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PERFORMANCE STUDY OF WINDOW-TYPE AIR CONDITIONING UNIT USING R134a AS AN ALTERNATIVE REFRIGERANT

BY
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DEDICATION

TO MY FAMILY

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Nomenclature

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BS	British Standard
CFCs	Chlorofluorocarbons
COP	Coefficient of Performance
GWE	Global Warming Effect
GWP	Global Warming Potential
h	Enthalpy, kJ/kg
HCs	Hydrocarbons
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
LFL	Lower Flammability Level
m	Charge Quantity of the Refrigerant, g
m	Mass Flow Rate of the Refrigerant per Kilowatt of Cooling Capacity, g/s/kW
M	Actual Refrigerant Mass Flow Rate, g/s
ODP	Ozone Depletion Potential
P	Pressure, MPa
PAGs	Polyalkylene glycols
q	Heat Exchanged per Kilogram of Refrigerant Circulated, kJ/kg

Q	Cooling Capacity, kW
R	Refrigerant
s	Specific Entropy, kJ/kg K
T	Temperature, °C
TEWI	Total Equivalent Warming Impact
w	Specific Work of Compression, kJ/kg
x	Volume Fraction of the Component

Subscripts:

c	Condenser
e	Evaporator
f	Saturated Liquid State
g	Saturated Vapor State
s	Supply or Outlet Condition

Abstract

Performance Study of Window-Type Air Conditioning Unit Using R134a as an Alternative Refrigerant

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The main purpose of this research is to test experimentally the performance parameters of R134a, which is harmless to the ozone layer, when it replaces R22 in a 5 kW window–type air conditioning unit. Then a comparison between the parameters of the original refrigerant, R22, and the new one, R134a, is made to decide if it is suitable or not.

Results of the present work indicates that refrigerant R134a can be used as an alternative refrigerant for R22 in this type of air conditioning units with optimum charge quantity around 660 g for the 5 kW unit capacity, but with less capacity. The value of the coefficient of performance when R134a is used is decreased by about 10%, while the reduction in the refrigerating capacity is 35%.

CHAPTER ONE
INTRODUCTION

1.1 Refrigerant Properties:

Refrigerants are the working fluids in refrigeration, air-conditioning, and heat pump systems. They absorb heat from one area, such as an air-conditioned space, and reject it into another, such as outdoors, usually through evaporation and condensation processes, respectively.

Refrigerant selection involves compromises between conflicting desirable thermodynamic properties. A refrigerant must satisfy many requirements, some of which do not directly relate to its ability to transfer heat.

Thus the refrigerant should possess as many as it is practicable of the following qualities (Jennings, 1978).

1- Chemical stability under conditions of use.

2- Safety which requires non-flammability and non-explosivity.

3- Non-toxicity

4- Low cost

5- Availability

6- Efficiency

7- Compatibility with compressor lubricants and materials with which the equipment is constructed.

8- Ease of handling

9- Low compressor discharge temperature to prevent possible break down or deterioration of refrigerant and lubricant in the system.

10- Low boiling temperature at atmospheric pressure so that no needs to vacuum operation with attendant possibility of leakage of damp air into the system.

11- High critical temperature to make it possible to condense the vapor at high temperature.

12- High latent heat of vaporization to have less mass, that must be circulated per minute per unit of refrigeration capacity.

13- Low specific heat of liquid, since the expansion valve throttles the liquid, which must be cooled at the expense of partial evaporation.

14- Low specific volume of vapor especially with reciprocating compressors.

15- Ease of locating leaks by odor or any suitable indicator.

16- The freezing temperature of the liquid should be appreciably below any temperature at which the evaporator might operate.

17- Environmentally safe substance.

1.2 **Depletion of Ozone Layer**:

Ozone is a gas, slightly bluish in color, with a pungent odor. It consists of three atoms of oxygen, O_3. The ozone layer consists of ozone in the stratosphere, high above the earth at an altitude of between eleven to forty-five kilometers. It absorbs and scatters ultraviolet radiation from the sun, preventing harmful amounts of ultraviolet radiation from reaching the earth. When ozone depletion occurs, more ultraviolet radiation penetrates to the earth surface causing the following effects:

a. Increase of skin cancer.

b. Suppression of the human immune response system.

c. Increase in cataracts.

d. Damage of crops.

e. Increase in ground-level ozone.

f. Increase of global warming effect (GWE).

Scientists have generally concluded that the weight of scientific evidence strongly indicates that man-made chlorinated chemicals (CFCs) and brominated chemicals (halons) are primarily responsible for the substantial decrease of stratospheric ozone. The factor that has been assigned to represent their relative ability to destroy stratospheric ozone is called the Ozone Depletion Factor or Ozone Depletion Potential (ODP). This scale is based on CFC11 having been assigned a factor of 1.0, HCFC22 has an ODP of 0.05, and HFC134a has an ODP of 0.0.

According to the Montreal Protocol and its amendments a complete cessation of the production of CFCs and HCFCs is called by the years 1996 and 2030, respectively.

1.3 **Current Study**:

In this study the refrigerant hydrochlorofluorocarbon 22 (HCFC22) in a small air conditioning unit of 5 kW cooling capacity is replaced by the refrigerant hydrofluorocarbon (HFC134a) which is harmless to the ozone layer. All performance parameters such as cooling effect, work of compression, coefficient of performance, mass flow rate per kilowatt of cooling capacity, cooling capacity, and supply temperature will be studied experimentally to decide upon the suitability of the alternative refrigerant, HFC134a for use in air conditioning units.

CHAPTER TWO

LITERATURE SURVEY

In this chapter the properties, range of application, and the recent international trend concerning different types of refrigerants and their future use are introduced. Also some related researches and studies concerning the substitution of CFCs and HCFCs are reported; besides, the future outlook that seems hopeful about the new alternatives.

