PERFORMANCE OF A CHEST FREEZER USING PROPANE/BUTANE MIXTURE AS SUBSTITUTE REFRIGERANT TO R-134a

By

Abdalla Jamil Nofal

Supervisor

Dr. Mohammad Al-Saad, Prof.

Co-Supervisor

Dr. Mahmoud Hammad, Prof.

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Faculty of Graduate Studies

The University of Jordan

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Examination Committee	**Signature**
Prof. Mohammad Al-Saad, Chairman Prof. of Thermal Sciences - Mechanical Engineering	
Prof. Mahmoud Hammad, Assistant Supervisor Prof. of Thermal Power - Mechanical Engineering	
Prof. Ali Badran, Member Prof. of Thermal Power - Mechanical Engineering	
Dr. Ahmad Al-Salaymeh, Member Assist. Prof. of Fluid Mechanics - Mechanical Engineering	
Dr. Salem Nijmeh, Member Assist. Prof. of Thermal Sciences -Mechanical Engineering (The Hashemite University)	

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LIST OF NOMENCLATURES

COP	Coefficient of performance
Cp	Specific heat (kJ/kg.K)
h	Specific enthalpy (kJ/kg)
M	Mass (kg)
m*	Mass flow rate (g/s)
P	Pressure (kPa)
Q_{ref}	Refrigeration capacity (Watt)
q_{ref}	Refrigerating effect (kJ/kg.K)
T	Temperature (°C)
t	Time (sec)
W	Power consumption (Watt)
w	Compression work (kJ/kg)

LIST OF SUBSCRIPTS

a	Ambient
c	Condenser
e	Evaporator
co	Container

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigeration, and Air- Conditioning Engineers
CFC	Chlorofluorocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HC	Hydrocarbon
GWP	Global Warming Potential
ODP	Ozone Depletion Potential

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ABSTRACT

This research handles an experimental study carried out to determine the performance of a chest freezer when a propane/butane mixture is used as substitute refrigerant to R-134a. The used propane/butane mixture is liquefied petroleum gas (LPG), which is locally available and comprises 24.4% propane, 56.4 % butane and 17.2% isobutane. The LPG is readily available, cheap and of an environmentally friendly nature.

A chest freezer of gross capacity of 200 liter is used to have the tests performed to investigate the performance parameters of the LPG and compare it with that of the R-134a refrigerant.

The freezer was charged with three charge quantities (150, 200 and 250) g of LPG, then the best charge quantity that corresponds to the optimum coefficient of performance is determined, whose performance is then compared to that of R-134a.

The freezer worked efficiently when the best-suited LPG charge is used instead of R-134a. The LPG reached an evaporating temperature down to –26.7 ° C and coefficient of performance of 4.96 at evaporating temperature of –5.6 °C, condensing temperature of 39 °C and ambient temperature of 22.4 °C. Moreover, the LPG refrigerant was found to have higher COP than R-134a by 20%, lower refrigeration capacity, and slightly lower power consumption, all at Te value of about –13 °C, T_c value of 39 °C.

Furthermore, the freezer has been working effectively without noticing any side effects or needing any adjustments. The results of this work indicate the successful use of LPG mixture as an alternative refrigerant to R-134a in chest freezers.

INTRODUCTION

1 Introduction

Refrigerants, by virtue of their low evaporation and freezing temperatures, are the working fluids in refrigeration, air conditioning and heat pump systems. Examples of commonly used refrigerants include chlorofluorocarbons (CFC) such as R-12 and R-22, hydrofluorocarbons (HFC) such as R-134a and R-407c, ammonia, hydrocarbons such as propane/butane mixture, water, air, CO2 and other refrigerant mixtures.

In the last decade CFC refrigerants were found to be responsible for ozone layer depletion and thus were labeled as environmentally harmful substances. Therefore, the search for acceptable substitutes has intensified and a new generation of refrigerants has emerged. The objective of this work is to experimentally study one substitute for R-134a refrigerant. The next section introduces the thermo physical characteristics of refrigerants and their environmental impact. The characteristics of the substitute refrigerants are then discussed followed by the specific objectives and method of approach.

2 Overview of Conventional Refrigerants

Chlorofluorocarbons (CFCs), like R-12 and R-11, are widely used as refrigerants in air conditioning and refrigeration systems. They provide good characteristics and properties: thermal and chemical stability, thermodynamic suitability, non-toxicity and non-flammability. However, as mentioned earlier, CFCs have a damaging effect on stratospheric ozone layer. This prompted scientists and engineers to undertake extensive research in search for alternatives that are environmentally friendly and at the same time have similar performance characteristics.

Two main aspects of refrigerants effect from the environmental point of view have recently been discussed. The first is concerned with the ozone layer depletion by CFCs and the second with the global warming (due to the CFCs chlorine chemical effect). CFCs, notably R-12 and R-11, find much use in the refrigeration and air conditioning industries as refrigerants. The former one is used almost universally in domestic refrigerators and freezers while the latter is used as a blowing agent in refrigeration and other applications.

It was accepted in the mid –1980s that CFCs reaching the upper layers of the earths atmosphere would react with the ozone molecules and destroy them. This is alarming since ozone protects the earth's surface against ultra-violet light which has damaging effects to life on earth. When a chlorine monoxide molecule meets a free ozone molecule in stratosphere, an oxygen molecule is formed and the chlorine monoxide molecule is free again to renew its reaction on another ozone molecule. This process can be repeated until up to 50,000 ozone molecules are destroyed. In the lower atmosphere, chlorine monoxide molecules absorb the infrared radiation, which results in contributing in the global warming of earth.

Due to the fact that CFCs damage the ozone layer, environmental groups and the Montreal Protocol, which was held in 1987, call for halting CFC production. Thus, alternative refrigerants must be found to replace CFCs.

Based on the above considerations, it is believed that the liquefied petroleum gas (LPG), which is a mixture of propane and butane, is a suitable substitutive refrigerant.

3 Alternative Refrigerants

Research and development efforts have led to the development of synthetic refrigerants that have favorable properties to replace current CFCs and at the same time do not contain chlorine atoms in their molecules. Industry succeeded in making the hydrofluorocarbon (HFC) refrigerants that seem to have all the required properties to replace CFC refrigerants. An example is R-152a and R-134a for replacing R-12.

In general the alternative refrigerants should possess the following characteristics:

1- Suitable physical and thermodynamic properties.
2- High chemical and thermal stability.

3- Good miscibility with lubricants.

4- Compatibility with materials.

5- Low toxity.

6- Low flammability.

In selecting a refrigerant, the most important selection criterion is the thermodynamic properties, which determine whether a substance is applicable as refrigerant in a certain temperature range or not. If the thermodynamic properties meet the requirements, the other requirements must be taken into consideration and be acceptable, at least. It is not an easy, if not an impossible, matter to find a candidate that can satisfy all the above requirements. Therefore, compromise must be made to ensure the functional and safety aspects of the refrigerant selected.

For example hydrocarbons (such as methane, ethane, propane, butane, ..., etc) are very stable but have only two reactive characteristics, combustion and halogenations. The most important thing about these compounds is their characteristics with respect to environment. Their ozone depletion potential is zero, and their greenhouse effect appears to be insignificant compared to R-12 (about 0.15 % of the effect of R-12). In addition, they have excellent thermodynamic, physical and chemical characteristics (as will be discussed in Chapter 2). Their only main disadvantage is their high flammability, and because of this characteristic they have been prohibited from being used in domestic applications as well as many commercial and industrial applications.

Recently, some of these hydrocarbon compounds have been put into application and proved successful in replacing R-12 and other CFC refrigerants. For example, IEA Heat Pump Center Newsletter (1993) showed that propane/butane filled refrigerators have now entered the German market and are proving extremely popular. At the same time, tests are being made to replace R-55 by propane in heat pumps, where propane has possessed better performance than R-55. Hence, the use of hydrocarbons in applications where small refrigerant amount are required, is gaining more and more popularity.

4 Importance of This Work

Performance of any refrigeration system depends mainly on the equipment design and the compatibility of the working refrigerant employed. The latter factor is the aim of the present project. In this work, a mixture of propane/butane will be used as an alternative refrigerant instead of refrigerant R-134a currently used in a chest freezer.

The performance parameters of the chest freezer will be determined experimentally and will be compared with those of R-134a. The motivation of choosing this refrigerant is that it is readily available, cheep, and environmentally friendly.

In this work, the optimum charge of propane/butane mixture will be determined and will be compared to that of the original refrigerant. The other performance parameters to be experimentally determined include compressor power, refrigeration capacity, and coefficient of performance.

The present study differs from previous works in that it uses the mixture of propane/butane as a possible substitute refrigerant to R134a in a chest freezer.

5 Layout of the Thesis

The layout of adopted in this study consists of the following phases:

Phase 1: Literature review of refrigerants characteristics of both the current and substitute ones.

Phase 2: Experiments and experimental setup design, instrumentation selection and cost estimation. Also, data collection and reduction procedures are developed.

Phase 3: Data collection and reduction and analysis of results.

Phase 4: Summary, conclusions and recommendations.

2 Literature Review

The problem CFC refrigerants replacement has attracted an increased attention in the past decade. Many investigations have appeared in the literature. While a single suitable alternative for all applications is difficult to find, Atwood (1991) invited the scientists to look for a suitable alternative refrigerant for each application individually.

James and Missenden (1992) investigated the performance of propane for use in R12 domestic refrigerator and compared it with the performance of R 12. Several tests were performed and the power consumption of the two refrigerants was monitored over a period of 45 days. The results showed small differences between the power consumption of the two units.

The most important tests done in this research are the safety tests. Three main safety issues regarding domestic refrigerators were addressed, which are:

1- Leakage inside a refrigerator cabinet and ignition.
2- Leakage near a flame such as a cooker or boiler.
3- The risks in the event of a fire.

The first of these is relatively easy to overcome. The evaporator can be placed between the insulation and the inner cabinet skin (which is already done by some manufactures for other reasons). Alternatively, both light switch and thermostat may be placed outside the refrigerated enclosure. In any event the consequences are not catastrophic as was proved by the authors.

A combustion test was done on a domestic refrigerator fitted with propane, where a connection was made to the evaporator that allowed the refrigerant into the cabinet and an internal ignition device was constructed to produce a high –energy spark. The resulting ignition was only partly explosive; a small short-lived flame was observed inside the cabinet and recorded by video. The intensity of the flame was not sufficient to burn the plastic liner even after numerous tests. The second problem can be overcome by instructing the user not to place the refrigerator next to the cooker or boiler; this is very bad practice anyway and few people would do this. Due to the small amount of propane used, in the case of any leakage, the concentration of propane in the room will not reach its lower explosion limit.

The third point was the subject of a fire test made by the authors in the Fire Services College, UK. Two identical refrigerator units, both originally operated with R-12, were used. The refrigerant in one was replaced by propane. Then the two units were mounted in the fire test room. The fire test showed that the greater hazard in a fire event are the toxic fumes from the cabinet and its insulation which include cyanides and choking smoke. The lubricant oil materially contributed to the severity of the fire and would cause particular hazard in a house fire. On the other hand, propane did not noticeably add to the conflagration nor escape catastrophically. The products of combustion from propane are much less dangerous than those of R-12 leaking near a flame, where intensely toxic products such as carbonyl chloride

(COCl2) are produced. It should be noted the most fire injuries are due to smoke inhalation, not due to burns or explosions.

It was concluded that propane presents an attractive alternative to current CFCs in small systems such as domestic refrigerators. It must be noted that the refrigeration temperature range tested is that normally present in domestic refrigerators. Whether or not the propane can be used for low freezing temperatures such as encountered in domestic freezers has not been investigated.

The International Institute of Refrigeration (IIR) (1993) has published an informatory note concerning the replacement of the currently used CFCs and HCFCs. The note presents and discusses all possible alternatives to CFCs and HCFCs including HFCs such as (R-134a), ammonia, hydrocarbons, water, air, CO2 and refrigerant mixtures. According to this note, hydrocarbons such as propane and butane are excellent alternative refrigerants from point of view of thermodynamic and chemical properties. Besides, they are also environmentally friendly.

Habash, (1994) tested experimentally an alternative refrigerant to R-12, which can workwith domestic refrigerators without changing the design of these refrigerators. He employed the liquefied petroleum gas (LPG) as a proposed alternative refrigerant to a refrigerator of gross capacity of 320 liter and carried out tests using both R-12 and the (LPG). He found that the (LPG) has a slightly higher (COP) than that of R-12, slightly lower refrigeration capacity and slightly lower power consumption. His results showed that the (LPG) is an attractive alternative refrigerant to R-12 in domestic refrigerator.

M.A. Alsaad, M.A. Hammad (1997) reported the result of an experimental study carried out to determine the performance of a domestic refrigerator when a propane/butane mixture is used as a possible replacement to the traditional refrigerant R12 in domestic refrigerators. The refrigerator used in this study is of medium size of with a gross capacity of 320 liter and is assigned to work with R-12. The performance parameters investigated are the refrigeration capacity, the compressor power and the coefficient of performance (COP). The refrigerator worked efficiently when LPG was used as refrigerant instead of R-12. The evaporator temperature reached −15 °C with COP value of 3.4 at a condenser temperature of 27 °C and an ambient temperature of 20 °C. They concluded that propane/butane mixture can be used as an alternative refrigerant to R12 in domestic refrigerators.

Hammad, (1998) investigated the use of liquefied petroleum gas (LPG) as a replacement to R-12 replacement. They showed how to determine the optimum charge of LPG as refrigerant in domestic refrigerators. They also determined the power consumption, refrigeration capacity, and coefficient of performance of a refrigerator of 172 W capacity. They observed that higher values of coefficient of performance, and lower compressor work were obtained when LPG was used; for all other parameters such as environmental impact, availability and cost, the LPG is considered very attractive to be used as a replacement for R-12 in household refrigerators.

M.A. Hammad and M.A. Alsaad (1998) carried out an experimental study for evaluating the performance parameters of a domestic refrigerator with gross capacity of 320 liter when four ratios of propane, butane and isobutene are used as possible alternative replacement to the traditional R-12 refrigerant. The domestic refrigerator was charged and tested with each of the four hydrocarbon mixtures that consists of a)100% propane, b) 75% propane, 19.1% butane,5.9% isobutane, c) 50% propane, 38.3% butane, 11.7% isobutene, d) 25% propane,57.5% butane, 17.5% isobutane. The parameters investigated are the refrigeration capacity, the consumed power, the coefficient of performance (COP) and the cooling rate characteristics. Their work showed that the hydrocarbon mixture with 50% propane, 38.3%butane, 11.7% isobutane is the most suitable alternative refrigerant with the best performance among all other charges investigated. The refrigerator worked satisfactorily with the proposed alternative refrigerant without need for any modification or adjustment.

McLinden and Didion (1992) used various constraints and eliminated chlorine and bromine due to their active participation in ozone layer depletion, concluded that the potential refrigerants should consists of the elements carbon, hydrogen, oxygen and fluorine., such as R-134a, R-32 and R-152a or any blend that consists of these refrigerants such as R-407C and R-410a.

Zoubi (1998) examined a locally manufactured domestic refrigerator using R-134a as an alternative refrigerant to R-12. He did not change or modify any design of the used refrigerator components. He concluded that R-134a gives a good performance as replacement to R-12 in domestic refrigerators. The coefficient of performance value of up to 6.1 was obtained at T_e of 5 °C, T_c of 47 °C and T_a of 29 °C.

German compressor Manufacturing Company BITZER (2000) demonstrated that R-134a has similar thermodynamics properties to R-12, and it is already available in sufficient quantities as an alternative for R-12, but it requires a large compressors displacement for different specific refrigeration capacity.

Abu-Jari (2002) employed R-407c as an alternative to refrigerant R-134a in a chest freezer of a gross capacity of 200 liter without changing the design or the components of the freezer. His experimental tests showed that the R407c is not a good replacement to R134a in chest freezers, since it exhibits a high compressor work, low COP, and consumes higher electrical power compared to that of R-134a.

Mobaideen (2004) carried out a computer simulation study of the performance of a chest freezer working with R-134a as an alternative refrigerant to R-12. A full set of reasonable performance curves for theoretical vapor compression cycles. The range of evaporating temperatures changes between –20 °C to 0.0 °C and between 30 to 50 °C for the condensing temperature. The results of this research revealed that R-134a is suitable alternative to R-12. R-134a had higher values of the coefficient of performance at high evaporating temperatures and high condensing temperatures. The ideal cycle of superheating and subcooling was constructed to show their effect on the standard cycle. The results revealed that the COP increased by 4.63% with 5 degrees of superheating and subcooling at condensing temperature of 40 °C.

From the literature surveyed so far, the work on this field did not cover the use of LPG as substitute refrigerant to R134 in chest freezers, besides, the lower range of evaporator temperatures (up to –30 oC) which is needed in the freezers are not examined using the LPG. Those issues are what this work handles, which could contribute to that appreciated and logical invitation by Atwood (1991) to have a wider range of researches that covers the approved alternatives for the specific application with the suitable temperature operating ranges.

R-134a Vs. PROPANE/BUTANE (LPG) MIXTURE

A COMPARATIVE STUDY

1 Introduction

When selecting a refrigerant for a specific application, the properties of this refrigerant have to satisfy a number of application requirements in order to be an acceptable proposal for that application. The requirements that must be satisfied by the refrigerant may be classified as thermodynamic, physical, and chemical requirements in addition to other factors as cost and availability. Each refrigerant has its own specific properties and characteristics which must be known well before deciding if a refrigerant is suitable proposal for an application or not. Also, these properties and characteristics from a good basis for comparisons among different refrigerants.

A comparative study between R-134a and the LPG mixture is introduced in this part, regarding to their thermodynamic, physical, and chemical properties in addition to other comparison factors. The objective of this chapter is to come up with a conclusion that the LPG has the suitable refrigerant properties to be a good proposed alternative refrigerant or not, which could tell that a further researches and experiments are justified to have the final experimental approved judgment statement.

2 Thermodynamic Properties

Thermodynamic properties are the most important properties in selecting refrigerants for any application. A refrigerant is not accepted as a effective working fluid in refrigeration equipment unless it posses the thermodynamic requirements for that equipment to operate properly. The thermodynamic properties of R134a, butane, propane and isobutene are listed in Table 1.

Table 1: Thermodynamic properties of refrigerants.

	Boiling point [°C]	Freezing point [°C]	Critical temperature [°C]	Critical pressure [bar]	Latent heat of vapor. [kJ/kg]
R134a	-26.16	-160	101.1	41	217.1
Propane	-42.07	- 187.7	96.8	42.54	423.3
Butane	- 0.5	-138.5	152	37.94	386
Isobutane	-11.73	-160	135	36.45	364.4

*At one atmospheric pressure.

2.1 Freezing Point

Low freezing temperature of the refrigerant is required because the refrigerant must not freeze under required evaporator temperature. As shown in Table (1), the four refrigerants have a sufficient low freezing temperature.

2.2 Boiling Point

Low boiling temperature at atmospheric pressure (normal boiling point) of the refrigerant is required for an efficient refrigerant. Otherwise it is required that the compressor is operated at high vacuums, which reduces the capacity of the system.

As shown in Table 1, the LPG constituents have sufficiently low boiling points.

2.3 Critical Temperature and Pressure

The critical temperature of the refrigerant should be higher than its temperature in the condenser for easy condensation of the vapor refrigerant, because we cannot get a good condensation for the refrigerant above its critical temperature regardless the amount of the applied pressure.

As shown in Table 1, the critical temperatures of LPG constituents are lower than that of R-134a but still enough above the temperature occurring in the condenser. Also the critical pressures for all refrigerants are much higher than any pressure in the system.

2.4 Latent Heat of Vaporization

The latent heat of vaporization (kJ/kg) is the amount of heat in kJ that required to vaporize one kg of the liquid at atmospheric pressure, the liquid to be at its boiling point when the operation begins. One of the required thermodynamic characteristics of general importance is high latent heat of vaporization this means a large refrigerating effect per unit mass of the refrigerant circulated, which must absorb heat exactly equal to its latent of vaporization. Thus, if a refrigerant with a high latent heat of vaporization is used, lower refrigerant charge mass and/or smaller compressor, condenser, and evaporator can be used.

As shown in Table 1, the latent heat of vaporization for the LPG constituents are comparatively higher than that for R-134a. This means a lower quantity of LPG can be used than that of R-134a because the refrigerant with a high latent heat (LPG) will absorb more heat per kg of its quantity than the refrigerant with a lower latent heat of vaporization (R-134a).

2.5 Evaporation and Condensing Pressure

The range of the operating pressure is one of the major considerations in the selection of refrigerant for the economical working of the refrigerant system.

Pressure in the evaporator and condenser should be positive and above atmospheric to prevent to prevent air from leaking into the refrigeration system. Also the pressure should not be too high above atmospheric because otherwise expensive piping and equipment will be required.

Low compression ratio result in low power consumption. Therefore, the refrigerant with the lowest compression ratio (condenser to evaporator pressure ratio) is desirable.

2.6 Coefficient of Performance

A high coefficient of performance is desirable because it indicates that a given amount of refrigeration requires only a small amount of work. In other words, it a measure of the cycle efficiency.

2.7 Compressor Discharge Temperature

Low discharge temperature gives a long life and less maintenance for the compressor because it reduces the possibility of overheating of the compressor.

2.8 Temperature Glide

Temperature glide is the difference between the bubble and dew point temperatures for zeotropic refrigerant blends. This difference will affect the performance of the condenser and the evaporator duties.

3 Physical and Chemical Properties

The important physical properties of R134a, propane and butane are listed in Table (2) below. A discussion of each property is then followed.

Table 2 Physical properties of refrigerants*.

	Specific heat [kJ/kg.K]		Thermal conductivity [mW/m.K]		Viscosity [μPa.sec.]	
	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
R134a	0.93	1.367	82.3	13.9	215.7	12
Propane	2.76	1.68	90.8	18.44	110	8.26
Butane		1.72		17.5		7.9

*At ambient temperature and saturated vapor pressure..

3.1 Specific Heat of Liquid and Vapor

The specific heat is the quantity of heat required to raise 1g of a substance 1 °C. Low specific heat of liquid and high specific heat of vapor are both desirable because they increase the refrigerating effect per kg of the refrigerant. Low specific heat of liquid tends to increase the sub cooling of liquid, and high specific heat of vapor tends to decrease the superheating of vapor. As shown in Table 2, both propane and butane have higher vapor specific heats than that of R-134a. Propane has also higher liquid specific heat than R134a. Data on the liquid state of butane is not available in literature.

3.2 Viscosity

The Viscosity is a measure of flowing quality. It is desirable to use refrigerants with low viscosities in both liquid and vapor states for higher heat transfer in the evaporator and condenser, low pumping power and small pressure drops during flow.

As shown in Table (2), propane and butane have low viscosity in both gaseous and liquid states compared to R134a

3.3 Thermal Conductivity

A high thermal conductivity of refrigerant in both and vapor state is desirable for efficient heat transfer in the evaporator and the condenser. As shown in Table (2), propane and butane have high thermal conductivities in both gaseous and liquid states compared to R134a.

3.4 Miscibility with Oil

Lubricants are an essential component of a refrigeration system .A refrigeration compressor requires lubrication like any mechanical equipment; oil is necessary to lubricate the bearings and the pistons in the case of reciprocating compressor. The oil helps to absorb and carry away the heat generate by the working of the compressor.

Miscibility of the oil and the refrigerant is the ability of the refrigerant to mix with the oil. Therefore, it is an important characteristic in the selection of any refrigerant, so the refrigerant must be completely miscible with the lubricating oil used in the system in order to assure good return of oil to the compressor and to avoid heat transfer degradation. However, hydrocarbons (such as propane, butane and isobutene) are highly miscible with all kinds of oils and thus are the best refrigerants from oil miscibility point of view.

3.5 Toxicity

Non-toxic nature of the refrigerant is one of the most important properties that make it desirable. Toxic refrigerant has the effect of a poison, which may cause the injury to the human body or death depending upon its percentage in air. This point is important because the refrigerant may leak from the refrigeration system.

In Table 3, the Underwriters Laboratories Classification of Comparative Hazard to Life of Gases and vapors is shown for R134a and the three hydrocarbon refrigerants (with the description of this classification given in appendix B). According to this table, R134a is considered as non-toxic (Group 6) refrigerant. Propane, butane and isobutane are classified as either non-toxic or slightly more toxic than Group 6 (Group 5b). Therefore, propane and butane are safe from this point especially in domestic refrigerators and freezers, where small refrigerant charges are used.

3.6 Flammability

Ideal refrigerant should not have any danger of explosion in the presence of air or in association with lubricating oil. R134a is a non-flammable refrigerant. The main drawback in the refrigerants of hydrocarbons is that they are flammable.

For a domestic refrigerating system, the quantity of refrigerant being charged is small, typically about 1.6 % of the hydrocarbons contained in the average LPG cylinder; an item which will be found in most houses and which is potentially more dangerous.

Such a vessel is fitted with a valve where as the refrigerator holds the compound in a sealed system.

Table 3 Toxicity and flammability

	Underwriters Laboratories Group Classification	Explosive limits in air (% by volume)	
		Lower limit	Upper limit
R-134a	6	Nonflammable	
Propane	5 b	2.3	7.3
Butane	5 b	1.6	6.5
Isobutene	5 b	1.8	8.4

In addition, a large proportion of the hydrocarbon mixture will not be released by the compressor oil in the short term. Hence, any leakage in the domestic refrigerator will not release gas quantity more than that may be released by one oven eye when it is opened for few minutes.

