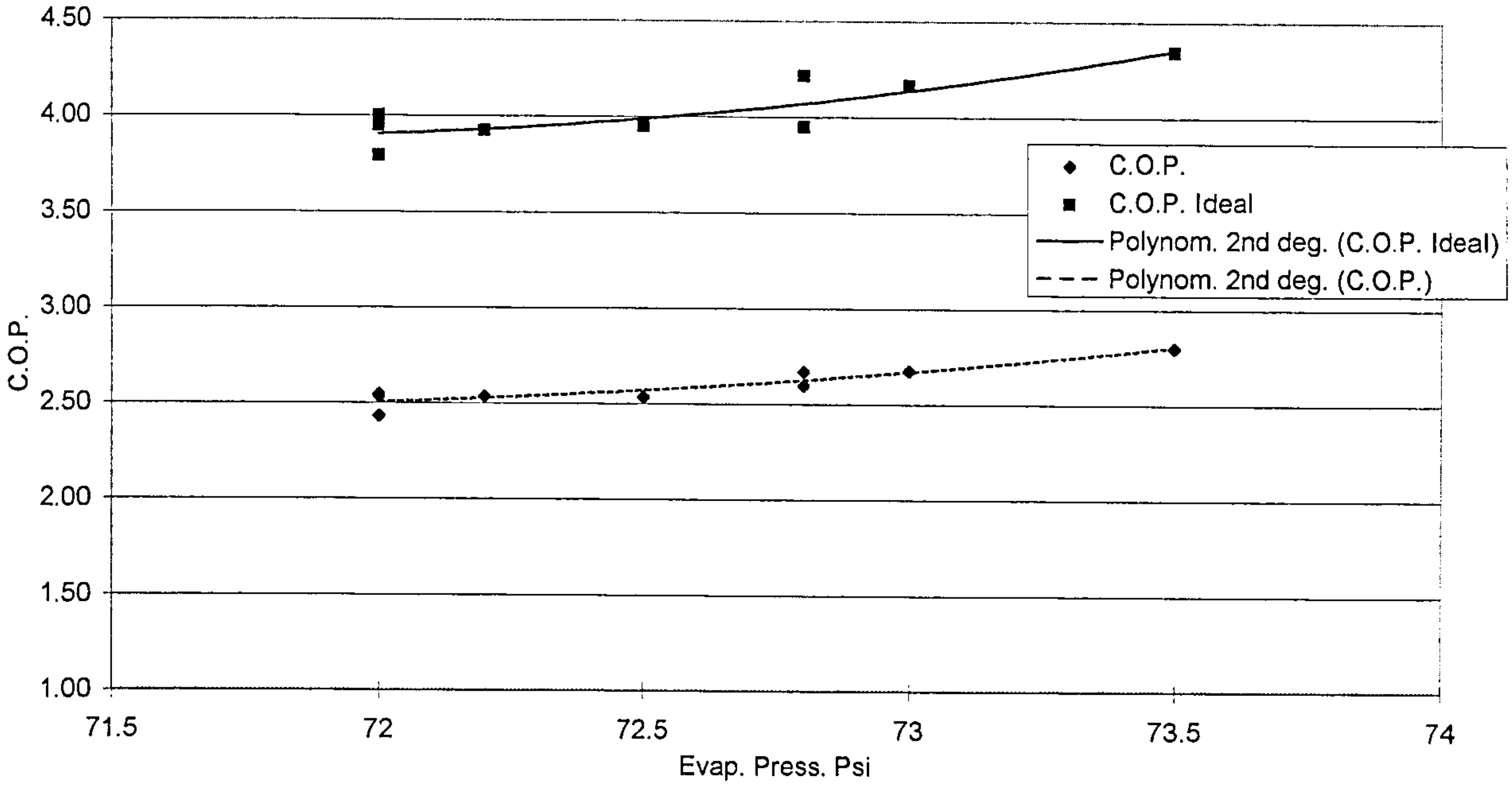


Figure (3.35) : C.O.P. vs. Evaporator Pressure for R22

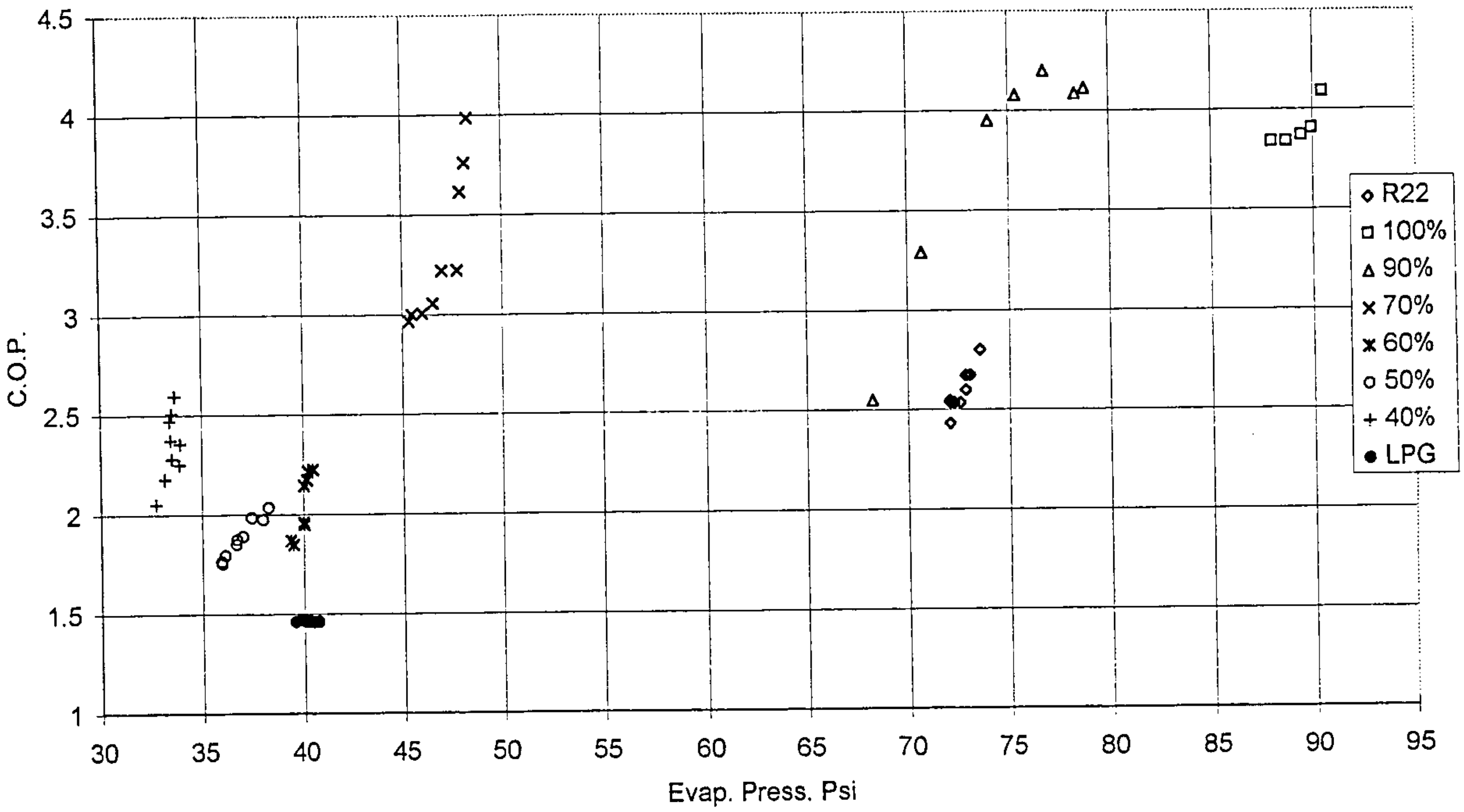


Figure (3.36): C.O.P. vs. Evaporator pressure.

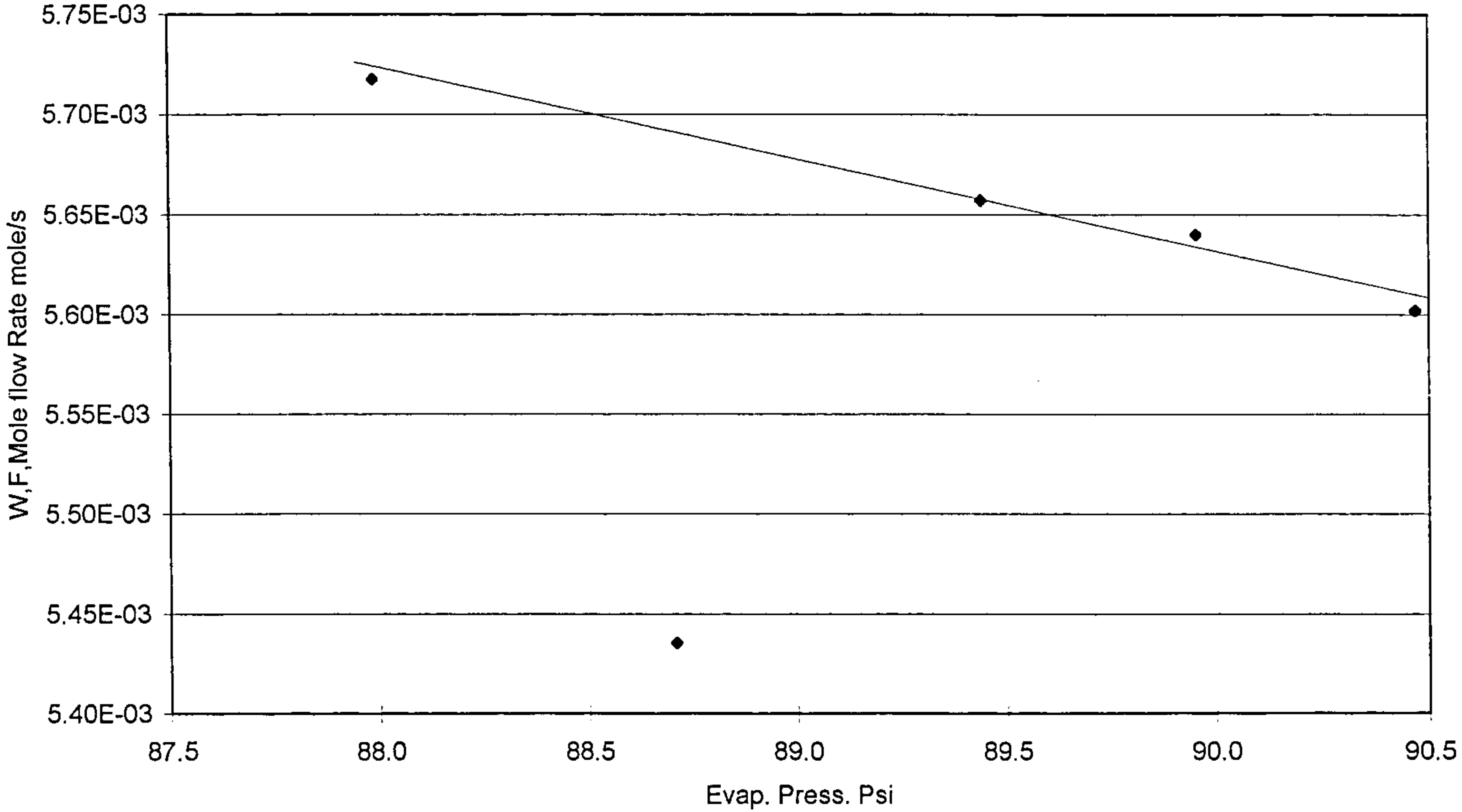


Figure (5.37) : Working fluid mole flow rate vs. evaporator pressure for 100% Propane

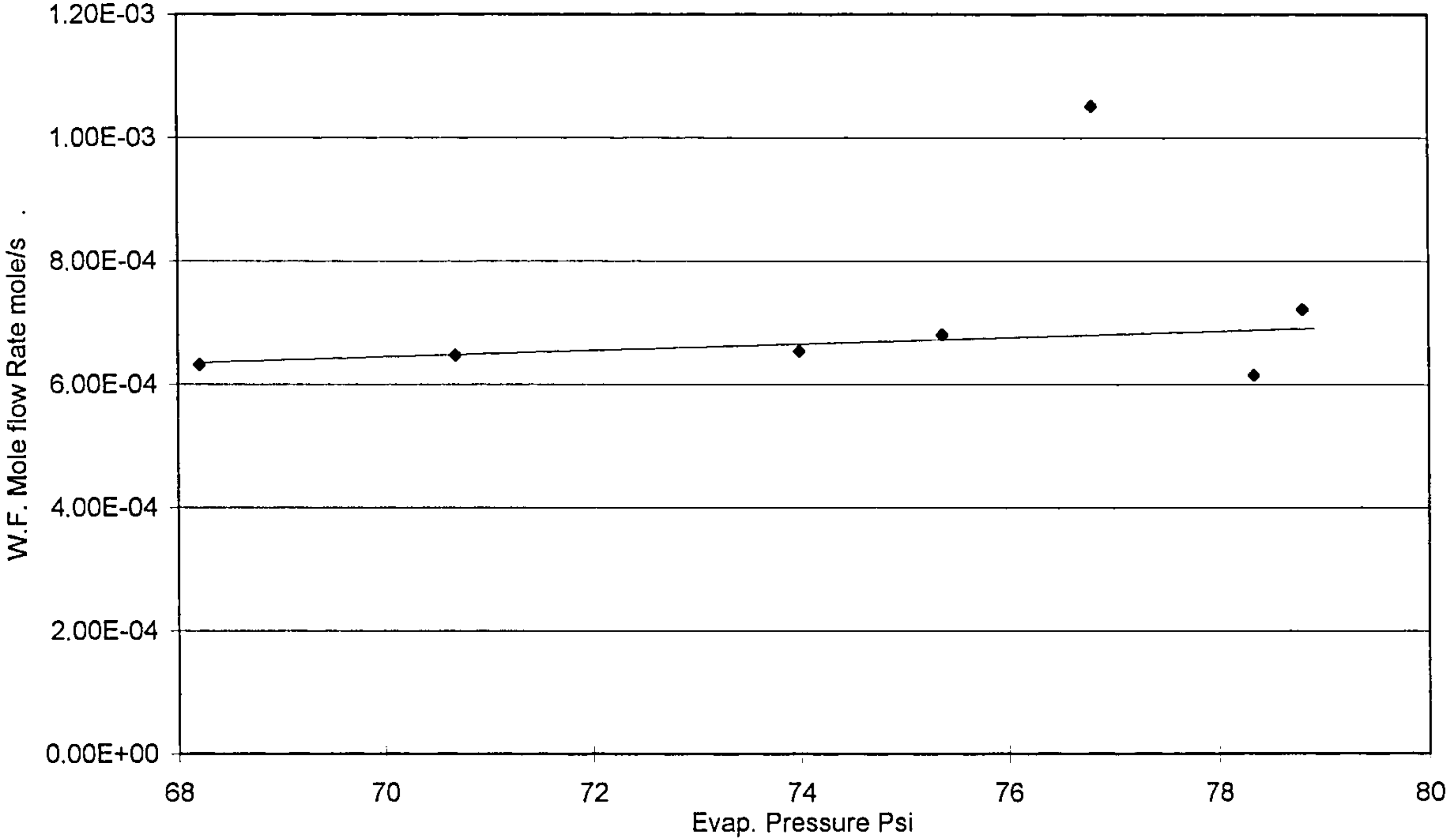


Figure (5.38) : Working fluid mole flow rate vs. evaporator pressure for 90% mass Propane.