2.1 **Early Refrigerants**:

The first pioneers of refrigeration units used ether as a refrigerant. Later, a large number of substances were tried with varying success. The main refrigerants in practical usage in the first 30–40 years of the twenty's century are as follows:

(1) **Ammonia (NH_3)**: It was used for medium and large stationary air conditioning systems and also sometimes in ships. It is often used with brine as a secondary refrigerant, but increasingly with direct cooling. There is no doubt about its excellent thermodynamic and transport properties. It is a well-known fact that an ammonia plant always has considerably better energy efficiency, tolerance to normal mineral oils, low sensitivity to small amounts of water in the system, simple leak detection, unlimited availability, and low price. But ammonia is poisonous and can burn with air. Also ammonia is corrosive to copper and copper or zinc alloys. So care should be exercised that these metals are not used in contact with such

alloys. Ammonia irritates eyes and mucous membrane and to most people unpleasant smell. The future rapid growth in ammonia usage is expected (Lorentzen, 1995).

(2) **Sulfur dioxide (SO_2), R764**: It was used formerly for household equipment and small commercial applications. But occasionally for capacities up to several hundred kW. It has a very irritating acrid vapor. It is a moderately low-pressure refrigerant and must be kept dry when it is in use because it forms an acid in the presence of water.

(3) **Carbon dioxide (CO_2), R744**: Before the development of the synthetic group of "Freon" refrigerants, carbon dioxide was an extremely important refrigerant because of its low toxicity. Carbon dioxide is non-corrosive and inert gas. It has no odor, non-irritating and essentially non-toxic refrigerant; however, in high concentrations over 6% by volume much discomfort is experienced and loss of consciousness and ultimately death can result if the person exposed is not moved into fresh air. Carbon dioxide has a very high pressure and low critical temperature refrigerant. Its lubrication is simple, it is very suitable for operation at temperatures down to about –51.11 °C. Solidification occurs at --56.6 °C. Lorentzen(1995) believed that a system using carbon dioxide refrigerant will have a bright future as a practical solution to the difficulties caused by the Montreal Protocol restriction.

2.2 **Hydrocarbon Refrigerants:**

Refrigerants of this group are all very flammable and explosive, not very toxic and soluble in lubricating oil. Different hydrocarbons can be selected to work in desired pressure and temperature ranges. Among those used are:

(1) **Butane (C_4H_{10}), R600**: It has a moderately low pressure. It is completely harmless to the environment. A great number of authors believed that butane or its mixtures will be a hopeful alternative refrigerant (Lorentzen, 1995).

(2) **Propane (C_3H_8), R290**: It has an intermediate pressure range, excellent thermodynamic properties; similar to those of ammonia. Its transport properties are correspondingly better; although do not quite match those of ammonia. Propane is compatible with normal lubricating oils. Its molar mass of 44 is ideal for turbo compressors. It is universally available and low in price. Also it is harmless to the environment. But as mentioned earlier it is combustible; so care must be taken in designing equipment using this refrigerant (Lorentzen, 1995).

(3) **Mixtures of propane and butane**: After years of hesitation hydrocarbon refrigerants are beginning to find application in household equipment. A 50/50 mixture of propane and isobutane (R290/R600a) is used to approach the pressure and capacity characteristics of R12 (Lorentzen, 1995).

(4) **Ethylene (C_2H_4), R1150**: It has been used to some extent for very low temperature. It has been used successfully like propane as a working media in large refrigeration plants for many years, notably in the petrochemical process industry.

(5) **Ethane (C_2H_6), R170**: It has a high-pressure range; about 1.655 MPa at –15 °C and 4.6 MPa at 30 °C, which is near the pressure range of carbon dioxide.

2.3 The Halocarbon (Halogenated Hydrocarbon) Refrigerants:

This group of refrigerants was developed in the early twenty's by Dr. Thomas Midgley where the extremely low toxicity is the most outstanding feature of it. This characteristic contributed to early acceptance of one of these refrigerants, for widespread use in air conditioning installations. Refrigerants of this group are substitution refrigerants in that halogen atoms; mainly chlorine and fluorine, are substituted in a hydrocarbon structure of hydrogen atoms. The hydrocarbon methane (CH_4) has been most widely featured in this pattern. Refrigerants of this group are given short name numbers according to ASHRAE designation as R12, R22, ...etc. The most known of these refrigerants are discussed briefly below.

(1) **Dichlorodifluoromethane (CCl_2F_2), R12**: It is commonly known as Freon-12 where it is used extensively in air conditioning systems. R12 is chemically stable and has practically no corrosive effect on the ordinary metals unless contaminated by impurities of which water is one. This

refrigerant is odorless, noncombustible and nontoxic. Its pressure range is moderate and its latent heat is low. So the mass of R12 circulated per minute per ton of refrigeration is very much larger as compared with ammonia. Mineral oil of selected grade and free of water is used which is mutually soluble with the refrigerant.

(2) **Chlorodifluoromethane ($CC1HF_2$), R22**: It is also known as Freon-22 where it is in extensive use for reciprocating compressors. Like R12, it is chemically stable, almost odorless, noninflammable, non-explosive, and nonirritating. This refrigerant is practically suitable for use in the low-temperature field (-40 to –73.3 °C). It has relatively high latent heat and pressure, so that it is used extensively in the moderate-temperature (air conditioning) range.

(3) **Trichloromonofluoromethane (CCl_3F), R11**: It is a so-called vacuum refrigerant. It exists as a liquid at normal atmospheric temperature and pressure. In order to obtain refrigeration temperatures in the evaporator, it is necessary to vaporize the refrigerant at pressures below atmospheric. It is practically odorless, relatively nontoxic, non-explosive, and noninflammable.