In Table 3, the explosive limits of propane, butane and Isobutene in air are given as % by volume. Even a very small kitchen would have a volume of a bout 18 m3, which requires much more quantity of hydrocarbons than the one contained in a refrigerator to reach the lower limit listed in the table.

3.7 Action with Water

It must be recognized that refrigeration or an air conditioning system is a closed circuit. Once a contaminant enters the system it will stay there till service engineer can remove it.

Water a most undesirable contaminant in refrigeration system because it may cause rusting corrosion, refrigerant decomposition, valve damage, and general deterioration of the system; so non-soluble refrigerants in water are preferred. The solubility of water in R-134a is low, whereas it is much lower in hydrocarbons like propane and butane and they do not absorb any moisture from air.

3.8 Ozone Depletion Potential and Global Warming

The environmental consequences of a refrigerant that leaks from a system must also be considered. Because of their great stability, fully halogenated compounds, such as chlorofluorocarbons (CFCs), persist in the atmosphere for many years and eventually diffuse into the stratosphere. The molecules of CFCs, such as R-11 and R-12, contain only carbon and the halogens chlorine and fluorine. Once in the upper atmosphere, CFC molecules break down and release chlorine, which destroys ozone (ozone depletion). In the lower atmosphere, these molecules absorb infrared radiation, which may contribute to the warming of the earth. R134a has global warming potential of 1300, and zero ozone depletion potential, whereas LPG causes no global warming, and zero ozone depletion potential.

4 Cost

The cost factor is critical in deciding which refrigerant to use especially if the alternative refrigerant.(LPG) provides acceptable environmental properties and the amount of charge required to charge the compressor of the freezer is small about (0.2kg). Table 4 shows the cost of R-134a and LPG.

Table 4 Refrigerants costs

Refrigerants costs	Estimated Cost (JD/kg)
R-134a	5
LPG	0.23

5 Availability

The availability of the refrigerant used in the refrigeration application is an important factor. LPG is available in enormous quantities in most countries including our local markets in Middle East, and therefore provides an attractive alternative for HFCs and CFCs.

EXPERIMENTAL SETUP AND WORK PROCEDURE

1 Introduction

The objective of this research is to study the performance of a chest freezer by replacing R-134a by LPG. In this research, a locally manufactured chest freezer unit is used to test the performance of the two refrigerants.

2 Freezer Unit Specification

The freezer used in this research is a simple chest freezer that contains a frozen food storage compartment, and it does not include defrosting devises or forced air circulation. The specifications of the freezer denoted by the manufacture are listed in Table 5.

Table 5 Specification of the freezer used in this research

Trade mark	ABDIN
Manufacturer	Abdin Industrial EST
Gross Capacity	200L
Freezer storage capacity	200L
Refrigerant R-134a charge mass	220 g
Power rating	186 Watt
Motor power	179 Watt
Nominal current and voltage	1.5 A (230 volts)
Compressor design	Reciprocating (Hermetically-sealed)
Compressor displacement size	12 cc
Capillary tube diameter	0.8 mm
Capillary tube length	3.15 m
Lubricant	Polyol ester oil

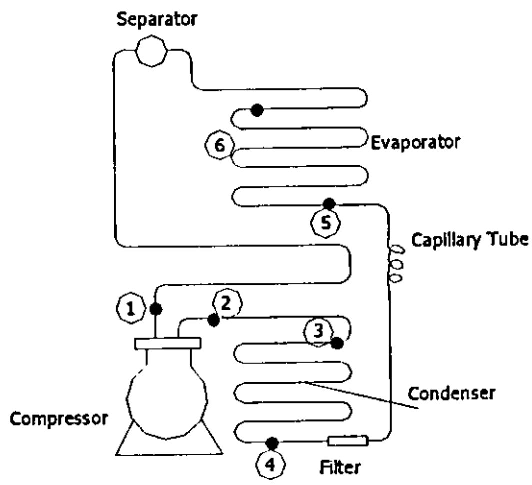


Fig. (1) Freezer system schematic diagram.

3 Measuring Devices and Procedure

The variables that were measured during the experiments are temperature, pressure, power consumption, and time interval.

3.1 Temperature Measurement

The temperatures readings were measured by copper-constantan thermocouples, which were connected to a microprocessor. The thermocouples were fixed in certain points in the system by a tape, then it will be well insulated to obtain a good results. Calibration of those thermocouples is done by immersing them in to boiling water at a temperature of 100 °C. These points (as shown in Figure 1) are:

1. Suction of the compressor, T1.

2. Discharge of the compressor, T2.

3. Midpoint of the condenser, T3..

4. Outlet of the condenser, T4.

5. Inlet of the evaporator, T5.

6. Midpoint of the evaporator, T6.

7. Inside the water load, T7.

8. The external surface of the container, T8.

9. Space (air) temperature, freezer compartment, T9.

10. The ambient temperature, T10.

3.2 Pressure Measurement

Two pressure gauges will be used, one on the suction line of the compressor, which is low pressure gauge, and the other on the discharge line which is a high pressure gauge. The measuring pressure device used in this work is the refrigeration gauge manifold.

3.3 Actual Electric Power Consumption Measurement

The actual electric power consumed by the motor-compressor unit will be measured by a single-phase watt-hour meter which was calibrated by measuring the power of well known out put device..

3.4 Time

Measuring time intervals is important for calculating the rate of heat removal from the load (refrigeration capacity). It is measured using simple stopwatch.

4 Propane/Butane (LPG) Mixture

The propane/butane mixture used in the tests was obtained from ordinary commercial LPG bottle, which is filled in the Jordanian Petroleum Refinery. The volumetric composition of the LPG used in the experiments was as follows: Propane 26.4%, n-butane 56.4% and isobutane 17.2%.

5 Experimental Work Procedure

Since the same freezer unit is used in the tests of the two refrigerants, the work was divided into two parts; the first part of the tests on R-134a and the second for the tests on LPG mixture. Each part experiments was performed as follows:

5.1 First Part: R-134a Experiments

In this part the freezer was operated with its original refrigerant R-134a. Two types of tests were done, which are:

A- Evaporation Temperature (T_e) Variation Test

In order to perform this experiment, a simulated load which consists of a steel container of known specific heat and mass (0.85 kg of steel) filled with a specified quantity of hot water (12 liter of water at average temperature 80 °C) was placed in the freezer compartment. After connecting thermocouple 7 and 8 to the load, it was placed in the freezer compartment. This will cause a rapid increase of T_e to a maximum value. Then, it decreases slowly until it reaches its low limit.

During the period of T_e variation, temperatures at the ten locations and time intervals were recorded. Assuming actual vapor compression refrigeration cycles the state at each point in the system can be determined using the temperature and pressure readings and R-134a tables.

B- Condensation Temperature (T_c) Variation Test

The condenser temperature (T_c) was varied and measurements were taken, in order to make performance curves versus T_c. The variation of T_c was performed by spraying cold water over the condenser and making a forced air stream over it, using a fan, in experiments were performed for each of the three LPG charge quantities (i.e. 150,200 and 250) g.

The objective of doing all these experiments is to determine which charge quantity gives the best system performance and compares it with that of R-134a. Finally, the same experiments described above in tests A, B, and C was performed again using the best charge of LPG.

MATHEMATICAL ANALYSIS

1 Introduction

In this section, a complete mathematical analysis will be performed, and various parameters will be calculated using the data readings collected. The calculation based on actual vapor compression cycle.

1.1 Theoretical and Actual Vapor Compression Refrigeration Cycle

The vapor compression cycle is the most widely used refrigeration cycle in practice. The vapor processes, which comprise the theoretical vapor compression cycle, are:

1- Isentropic compression from saturated vapor at low pressure to superheat vapor at high pressure.

2- Rejection of heat at constant pressure and condensation to saturated liquid.

3- Irreversible expansion at constant enthalpy from saturated liquid at high pressure to saturated mixture at low pressure.

4- Addition of heat at constant pressure and evaporation to saturated vapor.

Theoretical cycle is composed of idealized thermodynamics processes which is shown in P-h and T-S diagrams in Figures (2) and (3) respectively, while the actual systems operating steadily differ from the ideal cycle in many respects. Pressure drop occurs everywhere in the system except in the compression process. Heat transfer occurs between the refrigerant and its environment in all components. The actual compression process differs from the isentropic compression assumed for ideal cycle. The working fluid is not a pure refrigerant but a mixture of refrigerant an oil.

All of these deviations from a theoretical cycle cause irreversibilities within the system, and each irreversibility requires additional power into the compressor.

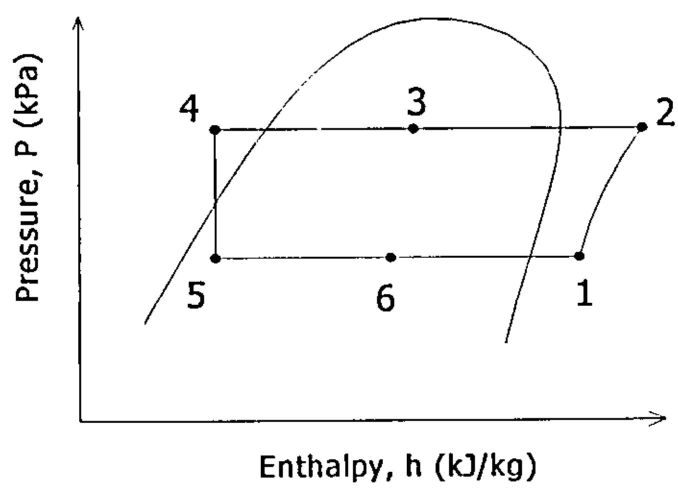


Fig. (2) P-h diagram of the freezer system.

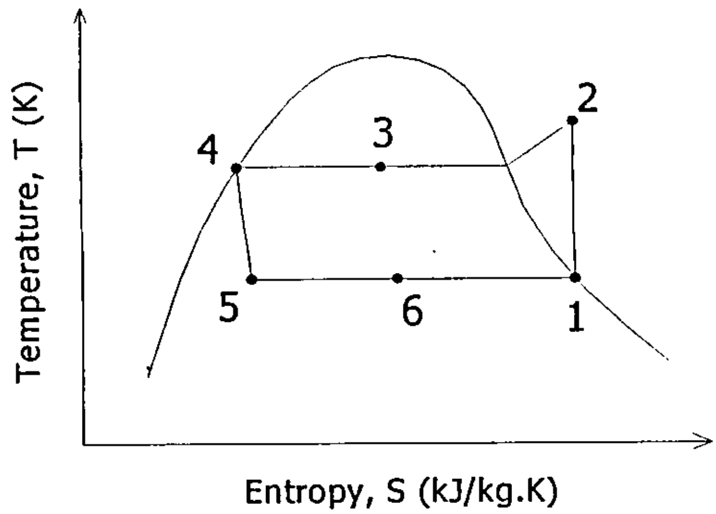


Fig. (3) The standard T-S diagram of the freezer system.

2 Measured Data

As discussed in section 4.3 of the previous chapter, the readings taken during the experimental work are: temperature readings (in oC), pressure readings (in kPa), power consumption readings (in kW.hr) and time intervals (in minutes). Temperature readings are taken at the locations mentioned in section 3.3.1.

The data, which were used in the calculations, are listed in the tables of Appendix A for Te variation test, Appendix B for Tc variation test, and Appendix C for time variation test. The tests introduced are for both refrigerants R134-and LPG mixture.

3 Calculations

From the data readings collected, the various performance parameters of the refrigeration system are calculated. The methods and equations used for calculating these parameters are discussed in this section. The results of the various calculating are plotted and discussed in the following chapter.

In the following subsections the different refrigeration quantities and parameters calculated are represented and discussed.

3.1 Enthalpy calculations

In order to calculate any refrigeration parameter cycle parameter, enthalpies at different locations in the cycle have to be calculated first. These locations include: inlet and outlet of the evaporator, compressor and condenser.

For R-134a, temperature and pressure values are enough to calculate the enthalpy at any location in the cycle using R-134a saturated and superheated tables. But for the propane /butane (LPG) mixture, further calculations have to be made.

One way to calculate the enthalpy of a LPG mixture is to calculate first the enthalpies of its main constituents (propane, butane and isobutene) and then calculate the enthalpy of the mixture using these enthalpies and the mass fraction of each constituent in the mixture The mass fractions of the three constituents are calculated from the volumes fractions, as shown in Table 6.

Table 6 Mass fractions of the LPG mixture constituents.

Component	Percent by volume	Mole fraction	Molecular weight	Mass (kg/kmole)	Mass fraction
Propane	26.4	0.264	44.10	11.64	21.39
Butane	56.4	0.564	58.13	32.78	60.23
Isobutane	17.2	0.172	58.13	10.00	18.38

Hence, the enthalpy of the LPG mixture, hm, at any states may be calculated using the mass fractions shown in the last columns of table 6, using the following equation:

$$h_m = 0.21390\ h_p + 0.6023\ h_B + 0.1838\ h_I \qquad (1)$$

Where h_p , h_B , h_I are the enthalpies of propane, butane and isobutane respectively.

For the sutured state points, the enthalpies of the pure constitutes are obtained at the saturated temperature using the propane , butane and isobutene saturated tables .Then the enthalpy of the mixture is calculated from Eq.(1).

For the superheated state points (at sections and discharge of compressor), an additional property is needed in order to calculate the enthalpy. Therefore, pressure measurements are taken for the low and high pressure sides of the system. By knowing the pressure and temperature of each constituent, the superheated enthalpy is obtained using propane, butane and isobutane superheated charts and the enthalpy of the mixture is calculated from Eq.(1).

The partial pressure of the LPG constituents are obtained from the total pressure of the gas mixture (the measured pressure) using the mole fraction of each constituent as follows:

$P_p = 0.264 \times P_t$

$P_B = 0.564 \times P_t$ (2)

$P_I = 0.172 \times P_t$

Where P_t is the total pressure of the mixture, and P_p, P_B and P_I are the partial pressures of propane, butane and isobutane, respectively in the mixture.

The enthalpy of LPG in the evaporator inlet is taken to equal that at condenser exit of liquid saturated conditions, due to the adiabatic throttling process.

3.2 Refrigerating Effect and Refrigeration Capacity

The refrigerating effect is the quantity of heat absorbed from the refrigerated space (freezer compartment) by the evaporator in kJ per kg of refrigerant circulated. It is thus given by:

$$q_e = h_1 - h_5 \qquad (3)$$

Where, q_e is the refrigerating effect in (kJ/kg), h_1 and h_5 are the enthalpies (in kJ/kg) of the refrigerant leaving and entering the evaporator, respectively.

The refrigeration capacity is the rate of heat removal (in kW) from the refrigerated compartment by the evaporator. It is calculated by multiplying the refrigerating effect by the mass flow rate of the refrigerant in the evaporator, thus:

$$Q_e = m\, q_e = m\,(h_1 - h_5) \qquad (4)$$

Where, Q_e is the refrigeration capacity in kW and m is the refrigerant mass flow rate in kg/s.

Usually, the refrigerant mass flow rate is difficult to measure directly; therefore, it is easier to measure the refrigeration capacity and then calculate the mass flow rate from eq.(4) :

$$m = Q_e / q_e \qquad (5)$$

The refrigeration capacity is calculated by measuring the rate of heat removal from a simulated load (which consists of a metal container filled with hot water), using the following equation:

$$Q_e = (M_w \; C_{pw} \; \Delta T_w \; + M_c \; C_{pc} \, \Delta T_c) / \Delta t \qquad (6)$$

Where, Q_e is the refrigeration capacity in kW.

M_w and M_c are the masses of the water load and the container in kg.

C_{pw} and C_{pc} are the specific heats of the water and container in kJ/kg.°C.

ΔT_w and ΔT_c are the temperature differences in oC of water and container during the time period Δt (in seconds).

3.3 Work of Compression and Power Consumption

The work of compression done by the compressor on the refrigerant is represent by the increase in refrigerant enthalpy during the compression process, that is:

$$W = h_2 - h_1 \qquad (7)$$

Where W is the work of compression in kJ per kg of refrigerant; h_1 and h_2 are the enthalpies of refrigerant at compressor suction and discharge respectively.

The power required by the compressor (in kW) is the product of the mass rate of flow of the refrigerant by the work of compression, that is:

$$Power = mW = m\,(h_2 - h_1) \qquad (8)$$

3.4 Mass Flow Rate of Refrigerant

The mass flow rate of the refrigerant in the refrigeration system may be calculated using Eq.(5).It is also common to represent the refrigerant mass flow rate per unit refrigeration capacity. In this case:

$$m = Q_e / q_e \tag{5.9}$$

The unit of m will be in kg/s.

3.5 Coefficient of Performance (COP)

By taking both the refrigeration capacity and the power consumption of a refrigeration system into consideration, the efficiency of this system may be represented as:

$$COP = Q_e / Power = q_e / W = (h_1 - h_5) / (h_2 - h_1) \tag{10}$$

The COP is thus a measure of the performance of the refrigeration system, since it indicates the amount of refrigeration capacity provided by the system per unit of power consumption.

4 Sample Calculation for the LPG Mixture:

A sample calculation is presented for the 210 g LPG charge using one set of reading from the data tables in appendix A. The readings are:

Suction pressure = 187.6 kPa.

Discharge pressure = 2090.8 kPa.

Inlet temperature of the compressor = 13 °C.

Outlet temperature of the compressor = 63.5 °C.

Condenser temperature = 39 °C.

Outlet temperature from the condenser = 27 °C.

Evaporator temperature = -5.6 °C.

Temperature difference of water load = 2 °C.

Temperature difference of air = 2.3 °C.

Time period during the difference = 255 sec.

For the two superheated state points at the suction and discharge of the compressor, the suction and discharge temperatures in addition to the suction and discharge components partial pressures are used to calculate the enthalpies of the components in the superheated states using the p-h charts of the components found in Appendix D.

For the refrigerant leaving the condenser, it may be assumed as a saturated liquid at this point, and in this case the saturated liquid tables for propane, butane and isobutane in Appendix D are used to obtain their enthalpies at T_4, then eq. (1) is used to get the enthalpy of the mixture. Due to high throttling through the capillary tube a pressure drop will occur with constant enthalpy, so the value of enthalpy at the inlet of the evaporator equals to the value of enthalpy at the outlet of the condenser, i.e. $h_4 = h_5$.

After calculating the enthalpies of the propane, butane and isobutane components at the four points (i.e. points 1,2,4 and 5) as described above, eq. (1) is used to calculate the enthalpy of the mixture at the mentioned points. The calculations and results regarding the data readings mentioned above are summarized in the following table:

Table (7): Sample calculation for the 210g LPG charge.

	P1(kPa)	P2(kPa)	h1(kJ/kg)	h2(kJ/kg)	h4(kJ/kg)
Propane	53	555.5	210	258	70.6
Butane	113	1187	220.6	240	65.7
isobutane	34.5	362	205.1	218	65.4
Mixture	187.6	2090.8	501.2	571	155

After calculating the enthalpies of the mixture at each point in the cycle, the system parameters may be obtained from equations (3) through (10), expect eq. (6). From these equations and the results listed in the table above, the following parameters are calculated:

$M_w = 12$ kg, $M_{co} = 0.85$ kg, and $M_{air} = 0.2$ kg.

$Q_{ref.} = (12*4.186*2+0.85*0.45*2+0.2*1.035*2.3)/(255)$

$Q_{ref.} = 398$ Watt.

$q_{ref.} = (h_1-h_4) = 501.2-155= 346.2$ kJ/kg.

$m = Q_{ref.}/ q_{ref.} = 398/346 = 1.15$ g/s.

$w = (h_2-h_1) = 571-501.2 = 69.8$ kJ/kg.

$COP = q_{ref.}/w = 346.2/69.8 = 4.96$.

The uncertainty in a measured variable is the deviation of an instrument reading from what is believed to be the true value. A precise method of estimating uncertainty in experimental results has been presented by Kline and McClintock (1953). The method is based on a careful specification of the uncertainties in the various primary experimental measurements.

Suppose a set of measurements is made and the uncertainty in each measurement may be expressed with the same odds. These measurements are then used to calculate some desired result of the experiments. We wish to estimate the uncertainty in the calculated result on the basis of the uncertainties in the primary measurements. The results R is a given function of the independent variables $\chi_1, \chi_2, \chi_3, \ldots, \chi_n$. Thus,

$$R = R(\chi_1, \chi_2, \chi_3, \ldots, \chi_n) \qquad (11)$$

Let w_R be the uncertainty in the result and $w_1, w_2, \ldots, w_n$ be the uncertainty in the result and $w_1, w_2, \ldots, w_n$ be the uncertainties in the independent variables. If the uncertainties in the independent variables are all given same odds, then the uncertainty in the results having these odds is given as

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2 \right]^{1/2} \qquad (12)$$

This applies to this sample calculation as follows:

$T = T \pm 1$ °C which implies that $w_T = \pm 1$ °C (uncertainty in temperature)

$P = P \pm 5\%$ which implies that $w_P = \pm 5$ % of the pressure (uncertainty in Pressure)

The two previous uncertainties are considered to be the two primary measurements from which one can calculate the uncertainty in any of the calculated result such as COP, work and refrigeration effect. This can be done by finding the mathematical relation that relates the calculated result with the primary measurements indicated above, namely temperature and pressure. Then substituting in Eq. (12) above to obtain the desired uncertainty of the calculated result

RESULTS AND DISCUSSION

1 Introduction

Each of the four components of a vapor-compression system, the compressor, the condenser, the expansion device (capillary tube), and the evaporator, has its own peculiar behavior. Each component is influenced by conditions imposed by the other members of the quarter.

First a comparison should be made between the performances of the different charge quantities of the LPG mixtures to find out the optimum quantity to be charged in the used chest freezer without making any changes or replacements in the freezer system. Then, the performance of the optimum LPG charge is compared to that of R-134a to prove weather the LPG represents a possible alternative replacement to the R-134a refrigerant or not. The aim of this chapter is to compare the performance curves for both LPG and R-134a with respect to the condensing and evaporating temperatures.

Two of the most important performance characteristics of a refrigeration system are its refrigeration capacity and its power requirement. These two characteristics are controlled extremely by the suction and discharge pressures, and consequently the evaporating and condensing temperatures. Therefore, it is a major trend in refrigeration literature and industry to make system performance curves with respect to these two temperatures.

2 System Performance versus Charge Quantity

As stated before, three different LPG charge quantities were charged in the used chest freezer to find out which quantity gives the best performance starting with the 150 g charge until reaching the charge of 250 g in steps of 50 g.

Figure 4 shows the variation of the coefficient of performance with the evaporating temperature for three different selected charge quantities at 39 °C condensing temperature. From this Figure, it is noticed that the COP of the 200 g charge is higher than those of the other two charge quantities.

Variation of the coefficient of performance with the charge quantity for refrigerant LPG is presented in Figure 5. From that Figure it is noticed that the COP increased as the charge increased until it reaches an optimum value, then it begins to degrease again. The optimum COP value was 4.34 and was reached at the 210g charge, which means that this charge is the most suitable one to work with the used chest freezer. The values of the coefficient of performance were calculated at the conditions stated in Figure 5 (Te = -8.2 °C, Tc = 39 °C, and Ta = 22.4 °C).

3 Variation with the Evaporating Temperatures (T_e)

Variation of the performance parameters of the chest freezer with the evaporating temperatures are presented for an evaporating temperature range from –27 to 0.0 °C, at 39 °C condensing temperature (T_c) and 22.4 °C ambient temperature (T_a). The performance parameters studied are the refrigerating effect, compression work, and coefficient of performance, refrigeration capacity, mass flow rate, theoretical power consumption, and actual electrical power consumption.

All T_e variation test data and results are presented in Appendix A and the results of these testing are presented graphically in Figures 6 to 12 for both R-134a and LPG at optimum charge.

3.1 Refrigerating Effect

Variation of the refrigerating effect with the evaporating temperatures is represented in Figure 6 for both R-134a and LPG, for constant condensing temperature (T_c = 39 °C). It is shown that the refrigerating effect increase slightly with an increase in the evaporating temperature. The increase is due to the slightly higher enthalpy at higher evaporating temperatures while the enthalpy of the refrigerant entering the capillary tube remains constant. Also, as noticed from the Figure, the LPG refrigerant has a higher refrigerating effect of about 180% of that of the R-134a.

This is due to the fact that at the same condensing and evaporating temperatures, the LPG has much higher enthalpies than R-134a in both liquid and vapor states. Therefore, any enthalpy difference between two different LPG enthalpy points in the system will be a bout 1.8 of that for R-134a.

3.2 Compression Work

Figure 7 shows the variation of the compressor work with respect to the evaporating temperature. The compressor work decreases as Te increases due to that the evaporating pressure and temperature is increased (and thus the suction enthalpy will increase) while keeping the discharge enthalpy constant, therefore, this will cause the work to be reduced as T_e increases, since the work equal to the enthalpy difference through compressor. Also, from Figure 7 it is noticed that the work of compression for the LPG mixture is higher than that of R-134a by about 160% with less percentage at higher evaporating temperatures. Also, this difference is interpreted by the consideration considered in section 3.1 above.