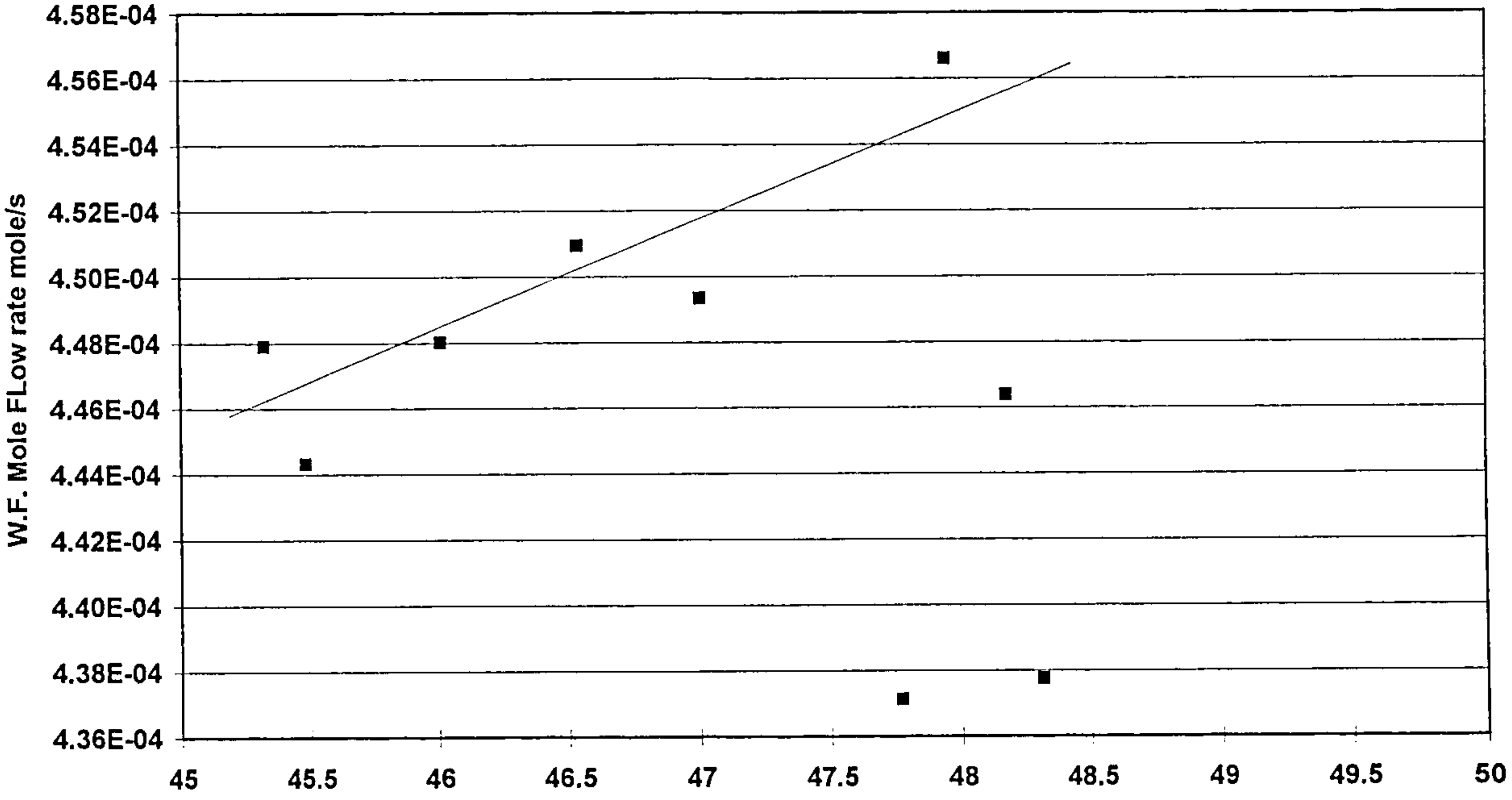


Figure (5.39) : W.F. mole flow rate vs. Evaporator Pressure for 70% mass Propane.

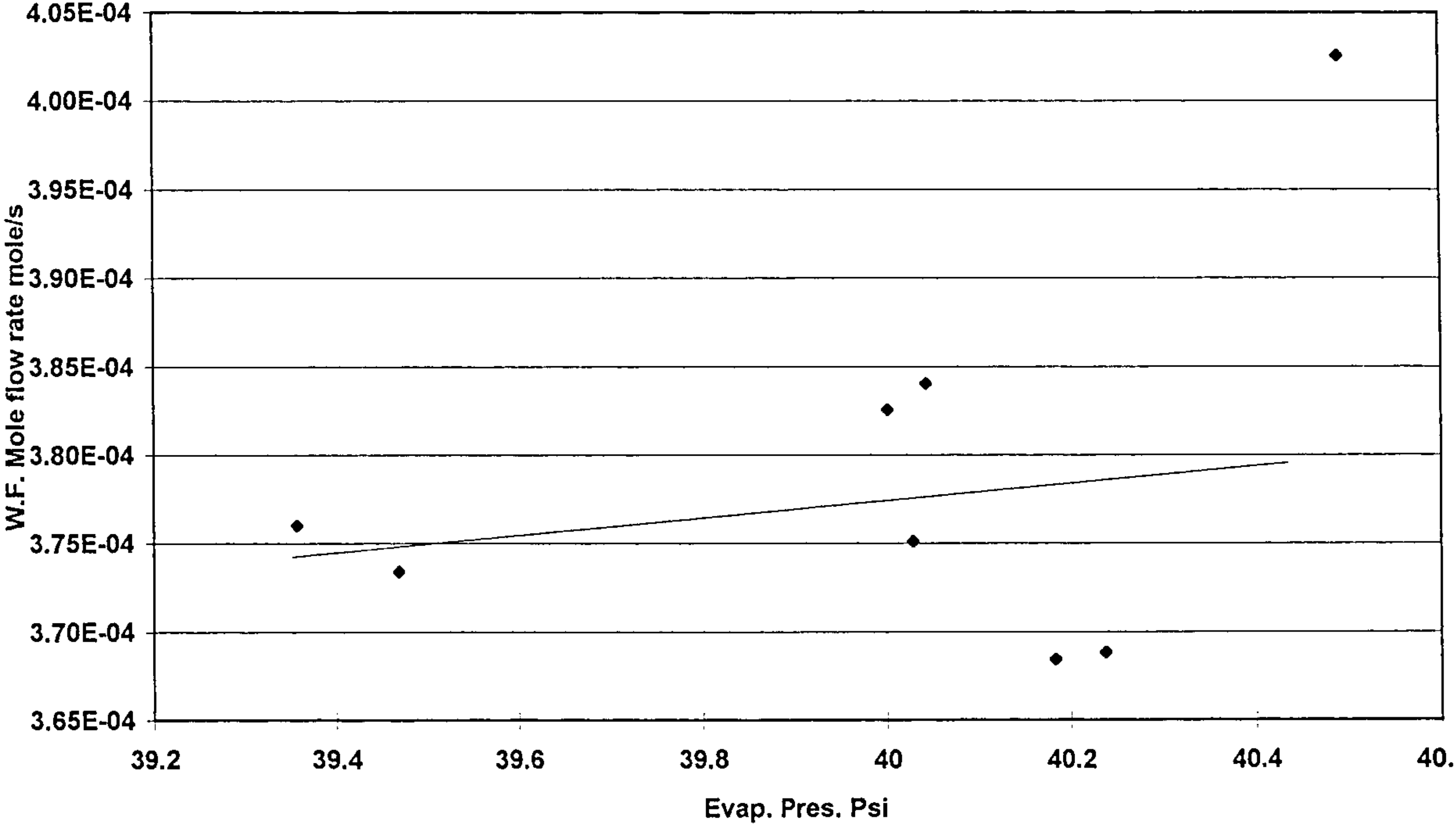


Figure (5.40) : Working fluid mole flow rate vs. evaporator pressure for 60% mass Propane.

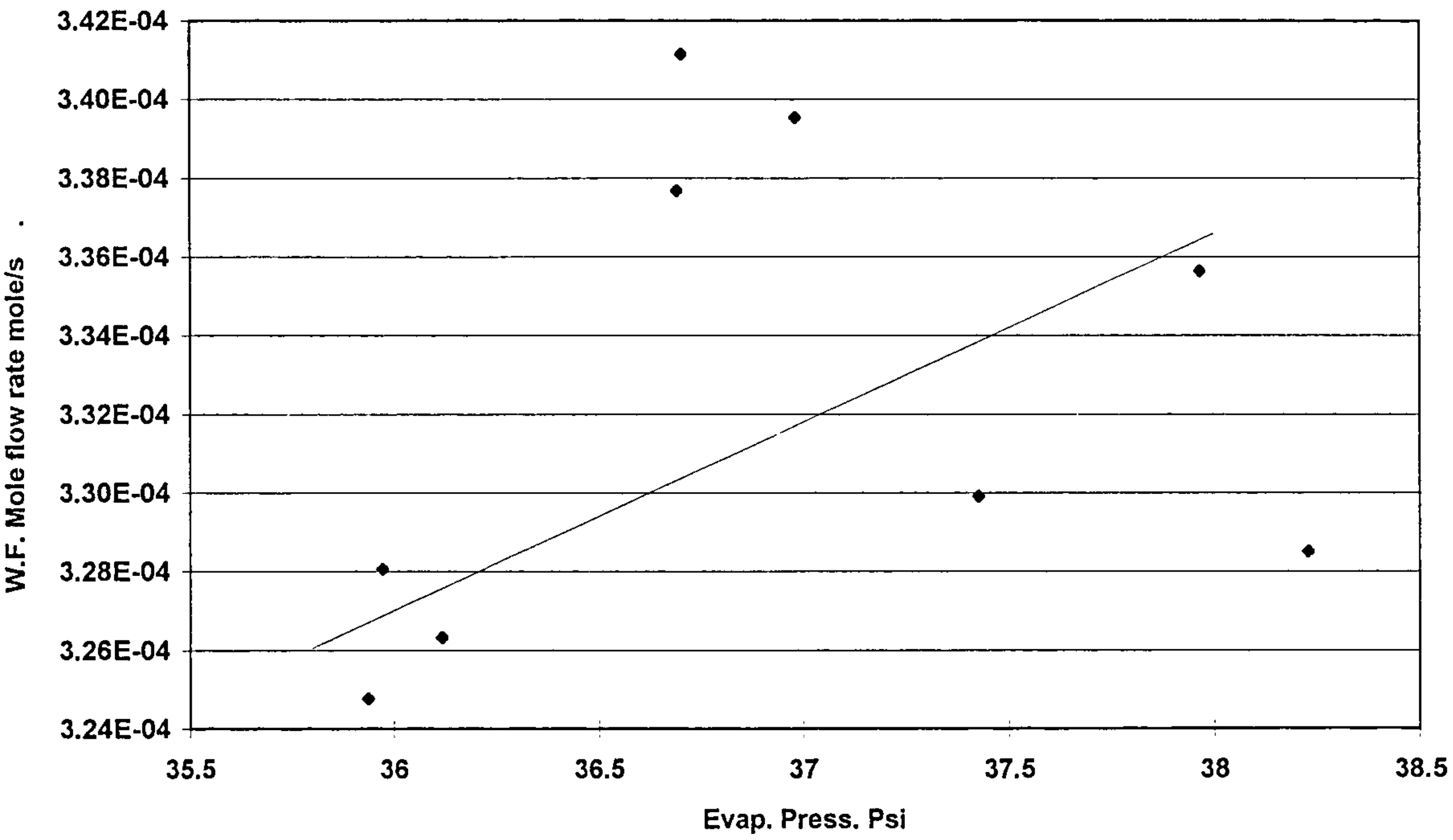


Figure (5.41) : Working fluid mole flow rate vs. Evaporator Pressure for 49% mass Propane.

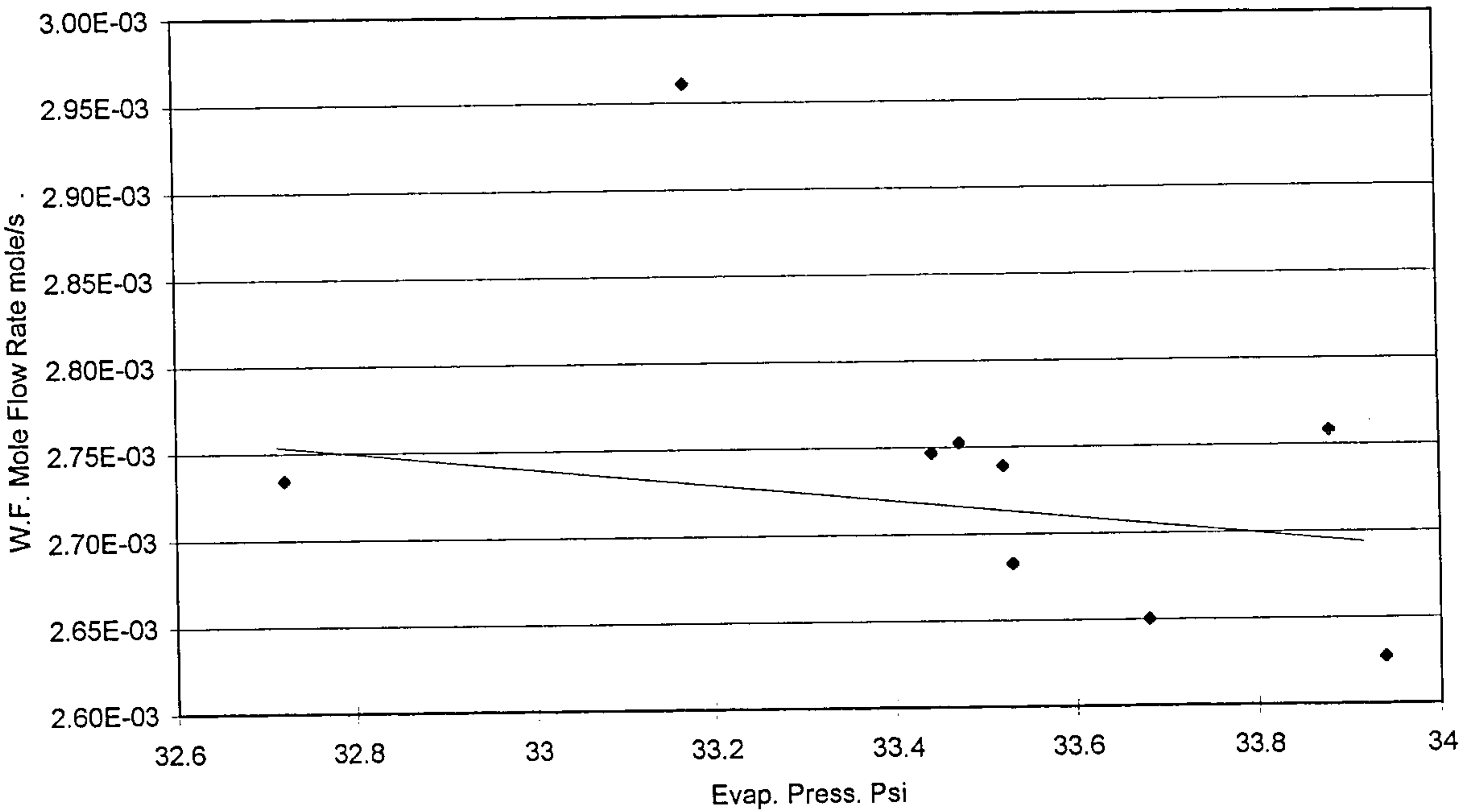


Figure (5.42) : Working fluid mole flow rate vs. evaporator pressure for 40% mass Propane.