(4) **Methyl chloride (CH_3Cl), R40**: It has limited use in small units. It is moderately inflammable and can be explosive between concentration limits of 8.1 and 17.2 % by volume in air. It has sweet smelling odor and toxic in concentrations above 2% by volume. Its pressure range is moderate. It is

stable and non corrosive to common metal of construction; with the exception of aluminum.

(5) **Dichloromonofluoromethane (CH_2Cl_2F), R21**: It is a vacuum-type refrigerant. It is somewhat less toxic than R40, and practically noninflammable and non-explosive.

(6) **Dichlorotetrafluoromethane ($C_2Cl_2F_4$), R114a and R114**: It is low-pressure refrigerant that characterized by low toxicity.

(7) **Methylene chloride (CH_2Cl_2), R30**: It has mild odor, non-explosive, and nonflammable. But it is toxic in concentrations of over 5% by volume.

(8) **Chloropentafluoroethane ($CClF_2CF_3$), R115**: It is an important refrigerant, and is considered as a component of two refrigerant azeotropes, namely R502 and R504.

2.4 **Azeotrope Halocarbon Refrigerants**:

An azeotrope is a mixture of two or more chemicals, which maintain the same ratio of constituent chemicals in both the liquid and vapor phases. The true azeotrope acts as though it is a distinct and new substance not subject to separation, possessing its own pressure-temperature relationship independent of that possessed by either of its constituents. Most of those are, R502, which is a mixture of R22 and R115, and R503, which is a mixture of R23 and R13.

(1) **R502**: It is a mixture of 48.8% R22 and 51.2% R115 by weight. It is used for moderately low-pressure applications such as are encountered in

frozen food cases and displays cabinets. Its pressure is higher and specific volume is lower than are the corresponding values of R22. Its specific volume is slightly larger than R115 but the pressure-compression ratio is favorable for the R502

(2) **R503**: It is composed of 40.1% R23 and 59.9% R13 by mass. For low-temperature application, R503 is now supplanting R13 as the preferred refrigerant.

2.5 **Phase Out of Refrigerants**:

The Montreal Protocol is an international treaty that controls the production of ozone-depleting substances; including refrigerants containing chlorine and / or bromine. The European Union and 24 nations including the United State signed the original Protocol on September 16, 1987. It entered into force on January 1, 1989, and limits the 1989 production of specified CFCs to 50% of their 1986 levels. Starting in 1992, the production of specified halons was frozen at 1986 levels. Developing countries were granted additional time to meet these deadlines. The original Protocol contained provisions for periodic revision. Two such revisions, referred to as the London and Copenhagen Amendments, were agreed to in 1990 and 1992, respectively. As of September 1996, 157 parties have been ratified the Montreal Protocol, 110 parties the London Amendment, and 58 parties the Copenhagen Amendment. The Copenhagen Amendment entered into force on June 14, 1994. It called for a complete cessation of the production of

CFCs by January 1, 1996 and of halons by January 1, 1994. Continued use from existing (reclaimed or recycled) stock is permitted. Allowance is also provided for continued production for very limited "essential use". In addition, HCFCs (including R22) are to be phased out relative to 1989 reference level for developed countries. Production was frozen at the reference on January 1, 1996. Production will be limited to 65% of the reference level by January 1, 2004; to 35% by January 1,2010; to 10% by January 1, 2015; and to 0.5% of the reference level by January 1,2020. Complete cessation of the production of HCFCs is called for by January 1, 2030. In addition to the international agreement, individual countries may have domestic regulations for ozone-depleting compounds. The production and use of hydrofluorocarbon (HFC) refrigerants (such as R32, R125, R134a, and R143a and their mixtures including R404, R407, and R410) are not regulated by the Montreal Protocol, but may be regulated by the individual countries (ASHRAE, 1997).

2.6 **Researches Concerning CFC and HCFC Substitutions**:

In 1989, the Montreal Protocol specified deadlines to phase out and control the production of all CFCs and HCFCs. Since that time scientists and manufacturers have been working to find out suitable substitutions for the banned refrigerants. HFCs are the most hopeful alternatives along with their binary and ternary mixtures, although some strongly supported the reuse of natural refrigerants. Some researches and studies concerning this subject are discussed below:

Wuebbles (1994) stated that the current use and emissions of CFCs are having a significant influence on the radiative forcing of climate. However, observed decreases in stratospheric ozone, thought to be connected to increasing stratospheric chlorine from CFCs, suggest a cooling tendency over the last decade. This cooling tendency has strong latitudinal gradients, but is, when globally averaged, about a complete in magnitude and opposite in sign to the radiative forcing from CFCs over this period. The effects of the changes in stratospheric ozone on radiative forcing are indicative of the strong coupling between atmospheric chemistry and climate. Because of their shorter atmospheric lifetime, the direct radiative influence on climate from the replacement compounds should be much smaller than CFCs.

Preisegger and Henrici (1992) discussed one of the favorite substances for replacing CFCs, that is R134a. Owing to the absence of chlorine atoms in the molecule of R134a this substance provides excellent chemical and thermal stability, which is significantly better than R22. As expected, R134a shows good compatibility with elastomers. Non of the conventional refrigerant oils are suitable for use with R134a if a lubricant that is readily miscible is required, although synthetic compounds with higher polarity can give partial miscibility; so, the polyalkylene glycols (PAGs) and ester type lubricants are developed and tested which give good results for lubricant miscibility. Many thermodynamic properties such as isentropic exponent, sonic velocity, coefficient of performance (COP), thermal conductivity, viscosity and capacity are investigated, which give good results comparable to those of R12.