3.3 Coefficient of Performance

From Figure 8 it is noticed that as T_e is increased, at constant T_c, the coefficient of performance (COP) increases. This is due to the fact that the enthalpy difference across the evaporator is increased, and the enthalpy difference across the compressor is decreased as T_e is increased, as indicated in Eq. 10.

A high coefficient of performance is one of the most desirable requirements for any refrigeration unit because it is an indication of the high efficiency of the system. It is also noticed that COP for LPG is higher than that for R-134a by about 20% at T_e = -10 °C and T_c = 39 °C.

3.4 Refrigeration Capacity

The refrigeration capacity was calculated by measuring the rate of heat removal in the freezer compartment. Variation of the refrigeration capacity with the evaporating temperature is presented in Figure 9, it is noticed that for constant condensing temperature, the refrigeration capacity increases with increasing the evaporating temperature.

Since refrigeration capacity equal to the mass flow rate multiplied by the enthalpy difference across the evaporator. Increasing T_e will cause both mass-flow rate and enthalpy difference to be increased; therefore, increasing the evaporating temperature can increase the refrigeration capacity.

Figure 9 indicates that the refrigeration capacities for both refrigerants are close and interfere at higher evaporating temperature (T_e = -7 °C), but becoming to be slightly higher for R-134a for Te < -7 °C. This is due to the considerably higher mass flow rate of R-134a, as will be shown in the next section.

3.5 Mass Flow Rate

Variation of the mass flow rate with the evaporating temperature for both LPG and R-134a, at constant condensing temperature (T_c = 39 °C) is shown in Figure 10.

As shown In Figure 10, increasing the evaporating temperature, at a constant condensing temperature, will increase the mass rate of flow.

Since the mass flow rate is rate proportional to the specific volume, as T_e increases, the specific volume decrease, which cause the mass flow rate to increase for constant T_c, also Figure 10 indicates that the mass flow rate for R-134a is higher than that for LPG by about 140 % at Te =-14 °C for the same conditions (T_c and T_a).This can be connected to the refrigeration capacity in the previous section, that is, to accommodate the same or more refrigeration capacity, considerably higher mass flow rate of R-134a, which has lower refrigerating effect than LPG, is required.

3.6 Theoretical Power Consumption

The curves of the theoretical power consumption for both LPG and R-134a are plotted against T_e at constant condensing temperature (T_c=39 °C) are shown in Figure 11.

As shown in Figure 11, the power increase with increasing the evaporating temperature, since when T_e increase, mass flow rate increase at a rate higher than the decrease rate of the enthalpy, which explains the increases in the theoretical compressor power.

Theoretical compressor power for R-134a is higher than LPG at low evaporating temperature (down to –25 ° C) and becoming close to each other at higher temperatures (up to –5 ° C).

3.7 Actual Electrical Power Consumption

The curves of the actual electrical power consumption for both LPG and R-134a are plotted against T_e at constant condensing temperature (T_c=39 °C) are shown in Figure 12.

As shown in Figure 12, the power increases with increasing the evaporating temperature, until it reaches a peak point, then the power will decrease, since when T_e increases, mass flow rate increases at a rate higher than the decrease rate of the enthalpy, and then, mass flow rate increases at a rate lower than the decrease rate of enthalpy.

As noticed from Figure 12, the actual power consumption for both refrigerants is close with slightly higher consumption for R-134a by about 10% which is due to its higher mass flow rate compared to LPG.

4 Variation with the Condensing Temperature

Variation of the performance parameters with the condensing temperatures are done at T_e = -17 ° C and T_a = 22.4 ° C for both LPG and R-134a. The tabulated data and results are introduced in Appendix B, and they are graphically presented in Figure 13 to 15.

4.1 Refrigeration Effect

Figure 13 shows that refrigeration effect decrease with increasing the condensing temperature, this is due to the following: T_c increase results in increasing the enthalpy of the refrigerant entering the evaporator while keeping the one leaving it constant, thus resulting in a decrease in the refrigeration effect.

The refrigeration effect for both refrigerants is recognized in the Figure to have the same behavior as that with respect to the evaporating temperature (section 3.1), where the LPG refrigerant has a considerably higher refrigerating effect than R-134a.

4.2 Compression Work

The compression work is plotted against Tc for R-134a and LPG in Figure 14 It is noted that as the condensing temperature increases, the work of compression will increase due to that the discharge pressure and temperature (and thus the discharge enthalpy of the refrigerant) will increase while keeping the suction enthalpy constant. Therefore, this will cause the compression work to increase as T_c increases.

The work of compression for both refrigerants is recognized in Figure 14 to have the similar behavior as that with respect to the evaporating temperature (section 3.2), where the LPG refrigerant has a considerably higher work of compression than R-134a.

4.3 Coefficient of Performance

Variation of the coefficient of performance with the condensing temperature for R-134a and LPG is shown in Figure 15. It is clear that as T_c increase, at a constant T_e the coefficient of performance will decrease since the enthalpy difference across the evaporator will decrease and the enthalpy difference across the compressor will increase.

The coefficient of performance for both refrigerants is recognized in Figure 15 to have the almost the same values with respect to condensing temperature.

5 Cooling Rate

All time variation testes are presented in Appendix C, and the resulting graphics are plotted in Figure 16 to 6.19.

Other aspects of comparisons can be made between R-134a and LPG refrigerants. The other comparison types experienced in this work are the cooling rate test and the evaporating temperature response to load. Those will be discussed below.

Cooling rate test is performed by inserting a simulated load (1.5 kg of water at 20 ^{o} C) into the freezer compartment using both refrigerants. The water load temperature is recorded versus the time for R-134a and LPG. This is portrayed graphically in Figure 16 for R-134a and Figure 17 for LPG. The cooling curves indicate

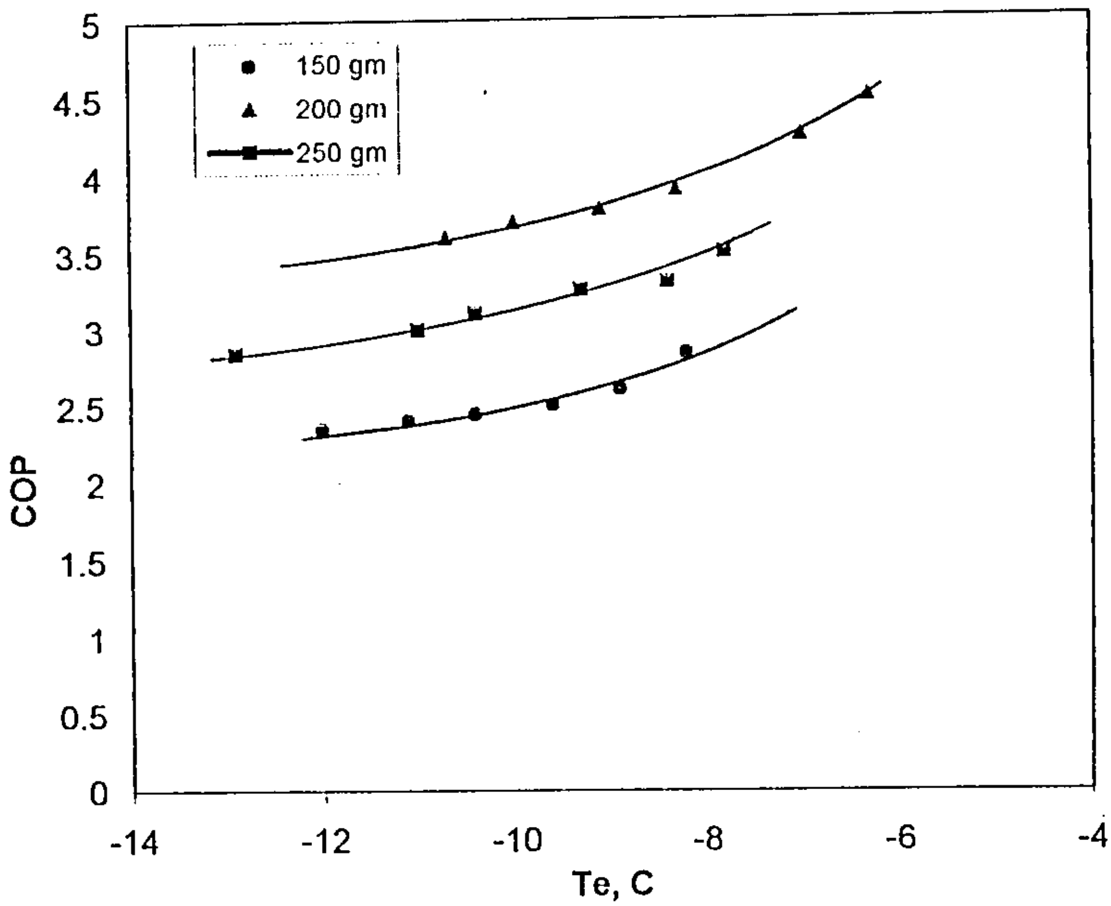
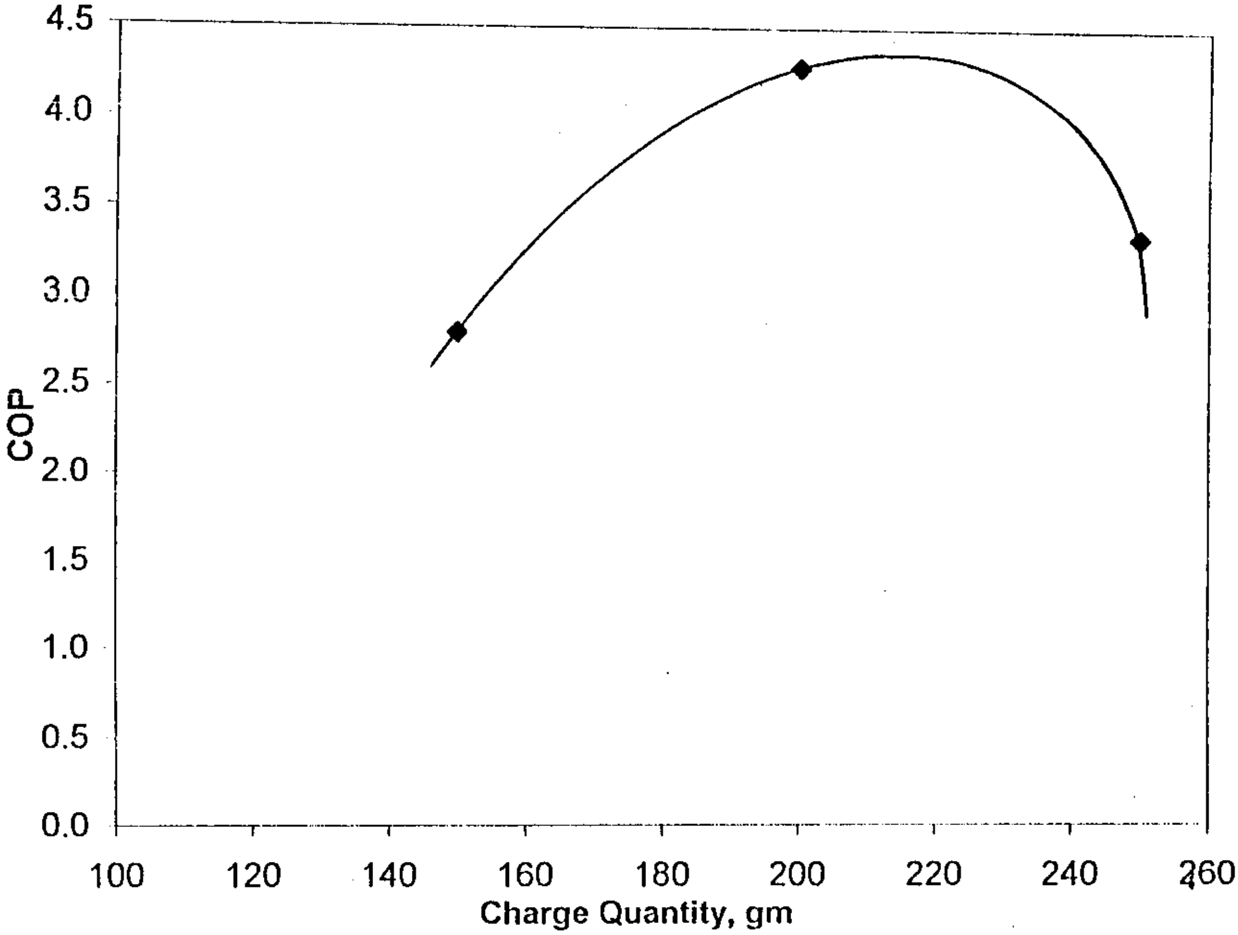


Figure 4 Coefficient of performance versus evaporating temperature for various charge quantities of LPG, a

$T_c = 39\ ^oC$.



,Figure 5 Coefficient of performance versus charge quantity of LPG,

at T_e = -8.2 °C, T_c = 39 °C.

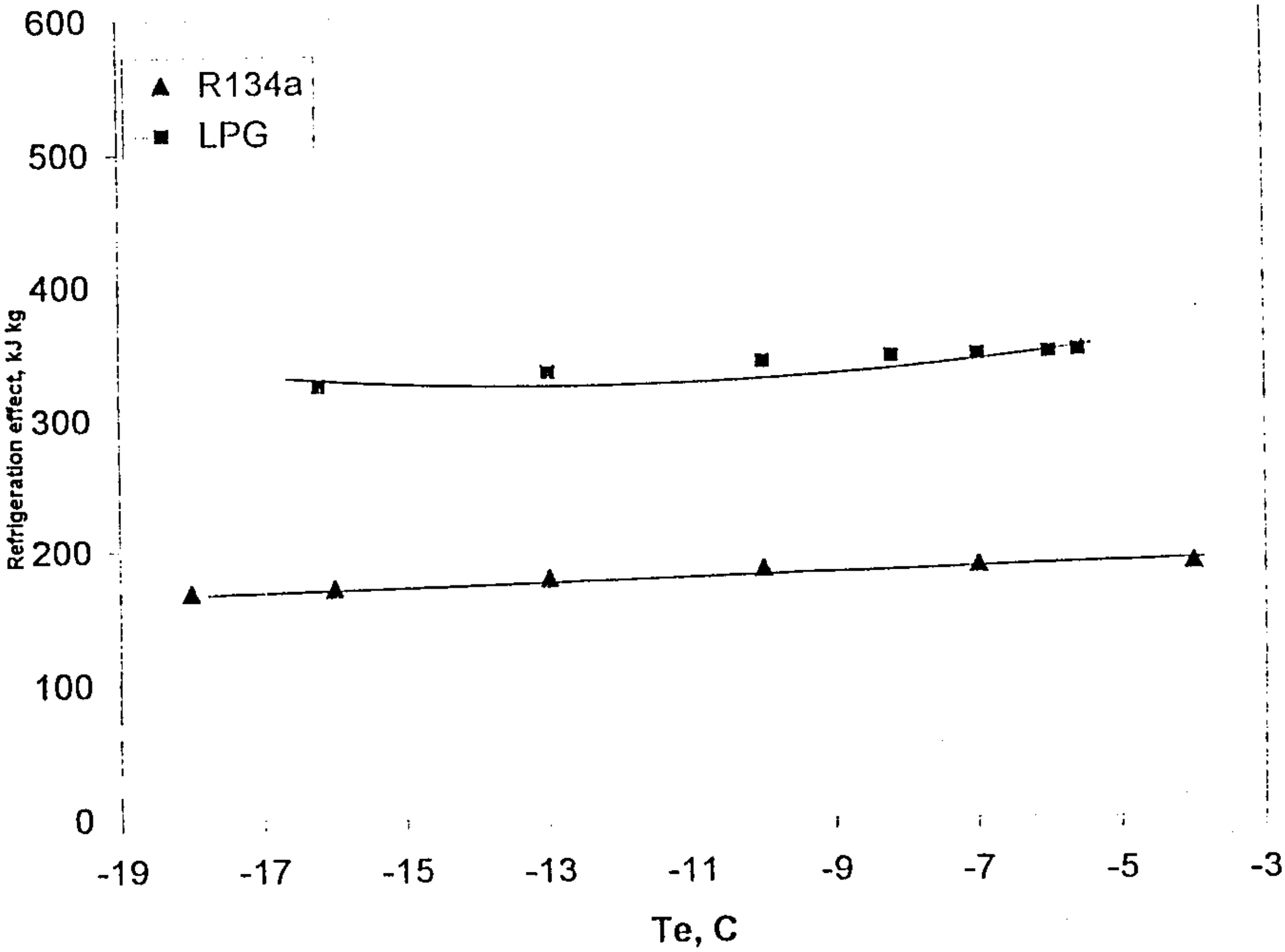


Figure 6 Refrigeration effect versus evaporating temperature, at T_c = 39 °C.

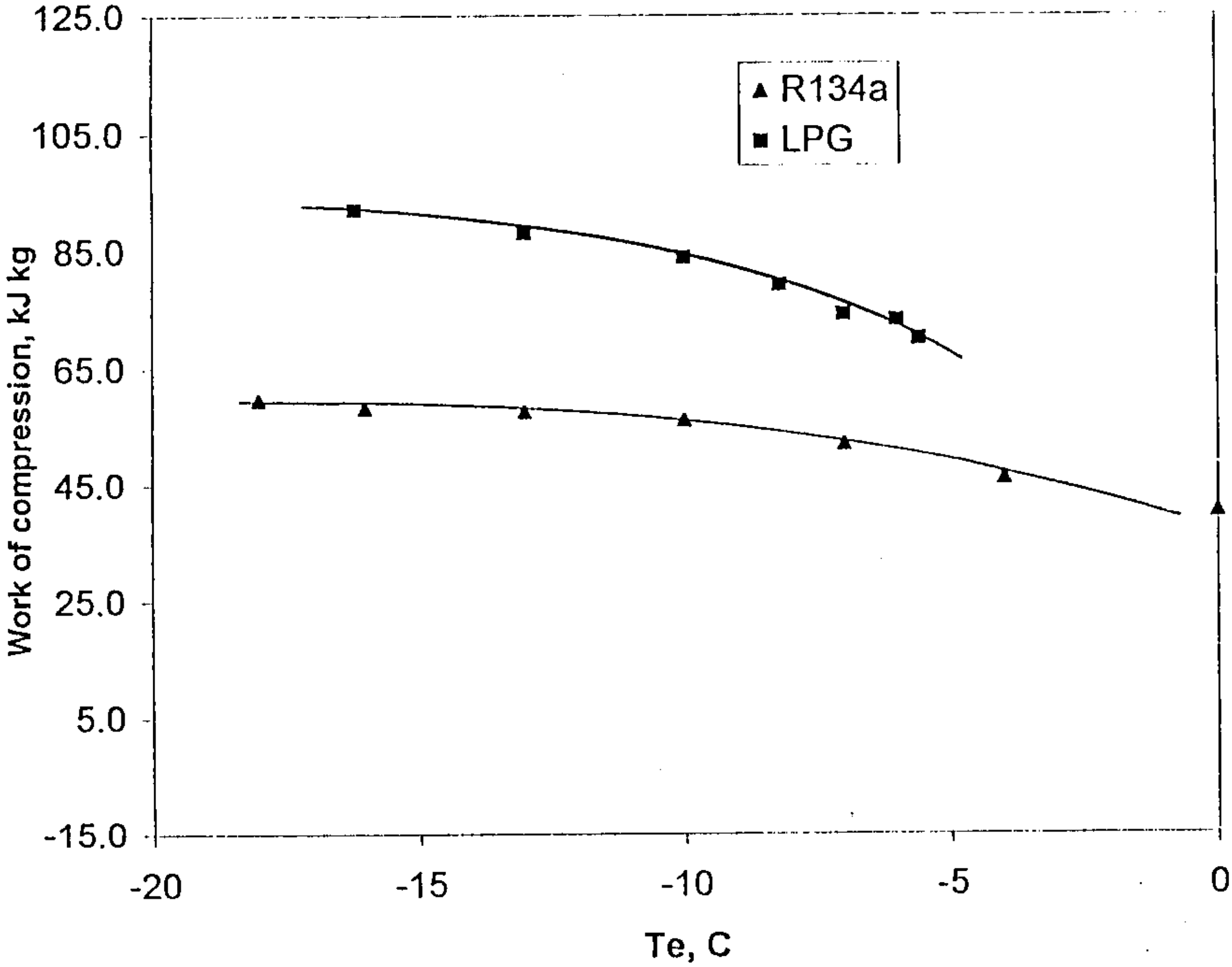


Figure 7 Work of compression versus evaporating temperature, at T_c = 39 °C.

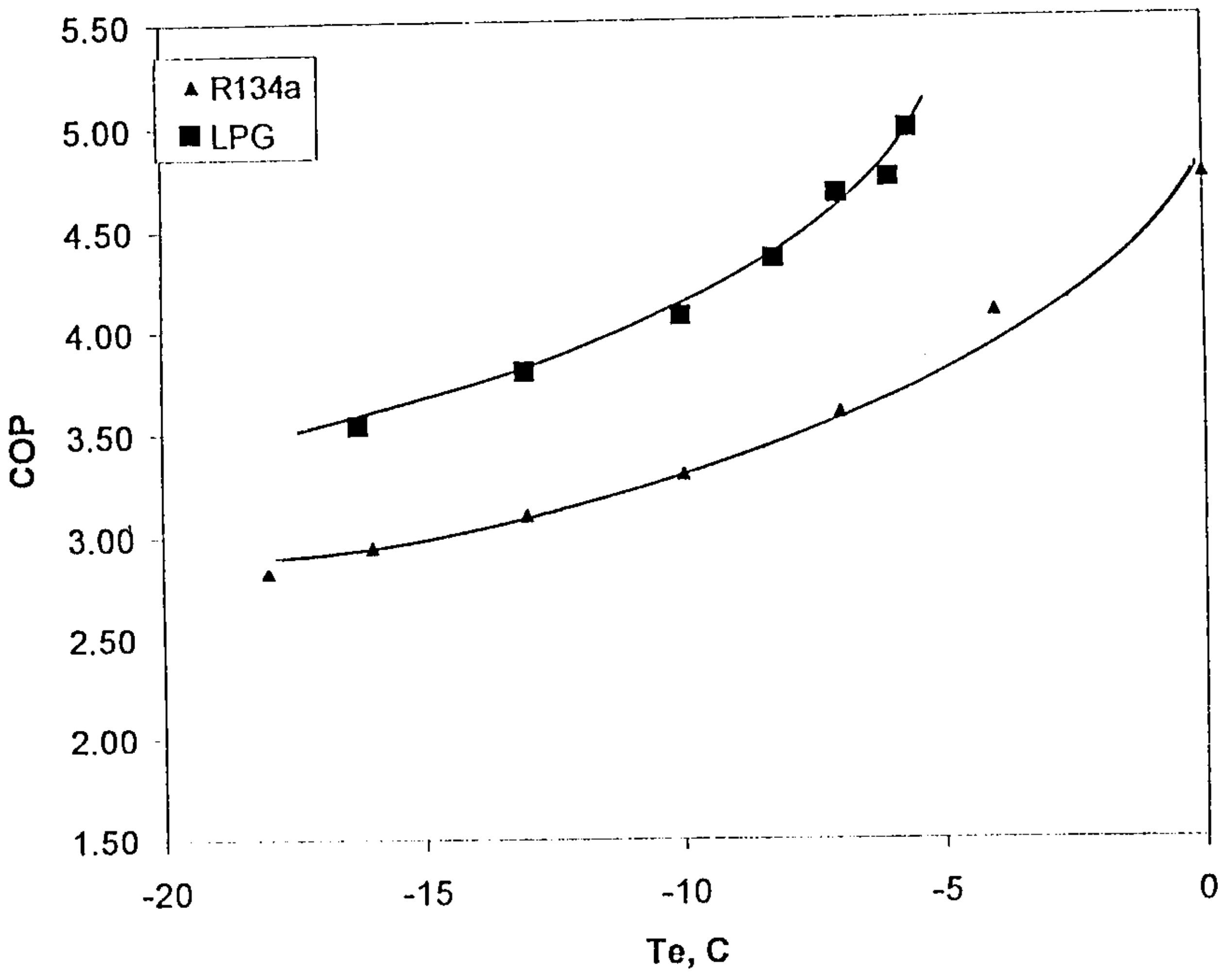


Figure 8 Coefficient of performance versus evaporating temperature,

at $T_c = 39\ ^oC$.