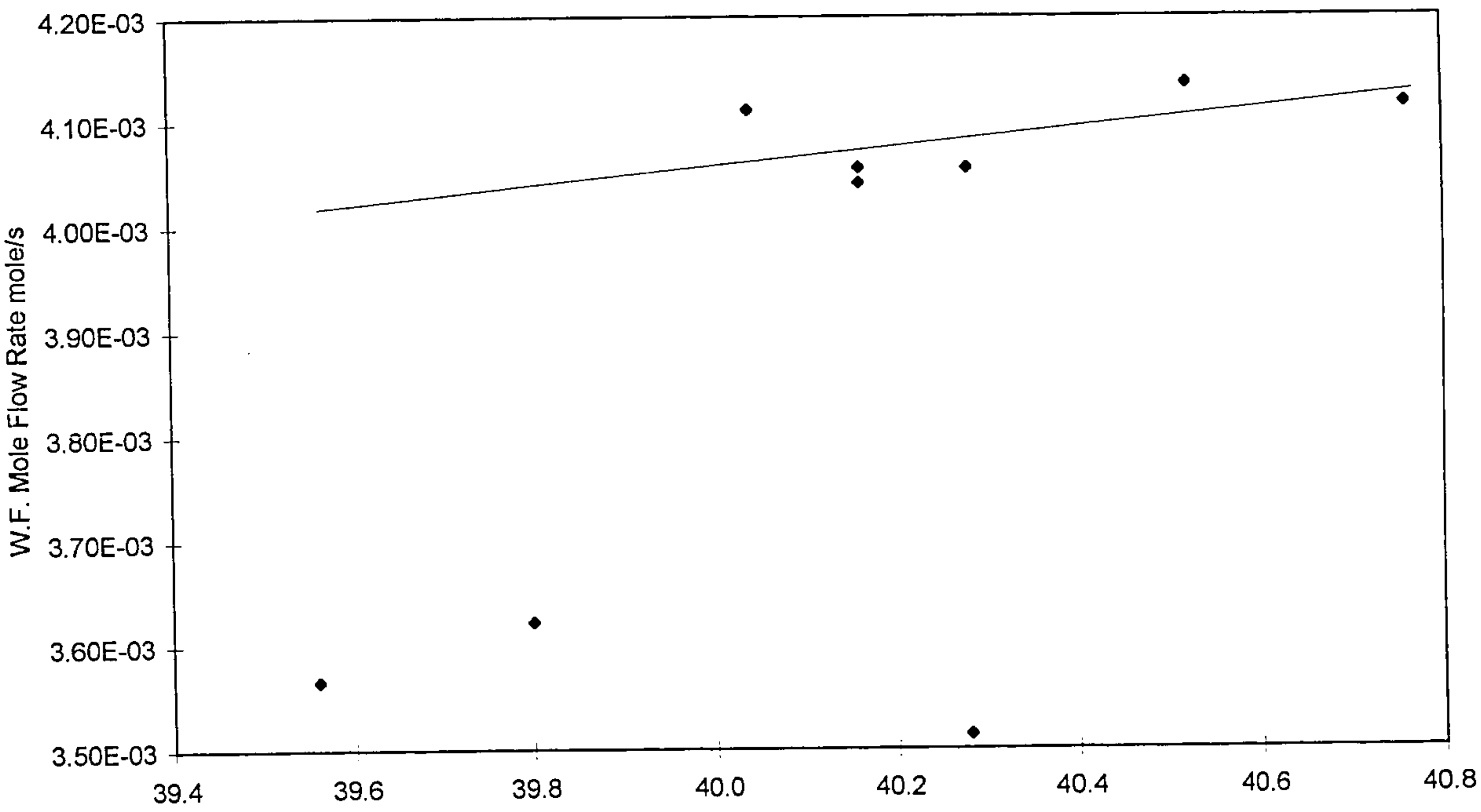


Figure (5.43) : Working fluid mole flow rate vs. evaporator pressure for LPG.

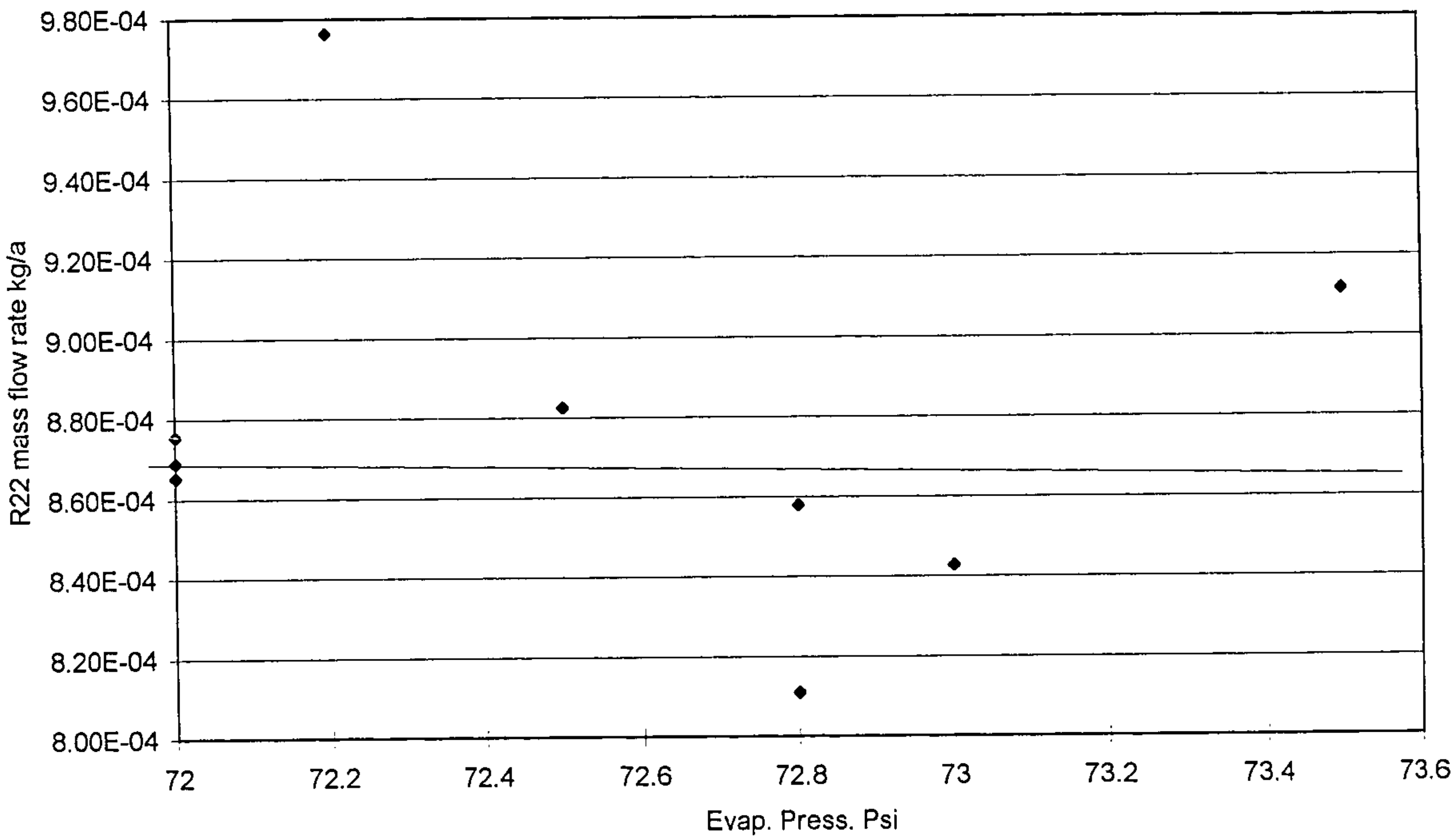


Figure (5.44) : R22 mass flow rate vs. Evaporator Pressure

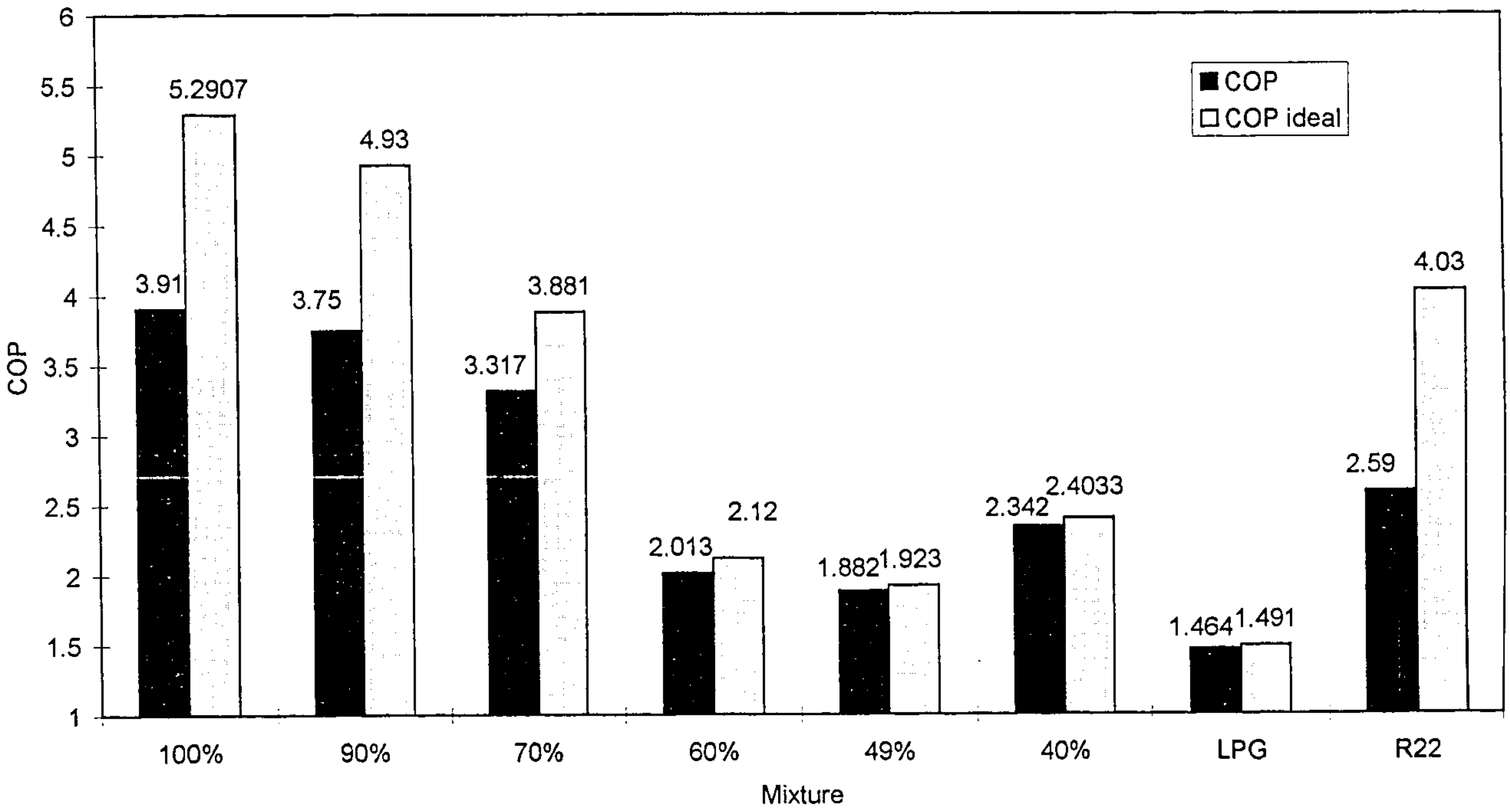


Figure (5.45) : Average values for actual, and ideal COP vs. mixture type

CHAPTER 6

Conclusions and Recommendations

This research covers an experimental and theoretical study of Propane, Butane, and Isobutane different mixtures, and compares them with R22 in a fully functional A/C split unit.

6.1- Conclusions

1- The mixtures of hydrocarbons from pure Propane to - 70% Propane 23% Butane and 7% Isobutane - proved to have a much better performance than R22, either in COP, discharge compressor temperature, or even the settling time Table 5-25 gives values of COP obtained, it is clear that pure Propane COP reached a maximum of 4.08, and an average of 3.91, while 90% Propane maximum COP reached 4.2, with an average value of 3.75, and the 70% Propane mixture reached a 3.99 COP, with an average value of 3.317, compared with R22 which have a COP maximum value of 2.8 and an average value of 2.59.

2- Although the C.O.P. is reduced slightly (in the range of pure Propane to 70% by mass Propane), with the reduction of the Propane percentage, the -70%Propane, 23% Butane, 7%

Isobutane- mixture demonstrate an over all better performance, due to its lower compressor discharge pressure and temperature. Which means longer life for the compressor and the refrigerant. The values of 70% evaporator pressure reached a maximum of 48 psi, while the R22 pressure values reached a maximum of 73.5 psi. The compressor discharge temperature of the 70% Propane mixture reached a maximum of 59°C, and that of R22 reached a maximum of 123.6 °C.

3- The mass used for hydrocarbons ranges from 35% to 75% of the mass used for R22. The lower the Propane percentage the higher the mass.

4- No side effects, what ever, where noticed. The compressor startup noise was noticed to be smoother.

5- The auther considers the mixtures (100% Propane), (90% Propane - 8% Butane - 2 % Isobutane), and (70% Propane - 23 % Butane - 7% Isobutane) to be very attractive replacements to R22.

6.2 Recommendations.

1- Hydrocarbons are suitable as an excellent alternatives of R22 in the A/C units.

2- More research could be done on the (100% Propane), and (90% Propane - 8% Butane - 2 % Isobutane), as they give better COP values.

3- More work could be done on calculating the properties of the mixture for the full range of percentages.

4- More experimental work can be done on the system by changing the expansion valve with a manuak one, to control evaporation pressure range.