Eckels and Pate (1991) compared experimentally between the evaporation and condensation heat transfer coefficients for HFC134a and CFC12, where they found that HFC134a shows a 30% increase in the heat transfer coefficients over CFC12, while the liquid thermal conductivity of HFC134a is 17% over that of CFC12. HFC134a shows a significant increase in evaporation heat transfer coefficients compared to CFC12, with increases ranging from 30-40%. Also HFC134a results in a 25-35% higher condensation heat transfer coefficients. Because of the increased enthalpy of vaporization for HFC134a, the mass flow rate of HFC134a was decreased by 15-20% to reflect equivalent heating capacity. The ratio of condensation heat transfer coefficients is 1.10 to 1.20.

Fischer (1993) concluded that for low-loss applications like refrigerators, freezers, and unitary air conditioners, centrifugal chillers and residential heat pumps; the direct contribution of the CFC alternative is only a small fraction of the Total Equivalent Warming Impact (TEWI). This is true using either the 100 year or 500 year Global Warming Potential (GWP) values to compute the TEWI. In these applications there is little benefit to be gained from using refrigerants with lower GWPs or technologies that do not use greenhouse gases. Also, concluded that the greatest reduction of TEWI can be made by using CFC alternatives in the applications that have relatively high losses, retail refrigeration and automobile air conditioning. In these cases the direct effect is still a large fraction of the TEWI and it may be possible to reduce TEWI even further by innovative or nex-generation technologies. Finally, recent findings are throwing some doubt on whether or not CFCs actually have a warming or cooling effect on the atmosphere. When these new questions are finally resolved, the result is that the GWPs of the CFCs and HCFCs listed in Table 2.1 are likely to be reduced. The consequence on this work is that the energy-contributions to TEWI will be even more dominant than they are now, which only emphasizes the fact that the most effective way to reduce contributions to global warming in the future will be to improve system efficiencies and reduce energy use.

Jung et al. (1999) studied the selection of capillary tubes used in residential air conditioners for HCFC22 alternatives, namely HFC134a, R407c, and R410A. It is found that R407c has refrigerant mass flow rate almost the same as that of HCFC22 at the same subcooling and condensing temperatures and of the same capillary tube diameter and length. Also HFC134a has refrigerant mass flow rate at the same conditions and

Table 2.1 Global Warming Potentials (GWP) for relevant CFCs, HCFCs, and HFCs. Only direct radiative effects are included; however, the sign of expected indirect effects due to chemical interaction is also shown**

Trace gas	Global Warming Potentials time horizon		
	20 years	100 years	500 years
CO_2	1	1	1
CFC11	4500	3400	1400
CFC12	7100	7100	4100
CFC114	6100	7000	5800
CFC115	5500	7000	8500
HCFC22	4200	1600	540
HCFC123	330	90	30
HCFC124	1500	440	150
HCFC141b	1800	580	200
HFC134a	3100	1200	400
HFC152a	530	150	49

**(Wuebbles, 1994)

capillary tube dimension almost comparable to that of HCFC22, but R410A has refrigerant mass flow rate differs largely from that of HCFC22.

Carrington et al. (1995) analyzed the performance of a dehumidifier using HFC134a. One feature of the system tested was the use of a scroll compressor, a low-side compliant type normally used with HCFC22. The swept volume was 14.8 m^3h^{-1}. It was anticipated that the compressor would be suitable for use with HFC134a at up to 35°C saturation suction temperature with the lubricant selected. The influence of operating conditions on the performance of the dehumidifier has been determined different system configurations. The results are in accord with the more restricted measurements reported that for a dehumidifier using HCFC22. The use of an evaporator economizer produced an enhancement of 130% in both the specific moisture extraction rate and moisture extraction rate at 30% relative humidity. The thermal effectiveness of the economizer was 38%. The maximum specific moisture extraction rate was 5.11 Kg kW/h obtained at 50°C dry-bulb, 90% relative humidity. These performance figures illustrated the opportunities for constructing high efficiency medium-temperature dehumidifiers using HFC134a.

Because of high discharge temperatures caused by high compression ratios of R22; staged compression system and liquid injection are two approaches to prevent compressor overheating in R22 low temperature applications. Also, R22 used in a two-stage vapor compression system can replace R502, even for low-temperature applications related to frozen foods and has long been used in many sectors of industrial refrigeration. At some time HFC134a was considered the only alternative to HCFC22 in unitary equipment, although the projections were that there would be significant efficiency losses by using HFC134a instead of HCFC22 assuming a fixed equipment and installation cost (Fischer, 1993).

Feng et al. (1994) studied some potential alternatives for HCFC22. Since HFC134a has zero ozone depleting potential (ODP), nontoxic and noninflammable with material compatibility and lubricant has been fulfilled; so, this refrigerant can be considered one of the hopeful alternatives for HCFC22. Under the air conditioning working conditions, the coefficient of performance (COP) of HFC134a is slightly higher than that of HCFC22, but the volumetric capacity of HFC134a is only as 63.5% as that of HCFC22; so, the volume of the compressor required for HFC134a will be larger than that for HCFC22.

Melo et al. (1994) presented extensive data that have been taken for flow of CFC12, HFC134a, and HC600a through capillary tubes. For the same condensing pressure and inlet subcooling, CFC12 and HFC134a generate almost the same mass flow rates. This trend is not observed for HC600a that generates mass flow rates 33% lower than CFC12 and HFC134a. For the same cooling capacity, operating conditions and internal diameter; HFC134a requires longer capillary tube than CFC12. By the other hand, changes on the capillary tube length might not be necessary for HC600a.