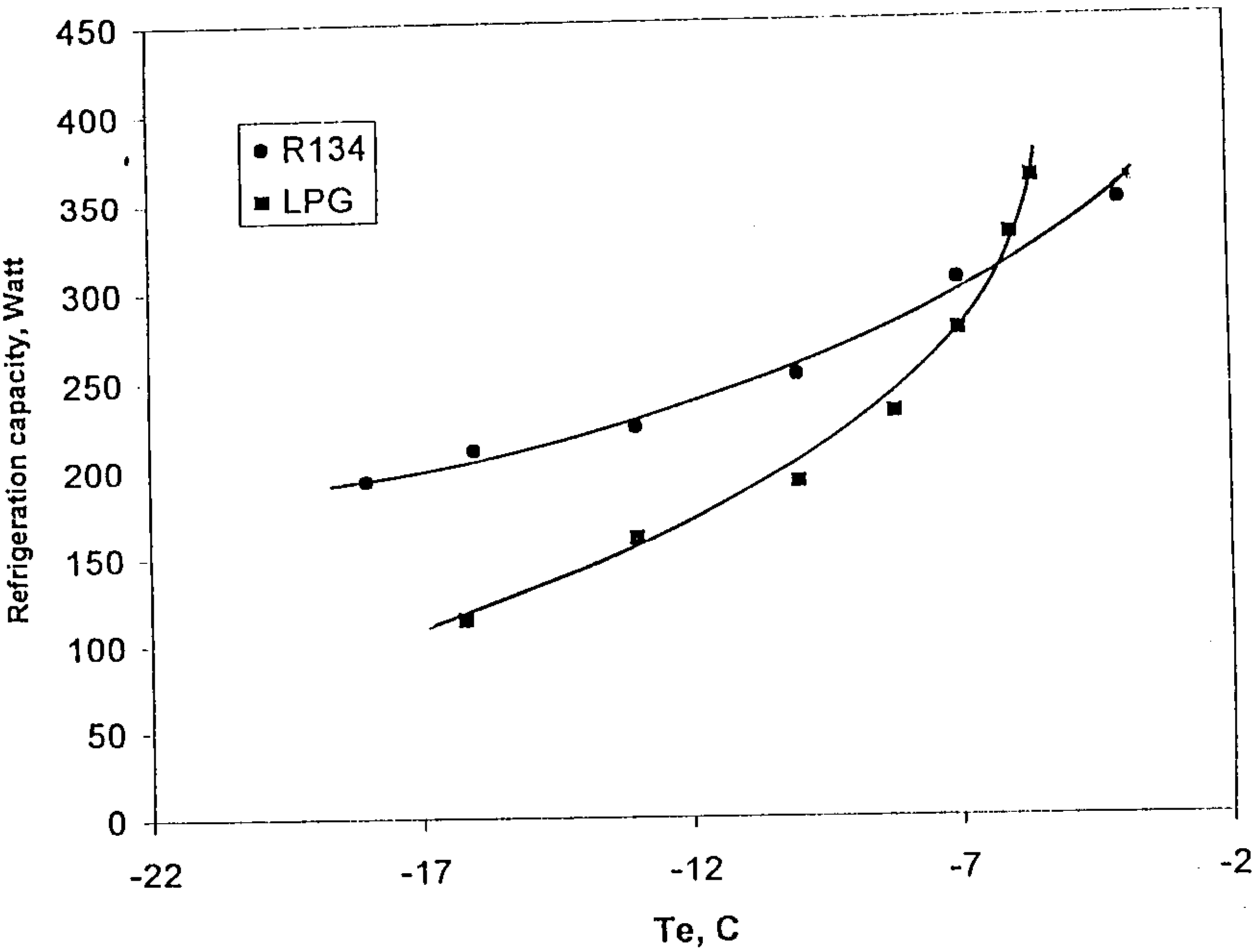


Figure 9 Refrigeration capacity versus evaporating temperature, at T_c = 39 °C.

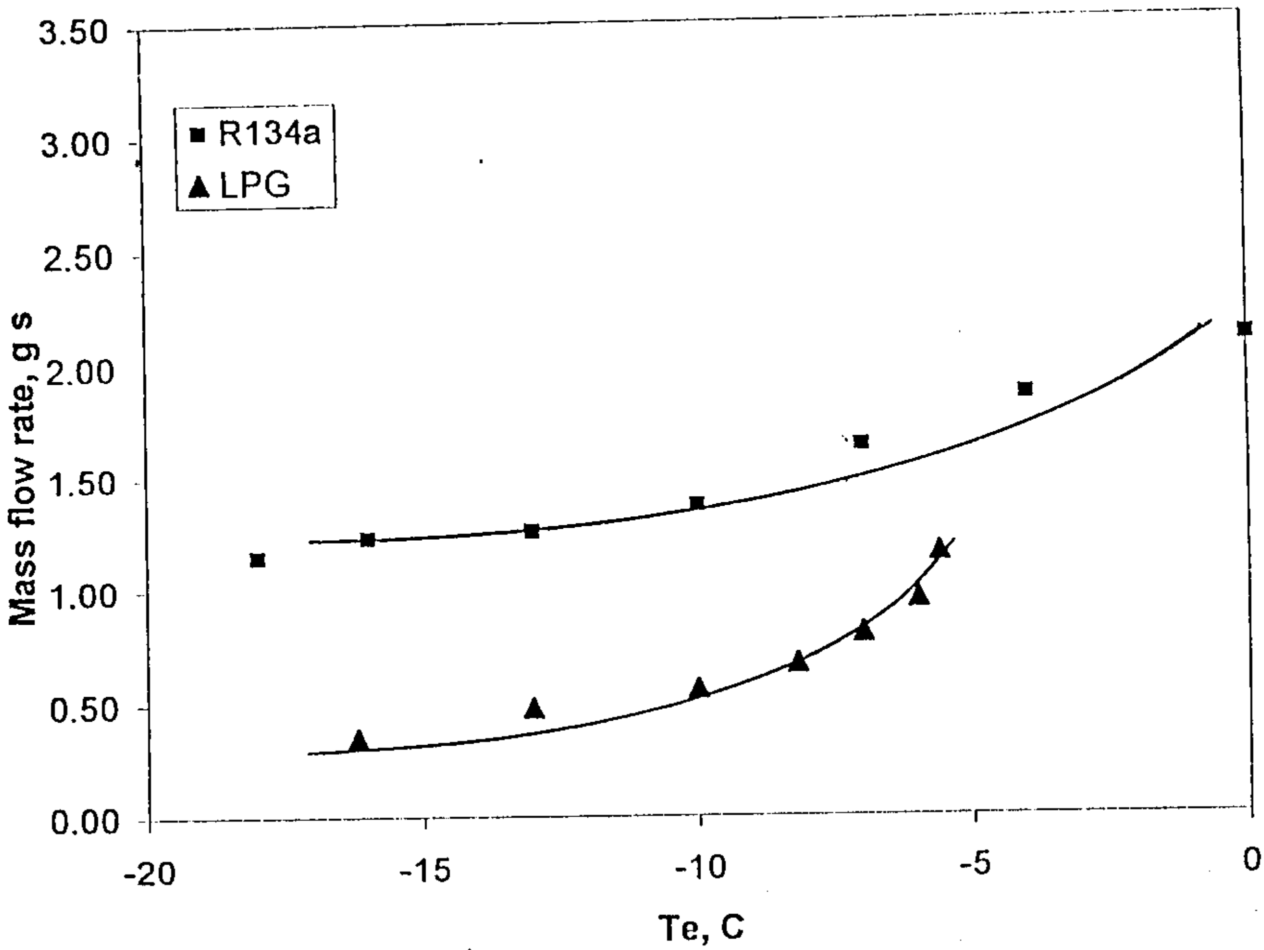


Figure 10 Mass flow rate versus evaporating temperature, at T_c = 39 °C.

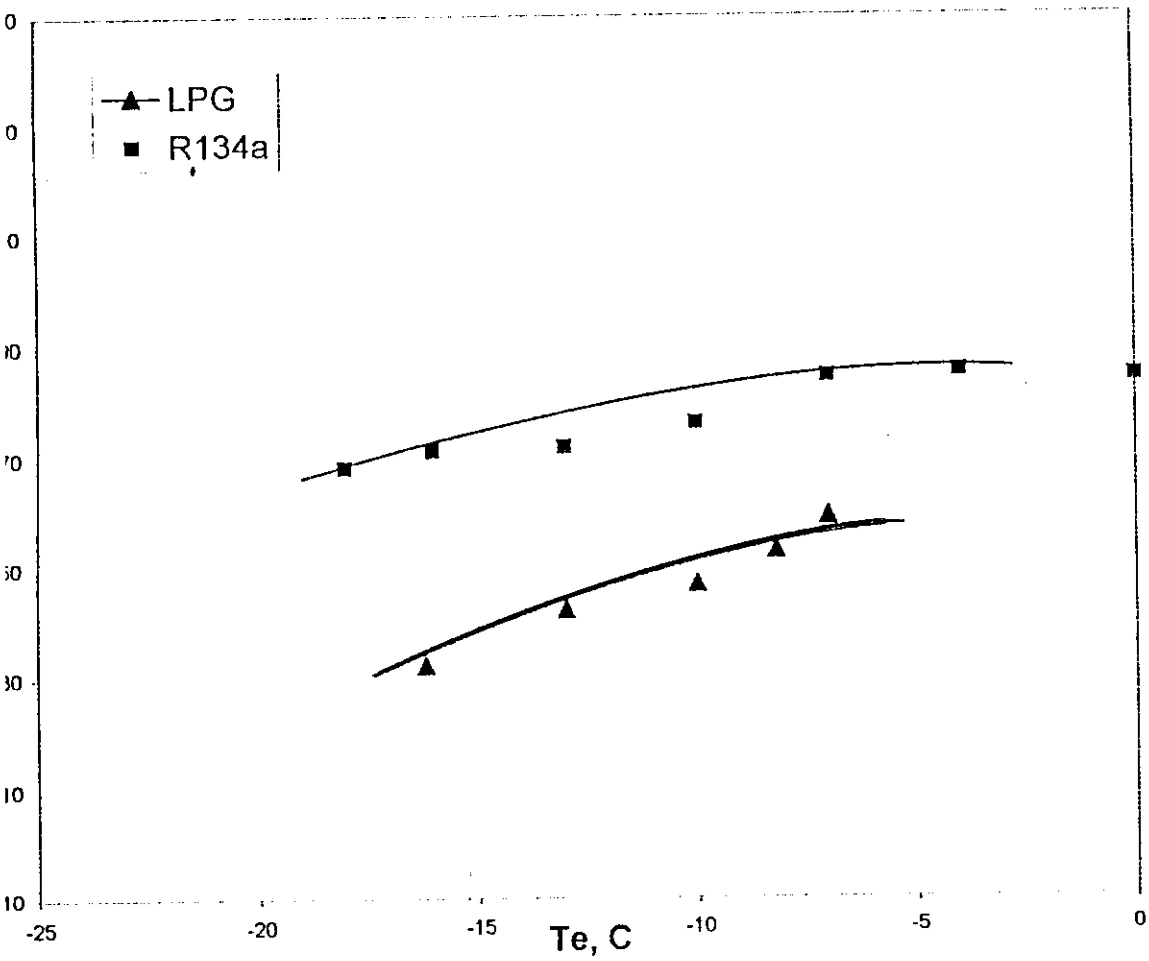


Figure 11 Theoretical power consumption versus evaporating temperature

at Tc = 39 °C.

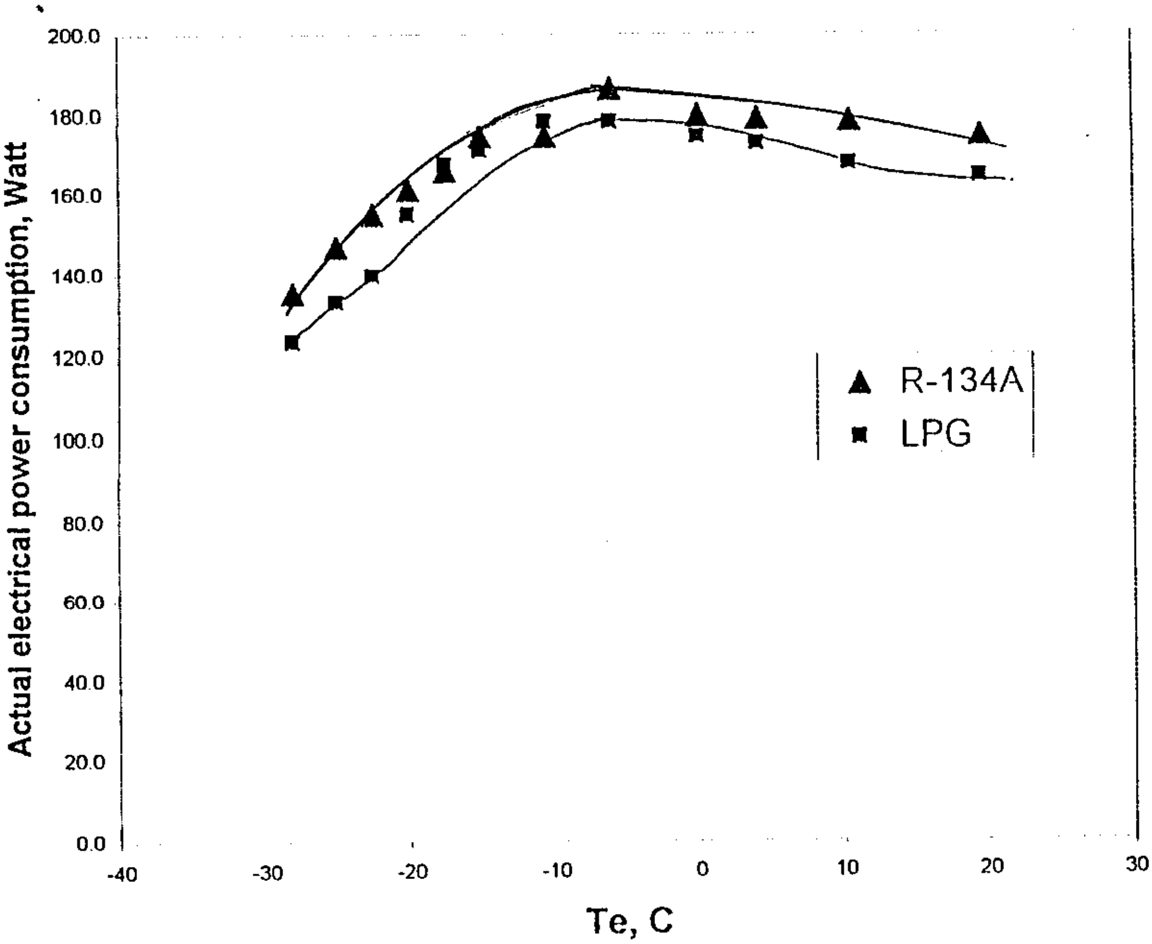


Figure 12 Actual electrical power consumption versus evaporating temperature at Tc = 39 °C.

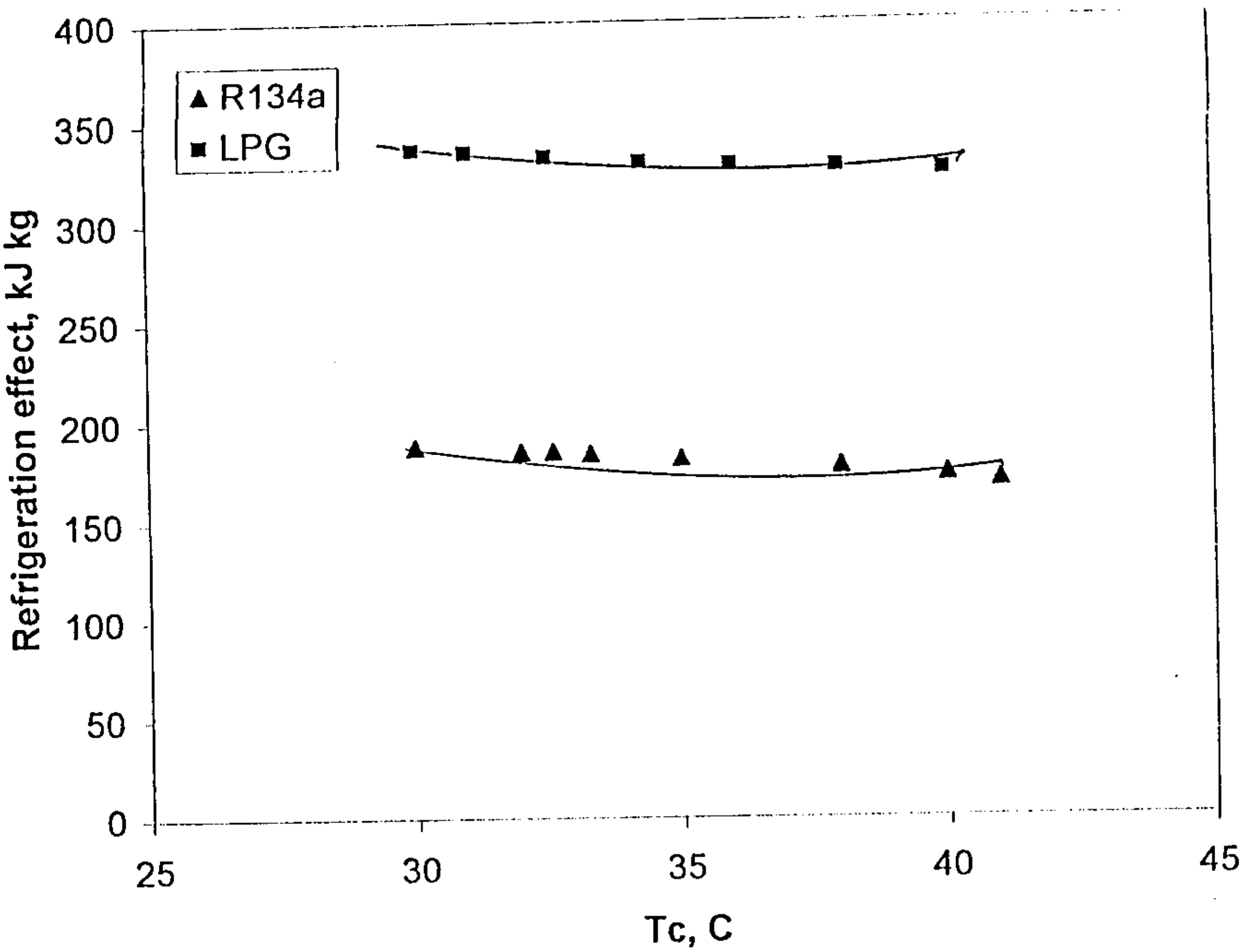


Figure 13 Refrigerating effect versus condensing temperature, at T_e = -17 °C.

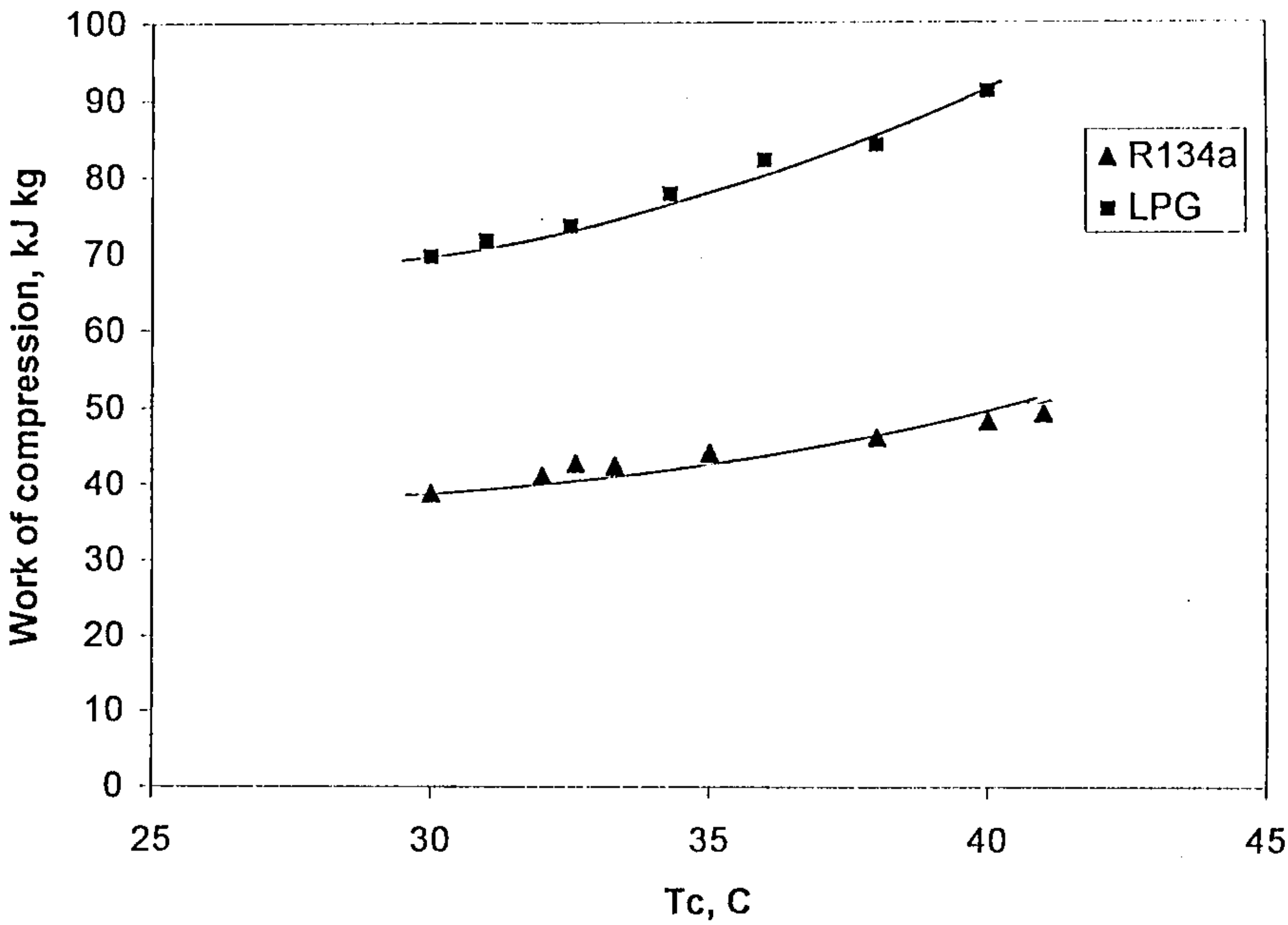


Figure 14 Work of compression versus condensing temperature, at T_e = -17 °C.

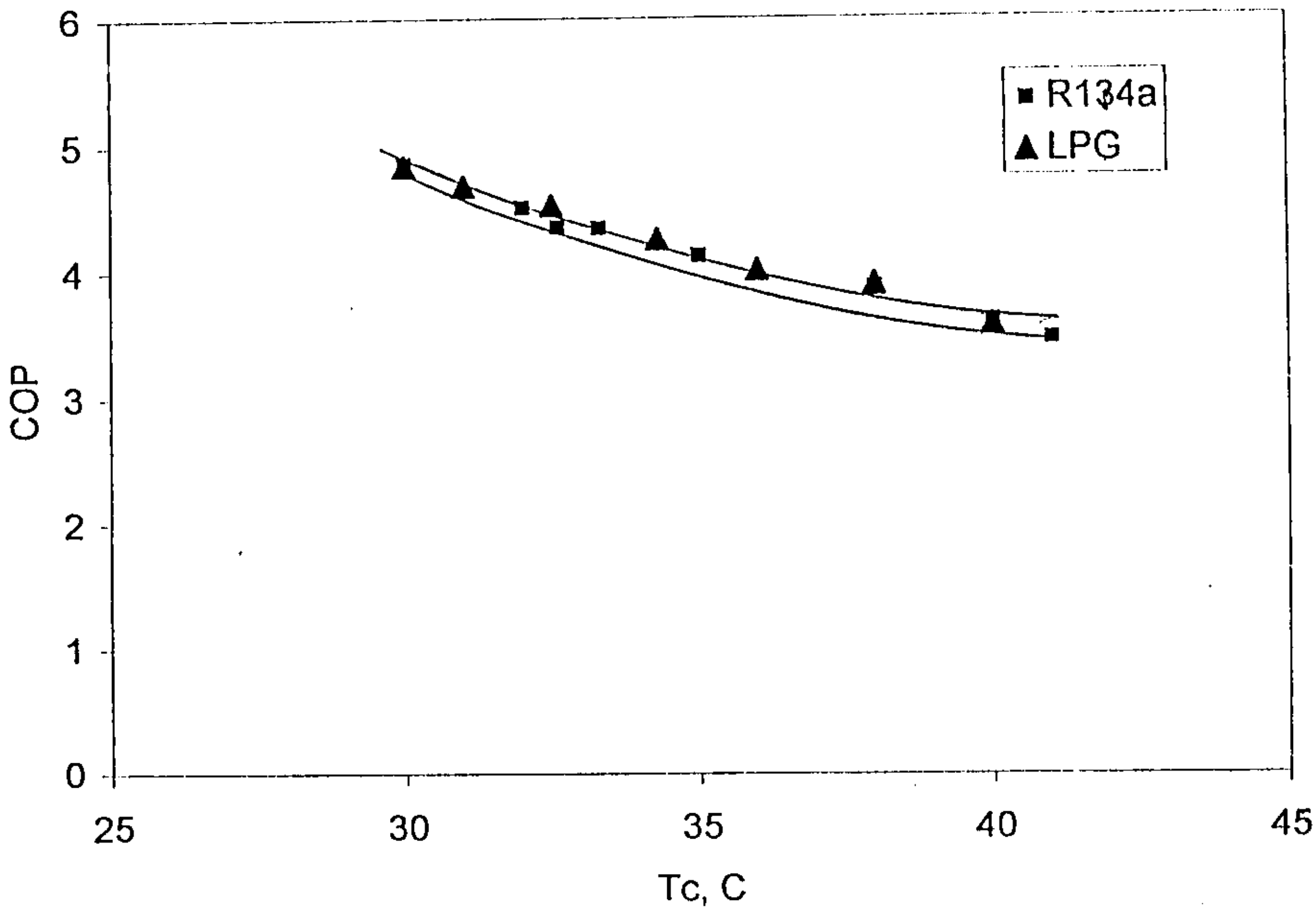


Figure 15 Coefficient of performance versus condensing temperature, at T_e = -17 °C.