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APPENDIX A

DATA TABLES

Table (A-1) : Temperature readings for 100% propane. in °C

	Cooling							
fan speed	High	High	High	Mid	Mid	Mid	Low	Low
T1	9.30	9.10	8.90	8.62	8.34	8.18	7.05	6.90
T2	27.50	27.90	28.30	28.05	28.27	28.33	28.33	28.29
T3	36.90	37.30	38.10	37.03	37.48	37.66	37.96	37.90
T4	73.80	75.50	76.80	75.55	75.46	75.95	76.13	76.19
T5	19.90	19.80	20.00	19.60	19.61	19.55	19.20	19.45
T6	-0.80	0.00	0.40	-0.38	-0.09	-0.20	-0.10	0.15
T7	85.70	87.60	88.90	88.25	88.30	88.45	88.68	88.75
T8	37.00	37.40	38.20	37.54	37.99	38.26	38.34	38.55
T9	0.97	1.73	1.59	1.30	1.83	1.47	1.51	1.47
T10	38.50	39.00	39.80	38.95	39.21	39.50	39.80	39.52
T11	15.30	16.00	15.70	16.70	16.50	16.50	16.30	16.20
T12	16.60	16.10	16.10	17.00	16.80	17.40	16.60	16.50
T13	7.80	7.50	7.40	8.00	7.80	7.90	6.60	6.70
T14	9.80	9.40	9.10	10.00	9.70	9.50	8.70	8.60
T15	34.90	35.30	35.90	35.10	35.40	35.70	35.70	35.60
T16	18.90	18.80	18.50	19.30	19.30	19.20	18.80	18.90
T17	19.50	19.30	19.10	20.00	19.90	19.80	19.90	19.90
T18	29.70	30.70	30.70	29.90	30.20	30.40	30.60	30.50
T19	17.30	17.00	16.60	18.20	17.80	17.80	17.40	17.30

Table (A-2) : Temperature readings for 90% propane. in °C

	Cooling						
FAN	High			Mid		Low	
T1	9.47	10.35	10.15	8.85	8.25	6.82	5.74
T2	26.12	26.67	26.78	26.45	26.14	25.98	25.59
T3	33.92	34.92	35.24	35.14	35.07	35.27	35.44
T4	70.81	72.6	72.86	72.74	72.58	72.49	72.27
T5	17.79	18.02	18.15	17.64	17.24	16.85	15.95
T6	3.47	3	3	2.49	2.36	2.31	2.28
T7	81.57	83.47	83.87	83.55	83.66	83.43	83.01
T8	34.46	35.48	35.66	35.57	35.59	35.75	35.89
T9	2.77	2.94	2.68	2.07	1.76	1.42	1.35
T10	35.79	36.84	37.02	36.93	36.91	37.08	37.22
T11	17.21	16.49	16.65	16.44	15.77	15.71	15.44
T12	17.66	17.87	16.76	16.6	16.07	16.13	15.79
T13	7.7	7.8	7.38	5.85	5.39	3.75	3.69
T14	9.33	8.57	8.7	7.84	6.84	5.99	5.61
T15	33.51	34.54	34.77	34.64	34.65	35	35.12
T16	17.13	17.66	16.23	15.39	14.83	15.18	15.05
T17	16.71	16.91	16.68	16.23	15.96	15.05	15.03
T18	28.17	29.08	29.09	29.09	29.24	29.6	29.54
T19	17.32	17.12	16.98	16.41	16.02	15.63	15.18

Table (A-3) : Temperature readings for 70% propane. in °C

	Cooling								
Fan Speed	Hign			Mid			Low		
T1	5.82	5.73	5.48	5.59	5	4.71	4.05	3.95	4.38
T2	14.51	14.19	14.27	15.38	14.93	15.03	14.35	14.04	14.01
T3	28.4	28.56	28.56	30.53	30.53	30.69	30.78	30.89	30.89
T4	49.9	49.87	49.78	50.81	49.49	48.55	46.78	46.2	46.87
T5	6.86	6.36	5.99	3.42	2.37	2.15	1.33	1.06	1.45
T6	-0.53	-0.87	-0.56	-0.24	-0.03	0.31	1.28	1.6	1.69
T7	58.5	58.4	58.32	59.08	57.75	56.97	55.55	55.28	55.81
T8	28.6	28.71	28.75	30.64	30.72	30.85	30.01	31.01	31.22
T9	-0.28	-0.35	-0.53	-0.23	-0.4	-0.12	0.27	0.61	0.59
T10	30.13	30.19	30.22	32.06	32.19	32.21	32.42	32.5	32.53
T11	11.96	11.69	11.59	11.99	11.44	11.29	11.58	11.46	11.6
T12	13.71	12.68	12.53	12.72	12.5	12.7	13.07	12.89	12.41
T13	5.64	5.34	5.13	5.08	4.56	4.45	3.77	3.5	3.73
T14	4.03	3.74	3.79	3.62	3.05	2.84	2.16	1.94	2.12
T15	28.61	28.53	28.78	30.55	30.98	31.01	31.19	31.34	31.05
T16	12.05	12.1	11.8	11.97	11.55	11.38	11.43	11.21	11.14
T17	13.24	12.92	12.73	13.14	12.82	12.58	11.84	11.87	12.13
T18	23.19	23.1	23.36	25.23	25.7	25.8	25.92	26.21	25.99
T19	12.83	12.36	12.92	13.08	12.69	12.51	11.93	12.15	12.13

Table (A-4) : Temperature readings for 60% propane. in °C

	Cooling							
Fan Speed	High			Mid			Low	
T1	5.35	5.17	5.13	5.02	5	5.03	4.62	4.54
T2	14.81	14.78	14.66	14.58	14	13.97	13.58	13.67
T3	30.45	30.78	30.79	30.72	30.7	30.79	30.66	30.67
T4	42.28	42.53	42.48	42.42	42.43	42.43	42.24	42.22
T5	9.5	9.56	9.37	9.29	9.14	9.41	8.8	8.94
T6	0.67	0.77	0.57	0.58	0.34	0.66	-0.02	0.15
T7	45.62	45.6	45.55	45.66	45.66	45.58	45.25	45.31
T8	31.01	31.24	31.22	31.19	31.2	31.26	31.12	31.14
T9	0.7	0.53	0.49	0.33	0.28	0.37	-0.02	-0.04
T10	32.34	31.58	32.58	32.51	32.5	32.6	32.36	32.41
T11	12.15	11.5	11.51	11.58	11.66	11.77	11.89	11.87
T12	12.9	12.54	13.03	13.14	13.36	13.11	13.59	13.16
T13	4.54	4.42	4.44	4.1	4.03	4.15	3.54	3.45
T14	5.36	5.71	5.52	5.44	5.28	5.17	5.01	4.81
T15	30.73	30.98	31.14	31.14	31.18	31.14	31.02	30.98
T16	12.27	12.24	12.08	12.16	14.03	12.28	12.5	12.51
T17	11.68	11.79	11.63	11.59	11.74	12.41	12.33	12.15
T18	25.49	26.16	25.63	26.22	26.13	26.06	26.03	26.27
T19	12.47	12.62	12.48	12.62	12.26	12.64	12.78	12.28

Table (A-5) : Temperature readings for 49% propane. in °C

	Cooling								
Fan speed	High			Mid			Low		
T1	7.69	7.47	7.02	6.65	6.42	6.41	5.93	5.81	5.78
T2	15.60	15.40	15.44	15.06	15.00	14.90	14.67	14.49	14.55
T3	28.52	28.44	28.70	28.55	28.54	28.63	28.68	28.67	28.92
T4	41.11	41.12	41.17	40.94	40.88	40.96	40.85	40.72	40.90
T5	10.71	10.57	10.53	10.11	9.95	10.07	9.69	9.50	9.53
T6	1.53	1.40	1.45	1.10	0.95	1.04	0.73	0.68	0.93
T7	43.61	43.68	43.71	43.22	43.13	43.24	43.03	42.89	43.01
T8	29.09	28.94	29.17	29.12	29.07	29.19	29.25	29.15	29.48
T9	1.63	1.36	1.41	1.09	0.94	0.79	0.44	0.62	0.55
T10	30.45	30.37	30.66	30.40	30.33	30.52	30.56	30.47	30.74
T11	12.56	12.59	12.46	12.44	12.31	12.27	12.35	12.33	12.32
T12	13.89	13.97	14.18	14.09	13.79	14.48	13.41	13.57	13.85
T13	6.40	6.29	6.23	5.76	5.57	5.59	5.01	4.92	5.00
T14	7.48	7.51	7.41	7.15	6.99	6.87	6.43	6.22	6.16
T15	28.78	28.68	28.96	28.77	28.85	28.98	28.97	28.95	29.24
T16	14.53	13.98	13.53	13.33	13.19	13.49	13.42	13.33	13.49
T17	13.53	12.88	12.83	12.85	12.46	12.83	12.29	12.70	12.31
T18	24.15	23.86	24.18	24.07	24.22	24.38	24.35	24.48	24.52
T19	13.42	13.50	13.73	13.49	13.13	13.59	12.75	12.39	12.98

Table (A-6) : Temperature readings for 40% propane. in °C

	Cooling								
Fan Speed	HIGH			MID			LOW		
T1	7.88	7.94	7.68	7.47	7.44	7.53	7.52	7.17	6.72
T2	14.78	15.06	15.56	15.1	15.31	15.38	14.84	14.57	14.18
T3	25.9	26.58	27.12	26.73	27.01	26.79	26.07	26.06	25.52
T4	38.61	39.2	39.7	39.32	39.49	39.46	38.65	38.59	38.08
T5	10.69	11.06	11.11	10.73	10.77	10.75	10.41	10.31	9.82
T6	1.53	1.57	1.93	1.55	1.83	1.84	1.22	1.08	0.67
T7	41.08	41.52	41.94	41.51	41.69	41.7	40.86	40.66	40.29
T8	26.11	26.84	27.48	27.07	27.34	27.15	26.33	26.26	25.85
T9	1.82	1.93	1.92	1.87	1.76	1.88	1.58	1.39	0.89
T10	27.44	28.09	28.71	28.29	28.62	28.44	27.6	27.39	27.05
T11	12.39	12.25	12.19	12.21	12.21	12.21	12.84	12.9	12.24
T12	13.43	13.92	13.77	13.3	13.51	14.07	15.01	13.93	14.43
T13	7.07	7.18	7.07	6.68	6.68	6.83	6.76	6.29	6.02
T14	7.94	7.88	7.79	7.6	7.53	7.61	7.34	7.46	6.9
T15	26.14	26.85	28.25	26.94	27.27	26.99	26.22	26	25.84
T16	13.13	13.25	13.01	13.18	12.96	13.1	13.88	12.96	13.01
T17	13.2	13.27	13.14	13.4	12.44	13.86	13.8	13.46	12.93
T18	21.88	22.57	23.03	23.2	23.39	23.19	22.27	22.23	22.08
T19	14.19	13.97	14.18	13.77	13.76	14	14.06	14.06	13.82

Table (A-7) : Temperature readings for LPG. in °C

	Cooling								
Fan speed	High			Mid			Low		
T1	19.8	19.6	19.3	19.3	19.2	19.4	19.4	18.8	19
T2	22.5	22.3	22.2	22.2	22.2	22.4	22.2	21.7	21.6
T3	35.5	35.4	35.4	35.6	35.8	35.9	35.8	35.5	34.9
T4	51.4	51.3	51.2	51.2	51.3	51.5	51.5	50.9	50.5
T5	18.3	18	17.7	17.7	17.4	17.7	17.5	16.9	16.9
T6	6.6	6.5	6.5	6.2	6.1	6.5	6.4	5.8	5.7
T7	56.6	56.6	56.5	56.3	56.4	56.6	56.5	55.8	55.5
T8	35.5	35.5	35.5	35.5	35.7	35.6	35.7	35.5	35
T9	6	5.9	5.7	5.4	5.5	5.9	5.3	5.5	5.2
T10	38	38	38	37.1	37.2	37.3	37.3	33.3	36.3
T11	19.3	19	18.8	18.6	18.5	18.7	18.9	18.1	18.2
T12	18.7	18.5	18.2	18.3	18.3	18.5	18.1	18	17.9
T13	11.5	11.2	11	10.9	10.8	11.1	10.8	10.5	10.2
T14	13.5	13.4	13.1	12.9	12.9	13.1	13	13.4	13.6
T15	34.1	34	34	34.1	34.3	34.2	34.3	30.2	33.7
T16	21.3	21.1	20.9	21	21	21.3	21.1	20.5	20.6
T17	21.3	21.1	20.9	21.1	21.1	21.5	21.4	20.9	21
T18	28.7	28.7	28.7	28.8	29	29	29.1	28.8	28.3
T19	22	21.9	21.7	21.6	21.5	21.5	21.7	21.2	21.3

Table (A-8) : Temperature readings for R22. in °C

	Cooling								
Fan Speed	High			Mid			Low		
T1	6.4	6.4	6.3	6	6.1	6	5.6	5.8	5.8
T2	35	35.5	35.3	34.7	34.9	35	34.3	34.3	34.9
T3	49.7	50.2	50.1	50.7	51.1	51.1	51.4	51.5	51.5
T4	98.9	99.8	100.1	100	100.7	101	100.7	100.7	101
T5	24.1	24.2	24.2	23	22.7	23.3	18.6	18.5	15
T6	0.2	0.2	0.2	0	0.3	0.3	-0.1	0.1	0.1
T7	120.9	122.2	122.2	122.5	122.9	123.3	123.2	123.2	123.6
T8	49.6	50.4	50.3	50.9	51.2	51.1	51.5	51.8	51.7
T9	0.7	0.7	0.7	0.5	0.8	0.8	0.4	0.6	0.6
T10	51.6	52	52	52.4	52.9	52.8	53.1	53.3	53.1
T11	19.5	19.1	19.1	19.3	19.3	19.7	19.8	19.8	19.8
T12	20.9	20.4	20.3	20.6	20.6	21.2	21.4	21.4	21.4
T13	9.1	8.9	8.4	7.9	7.9	7.7	7.6	7.3	7.4
T14	8.8	8.7	8.2	7.5	7.8	6.3	6.4	6.6	6.5
T15	44.8	45.5	45.3	46.1	46.1	46.4	46.5	46.3	46.4
T16	21.5	21.6	21.6	21.2	21.2	21	20.9	20.9	20.9
T17	23.1	22.6	22.8	22.8	23	23.4	23.8	23.6	23.8
T18	37.5	38.1	38	38.9	38.9	39.3	39.4	39.6	39.6
T19	18.1	18.1	18.1	17.7	17.7	17.5	17.4	17.4	17.4

APPENDIX B

COMPUTER PROGRAM

SAMPLE

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                            C
C              The main Subroutines          C
C                                            C
C                                            C
C       These Samples Calculates properties  C
C                for Pure Propane            C
C                                            C
C        Done By: Eng. Rami Awad Al-Tarawnah C
C                                            C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      EXTERNAL IVXHDL
       JUNKXX=LIB$ESTABLISH(IVXHDL)
       CALL ASPEN
       STOP
       END