Of all HFCs, refrigerant R134a has undergone the most comprehensive tests worldwide and is used in many refrigerating and air conditioning installations, showing good operating results. The advantages are the close thermodynamic relationship to R12 with the ability to be used with similar system techniques and proven compressor technology. Thereby the coefficient of performance (COP) of the compressor is relatively high with air conditioning and medium-temperature applications. In addition to this, both the thermal loads (discharge gas temperature) and pressure levels are comparatively low. Very high heat transfer is achieved with R134a and because of this design and efficiency of heat exchangers can be improved. The disadvantages of R134a against R22 are however, the specific refrigerating capacity and the limitations of the applications with lower evaporating temperatures.

Hodgkinson (1990) suggested reviewing all the alternatives that can provide refrigeration and dehumidification and see if these alternatives should provide more of the refrigerating and air conditioning services. The fire protection is an important factor because it affects more people either they use refrigeration or not.

Hainbach and Steimle (1994) investigated by theoretical computations that the use of propane (R290) in refrigerating plants constructed for R134a or R12 refrigerants does not yield the desired success. This conclusion is only valid; however, for the special case with its investigated temperature range. It can be concluded that the exchange of CFCs by a pure hydrocarbon or a mixture of hydrocarbons as a refrigerant is energetically sensible, if the refrigerant, which is to be replaced, has a similar vapor pressure. Furthermore, a dimensionless function for the behavior of the compressor was developed. An interpolation of the functional relation revealed that the polytropic exponent only characterizes the efficiency of the compressor. Thereby it is possible to quantify the efficiency of the compressor if the suction condition and the polytropic exponent are known.

Sicars and Tiedeman (1996) showed that CFC11; the refrigerant that is used in centralized air conditioning systems will be not converted to HCFC123 because of its toxicity, but it will be replaced by new equipment using HFC134a.

Carpenter (1992) carried out a comprehensive program to test the stability of HFC134a-ester oil combinations. HFC134a has been shown to be chemically and thermally more stable than CFC12 according to ASHRAE sealed-tube tests made at temperatures of 175°C for 14 days in the presence of copper, aluminum, iron and zinc. Test results showed that the composition of the refrigerant mixture when using HFC134a did not change, whereas 0.1% of CFC12 in mineral oil decomposed to HCFC22. The concentration of fluoride ions remained unchanged at less than 2 ppm, whereas the concentration of chloride ions in a CFC12-mineral oil mixture increased from 10 ppm to 100 ppm. The corrosion of the metal surfaces in a HFC134a system was below the detection limit of 0.01 mm per year and there was no copper plating. With CFC12-mineral oil mixtures, chlorides were formed on the metal sample surfaces and there was copper plating.

2.7 Future Outlook:

Most of the researches concerning CFCs replacement conclude that HFCs are a considerable substitution. Among those; R134a, which has zero (ODP) is considered an excellent alternative to R12 with almost the same performance parameters. It is impossible to find an alternative for some refrigerant suitable for all its applications (Atwood, 1991). So that, the properties of the refrigerant must be analyzed to find out the suitable alternative for the phased out refrigerant. R134a such as all old refrigerants meets all requirements which are important for its use, also, it has an additional important advantage over all other CFCs and HCFCs; that is its zero (ODP) as shown in Table 2.2. However, although, it is considered as a greenhouse gas its (GWP) value is less than that of all CFCs and HCFC22 refrigerants as shown in Table 2.1. Upon that R134a can be considered as a transitional refrigerant; since, some countries may change first to R134a and then to R600a (Melzer, 1994), or as a long term refrigerant; because it can replace R12 in almost all of its applications, and R22 in many applications including water chillers, unitary air conditioning equipment, and heat pumps. In this study, R134a, which is harmless to the ozone layer, will replace R22 in a small air conditioning unit.

Table 2.2 Characteristics and properties of some refrigerants**

Characteristic / property	CFC12	HCFC22	HFC134a	NH_3	CO_2
Natural substances?	No	No	No	Yes	Yes
ODP	1.0	0.05(1)	0	0	0
GWP(2)					
100 years	7100	1500	1200	-	1(0)(3)
20 years	7100	4100	3100	-	1(0)
TLV_{8h} (pp)	1000	1000	000(4)	25	5000
IDLH(5) (ppm)	50.00	-	-	500	50.00
Amount per room vol.(6) (vol% / $Kg\ m^{-3}$)	4.0/ 0.2	4.2/ 0.15	-	-	5.5/0.1
Flammable or explosive?	No	No(7)	No(7)	Yes	No
Toxic/irritating decomposition products?	Yes	Yes	Yes	No	No
Approx. Relative price	1	1	3-5	0.2	0.1
Molar mass	120.92	86.48	102.03	17.03	44.01
Volumic(8) refr. Capacity at 0°C ($kJ\ m^{-3}$)	2740	4344	2860	4360	22600

(1) Somewhat higher values have been suggested by recent studies.

(2) Global warming potential in relation to CO_2 with 20 and 100 years integration time (IPCC 1990, 1992).

(3) Abundant amounts of CO_2 recovered from waste gas. Thus GWP of commercial carbon dioxide, for instance used as refrigerant, is 0.

(4) Suggested by ICI etc.

(5) Maximum level from which one could escape within 30 min without any escape-impairing symptoms or any irreversible health effects.

(6) Maximum refrigerant charge in relation to refrigerated room volume, as suggested in ANSI/ASHRAE 15-1989: *Safety Code for Mechanical Refrigeration*.

(7) Although considered to be non-flammable, both R22 and R134a are combustible in certain mixtures with air at elevated pressures, but ignition may be difficult.

(8) Enthalpy of evaporation divided by saturated vapor volume.