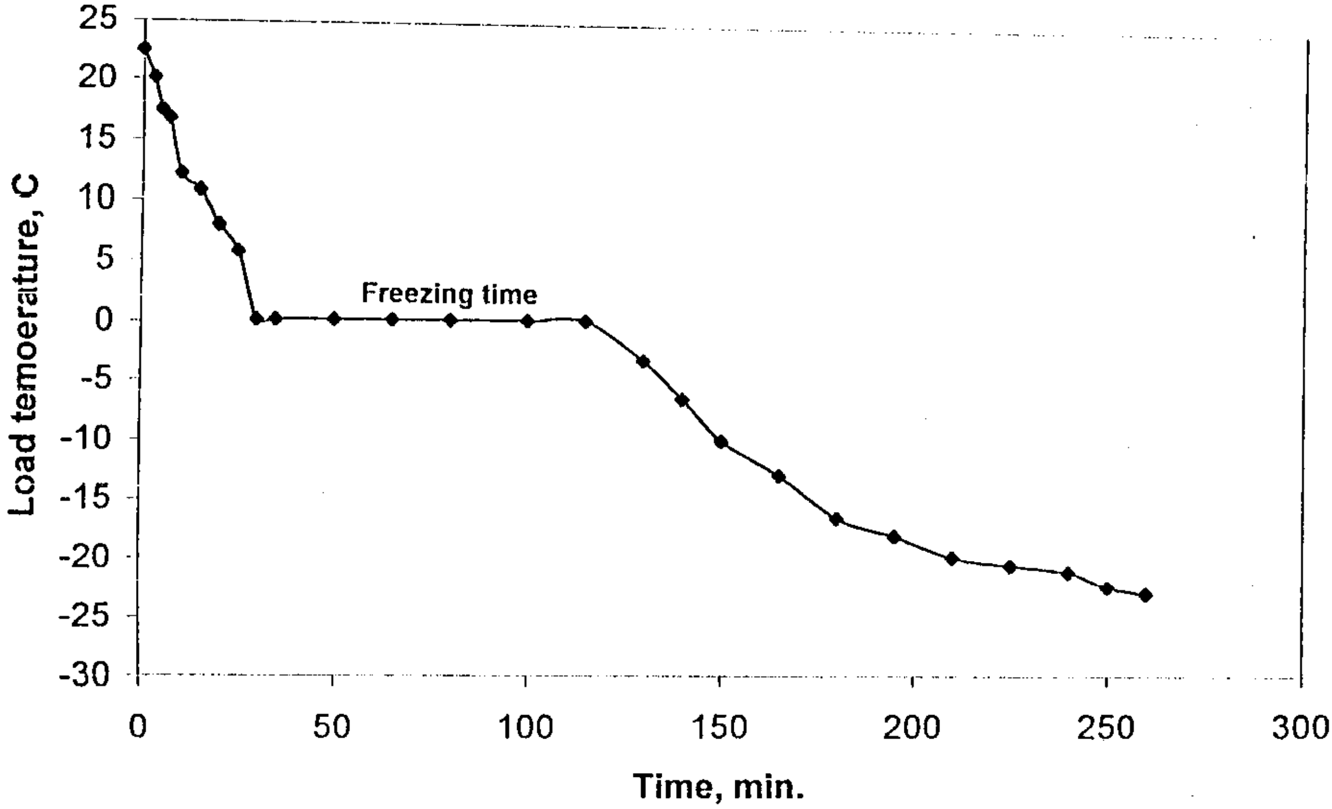


Figure 16 Load temperature versus time for R-134a.

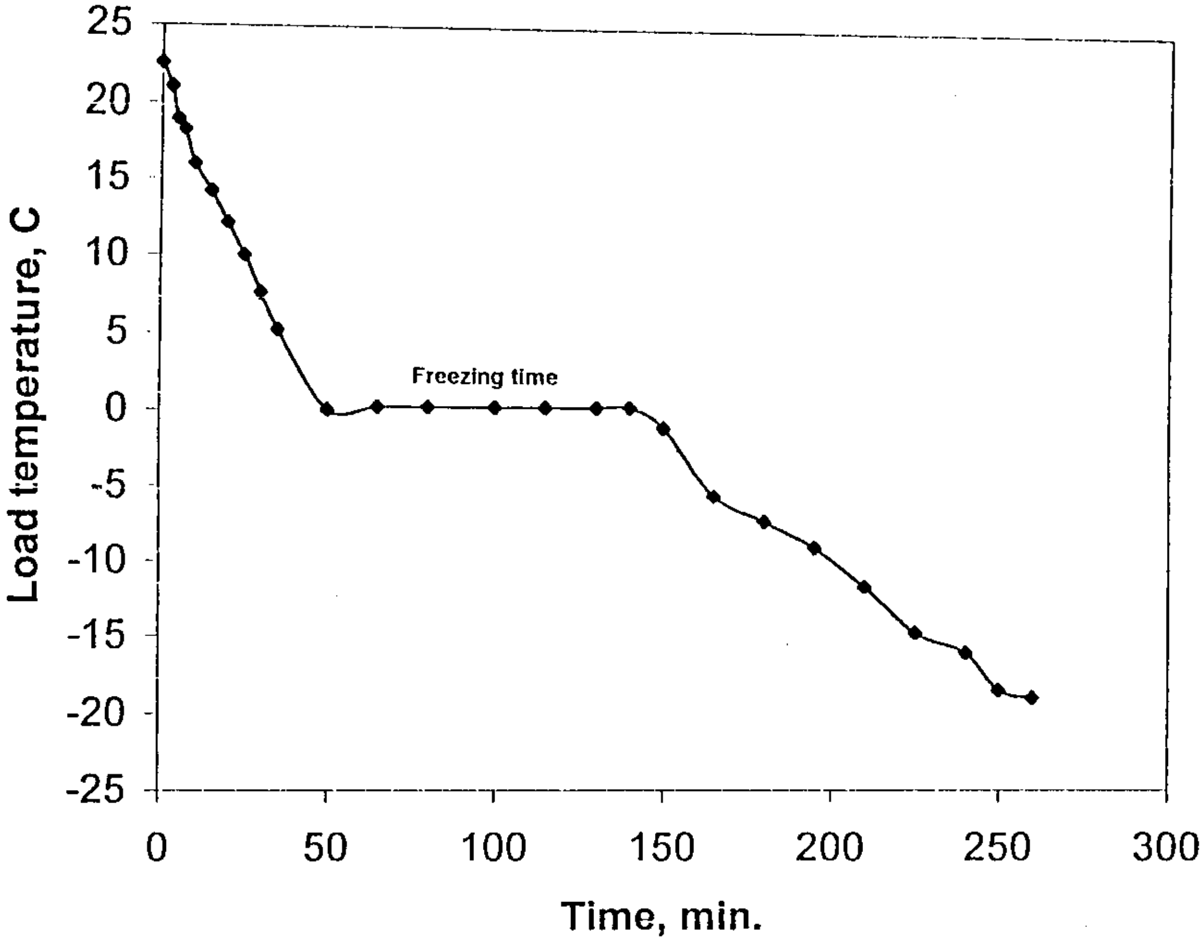


Figure 17 Load temperature versus time for LPG.

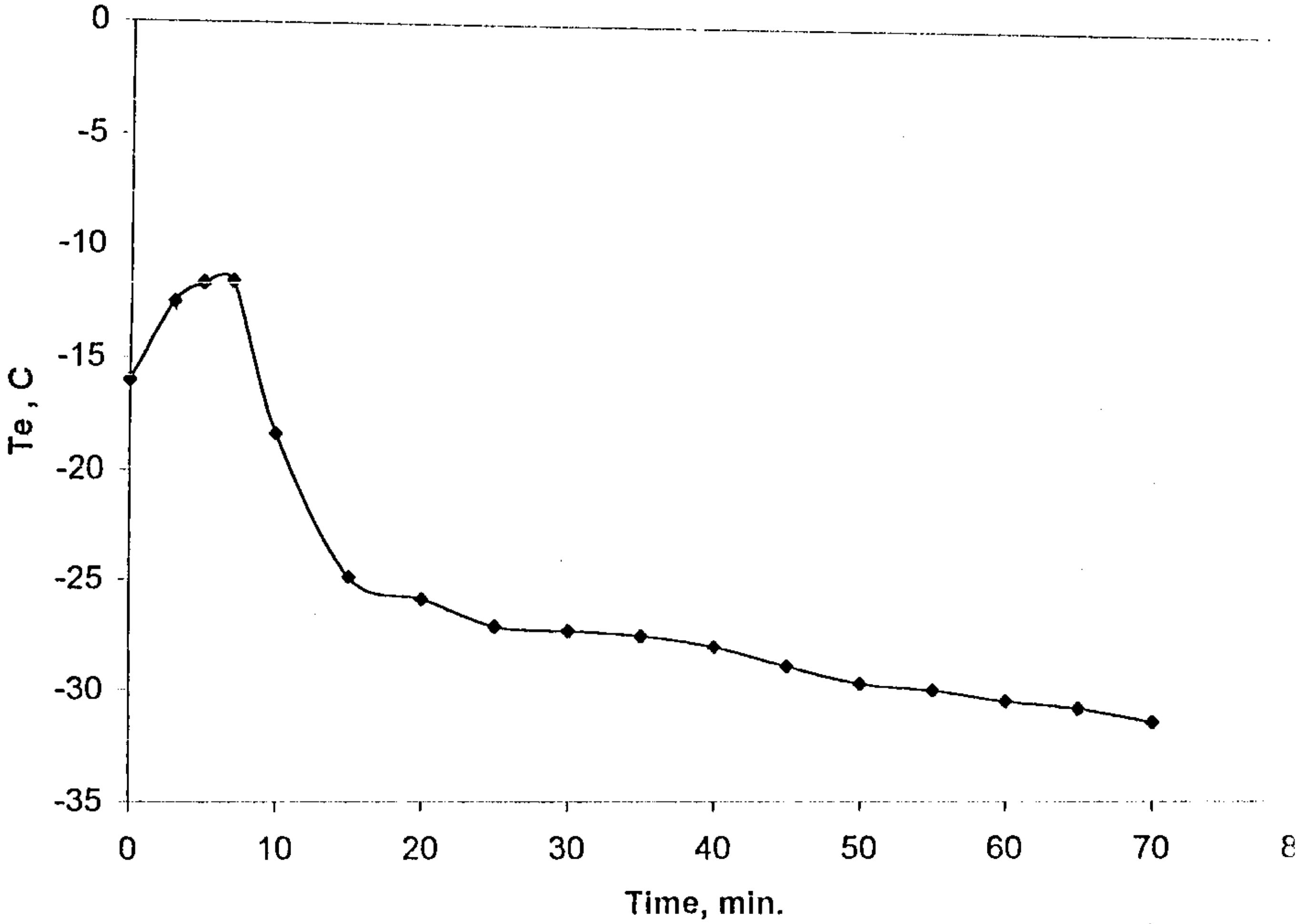


Figure 18 Evaporating temperature versus time for R-134a.

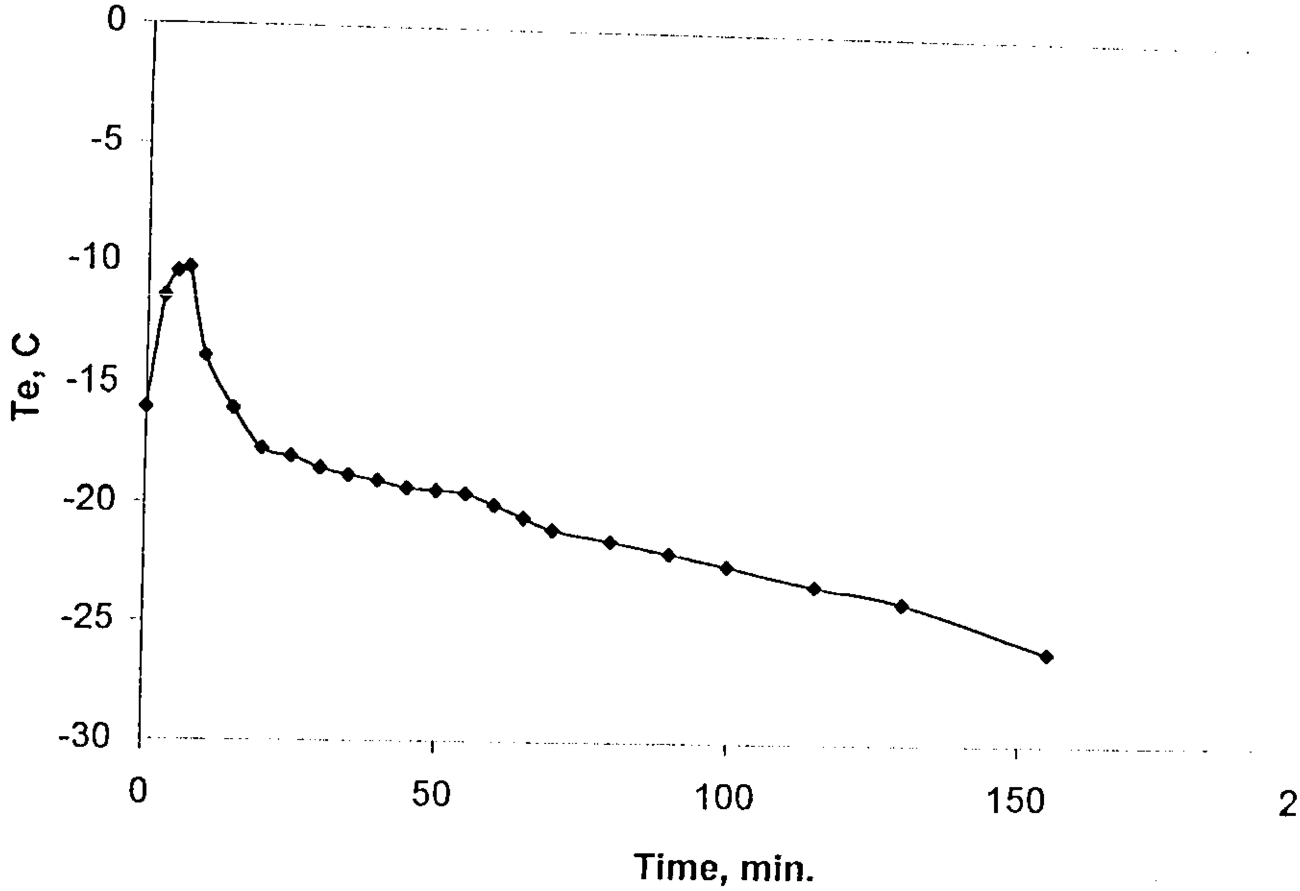


Figure 19 Evaporating temperature versus time for LPG.

CONCLUSIONS AND RECOMMENDATIONS

1 Introduction

This research covers an experimental study of the performance of propane/butane (LPG) mixture as an alternative refrigerant to R-134a in chest freezers.

The conclusions and recommendations extracted from the system performance curves discussed and judged in previous section will be stated in the following sections.

2 Conclusions

1- LPG can be used as an alternative refrigerant to R-134a in chest freezers.

2- Thermodynamic performance of LPG refrigerant is fairly competent with that of R-134a. Results revealed that the evaporator temperature reached a low values of about – 27 °C. The COP reached a value of 4.96 at T_e = –5.6 °C, T_c = 39 °C, and T_a = 22.4 °C. The corresponding value of COP for R-134a is 4.0 at the same operating conditions.

3- The refrigeration capacity and the compressor power consumption for LPG are 190 and 47 W, respectively, at T_e = -10 °C, T_c = 39 °C. The corresponding values for R-134a are 250 and 76 W, respectively at the same conditions.

4- No design changes, system optimizing or component replacement are needed for the chest freezer in order to employ the LPG refrigerant as an alternative for R-134a.

5- No replacement of the lubricating oil is required, since the LPG refrigerant is completely miscible with all refrigeration oils.

6- No leakage was detected during the period of operation with LPG, which indicates good material compatibility with the existing freezer materials including the rubber seals.

7- No side effects such as compressor overheating or frost accumulation was noticed during the period of operation.

8- In addition to the satisfactorily performance of the LPG, its availability, cheapness and environmentally friendly nature makes it to be considered as an attractive alternative refrigerant to R-134a in chest freezers.

3 Recommendations

1- More experimental work and studies are recommended to use different LPG mixtures with different compositions to determine the best mixture composition that has the optimum performance. .

2- The performance of the LPG refrigerant in chest freezers may be enhanced by making limited changes to some components, such as the length and diameter of the capillary tube. Such changes may enhance the LPG performance.

3- More research and studies are recommended on other promising and environmentally friendly alternative refrigerants, which will be very useful for the industry when phasing out existing CFCs and HCFCs.

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APPENDIX A

Data and Results Tables

(T_e Variation Test)

Table (A.1) Refrigerant R-134a, T_a = 22.4 °C and T_c = 39 °C.

- Data Readings

P_1 kPa	P_2 kPa	T_1 °C	T_2 °C	T_4 °C	T_6 °C	$T_{7[load]}$ °C	T_8 °C	T_9 °C
277.0	1146.7	39	90.5	31.8	0	58	59.6	0.6
242.5	1090.9	35.1	92	30.7	-4	57	58.6	-0.4
234.0	1090.9	28.5	92.9	29.5	-7	56.1	57.7	-1.8
193.6	1090.9	24.3	93.7	29.1	-10	53.6	55	-2.2
173.9	1090.9	24.3	94.2	31	-13	52.3	53.8	-4.7
148.1	1090.9	22	95.1	35.6	-16	51.3	52.4	-5.5
140.0	1090.9	20.2	94.4	36	-18	50.1	51.2	-6.8

- Results

$T_6 = T_e$ °C	w_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP	$Q_{ref.}$ Watt	m* g/s
0	40.1	190.033	4.74	397.92	2.09
-4	46.0	187.36	4.07	346.63	1.85
-7	51.8	185.87	3.59	302.81	1.63
-10	55.9	183.9	3.29	250.77	1.36
-13	57.4	177.5	3.09	222.56	1.25
-16	58.0	170.75	2.94	209.85	1.23
-18	59.5	167.95	2.82	192.84	1.15

Table (A.2) Refrigerant LPG , Charge quantity 150 g, $T_a = 22.4$ °C and $T_c = 39$ °C.

• Data Readings

P_1 KPa	P_2 Kpa	T_1 °C	T_2 °C	T_4 °C	T_6 °C
242.3	2745	21.1	95.7	33	-8.2
242.3	2676	21	99.1	33.3	-8.9
235	2642	20.7	99.4	33.1	-9.6
229	2607	20.4	98.8	32.1	-10.4
229	2607	19.9	98	32.2	-11.1
222	2504	18.9	93	30.3	-12

• Results

$T_6 = T_e$ °C	W_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP
-8.2	118	336	2.84
-8.9	123	319	2.6
-9.6	125	312.5	2.5
-10.4	129	314.7	2.44
-11.1	132	316.8	2.4
-12	136	319.6	2.35

Table (A.3) Refrigerant LPG , Charge quantity 200 g, $T_a = 22.4$ °C and $T_c = 39$ °C.

• Data Readings

P_1 KPa	P_2 kPa	T_1 °C	T_2 °C	T_4 °C	T_6 °C
277.3	2987	21	76.9	34	-6.3
277.3	2918	21.3	80.3	33.9	-7
270.4	2849	20.5	77.5	33.8	-8.3
264	2780	20.1	76.3	33.6	-9.1
256	2711	19.4	74.4	32.5	-10
249	2676	19	73	29.6	-10.7

• Results

$T_6 = T_e$ °C	w_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP
-6.3	74	333	4.5
-7	76.2	323.8	4.25
-8.3	81.1	348.7	3.9
-9.1	82	336.7	3.78
-10	86.3	319.3	3.7
-10.7	87.5	315	3.6

Table (A.4) Refrigerant LPG, Charge quantity 250 g, T_a = 22.4 °C and T_c = 39 °C.

- Data Readings

P_1 KPa	P_2 KPa	T_1 °C	T_2 °C	T_4 °C	T_6 °C
270.4	2642	18.3	63.2	31.8	-7.8
266	2607	18.1	63.1	31.8	-8.4
260	2538	17.4	62	31.7	-9.3
249	2469	16.5	60.6	31.4	-10.4
242	2435	15.9	60.1	30.8	-11
235	2332	15	56.6	30.5	-12.9

- Results

$T_6 = T_e$ °C	w_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP
-7.8	95.3	333.2	3.5
-8.4	98.2	326	3.3
-9.3	101.2	328.9	3.25
-10.4	106.6	327.4	3.1
-11	108.5	325.5	3
-12.9	113	322	2.85

Table (A.5) Refrigerant LPG, Optimum charge quantity 210 g, T_a = 22.4 °C and T_c = 39 °C.

- Data Readings

P_1 kPa	P_2 kPa	T_1 °C	T_2 °C	T_4 °C	T_6 °C	$T_{7[load]}$ °C	T_8 °C	T_9 °C
187.6	2090.8	13	63.5	27	-5.6	62.9	64.5	8.3
194.5	2159.6	12.3	62.3	26.2	-6	65.5	67	7.7
201.4	2194.1	11.8	60.8	23	-7	67.9	69.3	5.4
215.2	2263.0	11.1	58.4	22	-8.2	69.5	70.8	-0.2
222.1	2332.0	10.2	57.6	22	-10	70.8	72.5	-1.6
229.0	2366.5	8.7	55	23	-13	72.5	74.2	-5.5
229.0	2366.5	8	54	24.2	-16.2	73.6	75.2	-9.4

- Results

$T_6 = T_e$ °C	W_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP	$Q_{ref.}$ Watt	m* g/s
-5.6	69.8	346.24	4.96	398.18	1.15
-6	73.0	344.87	4.72	327.63	0.95
-7	74.0	344	4.65	275.20	0.80
-8.2	79.1	343	4.34	229.81	0.67
-10	83.8	340	4.06	190.40	0.56
-13	87.9	333	3.79	159.84	0.48
-16.2	92.0	324.779	3.53	113.67	0.35

Table (A.6) Actual electrical power consumption for refrigerant LPG with optimum charge of 210 g and for refrigerant R-134a, $T_a = 22.4$ °C, $T_c = 39$ °C.

- Data Readings

T_e °C	Δt/2rev. (sec.) R-134a	Δt/2rev. (sec.) LPG
19.5	48	51
10.5	47	50
4.1	46.8	48.5
0	46.6	48
-6	45	47
-10.5	48	47
-15	48	49
-17.4	50.5	50
-20	52	54
-22.5	54	60
-25	57	63
-26.7	62	67.8

- Results

T_e °C	Power (Watt) R-134a	Power (Watt) LPG
19.5	174.4	164.2
10.5	178.1	167.4
4.1	178.9	172.6
0	179.7	174.4
-6	186	178.1
-10.5	174.4	178.1
-15	174.4	170.9
-17.4	165.8	167.4
-20	161	155
-22.5	155	139.5
-25	147	132.9
-26.7	135	12.3

Table (B.2) Refrigerant LPG, Optimum charge quantity 210 g, T_a = 22.4 °C and T_e = -17 °C.

- Data Readings

P_1 KPa	P_2 kPa	T_1 °C	T_2 °C	T_3 °C	T_4 °C
180.67	1606.9	11.9	51.1	30	22.9
173.78	1675.8	13.2	51.7	31	22.4
180.67	1779.2	14.4	52.5	32.5	23
173.78	1848.1	15.2	53.0	34.3	24.3
180.67	1951.4	15.6	53.4	36	25
173.78	2020.3	16.2	53.9	38	27
180.67	2061.6	17.1	54.6	40	28

- Results

$T_3 = T_c$ °C	W_{comp} kJ/kg.	$q_{ref.}$ kJ/kg.	COP
30	69.6	336.44	4.84
31	71.6	335	4.68
32.5	73.5	332.5	4.52
34.3	77.7	329.6	4.24
36	82.0	328	4.00
38	84.0	326.8	3.89
40	91.0	324.6	3.57

APPENDIX C

Data Tables

(Time Variation Test)

Table (C.1) Variation of evaporating temperature for refrigerant LPG with optimum charge of 210 g, and for refrigerant R-134a, T_a = 22.4 °C and T_c = 39 °C.

- Data Readings

Time (min)	T_e (° C) R-134a	T_e (° C) LPG
0	-16	-16
3	-12.5	-11.4
5	-11.7	-10.4
7	-11.6	-10.3
10	-18.4	-13.8
15	-24.9	-16
20	-25.9	-17.7
25	-27.1	-18
30	-27.3	-18.5
35	-27.5	-18.8
40	-28	-19
45	-28.9	-19.3
50	-29.7	-19.4
55	-30	-19.5
60	-30.5	-20
65	-30.8	-20.5
70	-31.4	-21
80	-	-21.5
90	-	-22
100	-	-22.5
115	-	-23.3
130	-	-24
155	-	-26.7

Table (C.2) Variation of load temperature for refrigerant LPG with optimum charge of 210 g, and for refrigerant R-134a, 1.5 kg of water, $T_a = 22.4$ °C and $T_c = 39$ °C.