       SUBROUTINE ASPEN

C      THIS SUBROUTINE IS THE ACTUAL CALLING PROGRAM


        DECLARE RUN CONTROL LOGICAL FLAGS

       LOGICAL SIM,RPT,INTACT
       COMMON/ZZZRPT/ICALL,SIM,RPT
       COMMON /GLOBAL/ JUNK(29),IRNCLS

C       PLEX ARRAY DECLARATION

       COMMON /PLEX/ IPLEX (     60416 )
       COMMON /ICRD/ NICR, ICRD (     2 ,    59 )
       COMMON /PPERR1/  LNLSTK,LSTKPR,LOOSTK(7,30),
      1        NOPNFS(2),NCURFS(2),NOPNFM(2),
      1        NCURFM(2),IFSENT,IFSSLN,IFSMLN,
      1        IFLLIN,IFLLOC,IBKERR,
      1        LNMCHR,MSGNXT,MSGCHR(50)
       COMMON /PPERR2/  LNMSTK,MSTKPR,MSGSTK(14,40)
       CHARACTER*80 MSGCHR

       COMMON /WORK/ IWORK (      6472 )
       COMMON /STWORK/ ISTW (100)
       COMMON /STWKWK/ ISTWK (  1477 )

        INITIALIZE PLEX

       NICR  =     59
       LNLSTK=30
       LSTKPR=1
       LNMCHR=50
       MSGNXT=1
       LNMSTK=40
       MSTKPR=1
       NB=0
       CALL INTSIM
C      APLOAD LOADS PHYSICAL PROPERTY CONSTANTS,
C      FROM THE PLEX INTO LABELLED COMMONS,
C      AND EXECUTES PROPERTY INITIALIZATION ROUTINES
C      LDSTW LOADS THE STREAM WORK LABELED COMMON

       IF (IRNCLS .EQ. 10) GOTO 80
       CALL APLOAD

       IF DRS, LOCATE REPORT BEAD AND CALL RPTMON
       IF(IRNCLS .LT. 100) GO TO 79
       LBPROC=LOCATI(2)
       NRPTWR=IPLEX(LBPROC+26)
       IF(NRPTWR .EQ. 0) GO TO 500
       LRPTWR=LOCATI(NRPTWR)
       IF(IPLEX(LRPTWR) .EQ. 0) GO TO 500
       CALL LDSTW
       GO TO 300
    79 CALL LDSTW
```

```
C      CALL EXECUTION MONITOR TO SIMULATE,REPORT, OR QUIT
 80  ICALL=0
     ENTRY RENTRY
 90  CALL EXMON  (ICALL   ,LPROC  ,NBSMB  ,LRPTWR ,SIM   ,
  *         RPT     ,INTACT)

C     DETERMINE NEXT MODEL TO CALL
C     AND LOCATE BLOCK BEAD AND ITS MAJOR ARRAYS

100  IF (SIM)
    *CALL SEQINT(NBSMB,
  *         NGO    ,NB     ,L1     ,L2     ,L3    ,
  *         L4     ,L5     ,L6     ,L7     ,L8    ,
  *         L9     ,L10    ,L11    ,L12    ,L13   ,
  *         L14    ,L15    ,L16    ,L17    ,L18   ,
  *         L19    ,L20    ,L21    ,L22    ,INTACT ,
  *         ICALL)
     IF ( .NOT. RPT) GO TO 400
300  CALL RPTMON (IPLEX(LRPTWR),
  *         NGO    ,NB     ,L1     ,L2     ,L3    ,
  *         L4     ,L5     ,L6     ,L7     ,L8    ,
  *         L9     ,L10    ,L11    ,L12    ,L13   ,
  *         L14    ,L15    ,L16    ,L17    ,L18   ,
  *         L19    ,L20    ,L21    ,L22    )
     IF(IRNCLS .LT. 100) GO TO 400
500  CALL QUIT
     GO TO 99999
400  NGO = NGO + 1
9999 RETURN
     END


     SUBROUTINE APLOAD
     IMPLICIT REAL*8 (A-H,O-Z)
     COMMON /ERRTWO/ IFILLR(11),IGRSLC,IFILL2(7)
     COMMON /PLEX  / IPLEX(1)

C      DECLARE SYSTEM COMMONS

     COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
    1           NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
    1           NCCASS ,IDXWAT ,NG
     COMMON /BIOCMP/ IBCOMP (        3)
     COMMON /IDXCC / IDXCC  (        3)
     COMMON /IACC  / IACC   (        3)
     COMMON /PPCTBL/ IPPCTB(13)
     COMMON /RGLOB / RMISS
     COMMON /GLOBAL/ IDUMMY(7), IMISS
     COMMON /IDXTAB/IXTB(         66 )
     COMMON /TABLAR/DATA(         108 )
     COMMON /IPRFDX/IPRFDX(         5 )
     COMMON /PPFLAG/ IGFLG

C      DECLARE PHYSICAL PROPERTY WORK COMMONS

     COMMON /PPWORK/ PPWORK (        82)
     COMMON /IPWORK/ IPWORK (       237)
     COMMON /PPCKWK/ IRWLST, IIWLST
     COMMON /UPPWRK/ UPPVAL (       125)
     COMMON /UPPFL/ UPPFL(        40)

C      LOCATE PROCESS BEAD

     LPRO   = LOCATI (2)
     IGRSLC=2
     IGFLG=0

C      LOAD NCOMP
     NBCOMP = IPLEX(LPRO+36)
     LBCOMP = LOCATI(NBCOMP)
     NCC    = IPLEX(LBCOMP)
     NNCC   = IPLEX(LBCOMP+1)
     NC     = IPLEX(LBCOMP+2)
```

```
      NAC    = IPLEX(LBCOMP+3)
      NACC   = IPLEX(LBCOMP+4)
      NVCP   = IPLEX(LBCOMP+5)
      NVNCP  = IPLEX(LBCOMP+6)
      NVACC  = IPLEX(LBCOMP+7)
      NVANCC = IPLEX(LBCOMP+8)
      NASSAY = IPLEX(LBCOMP+9)
      NCCASS = IPLEX(LBCOMP+10)
      IDXWAT = IPLEX(LBCOMP+11)
      NG     = IPLEX(LBCOMP+12)

C     LOCATE AUXILLIARY PROCESS BEAD

      NBAUX  = IPLEX(LPRO+199)
      LAUXPR = LOCATI(NBAUX)

C     LOAD BIOCOMP

      NBEAD  = IPLEX(LAUXPR+11)
      CALL ILOAD (IBCOMP ,NBEAD  ,NC   ,0     )

C     UNLOCK AUXILLIARY PROCESS BEAD

      CALL UNLOCK(NBAUX)

C     LOAD PHYSICAL PROPERTY WORK COMMONS

      IRWLST =        82
      IIWLST =       237
      PPWORK( IRWLST ) = RMISS
      IPWORK( IIWLST ) = IMISS

C     LOAD SYSTEM COMMONS

      NBEAD  = IPLEX(LPRO+    43)
      IF (NCC .GT. 0) CALL ILOAD (IDXCC   ,NBEAD  ,NCC    ,0     )
      NBEAD  = IPLEX(LPRO+    45)
      IF (NCC .GT. 0) CALL ILOAD (IACC    ,NBEAD  ,NCC    ,0     )
      NBEAD  = IPLEX(LPRO+    39)
      CALL ILOAD (IPPCTB ,NBEAD  ,13    ,0     )
      CALL TPUNPK(     1 )
      CALL PCLD1
      CALL PCLD2
      CALL PCLD3
      CALL PCLD4
      CALL PCLD5
      CALL HIGTB ( 1)

C     CALL INITIALIZATION ROUTINES

      NBPPID = IPLEX (LPRO + 23)
      LBPPID = LOCATI (NBPPID )
      NISN   = IPLEX (LBPPID )
      IF (IPLEX(LBPPID+NISN*3+         1) .EQ. 1) THEN
        IMNDS = IPLEX(LBPPID+          3)
        CALL VL203 (IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+         2) .EQ. 1) THEN
        IMNDS = IPLEX(LBPPID+          6)
        CALL VL006 (IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+         3) .EQ. 1) THEN
        IMNDS = IPLEX(LBPPID+          9)
        CALL WATS01(IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+         4) .EQ. 1) THEN
        IMNDS = IPLEX(LBPPID+         12)
        CALL MUVLW1(IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+         5) .EQ. 1) THEN
        IMNDS = IPLEX(LBPPID+         15)
        CALL MUVLW2(IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+         6) .EQ. 1) THEN
```

```
       IMNDS = IPLEX(LBPPID+        18)
       CALL KVLW1 (IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+      7) .EQ. 1) THEN
       IMNDS = IPLEX(LBPPID+        21)
       CALL ES06  (IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+      8) .EQ. 1) THEN
       IMNDS = IPLEX(LBPPID+        24)
       CALL ES02  (IMNDS)
      ENDIF
      IF (IPLEX(LBPPID+NISN*3+      9) .EQ. 1) THEN
       IMNDS = IPLEX(LBPPID+        27)
       CALL ES06A (IMNDS)
      ENDIF
      RETURN
      END


      SUBROUTINE PCLD1
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PLEX  / IPLEX(1)
      COMMON /GLOBAL/ IDUMMY(7), IMISS

C     DECLARE SYSTEM COMMONS

      COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
     1         NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
     1         NCCASS ,IDXWAT ,NG
      REAL*8 ZC
     * ,TC     ,PC     ,MW     ,PLXANT ,TB     ,CPIG   ,DHVLWT ,OMEGA
     * ,DHFORM ,DGFORM ,VLSTD  ,SG     ,API    ,WATSOL ,CHARGE ,HIGPY
     * ,PSEUDO ,CPIGDP ,ATOMNO ,NOATOM ,CPIXP1 ,CPIXP2 ,CPIXP3 ,VC
     * ,RKTZRA ,RKTKIJ ,VCRKT  ,VLRKTA ,RACKET ,VB     ,MUP    ,LJPAR
     * ,STKPAR ,MUVDIP ,TRNSWT ,MULAND ,MULDIP ,KVDIP  ,KLDIP

C     DELCARE PROPERTY COMMONS

      COMMON /ZC    / ZC    (       3)
      COMMON /TC    / TC    (       3)
      COMMON /PC    / PC    (       3)
      COMMON /MW    / MW    (       3)
      COMMON /PLXANT/ PLXANT(      27)
      COMMON /TB    / TB    (       3)
      COMMON /CPIG  / CPIG  (      33)
      COMMON /DHVLWT/ DHVLWT(      15)
      COMMON /OMEGA / OMEGA (       3)
      COMMON /DHFORM/ DHFORM(       3)
      COMMON /DGFORM/ DGFORM(       3)
      COMMON /VLSTD / VLSTD (       9)
      COMMON /SG    / SG    (       3)
      COMMON /API   / API   (       3)
      COMMON /WATSOL/ WATSOL(      15)
      COMMON /CHARGE/ CHARGE(       3)
      COMMON /HIGPY / HIGPY (      30)
      COMMON /PSEUDO/ PSEUDO(       3)
      COMMON /CPIGDP/ CPIGDP(      21)
      COMMON /ATOMNO/ ATOMNO(      15)
      COMMON /NOATOM/ NOATOM(      15)
      COMMON /CPIXP1/ CPIXP1(      30)
      COMMON /CPIXP2/ CPIXP2(      30)
      COMMON /CPIXP3/ CPIXP3(      30)
      COMMON /VC    / VC    (       3)
      COMMON /RKTZRA/ RKTZRA(       3)
      COMMON /RKTKIJ/ RKTKIJ(       9)
      COMMON /VCRKT / VCRKT (       3)
      COMMON /VLRKTA/ VLRKTA(       9)
      COMMON /RACKET/ RACKET(       9)
      COMMON /VB    / VB    (       3)
      COMMON /MUP   / MUP   (       3)
      COMMON /LJPAR / LJPAR (       6)
      COMMON /STKPAR/ STKPAR(       6)
      COMMON /MUVDIP/ MUVDIP(      21)
      COMMON /TRNSWT/ TRNSWT(      15)
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      COMMON /MULAND/ MULAND(       15)
      COMMON /MULDIP/ MULDIP(       21)
      COMMON /KVDIP / KVDIP (       21)
      COMMON /KLDIP / KLDIP (       21)

C     LOCATE PROCESS BEAD

      LPRO   = LOCATI (2)

C     LOCATE LABELLED COMMON DIRECTORY

      NBDIR  = IPLEX(LPRO+   50)
      LDIR   = LOCATI (NBDIR  )