**(Lorentzen, 1994)

CHAPTER THREE

THEORETICAL PRESENTATION

In this chapter theoretical presentation of the air conditioning processes and performance parameter calculations, besides, the physical and thermodynamic properties of the two refrigerants used in this study are introduced.

3.1 **Air Conditioning Processes**:

As the refrigerant circulates through the system, it passes through a number of changes in state or conditions. There are four fundamental processes of the simple vapor-compression refrigeration cycle; which are compression, condensation, expansion, and evaporation processes. The properties of a refrigerant can be represented to advantage by plotting property values on coordinate diagrams. Commonly used diagrams are the temperature-entropy (T*s*) diagram and the pressure-enthalpy (*p*h) diagram. In refrigeration work the pressure-enthalpy diagram is by far the most useful type of plot, although the temperature-entropy plot, on which areas can represent the heat interchange, is also useful (Jennings, 1978). Figures 3.1 and 3.2 illustrates these four processes of refrigeration on a *p*h and T*s* charts respectively.

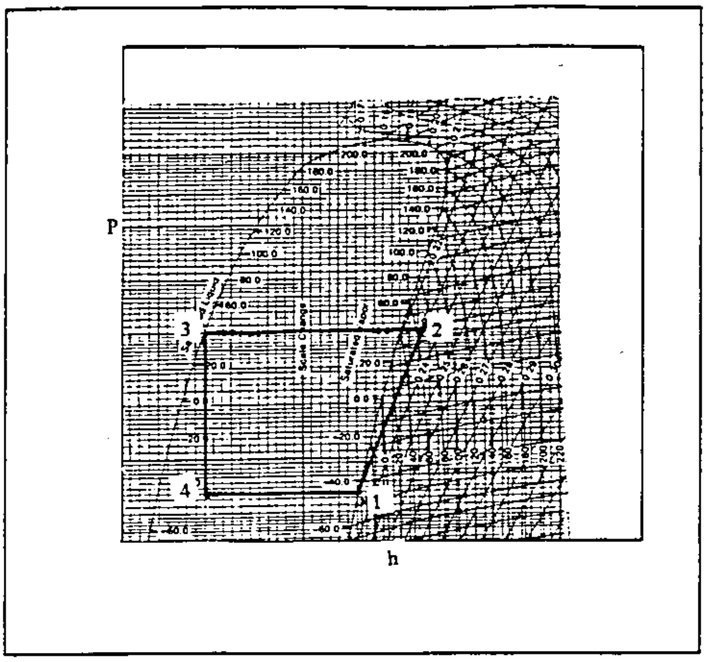


Fig. 3.1 *p*h diagram of vapor compression refrigeration cycle.

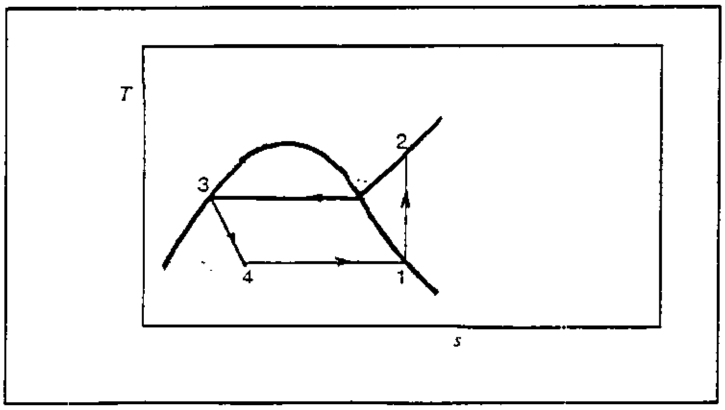


Fig. 3.2 T*s* diagram of vapor compression refrigeration cycle.

(1) **The compression process**:

Saturated or superheated refrigerant vapor enters the compressor. If the refrigerant at the compressor inlet is saturated, due to compression process, it becomes superheated before it reaches the compressor outlet. This results in an increase of the heat of compression per unit mass and of the heat rejected at the condenser.

Compression of refrigerant vapor in the compressor takes place under isentropic conditions, which requires the least work when performed isentropically. The work of compression per kilogram of refrigerant circulated, w, is:

$$w = h_2 - h_1 \tag{3.1}$$

Where, h_1 and h_2 are the enthalpy at compressor entrance (state 1) and discharge (state 2), respectively.

(2) **The condensing process**:

The condensing process occurs in the condenser, which removes heat from the refrigerant to change the superheated gas leaving the compressor into saturated or subcooled liquid. This process includes sensible and latent heat. The sensible heat process occurs in the upper part of the condenser and it represents the cooling of the vapor from the compressor discharge temperature to the condensing temperature, when the vapor rejects heat to the condensing medium. The latent heat process represents the condensation of the vapor in the condenser. The heat rejected at the condenser per kilogram of refrigerant circulated, q_c, is given by:

$$q_c = h_2 - h_3 \tag{3.2}$$

Where h_2 and h_3 are the enthalpy at the condenser inlet and outlet, respectively.

(3) **The expansion process**:

Liquid refrigerant, after it leaves the condenser, enters the expansion valve. Adiabatic process without work production or throttling process takes place in the expansion valve, where the enthalpy of the refrigerant does not change, thus:

$$h_3 = h_4 \qquad (3.3)$$

Where, h_4 is the enthalpy at the expansion valve exit.

Bringing of warm liquid to cold evaporator temperature occurs at the expense of evaporating a portion of liquid, with the loss of some refrigerating effect. This process results in the production of flash vapor, which can accomplish no useful cooling in the evaporator. Thus the expansion valve equation is:

$$h_3 = h_f + x\, h_{fg} \qquad (3.4)$$

Where h_f is the enthalpy of liquid at evaporator pressure (p_e); in kJ/kg, h_{fg} is the latent heat of refrigeration at evaporator pressure (p_e); in kJ/kg, and x is the quality, expressed as a decimal, of the refrigerant after passing through the expansion valve. Also the mass of the flash gas formed by unit mass of refrigerant enters the expansion valve.