- Data Readings

Time (min)	T_{load} (° C) R-134a	T_{load} (° C) LPG
0	22.5	22.5
3	20.1	21
5	17.5	19
7	16.8	18.3
10	12.1	16
15	10.8	14.2
20	8	12.2
25	5.8	10
30	0.2	7.6
35	0.2	5.2
50	0.2	.0.2
65	0.2	0.2
80	0.2	0.2
100	0.2	0.2
115	0.2	0.2
130	-3.1	0.2
140	-6.4	0.2
150	-9.9	-1.1
165	-12.8	-5.6
180	-16.5	-7.3
195	-18	-9
210	-19.8	-11.6
225	-20.5	-14.7
240	-21	-16
250	-22.3	-18.5
260	-22.9	-19

APPENDIX D

Table (D.1) Saturation properties for R-134a.

Temp,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb·°F Liquid	Entropy, Btu/lb·°F Vapor	Specific Heat c_p, Btu/lb·°F Liquid	Specific Heat c_p, Btu/lb·°F Vapor	c_p/c_v Vapor	Velocity of Sound, ft/s Liquid	Velocity of Sound, ft/s Vapor	Viscosity, lb_m/ft·h Liquid	Viscosity, lb_m/ft·h Vapor	Thermal Cond, Btu/h·ft·°F Liquid	Thermal Cond, Btu/h·ft·°F Vapor	Surface Tension, dyne/cm	Temp,* °F
-153.94a	0.057	99.34	561.85	32.989	80.335	0.09154	0.27880	0.2740	0.1392	1.1628	3773.	416	5.289	0.0160			28.15	-153.94
-150.00	0.072	98.95	449.29	31.902	80.783	0.08801	0.27588	0.2776	0.1409	1.1615	3670.	418.	4.913	0.0163	-	—	27.76	-150.00
-140.00	0.130	97.98	259.15	29.093	82.190	0.07968	0.26903	0.2837	0.1438	1.1583	3552.	424.	4.117	0.0168	—	—	26.78	-140.00
-130.00	0.222	97.01	155.69	26.238	83.618	0.07029	0.26294	0.2870	0.1467	1.1554	3448.	430	3.497	0.0173	—	—	25.81	-130.00
-120.00	0.367	96.05	97.027	23.359	85.056	0.06169	0.25752	0.2886	0.1497	1.1528	3352.	436.	3.006	0.0179	—	—	24.86	-120.00
-110.00	0.586	95.09	62.509	20.467	86.531	0.05330	0.25270	0.2895	0.1527	1.1507	3261.	441.	2.613	0.0184	—	—	23.92	-110.00
-100.00	0.906	94.13	41.496	17.569	88.011	0.04513	0.24842	0.2900	0.1559	1.1489	3173.	446	2.292	0.0190	—	—	22.99	-100.00
-90.00	1.363	93.17	28.303	14.665	89.504	0.03717	0.24462	0.2906	0.1591	1.1475	3087.	451.	2.028	0.0195	0.0721	—	22.08	-90.00
-80.00	1.997	92.21	19.783	11.755	91.005	0.02940	0.24125	0.2913	0.1624	1.1466	3001.	456.	1.808	0.0200	0.0705	—	21.17	-80.00
-75.00	2.396	91.73	16.680	10.297	91.759	0.02559	0.23972	0.2917	0.1641	1.1463	2959.	458	1.713	0.0203	0.0699	—	20.73	-75.00
-70.00	2.859	91.25	14.138	8.837	92.514	0.02182	0.23827	0.2922	0.1658	1.1462	2916.	460	1.623	0.0206	0.0691		20.28	-70.00
-65.00	3.393	90.77	12.045	7.374	93.270	0.01809	0.23691	0.2928	0.1676	1.1461	2874.	462.	1.542	0.0209	0.0684	—	19.84	-65.00
-60.00	4.006	90.28	10.310	5.907	94.026	0.01440	0.23563	0.2935	0.1694	1.1462	2832.	464.	1.465	0.0212	0.0677	0.00405	19.40	-60.00
-55.00	4.707	89.80	8.8656	4.437	94.783	0.01075	0.23443	0.2943	0.1712	1.1465	2790.	466.	1.395	0.0214	0.0659	0.00423	18.96	-55.00
-50.00	5.505	89.31	7.6569	2.963	95.539	0.00713	0.23331	0.2951	0.1731	1.1468	2747.	468.	1.331	0.0217	0.0662	0.00440	18.53	-50.00
-45.00	6.409	88.82	6.6405	1.484	96.295	0.00355	0.23225	0.2960	0.1750	1.1473	2705.	470.	1.271	0.0220	0.0654	0.00457	18.09	-45.00
-40.00	7.429	88.32	5.7819	0.000	97.050	0.00000	0.23125	0.2970	0.1769	1.1479	2663.	471.	1.215	0.0223	0.0647	0.00473	17.66	-40.00
-35.00	8.577	87.83	5.0533	1.489	97.804	0.00352	0.23032	0.2981	0.1789	1.1487	2621.	473.	1.163	0.0225	0.0639	0.00489	17.23	-35.00
-30.00	9.862	87.33	4.4325	2.984	98.556	0.00701	0.22945	0.2992	0.1810	1.1497	2579.	474.	1.113	0.0228	0.0632	0.00505	16.81	-30.00
-25.00	11.297	86.82	3.9014	4.484	99.306	0.01048	0.22863	0.3004	0.1831	1.1508	2536.	476.	1.068	0.0231	0.0625	0.00521	16.38	-25.00
-20.00	12.895	86.32	3.4452	5.991	100.054	0.01392	0.22785	0.3017	0.1852	1.1521	2494.	477.	1.024	0.0234	0.0617	0.00536	15.96	-20.00
-15.00	14.667	85.81	3.0519	7.505	100.799	0.01733	0.22714	0.3031	0.1874	1.1535	2452.	478.	0.981	0.0237	0.0610	0.00550	15.54	-15.00
-14.92b	14.696	85.80	3.0462	7.529	100.811	0.01739	0.22713	0.3031	0.1874	1.1535	2451.	478.	0.983	0.0237	0.0610	0.00551	15.54	-14.92
-10.00	16.626	85.29	2.7116	9.026	101.542	0.02073	0.22647	0.3045	0.1897	1.1552	2410.	479.	0.945	0.0240	0.0602	0.00565	15.12	-10.00
-5.00	18.787	84.77	2.4161	10.554	102.280	0.02409	0.22584	0.3060	0.1920	1.1570	2367.	480.	0.910	0.0243	0.0595	0.00579	14.71	-5.00
0.00	21.162	84.25	2.1587	12.090	103.015	0.02744	0.22525	0.3075	0.1943	1.1590	2325.	481.	0.875	0.0245	0.0588	0.00593	14.30	0.00
5.00	23.767	83.72	1.9337	13.634	103.745	0.03077	0.22470	0.3091	0.1968	1.1613	2283.	481.	0.843	0.0248	0.0580	0.00607	13.89	5.00
10.00	26.617	83.18	1.7365	15.187	104.471	0.03408	0.22418	0.3108	0.1993	1.1637	2240.	482.	0.813	0.0251	0.0573	0.00621	13.48	10.00
15.00	29.726	82.64	1.5630	16.748	105.192	0.03737	0.22370	0.3126	0.2018	1.1664	2198.	482.	0.784	0.0254	0.0565	0.00635	13.06	15.00
20.00	33.110	82.10	1.4101	18.318	105.907	0.04065	0.22325	0.3144	0.2045	1.1694	2155.	482.	0.756	0.0257	0.0558	0.00649	12.67	20.00
25.00	36.785	81.55	1.2749	19.897	106.617	0.04391	0.22283	0.3162	0.2072	1.1726	2113.	482	0.730	0.0260	0.0550	0.00662	12.27	25.00
30.00	40.768	80.99	1.1550	21.486	107.320	0.04715	0.22244	0.3182	0.2100	1.1761	2070.	482	0.705	0.0263	0.0543	0.00676	11.87	30.00
35.00	45.075	80.42	1.0484	23.085	108.016	0.05038	0.22207	0.3202	0.2129	1.1799	2027.	482.	0.681	0.0267	0.0536	0.00690	11.48	35.00
40.00	49.724	79.85	0.9534	24.694	108.705	0.05359	0.22172	0.3223	0.2159	1.1841	1985.	482.	0.654	0.0270	0.0528	0.00704	11.08	40.00
45.00	54.732	79.26	0.8685	26.314	109.386	0.05679	0.22140	0.3244	0.2190	1.1886	1942.	481.	0.635	0.0273	0.0521	0.00718	10.69	45.00
50.00	60.116	78.67	0.7925	27.944	110.058	0.05998	0.22110	0.3267	0.2222	1.1935	1899.	481.	0.615	0.0276	0.0513	0.00732	10.30	50.00
55.00	65.895	78.07	0.7243	29.586	110.722	0.06316	0.22081	0.3290	0.2255	1.1988	1856.	480.	0.595	0.0280	0.0506	0.00746	9.91	55.00
60.00	72.087	77.46	0.6630	31.239	111.376	0.06633	0.22054	0.3314	0.2289	1.2046	1813.	479.	0.575	0.0283	0.0499	0.00761	9.53	60.00
65.00	78.712	76.84	0.6077	32.905	112.019	0.06949	0.22028	0.3339	0.2325	1.2109	1770.	477.	0.557	0.0286	0.0491	0.00776	9.15	65.00
70.00	85.787	76.21	0.5577	34.583	112.652	0.07264	0.22003	0.3366	0.2363	1.2178	1726.	476	0.539	0.0290	0.0484	0.00791	8.77	70.00
75.00	93.333	75.57	0.5125	36.274	113.272	0.07578	0.21979	0.3393	0.2402	1.2252	1683.	474.	0.522	0.0294	0.0476	0.00806	8.39	75.00
80.00	101.37	74.91	0.4715	37.978	113.880	0.07892	0.21957	0.3422	0.2444	1.2334	1640.	472.	0.505	0.0297	0.0469	0.00822	8.02	80.00
85.00	109.92	74.25	0.4343	39.697	114.475	0.08205	0.21934	0.3453	0.2487	1.2424	1596.	470	0.489	0.0301	0.0462	0.00838	7.65	85.00
90.00	119.00	73.57	0.4004	41.430	115.055	0.08518	0.21912	0.3485	0.2533	1.2522	1552.	468	0.473	0.0305	0.0454	0.00855	7.28	90.00
95.00	128.63	72.87	0.3694	43.179	115.619	0.08830	0.21890	0.3519	0.2582	1.2630	1509.	466	0.458	0.0309	0.0447	0.00872	6.91	95.00
100.00	138.83	72.16	0.3411	44.943	116.166	0.09142	0.21868	0.3555	0.2633	1.2748	1465.	463.	0.443	0.0313	0.0439	0.00890	6.55	100.00
105.00	149.63	71.43	0.3153	46.725	116.694	0.09454	0.21845	0.3594	0.2689	1.2880	1421.	460.	0.428	0.0318	0.0432	0.00908	6.20	105.00
110.00	161.05	70.68	0.2915	48.524	117.203	0.09766	0.21822	0.3635	0.2748	1.3026	1376.	457	0.414	0.0322	0.0425	0.00926	5.84	110.00
115.00	173.11	69.91	0.2697	50.343	117.690	0.10078	0.21797	0.3680	0.2813	1.3189	1332.	454	0.400	0.0327	0.0417	0.00946	5.49	115.00
120.00	185.84	69.12	0.2497	52.181	118.153	0.10391	0.21772	0.3728	0.2881	1.3372	1288.	450.	0.387	0.0332	0.0410	0.00965	5.15	120.00
125.00	199.25	68.31	0.2312	54.040	118.591	0.10704	0.21744	0.3781	0.2957	1.3577	1243.	446.	0.374	0.0338	0.0403	0.00986	4.80	125.00
130.00	213.38	67.47	0.2141	55.923	119.000	0.11018	0.21715	0.3839	0.3040	1.3810	1198.	442.	0.361	0.0343	0.0395	0.01007	4.47	130.00
135.00	228.25	66.60	0.1983	57.830	119.377	0.11333	0.21683	0.3903	0.3133	1.4075	1153.	437.	0.348	0.0349	0.0388	0.01029	4.13	135.00
140.00	243.68	65.70	0.1836	59.764	119.720	0.11650	0.21648	0.3974	0.3236	1.4379	1108.	432.	0.335	0.0356	0.0380	0.01052	3.81	140.00
145.00	260.31	64.77	0.1700	61.727	120.024	0.11968	0.21609	0.4053	0.3353	1.4731	1062.	427	0.323	0.0363	0.0373	0.01075	3.48	145.00
150.00	277.57	63.80	0.1574	63.722	120.284	0.12288	0.21566	0.4144	0.3486	1.5143	1017.	421.	0.311	0.0370	0.0366	0.01100	3.17	150.00
155.00	295.69	62.78	0.1455	65.753	120.495	0.12611	0.21517	0.4247	0.3646	1.5636	971.	415	0.298	0.0378	0.0358	0.01125	2.86	155.00
160.00	314.69	61.72	0.1345	67.823	120.650	0.12938	0.21463	0.4368	0.3821	1.6213	924.	409.	0.285	0.0387	0.0351	0.01151	2.55	160.00
165.00	334.62	60.60	0.1241	69.939	120.739	0.13268	0.21400	0.4511	0.4036	1.6921	877.	403.	0.274	0.0397	0.0343	0.01178	2.26	165.00
170.00	355.51	59.42	0.1144	72.106	120.753	0.13603	0.21329	0.4683	0.4299	1.7798	829.	396	0.262	0.0407	0.0336	0.01206	1.97	170.00
175.00	377.40	58.16	0.1052	74.335	120.677	0.13945	0.21247	0.4896	0.4627	1.8908	781.	388.	0.249	0.0420	0.0329	0.01235	1.69	175.00
180.00	400.34	56.80	0.0965	76.636	120.493	0.14295	0.21151	0.5168	0.5048	2.0354	731.	380	0.237	0.0434	0.0321	0.01265	1.41	180.00
185.00	424.37	55.33	0.0881	79.027	120.175	0.14655	0.21037	0.5527	0.5612	2.2309	680.	372.	0.224	0.0450	0.0314	0.01296	1.15	185.00
190.00	449.55	53.70	0.0801	81.534	119.684	0.15029	0.20901	0.6031	0.6406	2.5087	627.	363.	0.211	0.0469	—	—	0.90	190.00
195.00	475.95	51.86	0.0723	84.196	118.963	0.15423	0.20733	0.6794	0.7512	2.9338	572.	353.	0.197	0.0493	—	—	0.67	195.00
200.00	503.64	49.70	0.0646	87.088	117.906	0.15847	0.20519	0.8100	0.9573	3.6640	514.	343.	0.182	0.0523	—	—	0.45	200.00
205.00	532.73	47.00	0.0566	90.368	116.289	0.16326	0.20226	1.0906	1.4012	5.2174	450.	331.	0.164	0.0566	—	—	0.25	205.00
210.00	563.24	43.03	0.0474	94.548	113.411	0.16933	0.19750	-	-	-	378.	316	0.142	0.0639			0.07	210.00
213.85c	588.27	32.01	0.0312	103.775	103.775	0.18128	0.18128	∞	∞	∞	0.	0			∞	∞	0.00	213.85

*temperatures are on the ITS-90 scale   a = triple point   b = normal boiling point   c = critical point

Figure (D.1) Pressure-Enthalpy Diagram for R-134a.

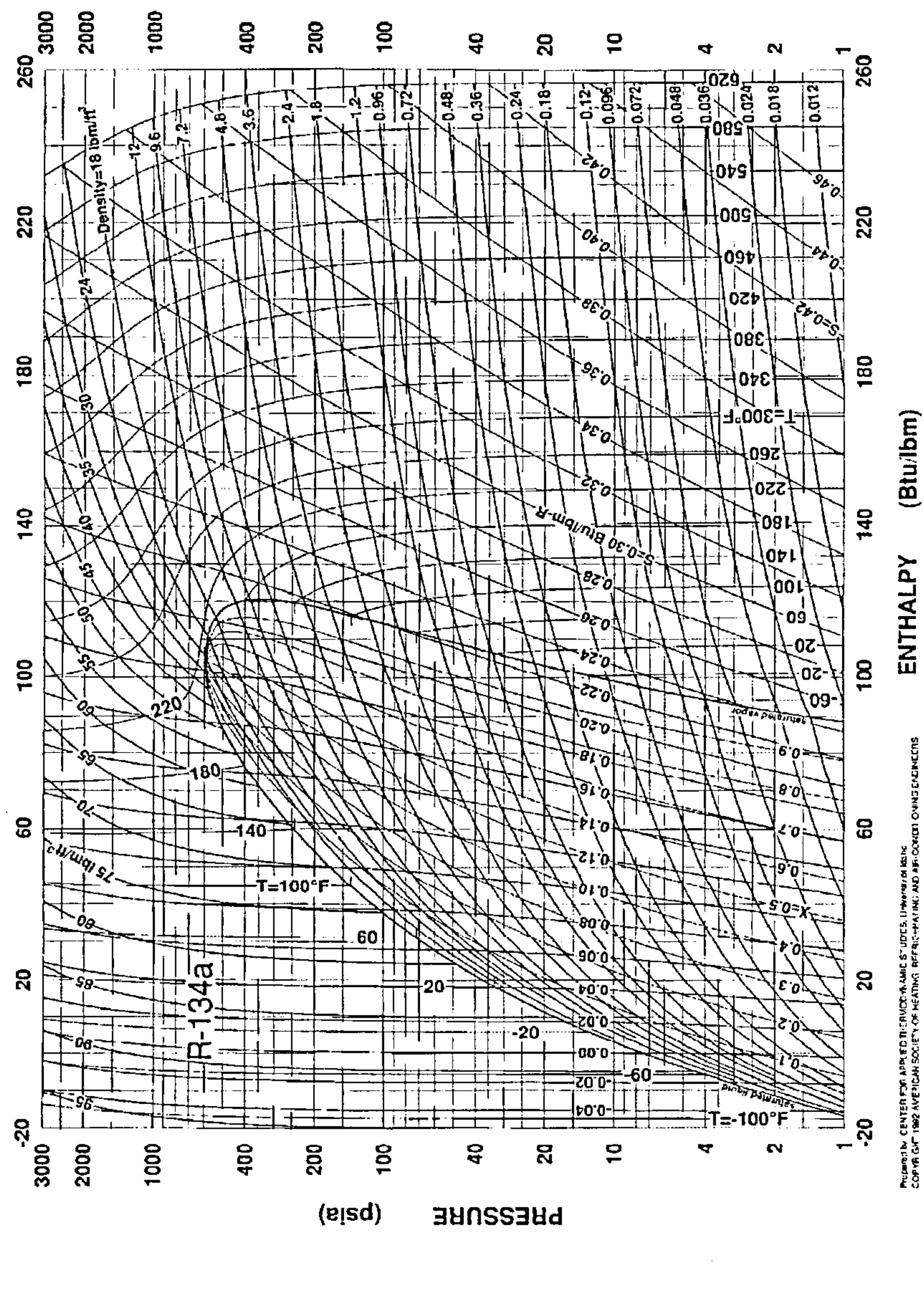


Table (D.2) Saturation properties for Propane.