C     LOCATE OFFSET LABELLED COMMON DIRECTORY

      NBCTB  = IPLEX(LPRO+   27)
      IF(NBCTB .NE. 0) LDIRX=LOCATI(NBCTB)
      NBEAD  = IPLEX(LDIR+      4)
      LOFF   = IPLEX(LDIR+      6)
      IF (LOFF .NE. IMISS) CALL RLOAD (ZC     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     10)
      LOFF   = IPLEX(LDIR+     12)
      IF (LOFF .NE. IMISS) CALL RLOAD (TC     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     16)
      LOFF   = IPLEX(LDIR+     18)
      IF (LOFF .NE. IMISS) CALL RLOAD (PC     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     22)
      LOFF   = IPLEX(LDIR+     24)
      IF (LOFF .NE. IMISS) CALL RLOAD (MW     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     28)
      LOFF   = IPLEX(LDIR+     30)
      IF (LOFF .NE. IMISS) CALL RLOAD (PLXANT ,NBEAD ,   27 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     34)
      LOFF   = IPLEX(LDIR+     36)
      IF (LOFF .NE. IMISS) CALL RLOAD (TB     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     40)
      LOFF   = IPLEX(LDIR+     42)
      IF (LOFF .NE. IMISS) CALL RLOAD (CPIG   ,NBEAD ,   33 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     46)
      LOFF   = IPLEX(LDIR+     48)
      IF (LOFF .NE. IMISS) CALL RLOAD (DHVLWT ,NBEAD ,   15 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     52)
      LOFF   = IPLEX(LDIR+     54)
      IF (LOFF .NE. IMISS) CALL RLOAD (OMEGA  ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     58)
      LOFF   = IPLEX(LDIR+     60)
      IF (LOFF .NE. IMISS) CALL RLOAD (DHFORM ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     64)
      LOFF   = IPLEX(LDIR+     66)
      IF (LOFF .NE. IMISS) CALL RLOAD (DGFORM ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     70)
      LOFF   = IPLEX(LDIR+     72)
      IF (LOFF .NE. IMISS) CALL RLOAD (VLSTD  ,NBEAD ,    9 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     76)
      LOFF   = IPLEX(LDIR+     78)
      IF (LOFF .NE. IMISS) CALL RLOAD (SG     ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     82)
      LOFF   = IPLEX(LDIR+     84)
      IF (LOFF .NE. IMISS) CALL RLOAD (API    ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     88)
      LOFF   = IPLEX(LDIR+     90)
      IF (LOFF .NE. IMISS) CALL RLOAD (WATSOL ,NBEAD ,   15 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     94)
      LOFF   = IPLEX(LDIR+     96)
      IF (LOFF .NE. IMISS) CALL RLOAD (CHARGE ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+    100)
      LOFF   = IPLEX(LDIR+    102)
      IF (LOFF .NE. IMISS) CALL RLOAD (HIGPY  ,NBEAD ,   30 ,LOFF  )
      NBEAD  = IPLEX(LDIR+    106)
      LOFF   = IPLEX(LDIR+    108)
      IF (LOFF .NE. IMISS) CALL RLOAD (PSEUDO ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+    112)
      LOFF   = IPLEX(LDIR+    114)
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IF (LOFF .NE. IMISS) CALL RLOAD (CPIGDP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      118)
LOFF   = IPLEX(LDIR+      120)
IF (LOFF .NE. IMISS) CALL RLOAD (ATOMNO ,NBEAD ,   15 ,LOFF  )
NBEAD  = IPLEX(LDIR+      124)
LOFF   = IPLEX(LDIR+      126)
IF (LOFF .NE. IMISS) CALL RLOAD (NOATOM ,NBEAD ,   15 ,LOFF  )
NBEAD  = IPLEX(LDIR+      130)
LOFF   = IPLEX(LDIR+      132)
IF (LOFF .NE. IMISS) CALL RLOAD (CPIXP1 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      136)
LOFF   = IPLEX(LDIR+      138)
IF (LOFF .NE. IMISS) CALL RLOAD (CPIXP2 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      142)
LOFF   = IPLEX(LDIR+      144)
IF (LOFF .NE. IMISS) CALL RLOAD (CPIXP3 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      148)
LOFF   = IPLEX(LDIR+      150)
IF (LOFF .NE. IMISS) CALL RLOAD (VC     ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      154)
LOFF   = IPLEX(LDIR+      156)
IF (LOFF .NE. IMISS) CALL RLOAD (RKTZRA ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      160)
LOFF   = IPLEX(LDIR+      162)
IF (LOFF .NE. IMISS) CALL RLOAD (RKTKIJ ,NBEAD ,    9 ,LOFF  )
NBEAD  = IPLEX(LDIR+      166)
LOFF   = IPLEX(LDIR+      168)
IF (LOFF .NE. IMISS) CALL RLOAD (VCRKT  ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      172)
LOFF   = IPLEX(LDIR+      174)
IF (LOFF .NE. IMISS) CALL RLOAD (VLRKTA ,NBEAD ,    9 ,LOFF  )
NBEAD  = IPLEX(LDIR+      178)
LOFF   = IPLEX(LDIR+      180)
IF (LOFF .NE. IMISS) CALL RLOAD (RACKET ,NBEAD ,    9 ,LOFF  )
NBEAD  = IPLEX(LDIR+      184)
LOFF   = IPLEX(LDIR+      186)
IF (LOFF .NE. IMISS) CALL RLOAD (VB     ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      190)
LOFF   = IPLEX(LDIR+      192)
IF (LOFF .NE. IMISS) CALL RLOAD (MUP    ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      196)
LOFF   = IPLEX(LDIR+      198)
IF (LOFF .NE. IMISS) CALL RLOAD (LJPAR  ,NBEAD ,    6 ,LOFF  )
NBEAD  = IPLEX(LDIR+      202)
LOFF   = IPLEX(LDIR+      204)
IF (LOFF .NE. IMISS) CALL RLOAD (STKPAR ,NBEAD ,    6 ,LOFF  )
NBEAD  = IPLEX(LDIR+      208)
LOFF   = IPLEX(LDIR+      210)
IF (LOFF .NE. IMISS) CALL RLOAD (MUVDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      214)
LOFF   = IPLEX(LDIR+      216)
IF (LOFF .NE. IMISS) CALL RLOAD (TRNSWT ,NBEAD ,   15 ,LOFF  )
NBEAD  = IPLEX(LDIR+      220)
LOFF   = IPLEX(LDIR+      222)
IF (LOFF .NE. IMISS) CALL RLOAD (MULAND ,NBEAD ,   15 ,LOFF  )
NBEAD  = IPLEX(LDIR+      226)
LOFF   = IPLEX(LDIR+      228)
IF (LOFF .NE. IMISS) CALL RLOAD (MULDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      232)
LOFF   = IPLEX(LDIR+      234)
IF (LOFF .NE. IMISS) CALL RLOAD (KVDIP  ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      238)
LOFF   = IPLEX(LDIR+      240)
IF (LOFF .NE. IMISS) CALL RLOAD (KLDIP  ,NBEAD ,   21 ,LOFF  )
CALL UNLOCK (NBDIR  )
IF(NBCTB .NE. 0) CALL UNLOCK(NBCTB)
RETURN
END


SUBROUTINE PCLD2
IMPLICIT REAL*8(A-H,O-Z)
COMMON /PLEX  / IPLEX(1)
COMMON /GLOBAL/ IDUMMY(7), IMISS
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```
C     DECLARE SYSTEM COMMONS

      COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
     1        NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
     1        NCCASS ,IDXWAT ,NG
      REAL*8 DVBLNC
     * ,DLWC   ,CHI    ,SIGDIP ,THRSWT ,NATOM  ,DHAQFM ,WAGNER ,CPIGYM
     * ,HCOM   ,DNLDIP ,PSANT  ,CPSPO1 ,DHSFRM ,CPSDIP ,CPSXP1 ,CPSXP2
     * ,CPSXP3 ,CPSXP4 ,CPSXP5 ,CPSXP6 ,CPSXP7 ,DGSFRM ,VSPOLY ,DNSDIP
     * ,KSPOLY ,TCPR   ,PCPR   ,OMGPR  ,PRKIJ  ,ESPRA  ,ESPRB  ,ESPRC
     * ,ESPRD  ,ESRKA  ,ESRKB  ,ESPRA0 ,ESPRB0 ,ESPRC0 ,DHVLDP

C     DELCARE PROPERTY COMMONS

      COMMON /DVBLNC/ DVBLNC(      3)
      COMMON /DLWC  / DLWC  (      3)
      COMMON /CHI   / CHI   (      3)
      COMMON /SIGDIP/ SIGDIP(     21)
      COMMON /THRSWT/ THRSWT(     24)
      COMMON /NATOM / NATOM (     33)
      COMMON /DHAQFM/ DHAQFM(      3)
      COMMON /WAGNER/ WAGNER(     12)
      COMMON /CPIGYM/ CPIGYM(     12)
      COMMON /HCOM  / HCOM  (      3)
      COMMON /DNLDIP/ DNLDIP(     21)
      COMMON /PSANT / PSANT (     15)
      COMMON /CPSPO1/ CPSPO1(     24)
      COMMON /DHSFRM/ DHSFRM(      3)
      COMMON /CPSDIP/ CPSDIP(     21)
      COMMON /CPSXP1/ CPSXP1(     30)
      COMMON /CPSXP2/ CPSXP2(     30)
      COMMON /CPSXP3/ CPSXP3(     30)
      COMMON /CPSXP4/ CPSXP4(     30)
      COMMON /CPSXP5/ CPSXP5(     30)
      COMMON /CPSXP6/ CPSXP6(     30)
      COMMON /CPSXP7/ CPSXP7(     30)
      COMMON /DGSFRM/ DGSFRM(      3)
      COMMON /VSPOLY/ VSPOLY(     21)
      COMMON /DNSDIP/ DNSDIP(     21)
      COMMON /KSPOLY/ KSPOLY(     21)
      COMMON /TCPR  / TCPR  (      3)
      COMMON /PCPR  / PCPR  (      3)
      COMMON /OMGPR / OMGPR (      3)
      COMMON /PRKIJ / PRKIJ (      9)
      COMMON /ESPRA / ESPRA (      9)
      COMMON /ESPRB / ESPRB (      3)
      COMMON /ESPRC / ESPRC (      3)
      COMMON /ESPRD / ESPRD (      3)
      COMMON /ESRKA / ESRKA (      3)
      COMMON /ESRKB / ESRKB (      3)
      COMMON /ESPRA0/ ESPRA0(      3)
      COMMON /ESPRB0/ ESPRB0(      3)
      COMMON /ESPRC0/ ESPRC0(      3)
      COMMON /DHVLDP/ DHVLDP(     21)

C     LOCATE PROCESS BEAD

      LPRO   = LOCATI (2)

C     LOCATE LABELLED COMMON DIRECTORY

      NBDIR  = IPLEX(LPRO+    50)
      LDIR   = LOCATI (NBDIR  )

C     LOCATE OFFSET LABELLED COMMON DIRECTORY

      NBCTB  = IPLEX(LPRO+    27)
      IF(NBCTB .NE. 0) LDIRX=LOCATI(NBCTB)
      NBEAD  = IPLEX(LDIR+     244)
      LOFF   = IPLEX(LDIR+     246)
      IF (LOFF .NE. IMISS) CALL RLOAD (DVBLNC ,NBEAD ,    3 ,LOFF  )
      NBEAD  = IPLEX(LDIR+     250)
      LOFF   = IPLEX(LDIR+     252)
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IF (LOFF .NE. IMISS) CALL RLOAD (DLWC   ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      256)
LOFF   = IPLEX(LDIR+      258)
IF (LOFF .NE. IMISS) CALL RLOAD (CHI    ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      262)
LOFF   = IPLEX(LDIR+      264)
IF (LOFF .NE. IMISS) CALL RLOAD (SIGDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      268)
LOFF   = IPLEX(LDIR+      270)
IF (LOFF .NE. IMISS) CALL RLOAD (THRSWT ,NBEAD ,   24 ,LOFF  )
NBEAD  = IPLEX(LDIR+      274)
LOFF   = IPLEX(LDIR+      276)
IF (LOFF .NE. IMISS) CALL RLOAD (NATOM  ,NBEAD ,   33 ,LOFF  )
NBEAD  = IPLEX(LDIR+      280)
LOFF   = IPLEX(LDIR+      282)
IF (LOFF .NE. IMISS) CALL RLOAD (DHAQFM ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      286)
LOFF   = IPLEX(LDIR+      288)
IF (LOFF .NE. IMISS) CALL RLOAD (WAGNER ,NBEAD ,   12 ,LOFF  )
NBEAD  = IPLEX(LDIR+      292)
LOFF   = IPLEX(LDIR+      294)
IF (LOFF .NE. IMISS) CALL RLOAD (CPIGYM ,NBEAD ,   12 ,LOFF  )
NBEAD  = IPLEX(LDIR+      298)
LOFF   = IPLEX(LDIR+      300)
IF (LOFF .NE. IMISS) CALL RLOAD (HCOM   ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      304)
LOFF   = IPLEX(LDIR+      306)
IF (LOFF .NE. IMISS) CALL RLOAD (DNLDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      310)
LOFF   = IPLEX(LDIR+      312)
IF (LOFF .NE. IMISS) CALL RLOAD (PSANT  ,NBEAD ,   15 ,LOFF  )
NBEAD  = IPLEX(LDIR+      316)
LOFF   = IPLEX(LDIR+      318)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSPO1 ,NBEAD ,   24 ,LOFF  )
NBEAD  = IPLEX(LDIR+      322)
LOFF   = IPLEX(LDIR+      324)
IF (LOFF .NE. IMISS) CALL RLOAD (DHSFRM ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      328)
LOFF   = IPLEX(LDIR+      330)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      334)
LOFF   = IPLEX(LDIR+      336)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP1 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      340)
LOFF   = IPLEX(LDIR+      342)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP2 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      346)
LOFF   = IPLEX(LDIR+      348)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP3 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      352)
LOFF   = IPLEX(LDIR+      354)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP4 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      358)
LOFF   = IPLEX(LDIR+      360)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP5 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      364)
LOFF   = IPLEX(LDIR+      366)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP6 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      370)
LOFF   = IPLEX(LDIR+      372)
IF (LOFF .NE. IMISS) CALL RLOAD (CPSXP7 ,NBEAD ,   30 ,LOFF  )
NBEAD  = IPLEX(LDIR+      376)
LOFF   = IPLEX(LDIR+      378)
IF (LOFF .NE. IMISS) CALL RLOAD (DGSFRM ,NBEAD ,    3 ,LOFF  )
NBEAD  = IPLEX(LDIR+      382)
LOFF   = IPLEX(LDIR+      384)
IF (LOFF .NE. IMISS) CALL RLOAD (VSPOLY ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      388)
LOFF   = IPLEX(LDIR+      390)
IF (LOFF .NE. IMISS) CALL RLOAD (DNSDIP ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      394)
LOFF   = IPLEX(LDIR+      396)
IF (LOFF .NE. IMISS) CALL RLOAD (KSPOLY ,NBEAD ,   21 ,LOFF  )
NBEAD  = IPLEX(LDIR+      400)
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      LOFF  = IPLEX(LDIR+    402)
      IF (LOFF .NE. IMISS) CALL RLOAD (TCPR   ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    406)
      LOFF  = IPLEX(LDIR+    408)
      IF (LOFF .NE. IMISS) CALL RLOAD (PCPR   ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    412)
      LOFF  = IPLEX(LDIR+    414)
      IF (LOFF .NE. IMISS) CALL RLOAD (OMGPR  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    418)
      LOFF  = IPLEX(LDIR+    420)
      IF (LOFF .NE. IMISS) CALL RLOAD (PRKIJ  ,NBEAD ,    9 ,LOFF  )
      NBEAD = IPLEX(LDIR+    424)
      LOFF  = IPLEX(LDIR+    426)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRA  ,NBEAD ,    9 ,LOFF  )
      NBEAD = IPLEX(LDIR+    430)
      LOFF  = IPLEX(LDIR+    432)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRB  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    436)
      LOFF  = IPLEX(LDIR+    438)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRC  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    442)
      LOFF  = IPLEX(LDIR+    444)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRD  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    448)
      LOFF  = IPLEX(LDIR+    450)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESRKA  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    454)
      LOFF  = IPLEX(LDIR+    456)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESRKB  ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    460)
      LOFF  = IPLEX(LDIR+    462)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRA0 ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    466)
      LOFF  = IPLEX(LDIR+    468)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRB0 ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    472)
      LOFF  = IPLEX(LDIR+    474)
      IF (LOFF .NE. IMISS) CALL RLOAD (ESPRC0 ,NBEAD ,    3 ,LOFF  )
      NBEAD = IPLEX(LDIR+    478)
      LOFF  = IPLEX(LDIR+    480)
      IF (LOFF .NE. IMISS) CALL RLOAD (DHVLDP ,NBEAD ,   21 ,LOFF  )
      CALL UNLOCK (NBDIR  )
      IF(NBCTB .NE. 0) CALL UNLOCK(NBCTB)
      RETURN
      END


      SUBROUTINE PCLD3
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PLEX  / IPLEX(1)
      COMMON /GLOBAL/ IDUMMY(7), IMISS

C     DECLARE SYSTEM COMMONS

      COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
     1               NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
     1               NCCASS ,IDXWAT ,NG
      REAL*8 DHVLB
     * ,GAMUS  ,DHLS   ,WHNRY  ,PHISPC ,GAMSPC ,GAMMAS ,PHIVMX ,PHILMX
     * ,PHISMX ,PHIV   ,PHIL   ,PHIS   ,HV     ,HL     ,HS     ,GV
     * ,GL     ,GS     ,SV     ,SL     ,SS     ,VV     ,VL     ,VS
     * ,VVINT  ,VLINT  ,VSINT  ,DHV    ,DHL    ,DHS    ,DHVPC  ,DHLPC
     * ,DHSPC  ,HNRY   ,PHILPC ,GAMPC  ,GAMPC1 ,HNRYPC ,GAMMA