(4) **The vaporizing process**:

In the evaporator the liquid from the expansion valve changes into vapor as it absorbs heat from the space being cooled. The heat absorbed appears as increased enthalpy of the refrigerant. The vapor leaving the evaporator may be dry-saturated, superheated, or slightly wet. The heat absorbed form the refrigerated space by a unit mass of refrigerant is called the refrigerating effect, q_e, which is given by:

$$q_e = h_1 - h_4 \tag{3.5}$$

3.2 Cooling Capacity:

The rate of heat removed from the refrigerated space is called the cooling capacity. It depends on the actual mass of refrigerant circulated per unit of time, $\dot{M}$, and refrigerating effect per unit mass circulated. It is given by:

$$Q = \dot{M}\, q_e \tag{3.6}$$

3.3 Coefficient of Performance:

The coefficient of performance is a measure of refrigeration cycle efficiency. It is the ratio of the heat absorbed from the refrigerated space to the work supplied to the compressor; so,

$$COP = q_e / w = (h_1 - h_4) / (h_2 - h_1) \tag{3.7}$$

3.4 Mass Flow Rate of the Refrigerant:

The mass of refrigerant, which must be circulated per second per kilowatt of refrigerating capacity for any operating conditions is found by:

$$\dot{m} = 1kw / q_e \tag{3.8}$$

3.5 Effect of Suction Temperature:

If the compressor suction temperature increases; its enthalpy will increase, and according to definitions above, the refrigerating effect increases, while the work of compression and mass flow rate of refrigerant per kilowatt of refrigerating capacity will decrease. So, the coefficient of performance increases. Thus, to improve the refrigeration system efficiency, the system should be always designed to operate at the highest practical temperature.

3.6 **Properties of Refrigerants Used**:

Chlorofluoromethane ($CClHF_2$), HCFC22 or R22 and 1,1,1,2-tetrafluoroethane (CH_2FCF_3), HFC134a or R134a are the two refrigerants used in this study. Their physical and thermodynamic properties are shown in the tables and figures illustrated below;

(1) **Designation of refrigerants**:

Standard designation of refrigerants according to ASHRAE standard 34 is shown in Table B.4.

(2) **Physical properties of refrigerants**:

Physical properties of selected refrigerants are shown in Table B.5.

(3) **Sound velocity**:

Table B.6 gives examples of sound velocity in vapor phase for various fluorinated refrigerants. The velocity increases when the temperature is increased and decreases when the pressure is increased. It can be used to measure the noise level of the refrigerant.

(4) **Latent heat of vaporization**:

Table B.7 shows latent heat of vaporization against boiling point for some refrigerants, also shows Trouton Constant, which is the ratio between the latent heat of vaporization at the boiling point on a molar basis and the temperature in absolute units.

(5) **Refrigerant theoretical performance**:

Table B.8 shows the theoretical calculated performance of a number of refrigerants for the US Standard Cycle of 258K evaporation and 303K condensation. Calculated data for other conditions are given in Table B.9. These tables can be used to compare the properties of different refrigerants; but actual operating conditions are somewhat different from the calculated data. In most cases, the suction vapor is assumed saturated, and the compression is assumed adiabatic or performed at constant entropy.

(6) **Safety**:

Table B.10 summarizes the toxicity and flammability characteristics of many refrigerants. In ASHRAE standard 34, refrigerants are classified according to the hazard involved in their use. The toxicity and flammability classification yields six safety groups (A1, A2, A3, B1, B2, and B3) for refrigerants. Group A1 refrigerants are the least hazardous. Group B3 the most hazardous. The safety classification in ASHRAE standard 34 consists of a capital letter and a numeral. The capital letter designates the toxicity of the refrigerant at considerations below 400 ppm by volume:

- Class A: - Toxicity not identified.

- Class B: - Evidence of toxicity identified.

The numeral denotes the flammability of the refrigerant:

- Class 1: - No flame propagation in air at 18 °C and 101 kPa.
- Class 2: - Lower flammability limit (LFL) greater than 0.10 kg / m^3 at 21°C and 101 kPa and heat of combustion less than 1900 kJ / kg.
- Class 3: - Higher flammable as defined by LFL less than or equal to 0.10 kg / m^3 at 21°C and 101 kPa and heat of combustion greater than 1900 kJ / kg (ASHRAE, 1997).

(7) **Leak detection**:

Leak detection in refrigeration equipment is a major problem for manufacturers and service engineers. The most known methods for leak detection are described below,

(a) **Electronic detector**: The electronic detector is widely used in the manufacture and assembly of refrigeration equipment. Instrument operation depends on the variation in current flow caused by ionization of composed refrigerant between two oppositely charged platinum electrodes. The electronic detector is the most sensitive of the various leak detection methods, reportedly capable of sensing a leak of 0.3 g of R12 per year (ASHRAE, 1997).

(b) **Halide torch**: The halide torch is a fast and reliable method of detecting leaks of chlorinated refrigerants. Air is drawn over a copper element heated by a methyl alcohol flame. If halogenated vapors are present, they decompose, and a color of the flame changes to bluishgreen. Although not as sensitive as the electronic detector; this method is suitable for most purposes (ASHRAE, 1997).

(C) **Bubble method**: The object to be tested is pressurized with air or nitrogen. The object is immersed in water, and any leaks are detected by observing the formation of bubbles in the liquid. (ASHRAE, 1997).