Temp,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb·°F Liquid	Entropy, Btu/lb·°F Vapor	Specific Heat c_p, Btu/lb·°F Liquid	Specific Heat c_p, Btu/lb·°F Vapor	c_p/c_v Vapor	Velocity of Sound, ft/s Liquid	Velocity of Sound, ft/s Vapor	Viscosity, lb_m/ft·h Liquid	Viscosity, lb_m/ft·h Vapor	Thermal Cond., Btu/h·ft·°F Liquid	Thermal Cond., Btu/h·ft·°F Vapor	Surface Tension, dyne/cm	Temp.* °F
-200.00	0.020	42.07	3133.0	-80.222	137.497	-0.23927	0.59918	0.4745	0.2596	1.2104	5653.	595.	1.800	0.0100	0.1072	0.00313	28.59	-200.00
-190.00	0.040	41.72	1636.4	-75.465	140.102	-0.22129	0.57808	0.4768	0.2638	1.2066	5531.	605.	1.589	0.0104	0.1053	0.00330	27.74	-190.00
-180.00	0.075	41.36	961.99	-70.685	142.743	-0.20389	0.55925	0.4792	0.2681	1.2031	5410.	615.	1.416	0.0107	0.1033	0.00348	26.90	-180.00
170.00	0.135	41.01	521.52	65.831	145.416	0.18701	0.54243	0.4817	0.2725	1.1998	5289.	625.	1.272	0.0111	0.1013	0.00366	26.05	170.00
-160.00	0.231	40.65	314.68	-61.050	148.122	-0.17062	0.52739	0.4845	0.2770	1.1967	5169.	635.	1.150	0.0114	0.0992	0.00384	25.22	-160.00
150.00	0.381	40.29	197.25	56.189	150.856	0.15466	0.51393	0.4875	0.2818	1.1938	5049.	644.	1.046	0.0117	0.0971	0.00404	24.39	150.00
-145.00	0.482	40.11	158.22	53.747	152.233	-0.14684	0.50775	0.4891	0.2842	1.1925	4990.	648.	1.000	0.0119	0.0960	0.00414	23.98	-145.00
-140.00	0.605	39.93	127.95	-51.297	153.616	-0.13912	0.50190	0.4908	0.2867	1.1912	4931.	653.	0.956	0.0121	0.0949	0.00424	23.56	-140.00
-135.00	0.754	39.75	104.26	46.838	155.005	-0.13149	0.49636	0.4925	0.2892	1.1900	4871.	657.	0.916	0.0123	0.0939	0.00434	23.15	-135.00
-130.00	0.932	39.57	85.583	-46.370	156.400	-0.12395	0.49112	0.4943	0.2918	1.1889	4812.	661.	0.878	0.0124	0.0928	0.00444	22.74	130.00
-125.00	1.144	39.39	70.737	-43.893	157.800	-0.11649	0.48617	0.4962	0.2945	1.1879	4753.	665.	0.843	0.0126	0.0917	0.00455	22.33	-125.00
-120.00	1.394	39.20	58.851	-41.406	159.205	-0.10912	0.48148	0.4981	0.2972	1.1869	4694.	669.	0.810	0.0128	0.0906	0.00466	21.92	-120.00
-115.00	1.683	39.02	49.269	-38.910	160.614	-0.10183	0.47765	0.5001	0.3000	1.1860	4635.	673.	0.779	0.0130	0.0896	0.00477	21.51	-115.00
110.00	2.031	38.84	41.493	36.403	162.028	0.09461	0.47287	0.5022	0.3029	1.1853	4576.	677.	0.749	0.0132	0.0885	0.00488	21.10	110.00
-105.00	2.429	38.65	35.141	-33.885	163.444	-0.08747	0.46891	0.5043	0.3059	1.1846	4517.	681.	0.722	0.0133	0.0874	0.00459	20.70	-105.00
-100.00	2.889	38.46	29.922	-31.357	164.864	-0.08040	0.46516	0.5066	0.3089	1.1840	4458.	684.	0.695	0.0135	0.0864	0.00511	20.29	-100.00
-95.00	3.417	38.28	25.608	-28.817	166.287	-0.07339	0.46163	0.5083	0.3120	1.1834	4400.	688.	0.671	0.0137	0.0853	0.00523	19.89	-95.00
-90.00	4.020	38.09	22.023	-26.265	167.713	-0.06645	0.45828	0.5112	0.3152	1.1830	4341.	691.	0.647	0.0139	0.0842	0.00535	19.43	-90.00
-85.00	4.708	37.90	19.027	-23.700	169.140	-0.05957	0.45513	0.5137	0.3184	1.1827	4282.	694.	0.625	0.0141	0.0832	0.00547	19.03	-85.00
-80.00	5.485	37.71	16.512	-21.124	170.569	-0.05274	0.45215	0.5162	0.3218	1.1825	4224.	697.	0.604	0.0143	0.0821	0.00559	18.68	-80.00
-75.00	6.364	37.52	14.389	-18.533	171.999	-0.04598	0.44934	0.5188	0.3252	1.1825	4165.	700.	0.584	0.0144	0.0811	0.00572	18.23	-75.00
-70.00	7.351	37.33	12.589	-15.930	173.430	-0.03927	0.44668	0.5215	0.3287	1.1825	4107.	703.	0.564	0.0146	0.0801	0.00585	17.89	-70.00
-65.00	8.456	37.13	11.057	-13.313	174.861	-0.03261	0.44418	0.5242	0.3323	1.1826	4048.	706.	0.546	0.0148	0.0790	0.00598	17.49	-65.00
-60.00	9.689	36.94	9.7463	-10.681	176.292	-0.02599	0.44182	0.5271	0.3360	1.1829	3989.	709.	0.529	0.0150	0.0780	0.00612	17.10	-60.00
-55.00	11.059	36.74	8.6209	-8.034	177.722	-0.01943	0.43960	0.5300	0.3398	1.1833	3931.	711.	0.512	0.0152	0.0770	0.00625	16.70	55.00
-50.00	12.577	36.55	7.6507	-5.372	179.151	-0.01291	0.43751	0.5331	0.3436	1.1838	3872.	713.	0.496	0.0154	0.0760	0.00639	16.31	-50.00
-45.00	14.253	36.35	6.8111	-2.694	180.579	-0.00644	0.43554	0.5362	0.3476	1.1845	3814.	715.	0.481	0.0156	0.0750	0.00653	15.92	-45.00
-43.76b	14.695	36.30	6.6203	-2.026	180.934	-0.00483	0.43507	0.5370	0.3485	1.1847	3799.	716.	0.477	0.0156	0.0718	0.00657	15.82	-43.76
-40.00	16.099	36.15	6.0819	0.000	182.005	0.00000	0.43369	0.5394	0.3517	1.1853	3755.	717.	0.466	0.0158	0.0741	0.00668	15.53	-40.00
-35.00	18.126	35.94	5.4464	2.711	183.429	0.00640	0.43195	0.5427	0.3558	1.1861	3696.	719.	0.451	0.0160	0.0731	0.00683	15.14	-35.00
-30.00	20.344	35.74	4.8906	5.439	184.849	0.01276	0.43031	0.5462	0.3601	1.1874	3638.	721.	0.438	0.0162	0.0721	0.00698	14.76	-30.00
-25.00	22.767	35.54	4.4031	8.185	186.267	0.01908	0.42878	0.5497	0.3644	1.1887	3579.	722.	0.425	0.0164	0.0712	0.00713	14.37	-25.00
-20.00	25.405	35.33	3.9740	10.949	187.680	0.02537	0.42733	0.5533	0.3689	1.1902	3520.	724.	0.413	0.0166	0.0702	0.00729	13.99	20.00
-15.00	28.272	35.12	3.5952	13.737	189.089	0.03163	0.42598	0.5571	0.3735	1.1918	3462.	725.	0.401	0.0168	0.0693	0.00745	13.61	-15.00
-10.00	31.380	34.91	3.2600	16.535	190.493	0.03786	0.42472	0.5610	0.3782	1.1936	3403.	726.	0.389	0.0170	0.0684	0.00761	13.23	-10.00
-5.00	34.742	34.69	2.9624	19.357	191.891	0.04407	0.42354	0.5650	0.3830	1.1957	3344.	726.	0.378	0.0172	0.0675	0.00778	12.85	-5.00
0.00	38.370	34.48	2.6975	22.201	193.283	0.05024	0.42243	0.5691	0.3880	1.1979	3285.	727.	0.367	0.0174	0.0666	0.00795	12.48	0.00
5.00	42.278	34.26	2.4611	25.065	194.668	0.05639	0.42139	0.5733	0.3931	1.2004	3226.	727.	0.357	0.0176	0.0657	0.00812	12.11	5.00
10.00	46.480	34.04	2.2496	27.951	196.045	0.06252	0.42042	0.5777	0.3983	1.2032	3167.	727.	0.346	0.0179	0.0648	0.00829	11.74	10.00
15.00	50.983	33.81	2.0590	30.850	197.414	0.06863	0.41952	0.5823	0.4037	1.2061	3107.	727.	0.337	0.0181	0.0635	0.00847	11.37	15.00
20.00	55.817	33.59	1.8895	33.793	198.774	0.07472	0.41867	0.5870	0.4092	1.2094	3048.	727.	0.327	0.0183	0.0630	0.00866	11.00	20.00
25.00	60.980	33.36	1.7359	36.749	200.124	0.08079	0.41788	0.5918	0.4149	1.2130	2989.	726.	0.318	0.0185	0.0622	0.00884	10.64	25.00
30.00	66.492	33.13	1.5973	39.730	201.463	0.08685	0.41714	0.5969	0.4208	1.2169	2929.	725.	0.309	0.0188	0.0613	0.00903	10.27	30.00
35.00	72.367	32.89	1.4718	42.736	202.790	0.09289	0.41645	0.6021	0.4269	1.2212	2869.	724.	0.300	0.0190	0.0605	0.00923	9.91	35.00
40.00	78.619	32.65	1.3580	45.769	204.105	0.09892	0.41580	0.6075	0.4332	1.2258	2810.	723.	0.292	0.0192	0.0597	0.00943	9.55	40.00
45.00	85.263	32.41	1.2547	48.829	205.406	0.10494	0.41520	0.6131	0.4397	1.2309	2750.	722.	0.283	0.0195	0.0588	0.00963	9.20	45.00
50.00	92.314	32.16	1.1606	51.918	206.691	0.11095	0.41462	0.6190	0.4465	1.2364	2690.	720.	0.275	0.0197	0.0580	0.00984	8.85	50.00
55.00	99.785	31.91	1.0749	55.035	207.961	0.11695	0.41409	0.6251	0.4535	1.2425	2630.	718.	0.267	0.0200	0.0572	0.01005	8.49	55.00
60.00	107.70	31.66	0.9965	58.183	209.212	0.12295	0.41358	0.6314	0.4609	1.2491	2570.	715.	0.260	0.0202	0.0564	0.01027	8.15	60.00
65.00	116.06	31.40	0.9247	61.362	210.445	0.12894	0.41306	0.6381	0.4635	1.2563	2509.	713.	0.252	0.0205	0.0526	0.01049	7.80	65.00
70.00	124.89	31.13	0.8590	64.573	211.657	0.13494	0.41263	0.6450	0.4755	1.2642	2449.	710.	0.245	0.0208	0.0548	0.01072	-7.45	70.00
75.00	134.20	30.86	0.7985	67.818	212.846	0.14093	0.41218	0.6523	0.4850	1.2728	2388.	707.	0.238	0.0210	0.0540	0.01095	7.12	75.00
80.00	144.01	30.59	0.7430	71.098	214.011	0.14692	0.41174	0.6599	0.4938	1.2823	2327.	703.	0.231	0.0213	0.0523	0.01119	6.78	80.00
85.00	154.34	30.31	0.6917	74.414	215.149	0.15293	0.41131	0.6680	0.5037	1.2928	2266.	699.	0.224	0.0216	0.0525	0.01144	6.45	85.00
90.00	165.20	30.02	0.6445	77.768	216.259	0.15891	0.41089	0.6765	0.5131	1.3043	2205.	695.	0.218	0.0219	0.0517	0.01169	6.12	90.00
95.00	176.61	29.73	0.6008	81.152	217.337	0.16495	0.41046	0.6855	0.5237	1.3171	2144.	691.	0.211	0.0222	0.0510	0.01195	5.79	95.00
100.00	188.58	29.43	0.5601	84.598	218.380	0.17098	0.41002	0.6951	0.5350	1.3313	2083.	686.	0.205	0.0225	0.0502	0.01222	5.47	100.00
110.00	214.30	28.80	0.4879	91.602	220.352	0.18310	0.40911	0.7163	0.5604	1.3648	1958.	675.	0.192	0.0232	0.0487	0.01279	4.83	110.00
120.00	242.50	28.14	0.4252	98.799	222.142	0.19530	0.40808	0.7408	0.5903	1.4071	1832.	663.	0.180	0.0239	0.0472	0.01340	4.21	120.00
130.00	273.33	27.44	0.3706	106.214	223.711	0.20763	0.40689	0.7699	0.6256	1.4618	1705.	649.	0.168	0.0247	0.0457	0.01408	3.60	130.00
140.00	306.96	26.68	0.3227	113.879	225.009	0.22014	0.40545	0.8055	0.6723	1.5342	1576.	634.	0.157	0.0256	0.0442	0.01485	3.02	140.00
150.00	343.57	25.87	0.2803	121.839	225.962	0.23287	0.40366	0.8509	0.7322	1.6340	1444.	616.	0.145	0.0266	0.0428	0.01576	2.46	150.00
160.00	383.36	24.97	0.2425	130.151	226.466	0.24594	0.40135	0.9123	0.8154	1.7785	1308.	597.	0.134	0.0278	0.0414	0.01668	1.92	160.00
170.00	426.55	23.96	0.2084	138.952	226.358	0.25949	0.39830	1.0029	0.9410	2.0040	1165.	575.	0.123	0.0292	0.0403	0.01836	1.41	170.00
180.00	473.42	22.78	0.1770	148.412	225.346	0.27381	0.39408	1.1563	1.1564	2.4021	1013.	551.	0.111	0.0311	0.0394	0.02050	0.94	180.00
190.00	524.30	21.30	0.1469	158.996	222.796	0.28956	0.38776	1.4915	1.6272	3.2904	847.	523.	0.098	0.0336	0.0392	0.02399	0.51	190.00
200.00	579.74	19.07	0.1147	172.340	216.510	0.30916	0.37612	—	—	—	—	—	0.082	0.0382	—	—	0.15	200.00
206.06c	616.07	13.77	0.0726	195.358	195.358	0.34325	0.34325	∞	∞	∞	0.	0.	—	—	∞	∞	0.00	206.06

*temperatures are on the IPTS-68 scale b = normal boiling point c = critical point

Figure (D.2) Pressure-Enthalpy Diagram for Propane.

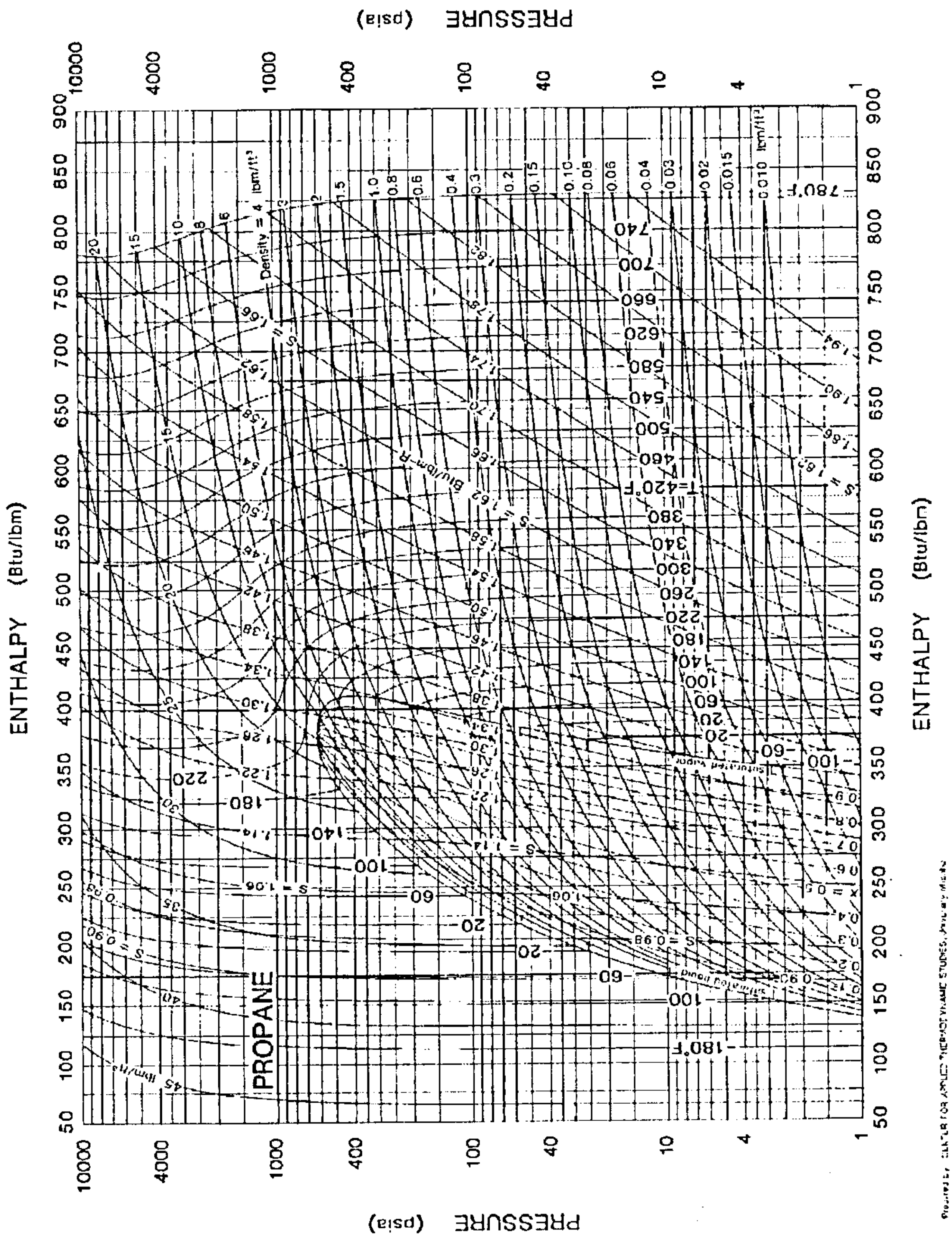


Table (D.3) Saturation properties for Butane.

Temp,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb-°F Liquid	Entropy, Btu/lb-°F Vapor	Specific Heat c_p, Btu/lb-°F Liquid	Specific Heat c_p, Btu/lb-°F Vapor	c_p/c_v Vapor	Velocity of Sound, ft/s Liquid	Velocity of Sound, ft/s Vapor	Viscosity, lb_m/ft-h Liquid	Viscosity, lb_m/ft-h Vapor	Thermal Cond, Btu/h-ft-°F Liquid	Thermal Cond, Btu/h-ft-°F Vapor	Surface Tension, dyne/cm	Temp,* °F
-150.00	0.021	43.72	2680.0	-54.034	145.702	-0.14904	0.49595	0.4804	0.2930	1.1323	4976.	548.	1.945	0.0109	0.0991	0.00362	28.19	-150.00
-140.00	0.038	43.39	1536.9	-49.229	148.643	-0.13377	0.48522	0.4807	0.2971	1.1304	4906.	556.	1.737	0.0112	0.0967	0.00381	27.41	-140.00
-130.00	0.066	43.06	917.01	-44.419	151.622	-0.11895	0.47570	0.4815	0.3012	1.1286	4833.	564.	1.564	0.0115	0.0943	0.00399	26.64	-130.00
-120.00	0.110	42.74	567.05	-39.597	154.636	-0.10455	0.46728	0.4829	0.3055	1.1268	4757.	572.	1.416	0.0118	0.0921	0.00415	25.87	-120.00
-110.00	0.178	42.41	362.20	-34.759	157.687	-0.09051	0.45985	0.4848	0.3099	1.1251	4678.	579.	1.296	0.0121	0.0901	0.00439	25.11	110.00
-100.00	0.278	42.03	238.26	-29.899	160.772	-0.07681	0.45332	0.4873	0.3145	1.1236	4597.	587.	1.182	0.0124	0.0881	0.00459	24.35	-100.00
-90.00	0.423	41.75	160.98	-25.011	163.890	-0.06340	0.44759	0.4903	0.3192	1.1221	4514.	594.	1.087	0.0127	0.0862	0.00480	23.59	-90.00
-80.00	0.626	41.41	111.45	-20.090	167.042	-0.05027	0.44261	0.4938	0.3241	1.1208	4428.	601.	1.003	0.0130	0.0843	0.00502	22.84	-80.00
-70.00	0.907	41.08	78.895	-15.133	170.225	-0.03739	0.43829	0.4976	0.3292	1.1196	4341.	608.	0.930	0.0133	0.0826	0.00524	22.10	-70.00
-60.00	1.285	40.74	56.999	10.134	173.438	-0.02473	0.43458	0.5019	0.3344	1.1185	4252.	614.	0.865	0.0136	0.0809	0.00547	21.36	60.00
50.00	1.786	40.40	41.955	5.091	176.679	0.01227	0.43143	0.5065	0.3399	1.1177	4161.	620.	0.806	0.0139	0.0793	0.00571	20.63	50.00
-40.00	2.438	40.06	31.414	0.000	179.946	0.00000	0.42878	0.5114	0.3455	1.1170	4070.	626.	0.754	0.0143	0.0777	0.00595	19.90	40.00
-30.00	3.273	39.71	23.893	5.142	183.238	0.01210	0.42659	0.5165	0.3515	1.1166	3977.	631.	0.706	0.0146	0.0762	0.00621	19.18	-30.00
-20.00	4.327	39.35	18.436	10.337	186.552	0.02404	0.42483	0.5219	0.3576	1.1163	3883.	637.	0.663	0.0149	0.0747	0.00647	18.46	-20.00
-10.00	5.638	39.01	14.416	15.587	189.887	0.03583	0.42345	0.5275	0.3640	1.1163	3788.	641.	0.622	0.0153	0.0733	0.00674	17.75	-10.00
0.00	7.251	38.66	11.410	20.896	193.240	0.04749	0.42242	0.5334	0.3705	1.1166	3693.	646.	0.587	0.0156	0.0719	0.00701	17.04	0.00
5.00	8.184	38.48	10.191	23.573	194.922	0.05328	0.42203	0.5361	0.3740	1.1168	3645.	648.	0.570	0.0158	0.0712	0.00716	16.69	5.00
10.00	9.211	38.30	9.1329	26.266	196.608	0.05903	0.42171	0.5394	0.3774	1.1171	3597.	650.	0.554	0.0159	0.0705	0.00730	16.34	10.00
15.00	10.337	38.12	8.2031	28.974	198.298	0.06475	0.42147	0.5426	0.3810	1.1175	3549.	651.	0.539	0.0161	0.0698	0.00745	16.00	15.00
20.00	11.569	37.93	7.3863	31.698	199.991	0.07045	0.42130	0.5457	0.3845	1.1180	3500.	653.	0.524	0.0163	0.0691	0.00760	15.65	20.00
25.00	12.914	37.75	6.6666	34.438	201.686	0.07612	0.42119	0.5489	0.3882	1.1185	3452.	655.	0.509	0.0165	0.0585	0.00775	15.31	25.00
30.00	14.378	37.56	6.0309	37.194	203.384	0.08176	0.42115	0.5522	0.3919	1.1191	3403.	656.	0.495	0.0166	0.0578	0.00790	14.96	30.00
31.03b	14.696	37.52	5.9090	37.765	203.735	0.08292	0.42115	0.5528	0.3927	1.1193	3393.	656.	0.492	0.0167	0.0577	0.00793	14.89	31.03
35.00	15.969	37.38	5.4677	39.967	205.084	0.08738	0.42117	0.5555	0.3957	1.1198	3354.	657.	0.482	0.0168	0.0572	0.00806	14.62	35.00
40.00	17.693	37.19	4.9676	42.757	206.786	0.09297	0.42125	0.5588	0.3995	1.1206	3305.	659.	0.469	0.0170	0.0565	0.00822	14.28	40.00
45.00	19.559	37.00	4.5224	45.564	208.490	0.09854	0.42138	0.5622	0.4035	1.1215	3256.	660.	0.456	0.0172	0.0559	0.00838	13.94	45.00
50.00	21.574	36.81	4.1251	48.389	210.194	0.10409	0.42156	0.5657	0.4074	1.1225	3207.	661.	0.444	0.0174	0.0552	0.00854	13.61	50.00
55.00	23.746	36.62	3.7697	51.231	211.899	0.10962	0.42180	0.5692	0.4115	1.1236	3158.	661.	0.432	0.0176	0.0546	0.00871	13.27	55.00
60.00	26.081	36.42	3.4512	54.091	213.605	0.11513	0.42208	0.5728	0.4157	1.1248	3108.	662.	0.421	0.0178	0.0539	0.00888	12.94	60.00
65.00	28.590	36.23	3.1649	56.970	215.311	0.12062	0.42241	0.5764	0.4199	1.1261	3059.	662.	0.410	0.0179	0.0533	0.00905	12.61	65.00
70.00	31.279	36.03	2.9072	59.867	217.017	0.12609	0.42278	0.5801	0.4242	1.1276	3009.	663.	0.400	0.0181	0.0527	0.00923	12.28	70.00
75.00	34.157	35.83	2.6747	62.783	218.721	0.13154	0.42319	0.5839	0.4285	1.1291	2960.	663.	0.389	0.0183	0.0521	0.00941	11.95	75.00
80.00	37.232	35.63	2.4646	65.719	220.425	0.13697	0.42364	0.5877	0.4331	1.1308	2910.	663.	0.379	0.0185	0.0514	0.00959	11.63	80.00
85.00	40.513	35.42	2.2742	68.673	222.127	0.14239	0.42413	0.5916	0.4377	1.1326	2860.	663.	0.370	0.0187	0.0508	0.00977	11.30	85.00
90.00	44.009	35.22	2.1015	71.648	223.827	0.14780	0.42465	0.5956	0.4424	1.1346	2810.	663.	0.360	0.0189	0.0502	0.00996	10.98	90.00
95.00	47.728	35.01	1.9445	74.643	225.524	0.15318	0.42520	0.5997	0.4472	1.1367	2760.	662.	0.351	0.0191	0.0596	0.01015	10.66	95.00
100.00	51.679	34.80	1.8015	77.658	227.219	0.15856	0.42579	0.6038	0.4521	1.1390	2710.	662.	0.342	0.0194	0.0590	0.01035	10.34	100.00
105.00	55.871	34.59	1.6711	80.694	228.909	0.16392	0.42640	0.6080	0.4571	1.1415	2660.	661.	0.332	0.0196	0.0584	0.01055	10.03	105.00
110.00	60.314	34.37	1.5519	83.752	230.596	0.16927	0.42704	0.6123	0.4622	1.1442	2610.	660.	0.325	0.0198	0.0578	0.01075	9.71	110.00
115.00	65.015	34.15	1.4428	86.831	232.278	0.17461	0.42770	0.6168	0.4675	1.1470	2559.	659.	0.316	0.0200	0.0572	0.01096	9.40	115.00
120.00	69.986	33.93	1.3429	89.933	233.954	0.17993	0.42839	0.6213	0.4729	1.1501	2509.	657.	0.308	0.0202	0.0566	0.01117	9.09	120.00
125.00	75.234	33.71	1.2511	93.057	235.625	0.18525	0.42909	0.6259	0.4784	1.1534	2459.	656.	0.301	0.0204	0.0560	0.01138	8.78	125.00
130.00	80.770	33.48	1.1667	96.204	237.288	0.19056	0.42982	0.6307	0.4841	1.1570	2408.	654.	0.293	0.0207	0.0554	0.01160	8.48	130.00
135.00	85.603	33.25	1.0889	99.375	238.945	0.19586	0.43056	0.6356	0.4900	1.1609	2357.	652.	0.285	0.0209	0.0548	0.01182	8.18	135.00
140.00	92.743	33.02	1.0173	102.570	240.592	0.20115	0.43131	0.6406	0.4961	1.1650	2307.	650.	0.278	0.0211	0.0542	0.01205	7.88	140.00
145.00	99.199	32.78	0.9511	105.790	242.231	0.20644	0.43208	0.6458	0.5023	1.1695	2256.	647.	0.271	0.0214	0.0536	0.01228	7.58	145.00
150.00	105.98	32.54	0.8899	109.035	243.859	0.21172	0.43286	0.6512	0.5088	1.1744	2205.	645.	0.264	0.0216	0.0530	0.01251	7.28	150.00
155.00	113.10	32.30	0.8332	112.306	245.476	0.21700	0.43365	0.6567	0.5155	1.1796	2154.	642.	0.257	0.0219	0.0524	0.01275	6.99	155.00
160.00	120.57	32.05	0.7807	115.604	247.081	0.22227	0.43444	0.6625	0.5225	1.1853	2103.	639.	0.250	0.0221	0.0519	0.01300	6.70	160.00
165.00	128.39	31.80	0.7319	118.930	248.672	0.22754	0.43524	0.6685	0.5298	1.1915	2052.	635.	0.243	0.0224	0.0513	0.01325	6.41	165.00
170.00	136.59	31.54	0.6865	122.284	250.249	0.23281	0.43604	0.6747	0.5374	1.1982	2001.	632.	0.237	0.0227	0.0507	0.01350	6.12	170.00
175.00	145.16	31.28	0.6443	125.668	251.809	0.23809	0.43684	0.6812	0.5454	1.2055	1949.	628.	0.230	0.0229	0.0501	0.01376	5.84	175.00
180.00	154.12	31.01	0.6049	129.082	253.351	0.24336	0.43763	0.6880	0.5537	1.2135	1898.	624.	0.224	0.0232	0.0496	0.01403	5.56	180.00
185.00	163.48	30.73	0.5682	132.527	254.873	0.24864	0.43842	0.6951	0.5625	1.2222	1846.	619.	0.218	0.0235	0.0490	0.01430	5.28	185.00
190.00	173.25	30.46	0.5339	136.006	256.374	0.25392	0.43920	0.7026	0.5719	1.2318	1794.	615.	0.212	0.0238	0.0484	0.01458	5.01	190.00
195.00	183.45	30.17	0.5018	139.518	257.851	0.25921	0.43996	0.7106	0.5817	1.2424	1742.	610.	0.206	0.0241	0.0479	0.01486	4.74	195.00
200.00	194.09	29.88	0.4717	143.066	259.302	0.26451	0.44071	0.7190	0.5923	1.2540	1690.	604.	0.200	0.0244	0.0473	0.01516	4.47	200.00
210.00	216.71	29.27	0.4170	150.277	262.113	0.27515	0.44215	0.7377	0.6157	1.2814	1585.	593.	0.188	0.0251	0.0462	0.01577	3.94	210.00
220.00	241.23	28.62	0.3687	157.654	264.783	0.28585	0.44347	0.7594	0.6433	1.3158	1480.	579.	0.177	0.0258	0.0451	0.01641	3.43	220.00
230.00	267.76	27.94	0.3256	165.218	267.276	0.29664	0.44462	0.7853	0.6765	1.3599	1372.	565.	0.165	0.0266	0.0440	0.01710	2.93	230.00
240.00	296.42	27.20	0.2871	173.001	269.548	0.30757	0.44556	0.8173	0.7182	1.4183	1263.	548.	0.154	0.0274	0.0430	0.01784	2.45	240.00
250.00	327.34	26.40	0.2523	181.042	271.533	0.31868	0.44619	0.8587	0.7726	1.4988	1152.	529.	0.143	0.0281	0.0419	0.01866	1.99	250.00
260.00	360.69	25.51	0.2207	189.406	273.135	0.33005	0.44639	0.9155	0.8484	1.6157	1038.	509.	0.132	0.0295	0.0408	0.01962	1.55	260.00
270.00	395.64	24.50	0.1915	198.197	274.203	0.34181	0.44597	1.0008	0.9633	1.8000	918.	485.	0.121	0.0308	0.0396	0.02082	1.14	270.00
280.00	435.43	23.32	0.1640	207.608	274.456	0.35421	0.44459	1.1490	1.1632	2.1306	792.	459.	0.109	0.0325	0.0387	0.02256	0.75	280.00
290.00	477.36	21.80	0.1370	218.088	273.383	0.36782	0.44144	1.4853	1.6135	2.8921	655.	428.	0.096	0.0348	0.0384	0.02571	0.40	290.00
300.00	522.95	19.41	0.1068	231.321	268.472	0.38481	0.43371	—	—	—	—	—	0.079	0.0392	—	—	0.11	300.00
305.62c	550.56	14.22	0.0703	251.554	251.554	0.41093	0.41093	∞	∞	∞	0.	0.	—	—	∞	∞	0.00	305.62

*temperatures are on the IPTS-68 scale

b = normal boiling point

c = critical point

Figure (D.3) Pressure-Enthalpy Diagram for Butane.