C     DELCARE PROPERTY COMMONS

      COMMON /DHVLB / DHVLB (       3)
      COMMON /GAMUS / GAMUS (       9)
      COMMON /DHLS  / DHLS  (       9)
      COMMON /WHNRY / WHNRY (       9)
      COMMON /PHISPC/ PHISPC(       9)
      COMMON /GAMSPC/ GAMSPC(       9)
      COMMON /GAMMAS/ GAMMAS(       9)
      COMMON /PHIVMX/ PHIVMX(       9)
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      COMMON /PHILMX/ PHILMX(      9)
      COMMON /PHISMX/ PHISMX(      9)
      COMMON /PHIV  / PHIV  (      9)
      COMMON /PHIL  / PHIL  (      9)
      COMMON /PHIS  / PHIS  (      9)
      COMMON /HV    / HV    (      9)
      COMMON /HL    / HL    (      9)
      COMMON /HS    / HS    (      9)
      COMMON /GV    / GV    (      9)
      COMMON /GL    / GL    (      9)
      COMMON /GS    / GS    (      9)
      COMMON /SV    / SV    (      9)
      COMMON /SL    / SL    (      9)
      COMMON /SS    / SS    (      9)
      COMMON /VV    / VV    (      9)
      COMMON /VL    / VL    (      9)
      COMMON /VS    / VS    (      9)
      COMMON /VVINT / VVINT (      9)
      COMMON /VLINT / VLINT (      9)
      COMMON /VSINT / VSINT (      9)
      COMMON /DHV   / DHV   (      9)
      COMMON /DHL   / DHL   (      9)
      COMMON /DHS   / DHS   (      9)
      COMMON /DHVPC / DHVPC (      9)
      COMMON /DHLPC / DHLPC (      9)
      COMMON /DHSPC / DHSPC (      9)
      COMMON /HNRY  / HNRY  (      9)
      COMMON /PHILPC/ PHILPC(      9)
      COMMON /GAMPC / GAMPC (      9)
      COMMON /GAMPC1/ GAMPC1(      9)
      COMMON /HNRYPC/ HNRYPC(      9)
      COMMON /GAMMA / GAMMA (      9)

C     LOCATE PROCESS BEAD

      LPRO   = LOCATI (2)

C     LOCATE LABELLED COMMON DIRECTORY

      NBDIR  = IPLEX(LPRO+    50)
      LDIR   = LOCATI (NBDIR  )

C     LOCATE OFFSET LABELLED COMMON DIRECTORY

      NBCTB  = IPLEX(LPRO+    27)
      IF(NBCTB .NE. 0) LDIRX=LOCATI(NBCTB)
      NBEAD  = IPLEX(LDIR+     484)
      LOFF   = IPLEX(LDIR+     486)
      IF (LOFF .NE. IMISS) CALL RLOAD (DHVLB  ,NBEAD ,     3 ,LOFF  )
      CALL UNLOCK (NBDIR  )
      IF(NBCTB .NE. 0) CALL UNLOCK(NBCTB)
      RETURN
      END


      SUBROUTINE PCLD4
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PLEX  / IPLEX(1)
      COMMON /GLOBAL/ IDUMMY(7), IMISS

C     DECLARE SYSTEM COMMONS

      COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
     1              NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
     1              NCCASS ,IDXWAT ,NG
      REAL*8 PL
     * ,PS     ,DHVL   ,VLPM   ,HIG    ,SIG    ,GIG    ,DGV    ,DGL
     * ,DGS    ,DGVPC  ,DGLPC  ,DGSPC  ,DSV    ,DSL    ,DSS    ,PI
     * ,MUV    ,MUL    ,KV     ,KL     ,KS     ,DVMX   ,DLMX   ,SIGL
     * ,DHVS   ,PORPI  ,GAMINF ,WSL    ,LNKI   ,GMTRUE ,XTRUE  ,ITRUE
     * ,IDXSLT ,XSALT  ,DL     ,DV

C     DELCARE PROPERTY COMMONS
```

```
      COMMON /PL    / PL    (       9)
      COMMON /PS    / PS    (       9)
      COMMON /DHVL  / DHVL  (       9)
      COMMON /VLPM  / VLPM  (       9)
      COMMON /HIG   / HIG   (       9)
      COMMON /SIG   / SIG   (       9)
      COMMON /GIG   / GIG   (       9)
      COMMON /DGV   / DGV   (       9)
      COMMON /DGL   / DGL   (       9)
      COMMON /DGS   / DGS   (       9)
      COMMON /DGVPC / DGVPC (       9)
      COMMON /DGLPC / DGLPC (       9)
      COMMON /DGSPC / DGSPC (       9)
      COMMON /DSV   / DSV   (       9)
      COMMON /DSL   / DSL   (       9)
      COMMON /DSS   / DSS   (       9)
      COMMON /PI    / PI    (       9)
      COMMON /MUV   / MUV   (       3)
      COMMON /MUL   / MUL   (       3)
      COMMON /KV    / KV    (       3)
      COMMON /KL    / KL    (       3)
      COMMON /KS    / KS    (       3)
      COMMON /DVMX  / DVMX  (       3)
      COMMON /DLMX  / DLMX  (       3)
      COMMON /SIGL  / SIGL  (       3)
      COMMON /DHVS  / DHVS  (       9)
      COMMON /PORPI / PORPI (       3)
      COMMON /GAMINF/ GAMINF(      27)
      COMMON /WSL   / WSL   (       9)
      COMMON /LNKI  / LNKI  (       6)
      COMMON /GMTRUE/ GMTRUE(       3)
      COMMON /XTRUE / XTRUE (       9)
      COMMON /ITRUE / ITRUE (       9)
      COMMON /IDXSLT/ IDXSLT(       3)
      COMMON /XSALT / XSALT (       3)
      COMMON /DL    / DL    (       9)
      COMMON /DV    / DV    (       9)
      COMMON /FRMULA/ FRMULA(       9)
      COMMON /IDSCC / IDSCC (       6)

C     LOCATE PROCESS BEAD

      LPRO   = LOCATI (2)

C     LOCATE LABELLED COMMON DIRECTORY

      NBDIR  = IPLEX(LPRO+    50)
      LDIR   = LOCATI (NBDIR  )

C     LOCATE OFFSET LABELLED COMMON DIRECTORY

      NBCTB  = IPLEX(LPRO+    27)
      IF(NBCTB .NE. 0) LDIRX=LOCATI(NBCTB)
      NBEAD  = IPLEX(LDIR+      946)
      LOFF   = IPLEX(LDIR+      948)
      IF (LOFF .NE. IMISS) CALL ILOAD (FRMULA ,NBEAD ,    9 ,LOFF  )
      NBEAD  = IPLEX(LDIR+      952)
      LOFF   = IPLEX(LDIR+      954)
      IF (LOFF .NE. IMISS) CALL ILOAD (IDSCC  ,NBEAD ,    6 ,LOFF  )
      CALL UNLOCK (NBDIR  )
      IF(NBCTB .NE. 0) CALL UNLOCK(NBCTB)
      RETURN
      END


      SUBROUTINE PCLD5
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PLEX  / IPLEX(1)
      COMMON /GLOBAL/ IDUMMY(7), IMISS

C     DECLARE SYSTEM COMMONS

      COMMON /NCOMP / NCC    ,NNCC   ,NC     ,NAC,NACC,
     1         NVCP   ,NVNCP  ,NVACC  ,NVANCC,NASSAY,
```

```
     1            NCCASS ,IDXWAT ,NG
      INTEGER FRMULA
C     DELCARE PROPERTY COMMONS

      COMMON /IDSCID/ IDSCID(       6)

C     LOCATE PROCESS BEAD

      LPRO   = LOCATI (2)

C     LOCATE LABELLED COMMON DIRECTORY

      NBDIR  = IPLEX(LPRO+    50)
      LDIR   = LOCATI (NBDIR  )

        LOCATE OFFSET LABELLED COMMON DIRECTORY

      NBCTB  = IPLEX(LPRO+    27)
      IF(NBCTB .NE. 0) LDIRX=LOCATI(NBCTB)
      NBEAD  = IPLEX(LDIR+      964)
      LOFF   = IPLEX(LDIR+      966)
      IF (LOFF .NE. IMISS) CALL ILOAD (IDSCID ,NBEAD ,     6 ,LOFF  )
      CALL UNLOCK (NBDIR  )
      IF(NBCTB .NE. 0) CALL UNLOCK(NBCTB)
      RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                               C
C          Data needed to overcome expiration date          C
C                                               C
C          Done By: Eng. Rami Awad Al-Tarawnah          C
C                                               C
C          THIS FILE HAS TO BE GIVEN TO THE COMPUTER          C
C          EXACTLY AS IT IS WRITTEN HERE, ANY CHANGE IN          C
C          THE FILE, EVEN A SPACE WOULD LEAD TO AN ERROR          C
C          MASSAGE SAYING THAT ASPEN IS EXPIRED          C
C                                               C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

MMSUMMARY8.5-4
 IDSET RUNID (PROPERTIES) (114 *5)
 IDSET IT (PROPERTIES) (117 *6 119 *6 115 *1)
 LSET RUNID (%RUNID)
 LSET IT (%IT)
 IDSET VERS (PROPERTIES) (345 *6 346 *6 347 *6 348 *6 355 *6)
 LSET VERS (%VERS)
 DSET RUN-STATUS VERS @VERS ( "8.5-4" "DEC-VAX" "U-JORDAN" "TARAWNAH" "ENG" )
 DSET RUNID @RUNID (PROP)
 DSET RUN-STATUS IT @IT ( "DECEMBER 9, 1995   9:00:06 P.M."
 "STUDENT:[ME.TARAWNAH.DATA.TEST.PROP]PROP.INP;2 " 1)
 IDSET ID_NCC (COMPONENTS) (PROP NBUT ISBUT)
 IDSET STATUS (PROPERTIES) (125 *1 126 *1 127 *1 128 *1 129 *1 130 *1)
 LSET STATUS (%STATUS)
 IDSET PPSTAT (PROPERTIES) (272 *1)
 LSET PPSTAT (%PPSTAT)
 IDSET DESC (PROPERTIES) (113 *6)
 LSET DESC (%DESC)
 IDSET IDPH_V (PHASE) (VAPOR)
 IDSET IDPH_L (PHASE) (LIQUID)
 IDSET IDPH_S (PHASE) (SOLID)
 IDSET IDPH_L1 (PHASE) (LIQUID_1)
 IDSET IDPH_T (PHASE) (TOTAL)
 IDSET IDPH_L2 (PHASE) (LIQUID_2)
 IDSET IDWET (BASIS) (WET)
 IDSET IDDRY (BASIS) (DRY)
 IDSET SP (SPDATA) (118 *6)
 LSET SP (%SP)
 IDSET SPSTAT (SPSTAT) (116 *1)
 LSET SPSTAT ( %SPSTAT)
 IDSET IDERR (PROPERTIES) (131 *1)
 DSET RUN-STATUS SP @SP ( "DECEMBER 9, 1995 9:03:17 P.M." )
 IDSET ID_1 (PROPERTIES) (7002 *2 <20> 7001 *2 <22> )
 IDSET ID_2 ( PROPERTIES, PHASE) (2002 *2 <39> , TOTAL 7004 *2 , TOTAL )
 IDSET ID_3 (NPOINT) ( #108)
 LSET L_1 ((%IDERR %ID_1 %ID_2) & %ID_3)
 DSET PROP-TABLE FLASHCURVE TABLE1 PROPTAB @L_1 (0 2.50700000D+02 <2>
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 6.40000000D+00 <4> -5.21127506D+08 <1> 1.00000000D+00 0 2.50700000D+02 <2>
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```

```
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```

```
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7.00000000D+00 <4> -5.03700501D+08 <1> 0.D0 0 8.72000000D+01 <2>
7.00000000D+00 <4> -5.03700501D+08 <1> 0.D0 )
DSET RUN-STATUS PPSTAT @PPSTAT (0)
DSET SPSTAT @SPSTAT (0)
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                          C
C        Aspen definition of the process to be calculated    C
C                                          C
C                                          C
C         Done By: Eng. Rami Awad Al-Tarawnah          C
C                                          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC


COMPONENTS PROP PROPANE/NBUT N-BUTANE/ISBUT ISOBUTANE
IN-UNITS SI  TEMPERATURE=C PRESSURE=PSI
OUT-UNITS SI TEMPERATURE=C PRESSURE=PSI MASS-ENTHALPY='KJ/KG'