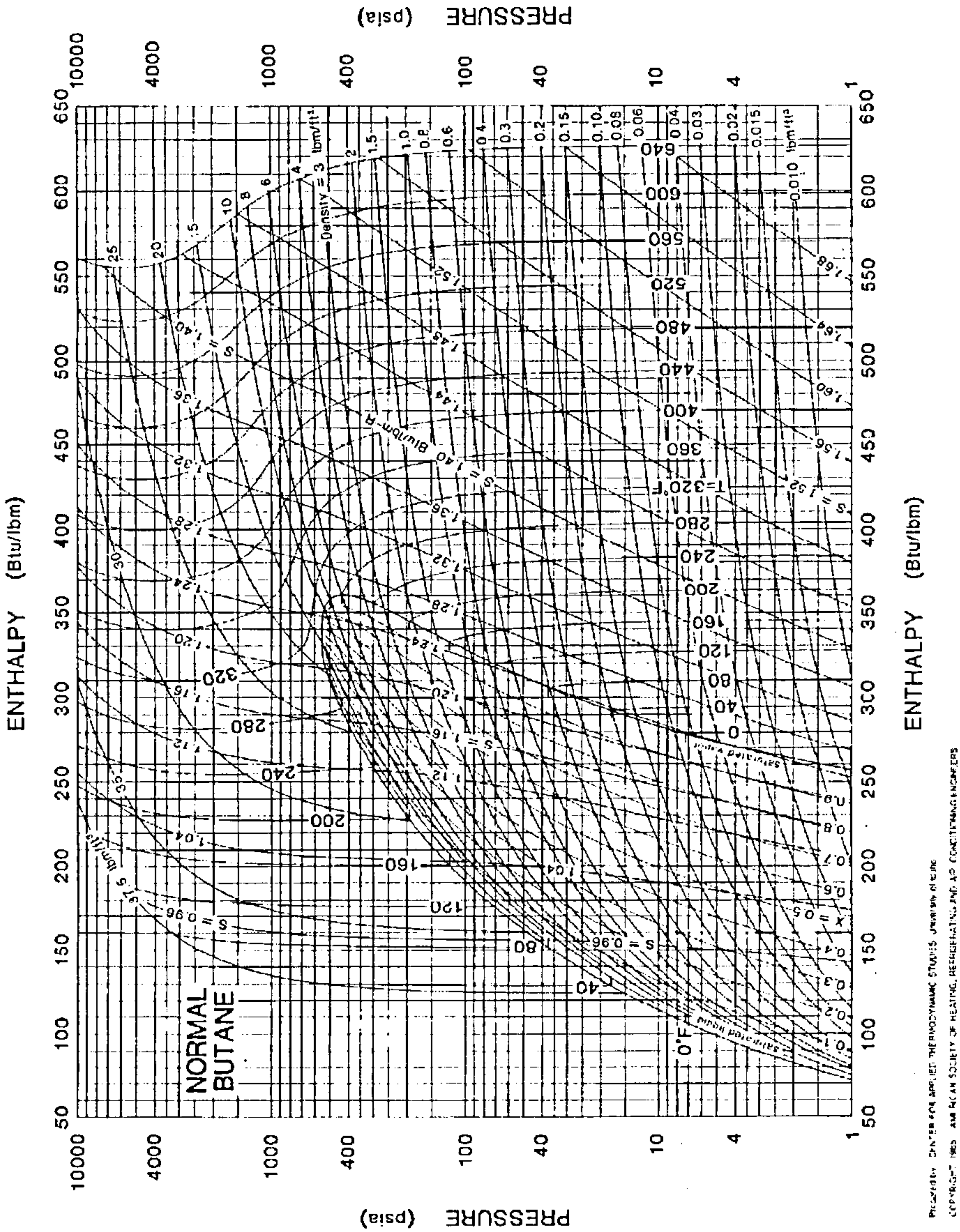


Table (D.4) Saturation properties for Isobutane.

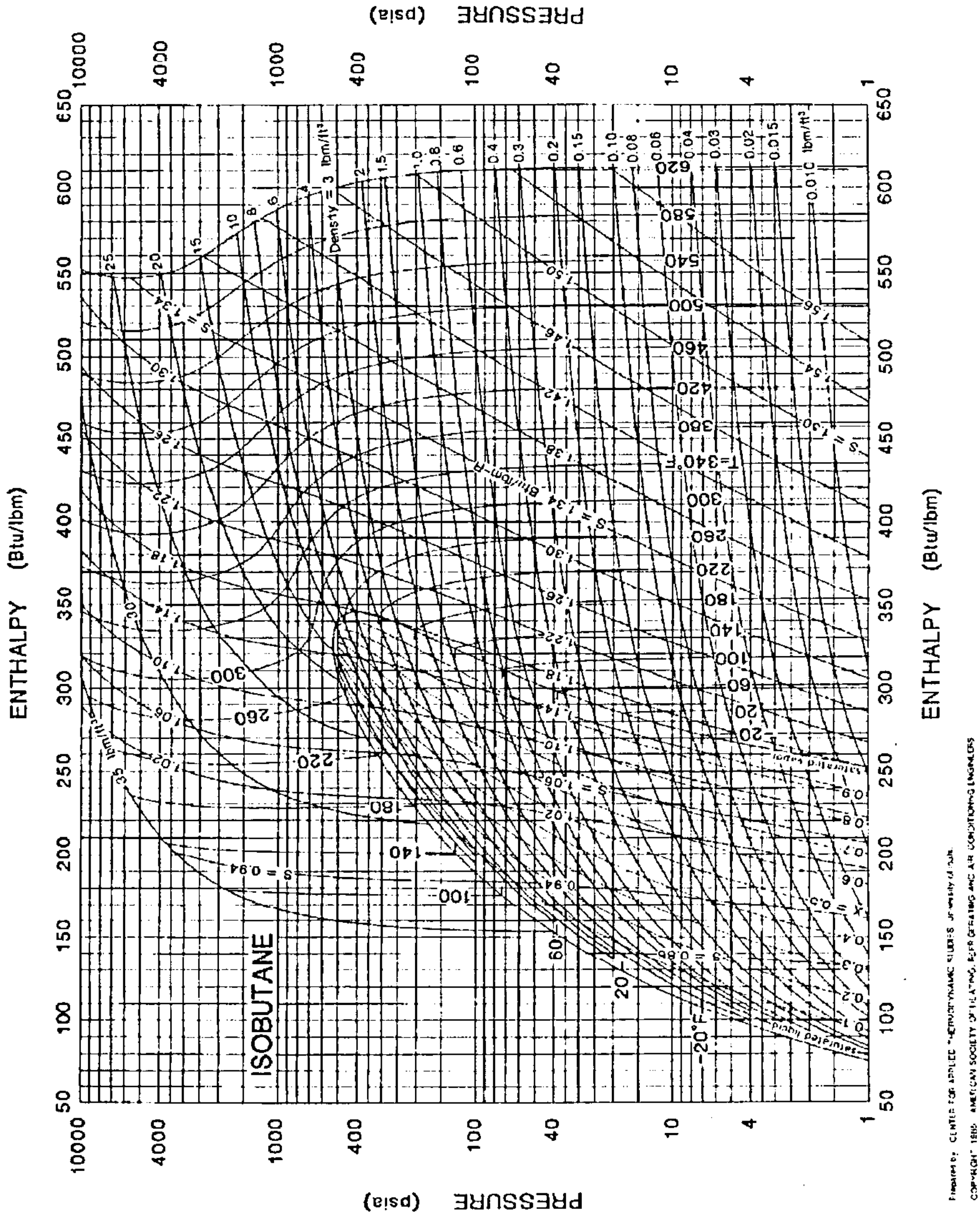
Temp,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb Liquid	Enthalpy, Btu/lb Vapor	Entropy, Btu/lb-°F Liquid	Entropy, Btu/lb-°F Vapor	Specific Heat c_p, Btu/lb-°F Liquid	Specific Heat c_p, Btu/lb-°F Vapor	c_p/c_v Vapor	Velocity of Sound, ft/s Liquid	Velocity of Sound, ft/s Vapor	Viscosity, lb_m/ft·h Liquid	Viscosity, lb_m/ft·h Vapor	Thermal Cond, Btu/h·ft·°F Liquid	Thermal Cond, Btu/h·ft·°F Vapor	Surface Tension, dyne/cm	Temp,* °F
-150.00	0.047	42.76	1219.7	-52.320	136.451	-0.14409	0.46549	0.4486	0.2694	1.1460	4750.	551.	2.313	0.0108	0.0799	0.00345	25.67	-150.00
-140.00	0.082	42.42	722.16	-47.811	139.153	-0.12976	0.45510	0.4532	0.2747	1.1431	4675.	559.	2.040	0.0111	0.0800	0.00363	24.95	-140.00
-130.00	0.137	42.08	443.87	-43.255	141.900	-0.11573	0.44590	0.4579	0.2801	1.1404	4589.	566.	1.813	0.0114	0.0798	0.00382	24.24	-130.00
-120.00	0.222	41.74	262.21	-38.653	144.691	-0.10198	0.43779	0.4626	0.2856	1.1379	4503.	574.	1.623	0.0117	0.0794	0.00402	23.53	-120.00
-110.00	0.348	41.40	185.01	-34.002	147.523	-0.08849	0.43064	0.4675	0.2911	1.1356	4416.	581.	1.461	0.0120	0.0789	0.00422	22.82	-110.00
-100.00	0.530	41.06	124.71	-29.302	150.396	-0.07524	0.42438	0.4724	0.2968	1.1335	4329.	588.	1.323	0.0123	0.0783	0.00443	22.11	-100.00
-90.00	0.787	40.72	86.220	-24.551	153.305	-0.06222	0.41891	0.4775	0.3026	1.1317	4241.	595.	1.203	0.0126	0.0775	0.00464	21.40	-90.00
-80.00	1.141	40.37	60.998	-19.749	156.251	-0.04940	0.41416	0.4827	0.3086	1.1301	4153.	602.	1.099	0.0130	0.0765	0.00486	20.70	-80.00
-70.00	1.618	40.02	44.072	-14.895	159.230	-0.03679	0.41006	0.4880	0.3148	1.1288	4054.	608.	1.008	0.0133	0.0755	0.00509	20.00	-70.00
-60.00	2.248	39.67	32.466	-9.986	162.240	-0.02436	0.40656	0.4934	0.3212	1.1277	3973.	614.	0.928	0.0136	0.0744	0.00533	19.30	-60.00
-50.00	3.065	39.32	24.331	-5.021	165.280	-0.01210	0.40361	0.4990	0.3278	1.1269	3883.	620.	0.856	0.0139	0.0733	0.00557	18.60	-50.00
-40.00	4.109	38.96	18.534	0.000	168.346	0.00000	0.40114	0.5047	0.3346	1.1263	3791.	625.	0.792	0.0143	0.0719	0.00583	17.91	-40.00
-30.00	5.421	38.60	14.328	5.080	171.438	0.01195	0.39912	0.5106	0.3416	1.1261	3698.	630.	0.735	0.0146	0.0706	0.00609	17.22	-30.00
-20.00	7.049	38.23	11.226	10.220	174.552	0.02376	0.39752	0.5166	0.3489	1.1261	3604.	634.	0.684	0.0150	0.0693	0.00636	16.53	-20.00
-10.00	9.042	37.86	8.9062	15.423	177.688	0.03543	0.39629	0.5228	0.3564	1.1264	3510.	638.	0.637	0.0153	0.0678	0.00664	15.85	-10.00
0.00	11.456	37.48	7.1465	20.690	180.841	0.04699	0.39540	0.5292	0.3642	1.1271	3415.	642.	0.595	0.0157	0.0664	0.00693	15.17	0.00
5.00	12.838	37.29	6.4271	23.348	182.425	0.05273	0.39507	0.5325	0.3682	1.1276	3367.	643.	0.575	0.0158	0.0657	0.00708	14.84	5.00
10.00	14.347	37.10	5.7947	26.022	184.012	0.05844	0.39482	0.5358	0.3722	1.1281	3319.	645.	0.556	0.0160	0.0650	0.00724	14.50	10.00
11.10b	14.696	37.06	5.6663	26.611	184.361	0.05969	0.39478	0.5366	0.3731	1.1283	3308.	645.	0.552	0.0161	0.0648	0.00727	14.43	11.10
15.00	15.990	36.91	5.2370	28.714	185.603	0.06412	0.39464	0.5392	0.3764	1.1288	3271.	646.	0.538	0.0162	0.0642	0.00739	14.16	15.00
20.00	17.775	36.72	4.7439	31.423	187.196	0.06978	0.39453	0.5427	0.3806	1.1295	3222.	647.	0.521	0.0164	0.0635	0.00755	13.83	20.00
25.00	19.711	36.52	4.3068	34.150	188.793	0.07541	0.39448	0.5462	0.3849	1.1304	3174.	648.	0.504	0.0166	0.0628	0.00771	13.50	25.00
30.00	21.805	36.32	3.9181	36.895	190.393	0.08103	0.39450	0.5497	0.3892	1.1313	3125.	649.	0.488	0.0168	0.0620	0.00787	13.16	30.00
35.00	24.065	36.13	3.5718	39.658	191.994	0.08662	0.39457	0.5534	0.3936	1.1324	3076.	650.	0.473	0.0170	0.0613	0.00803	12.83	35.00
40.00	26.500	35.92	3.2624	42.439	193.598	0.09219	0.39470	0.5571	0.3982	1.1336	3027.	651.	0.458	0.0172	0.0606	0.00820	12.50	40.00
45.00	29.119	35.72	2.9853	45.240	195.203	0.09774	0.39489	0.5608	0.4028	1.1349	2978.	651.	0.444	0.0174	0.0598	0.00837	12.17	45.00
50.00	31.929	35.52	2.7366	48.060	196.809	0.10327	0.39512	0.5647	0.4074	1.1363	2928.	651.	0.431	0.0176	0.0591	0.00855	11.85	50.00
55.00	34.941	35.31	2.5129	50.899	198.415	0.10876	0.39541	0.5686	0.4122	1.1379	2879.	652.	0.418	0.0178	0.0584	0.00872	11.52	55.00
60.00	38.162	35.10	2.3112	53.758	200.024	0.11428	0.39574	0.5726	0.4171	1.1396	2829.	651.	0.405	0.0180	0.0577	0.00890	11.20	60.00
65.00	41.602	34.89	2.1290	56.638	201.631	0.11976	0.39611	0.5766	0.4221	1.1415	2779.	651.	0.393	0.0182	0.0570	0.00908	10.87	65.00
70.00	45.270	34.68	1.9641	59.538	203.237	0.12522	0.39652	0.5808	0.4271	1.1435	2729.	651.	0.381	0.0184	0.0562	0.00927	10.55	70.00
75.00	49.175	34.46	1.8145	62.459	204.843	0.13067	0.39697	0.5851	0.4323	1.1457	2679.	650.	0.370	0.0186	0.0555	0.00946	10.23	75.00
80.00	53.323	34.25	1.6786	65.402	206.446	0.13611	0.39746	0.5894	0.4376	1.1481	2629.	650.	0.359	0.0189	0.0548	0.00965	9.92	80.00
85.00	57.735	34.03	1.5549	68.367	208.047	0.14153	0.39798	0.5939	0.4431	1.1507	2578.	649.	0.348	0.0191	0.0541	0.00984	9.60	85.00
90.00	62.409	33.80	1.4420	71.355	209.646	0.14695	0.39853	0.5985	0.4486	1.1536	2528.	647.	0.338	0.0193	0.0535	0.01004	9.29	90.00
95.00	67.358	33.58	1.3389	74.365	211.240	0.15235	0.39912	0.6032	0.4544	1.1566	2477.	646.	0.328	0.0195	0.0528	0.01024	8.97	95.00
100.00	72.592	33.35	1.2445	77.399	212.830	0.15774	0.39973	0.6080	0.4602	1.1600	2426.	644.	0.319	0.0198	0.0521	0.01044	8.66	100.00
105.00	78.121	33.11	1.1580	80.458	214.415	0.16313	0.40036	0.6129	0.4663	1.1636	2376.	643.	0.309	0.0200	0.0514	0.01065	8.35	105.00
110.00	83.955	32.88	1.0785	83.540	215.993	0.16851	0.40101	0.6181	0.4725	1.1675	2325.	641.	0.300	0.0203	0.0508	0.01086	8.05	110.00
115.00	90.104	32.64	1.0054	86.649	217.565	0.17388	0.40169	0.6233	0.4789	1.1718	2273.	638.	0.291	0.0205	0.0501	0.01108	7.74	115.00
120.00	96.578	32.40	0.9381	89.783	219.128	0.17924	0.40238	0.6288	0.4855	1.1764	2222.	636.	0.283	0.0208	0.0495	0.01129	7.44	120.00
125.00	103.39	32.15	0.8760	92.943	220.682	0.18461	0.40308	0.6344	0.4924	1.1815	2171.	633.	0.275	0.0211	0.0488	0.01152	7.14	125.00
130.00	110.55	31.90	0.8186	96.132	222.225	0.18996	0.40380	0.6403	0.4995	1.1870	2119.	630.	0.267	0.0213	0.0482	0.01174	6.84	130.00
135.00	118.06	31.64	0.7655	99.348	223.757	0.19532	0.40453	0.6463	0.5070	1.1930	2068.	627.	0.259	0.0216	0.0476	0.01197	6.54	135.00
140.00	125.94	31.38	0.7163	102.594	225.275	0.20068	0.40526	0.6527	0.5147	1.1996	2016.	623.	0.251	0.0219	0.0470	0.01221	6.25	140.00
145.00	134.21	31.11	0.6706	105.870	226.778	0.20604	0.40600	0.6593	0.5229	1.2068	1964.	619.	0.243	0.0222	0.0464	0.01244	5.96	145.00
150.00	142.86	30.84	0.6282	109.177	228.265	0.21140	0.40673	0.6662	0.5314	1.2148	1912.	615.	0.236	0.0225	0.0458	0.01269	5.67	150.00
155.00	151.92	30.57	0.5887	112.516	229.732	0.21677	0.40746	0.6734	0.5404	1.2235	1859.	610.	0.229	0.0228	0.0452	0.01293	5.38	155.00
160.00	161.39	30.28	0.5518	115.889	231.179	0.22214	0.40819	0.6811	0.5500	1.2332	1807.	606.	0.222	0.0232	0.0446	0.01319	5.10	160.00
165.00	171.29	29.99	0.5175	119.297	232.603	0.22752	0.40890	0.6891	0.5601	1.2440	1754.	601.	0.215	0.0235	0.0440	0.01345	4.82	165.00
170.00	181.62	29.70	0.4854	122.741	234.000	0.23291	0.40960	0.6977	0.5710	1.2560	1701.	595.	0.209	0.0239	0.0434	0.01371	4.54	170.00
175.00	192.42	29.39	0.4553	126.224	235.369	0.23831	0.41028	0.7068	0.5827	1.2694	1648.	589.	0.202	0.0242	0.0428	0.01398	4.27	175.00
180.00	203.67	29.08	0.4271	129.747	236.705	0.24373	0.41093	0.7166	0.5953	1.2845	1595.	583.	0.196	0.0246	0.0423	0.01426	4.00	180.00
185.00	215.41	28.76	0.4007	133.312	238.005	0.24916	0.41156	0.7271	0.6092	1.3015	1541.	577.	0.189	0.0250	0.0417	0.01455	3.73	185.00
190.00	227.64	28.43	0.3758	136.922	239.264	0.25462	0.41215	0.7385	0.6240	1.3208	1486.	570.	0.183	0.0254	0.0411	0.01484	3.47	190.00
195.00	240.39	28.08	0.3524	140.580	240.477	0.26010	0.41269	0.7510	0.6406	1.3429	1432.	562.	0.177	0.0259	0.0406	0.01515	3.21	195.00
200.00	253.66	27.73	0.3304	144.290	241.639	0.26561	0.41318	0.7647	0.6592	1.3683	1377.	554.	0.171	0.0263	0.0400	0.01546	2.96	200.00
210.00	281.84	26.98	0.2898	151.878	243.781	0.27674	0.41397	0.7970	0.7037	1.4322	1265.	538.	0.159	0.0273	0.0389	0.01614	2.46	210.00
220.00	313.35	26.16	0.2534	159.731	245.618	0.28806	0.41443	0.8388	0.7629	1.5318	1150.	519.	0.148	0.0285	0.0378	0.01680	1.98	220.00
230.00	345.33	25.25	0.2203	167.910	247.050	0.29956	0.41441	0.8964	0.8467	1.6544	1031.	498.	0.136	0.0299	0.0367	0.01782	1.53	230.00
240.00	380.98	24.22	0.1900	176.521	247.915	0.31167	0.41371	0.9837	0.9765	1.8676	906.	475.	0.124	0.0315	0.0356	0.01903	1.10	240.00
250.00	419.52	22.99	0.1615	185.763	247.926	0.32436	0.41195	1.1383	1.2081	2.2589	773.	450.	0.112	0.0337	0.0347	0.02084	0.71	250.00
260.00	461.23	21.40	0.1337	195.109	246.440	0.33835	0.40828	1.5073	1.7513	3.1957	628.	420.	0.098	0.0367	0.0345	0.02405	0.36	260.00
270.00	506.48	18.76	0.1025	209.553	240.979	0.35632	0.39938						0.080	0.0427			0.08	270.00
274.46c	527.94	14.01	0.0714	226.821	226.821	0.37957	0.37957	∞	∞	∞	0.	0.	—	...	∞	∞	0.00	274.46

*temperatures are on the IPTS-68 scale

b normal boiling point

c critical point

Figure (D.4) Pressure-Enthalpy Diagram for Isobutane.



أداء مجمدة عرض بأستخدام خليط البروبان و البيوتان كغاز تبريد بديل عن غاز R-134a

أعداد

عبدالله جميل نوفل

المشرف

أ.د. محمد السعد

المشرف المشارك

أ.د. محمود حماد

ملخـــــــص

يتناول هذا البحث فحص و دراسة أداء ثلاجة عرض عند أستخدام غاز خليط البروبان و البيوتان كبديل عن غازR-134a .خليط الغاز المستعمل هو غاز النفط المسال المستعمل في المطابخ، و المعروف بتوفره و يتكون من ٢٤,٤ % بروبان، ٥٦,٤ % بيوتان و ١٧,٢% أيزوبيوتان. من مميزاته أنه متوفر ،رخيص و غير ضار بالبيئة.

تم أجراء هذا البحث بأستعمال مجمدة عرض سعة ٢٠٠ لتر لفحص أداء غاز البروبان و البيوتان و مقارنته مع الغاز الأصلي، R-134a.

قد تم أجراء التجارب على ثلاث شحنات مختلفة لخليط البروبان و البيوتان، و هي ١٥٠، ٢٠٠، ٢٥٠ غرام و ذلك لمعرفة كمية الشحنة التي تعطي الأداء الأمثل و مقارنتها بأداء غاز R-134a.

أظهرت النتائج كفاءة عالية لغاز البروبان و البيوتان، حيث تم الحصول على درجة حرارة للمبخر تصل الى - ٢٦,٧ ° م ومعامل أداء ٤,٩٦ عند درجة حرارة للمبخر- ٥,٦ ° م، درجة حرارة المكثف ٣٩°م و درجة حرارة جوية ٢٢,٤ ° م.

بالخلاصة، فأن النتائج قد أثبتت أداء مقبولا لغاز البروبان و البيوتان كغاز بديل عنR-134a بالمجمدات الصندوقية، وذلك بدون أي أثار جانبية و بدون الحاجة لأجراء اي تعديلات بالجهاز.