PROPERTIES SYSOP4

PROP-SET LIST1 HMX LFRAC PHASE=T

PROP-TABLE TABLE1 FLASHCURVE
  MASS-FLOW PROP 1/NBUT 0/ISBUT 0
  STATE PRES=152.7 TEMP=0
  VARY PRES
        RANGE LIST=250.7 87.2
  VARY TEMP
        RANGE LIST= 6.4   6.4   6.3   6     6.1   6     5.6   5.8   5.8   &
                35    35.5  35.3  34.7  34.9  35    34.3  34.3  34.9  &
                98.9  99.8  100.1 100   100.7 101   100.7 100.7 101   &
                120.9 122.2 122.2 122.5 122.9 123.3 123.2 123.2 123.6 &
                49.6  50.4  50.3  50.9  51.2  51.1  51.5  51.8  51.7  &
                27.2  7.1   7.1   6.9   7.2   7.2   6.8   7     7
  TABULATE PROPERTIES=LIST1
```

APPENDIX C

PHASE EQUILIBIUM

C.1 Introduction

To make a study of performance for a system, is usually a trivial task. That is when the working fluid has tables and all the needed properties available. This is not the case in this work, where there is no data what ever regarding the mixtures used, since it requires lots of complex calculations for fugacity of the mixture, in which without, there is no way to get the required properties - physical or thermodynamic. Even previous work at the university, did not take the fugacity into account, and both calculated the properties simply by the general rule: $P_m=x_1P_1+x_2P_2$.

C.2 Fugacity. Fugacity Coefficient.

The Gibbs free energy is a property of particular importance in chemical thermodynamics, because of its unique relation to temperature and pressure through the basic equation

$$dG = -SdT + VdP \qquad \text{(C-1)}$$

Applied to 1(mol) of pure fluid I at a constant T, this equation becomes

$$dG_i = V_i dP \quad \text{(constant T)} \qquad \text{(C-2)}$$

For an ideal gas, V_i=RT/P and

$$dG_i = RT\frac{dP}{p} \quad \text{(constant T)}$$

or

$$dG_i = RTd\ln P \quad \text{(constant T)}$$

Although correct only for ideal gas, the simplicity of this equation suggests that it would be convenient to replace the pressure P by a new function, which by definition makes the resulting equation universally valid. Thus

$$dG_i = RTd\ln f_i \text{ (constant T)} \qquad \text{(C-3)}$$

where f_i is called the fugacity of pure i, is a property of i with the units of pressure. Equation (C-3) provides only partial definition of f_i, for it allows calculation of change in f_i but not the absolute values. For the special case of an ideal gas, dG_i as given by equation (C-3) may be set to equal to $RTd\ln P$, the particular expression for dG_i applicable to an ideal gas:

$$RTd\ln f_i = RTd\ln P \quad \text{(ideal gas)}$$

Integration gives

$$\ln f_i = \ln P + \ln c$$

where c is a constant. Then to complete the definition of f_i, we put c=1; that is the fugacity is defined so that for an ideal gas it is equal to pressure. Since the only state of a real gas that represents an ideal-gas state is that at zero pressure, the formal statement the complete the definition of f_i is

$$\lim_{P \to 0} \frac{f_i}{P} = 1 \qquad \text{(C-4)}$$

Equation (C-3) and (C-4) together provide the definition of the fugacity of a pure substance.

The fugacity of a component in solution $\hat{f}_i$ is defined in a similar way. The expression analogous to equation (C-3) is:

$$d\overline{G}_i = RTd\ln\hat{f}_i \text{ (constant T)} \qquad \text{(C-5)}$$

The definition is completed by the specification, analogous to Equation (C-4), that

$$\lim_{P \to 0} \frac{\hat{f}_i}{x_i P} = 1 \qquad \text{(C-6)}$$

Since an ideal-gas mixture behaves like a real-gas mixture at P→o, Equation (C-6) may be written for any component in a mixture of ideal cases:

$$\hat{f}_i = x_i P \text{ (ideal gas)} \qquad \text{(C-7)}$$

The product x_iP, known as partial pressure p_i of component i in the gas mixture is frequently used in phase and chemical-reaction equilibrium. Since, by definition $p_i=x_iP$, we can write

$$\sum P_i = \sum x_i P = P \sum x_i = P \qquad \text{(C-8)}$$

That is the pressure of a gas mixture is equal to the sum of the partial pressure of its individual components.

The total pressure exerted by 1(mol) of a mixture of ideal gas is

$$P = \frac{RT}{V}$$

where V is the molar volume of the mixture. If the mixture contains xi moles of component i, then this amount of pure i occupying the same volume at the same temperature T exerts a *pure-component pressure* given by

$$P_{pure\_i} = \frac{x_i RT}{V} = x_i P = p_i$$

Thus, the partial pressure is equal to the pure-component pressure for mixtures of ideal gases. However, for real gases this is not true, and the *partial pressure has no physical significance.*

When the pressure approaches zero, the molar volume of the gas approaches infinity. Equation (C-2) therefor leads one to conclude that the Gibbs free energy approaches minus infinity as P→0. On the other hand, Equation (C-4) defines the fugacity so it approaches the pressure as P→0. The bounded nature of the fugacity is a major reason that is more useful than Gibbs free energy in many applications.

The Fugacity coefficient is defined as the ratio of the fugacity of a material to its pressure. For the two cases of pure component and a component in a homogeneous mixture, the defining equations are:

For a pure substance:

$$\phi_i = \frac{f_i}{P} \tag{C-9}$$

For the component in a solution:

$$\hat{\phi}_i = \frac{\hat{f}_i}{x_i P} \tag{C-10}$$

Since fugacity has the units of pressure, the fugacity coefficients are dimensionless.

Values of ϕ_i and $\hat{\phi}_i$ are usually calculated from PVT data. The necessary equations and their derivations are similar, so I will present the derivation for ϕ_i only. Equation (C-2) and (C-3) may be combined to give

$$RTd\ln f_i = V_i dP \quad \text{(constant T)} \tag{C-11}$$

Logarithmic differentiation of the defining expression for ϕ_i [equation(C-9)] yields

$$d\ln f_i = d\ln\phi_i + d\ln P = d\ln\phi_i + \frac{dP}{P}$$

Substitution of this expression for $d\ln f$ into equation (C-11) gives

$$d\ln\phi_i = \frac{PV_i}{RT}\frac{dP}{P} - \frac{dP}{P} \quad \text{(constant T)}$$

Since $Z_i = PV_i/RT$, we have

$$d\ln\phi_i = (Z_i - 1)\frac{dP}{P} \quad \text{(constant T)}$$

Finally, integration from the zero-pressure state, where $\phi_i = 1$ according to Equation (C-4), to the sate of pressure P gives the required equation:

$$Ln\phi_i = \int_0^P (Z_i - 1)\frac{dP}{p} \quad \text{(constant T)} \qquad \text{(C-12)}$$

Since the residual volume is related to the compressibility factor by the expression : $\Delta V_i' = V_i' - V_i = \frac{RT}{p} - V_i = \frac{RT}{P} - \frac{Z_i RT}{P} = -\frac{RT}{p}(Z_i - 1)$

Equation (C-12) may be written in an equivalent form as

$$\ln\phi_i = \frac{-1}{RT}\int_0^P \left(\frac{RT}{P} - V_i\right)dp = \frac{-1}{RT}\int_0^P \Delta V_i' dp \quad \text{(constant T)} \qquad \text{(C-13)}$$

An equation for $\hat{\phi}_i$, analogous to Equation (C-12), may be derived in a similar way:

$$\ln\hat{\phi}_i = \int_0^P (\bar{Z}_i - 1)\frac{dP}{P} \quad \text{(constant T)} \qquad \text{(C-14)}$$

Since $\bar{Z}_i = P\bar{V}_i / RT$, another form of Equation (C-14) is given by:

$$\ln\hat{\phi}_i = \frac{-1}{RT}\int_o^P \left(\frac{RT}{P} - \bar{V}_i\right)dP \quad \text{(constant T,x)}$$

Note that for an ideal gas $Z_i = \bar{Z}_i = 1$, and Equations (C-11) and (C-13) then give

$$\phi_i = \hat{\phi}_i = 1 \qquad \text{(C-15)}$$

C-3 Criteria of equilibrium.

The equilibrium state of a closed system is that that state for which the total gibes free energy is a minimum with respect to all possible changes at the given T and P.

This criterion of equilibrium provides a general for determination of equilibrium states. One writes an expression for G^t as a function of the number of moles (mole numbers) of the components in the several phases, and then finds the set of values for the mole numbers which minimizes G^t, subject to the constraints of mass conservation. This procedure can be applied to problems of phase, chemical reaction , and combined phase and chemical reaction equilibrium; it is most useful for complex equilibrium problems.

At the equilibrium state deferential variations can accrue in the system at constant T and P without producing any change in G^t. Thus a general criterion for a system to be at equilibrium is that

$$(dG^t)_{T,P}=0 \qquad \text{(C-16)}$$

To apply this criterion, one develops for dG^t as the function of the mole numbers of the components in the various phases, and sets it equal to 0. The resulting equation along with those representing the conservation of mass allow solution for the mole numbers.

If we now restrict consideration to phase equilibrium, we can apply equation (C-16) to the development of more specialized and more directly usable equilibrium criteria. Consider two phases in equilibrium in a closed system. Each phase taken separately is an open system capable of mass transfer to the other. The variable composition system equation for the Gibbs function may there for be written for each phase as :

$$d(nG)^{\alpha} = -(nS)^{\alpha} dT + (nV)^{\alpha} dP + \sum(\mu_i^{\alpha} dn_i^{\alpha})$$

$$d(nG)^{\beta} = -(nS)^{\beta} dT + (nV)^{\beta} dP + \sum(\mu_i^{\beta} dn_i^{\beta})$$

where the superscripts α and β denote the two phases, and μ_i is given by $\mu_i = \left[\frac{\partial(nU)}{\partial n_i}\right]_{nV,nS,nj}$, and n_j indicates that all mole numbers except the *i*th are held constant.

Note that T and P have been assumed uniform throughout both phases. Addition of these equations gives dG^t and, if the equilibrium condition of equation (C-6) is imposed, the result is

$$(dG^t)_{T,P} = \sum(\mu_i^{\alpha} dn_i^{\alpha}) + \sum(\mu_i^{\beta} dn_i^{\beta}) = 0$$

However, the system is closed and without chemical reaction; material balances therefore require that

$$dn_i^{\beta} = -dn_i^{\alpha}$$

As a result, we have

$$\sum(\mu_i^\alpha - \mu_i^\alpha)dn_i^\alpha = 0$$

Since the quantities dn_i^α are independent and arbitrary, the only way that this equation can be satisfied in general is for each term to be separately zero; that is,

$$\mu_i^\alpha = \mu_i^\alpha$$

We may readily generalize this result to more than two successively considering the phases by pairs. The general result is expressed for π phases and N chemical species by

$$\mu_i^\alpha = \mu_i^\alpha = \ldots = \mu_i^\pi \text{ (i=1,2,...,N)} \qquad \text{(C-17)}$$

Equation (C-17) is a general criterion for phase equilibrium. It states that for multiple phases at the same T and P the equilibrium conditions is satisfied when the chemical potential of each chemical species in the system is the same in all the phases.

An alternative and equally general criterion for phase equilibrium is readily derived from equation (C-5); since $\mu_i = \overline{G}_i$, this equation may be written:

$$d\mu_i = RTd\ln\hat{f}_i \quad \text{(constant T)}$$

Integration gives

$$\mu_i = RT\ln\hat{f}_i + \theta_i$$

where θ_i is a constant that depends on temperature only. Since all phases are at the same temperature, substitution of the preceding equation for the μ_i's in Equation (C-17) leads immediately to

$$\hat{f}_i^{\alpha} = \hat{f}_i^{\beta} = \ldots = \hat{f}_i^{\pi} \quad (i=1,2,\ldots,N) \tag{C-18}$$

This last criterion for phase equilibrium that for multiple phases at the same T and P to be in equilibrium the fugacity of each component must be the same in all phases. It is Equation (C-18) that is of greatest practical utility for the solution of phase equilibrium problems.

C-4 The phase Rule

Consider a system made up of π phases containing N nonreacting chemical species. The number of degrees of freedom F at equilibrium is the difference between the number of variables needed to characterize the intensive state of the system and the number of independent equations that may be written connecting these variables. The phase rule variables are T, P, and N-1 mole fractions for each phase. The total number of these variables is $2+(N-1)(\pi)$. The masses of the phases are not phase rule variables, because the have no influence on the intensive state of the system.

The equations that may be written connecting the phase rule variables are given by equation (C-17) or (C-18). The number of independent phase equations represented is $(\pi-1)(N)$. These equations relate chemical potentials, which are functions of temperature, pressure, and composition; the equations therefore represent relations connecting the phase rule variables. Since F is given by the difference between the number of variables and the number of equations, we have

$$F=2+(N-1)(\quad \pi)-(\pi-1)(N)$$

or

$$F=2-\pi+N \tag{C-19}$$

C-5 Vapor-Liquid Equilibrium.

Vapor-liquid equilibrium (VLE) relationships are needed for the solution of many engineering problems. The required data can be, and often are, directly measured be experiment. However such measurement are difficult, even for binary systems, and they become increasingly tedious as the number of components grows. This is the incentive for the application of thermodynamics to the calculation of phase-equilibrium relation ships. However, thermodynamics dose not generate data; it provides only the mathematical frame work which allows maximum use of what ever data are available. Thus it forms the basis for systematic correlation, extension, generalization, evaluation, and interpretation of data. Moreover, it provides the means by which the prediction of various theories of molecular physics and statistical mechanics may be applied to practical prepuces.

The fundamental problem of VLE deals with a multi-component system of N nonreacting chemical species for which the phase-rule variables are T, P, N-1 liquid mole fractions, and N-1 vapor mole fraction. Thus there are 2N variables. Application of the phase rule yields F=N, and this means that for an equilibrium state only N of the 2N are independent. Once N phase-rule variables are specified, the remaining N variables can be determined, in principle, by simultaneous solution of the N equilibrium relations of the form of Equation (C-18)

$$\hat{f}_i^v = \hat{f}_i^l \quad (i=1,2,\ldots,N) \tag{C-20}$$

where the superscripts v and l denote the vapor and liquid phases.

In practice one usually specify either T or P and either the liquid-phase or the vapor-phase composition, fixing 1+(N-1)=N phase-rule variables. The remaining N variables are then subject to calculation provided that sufficient data are available to allow determination of all necessary thermodynamic properties.

The defining expression for the fugacity coefficient Equation (C-10) is written for each phase:

Vapor:

$$\hat{f}_i^v = \hat{\phi}_i^v y_i P$$

Liquid:

$$\hat{f}_i^l = \hat{\phi}_i^l x_i P$$

equation (C-9) now becomes

$$y_i\hat{\phi}_i^v = x_i\hat{\phi}_i^l \quad (i=1,2,\ldots,N) \tag{C-21}$$

The vapor and Liquid mole fractions yi and xi, quantities of physical reality, now appear in the equilibrium relation, but neither is explicit, because $\hat{\phi}_i$'s are functions of N complex relationships connecting T,P, and the xi's and yi's. Even for computer solution of these equations it is essential that the $\hat{\phi}_i$'s be expressed analytically as a function of T, P and composition. This requires an Equation of state which accurately represents the volumetric properties of both liquid and vapor phases throughout the range of temperature and pressures, and compositions of interest. Given such equation of state, Equation (C-14) provides the expression of the $\hat{\phi}_i$'s as a function of T, P, and compositions.

ملخص

أداء وحدات التبريد العاملة بمخلوطات من غازي البروبان والبيوتان بنسب مختلفة

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على الرغم من أن الخواص الثرماحية للهيدروكربونات النقية و أداءها كسوائل تبريد قد تمت دراستها منذ وقت طويل، إلا أن دراسة خصائص خلائط الهيدروكربونات لم تحظ بالدراسة الكافية. هذه الدراسة تناولت الأداء الحقيقي لخلائط مختلفة من البروبان، البيوتان، والأيزوبيوتان أثناء استخدامها في وحدة تبريد منفصلة. كما تم تصميم برنامج حاسوب، بالاعتماد على حزمة البرمجة "أسبين"، لإيجاد خصائص الخليط، وبالتالي تم إنشاء رسومات الـ P-H لهذه الخلائط.

لقد تم التوصل إلى أن زيادة نسبة البروبان في الخليط يؤدي إلى زيادة كفاءته كسائل تبريد، فعلى سبيل المثال عندما كانت نسبة البروبان ٩٠% كان معامل الكفاءة ٤,٢ بينما كفاءة غاز الـ R22 تساوي ٢,٨ عند نفس ظروف التشغيل وعلى نفس الجهاز. أيضا معاملات الأداء الأخرى للخليط كانت أفضل من تلك لغاز R22، كضغط التبخر ودرجة حرارة الطرد للضاغطة. حيث كانت تلك القيم على سبيل المثال ٤٨ psi و ٥٩ درجة مئوية لدى نسبة الـ ٧٠%، بالترتيب، مقارنة مع ٧٣,٥ psi و ١٢٣,٦ درجة مئوية لغاز R22.

تم شحن و تفريغ الوحدة التي تم استخدامها في هذه الدراسة، بالخلائط المختلفة، بدون اتخاذ أي إجراءات غير اعتيادية. و تمت دراسة الجهاز بالظروف الواقعية