(8) **Enthalpy**:

The values of the enthalpy of R22 and R134a are shown in tables B.1, B.2, and B.3, and charts Fig. B.1, and Fig. B.2, in appendix B.

CHAPTER FOUR

EXPERIMENTAL APPARATUS AND PROCEDURE

In this research, a window-type air conditioning unit is used to determine experimentally all performance parameters. Two test stages have been done using the same unit. In the first stage, R22 was the refrigerant, and then R134a was used instead of R22 in the second stage.

4.1 **Specifications of the Air Conditioning Unit**:

Table 4.1 below shows the specifications of the air conditioning unit used as supplied by the manufacturer.

Table 4.1 Specifications of the air conditioning unit.

Type	Window-type
Model	AD 917 WIGI, Ser. No. G241265
Voltage	240 –220 V
Start Current	11.2 Amperes
Frequency	50Hz
Cooling Capacity	5kw
Refrigerant	R22, 0.965 kg
Lubricant Capacity	650 cc
Pressure Limits	2.413 MPa (high), 1.034 MPa (low)

4.2 Instrumentation and Procedure:

To determine the performance of the unit the following parameters must be measured: temperature, pressure, air speed, power consumption, refrigerant mass, and time.

(1) Temperature measurement:

Copper-Constantan thermocouple wires were used to measure the temperature of the refrigerant flowing inside the air conditioning unit tubes. Thermocouple wires connected to a Data Logger System model (Orion 8531) with an accuracy of 0.01°C. This device can be programmed to measure the temperature digitally either on its display or recorded on a special paper by using its printer at a selected time interval. Thermocouple wires were fixed to ten locations at which temperatures have to be measured while the other ends of the thermocouple wires were connected to the data logger. Figure 4.2 shows these locations.

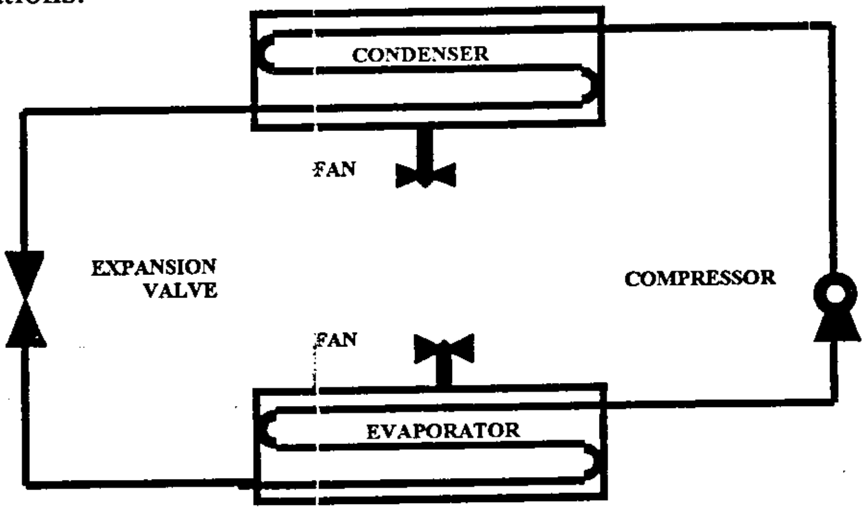


Fig.4.1 Schematic Diagram of Apparatus.

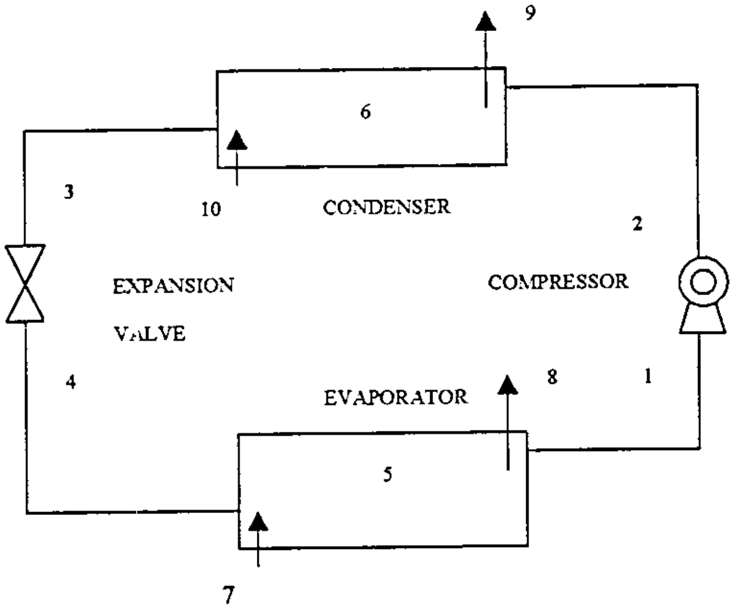


Fig.4.2 Temperature Measuring Points.

(2) **Pressure measurement**:

Pressure was measured at two points, before and after the compressor; p_1 and p_2, respectively, using two pressure gages connected to two valves fixed at measuring points.

(3) **Air speed measurement**:

The speed of cold air leaving the air conditioning unit is needed in order to calculate its mass flow rate and the cooling capacity of the unit. The air speed is measured by an air handgrip anemometer calibrated to measure the air speed either in meter per second or in kilometer per hour. This instrument was used to measure the speed of air coming out of the evaporator. The speed was measured at several positions at the exit face. The average speed was fixed at 12 m/s and the cross-section area was 0.01 m².

(4) **Power consumption measurement**:

The actual power consumption for the air conditioning unit was measured by a kilowatt-hour, single-phase meter connected to the electric power source. Its accuracy was 0.01 kWh. Also the instantaneous current, which was used by the compressor only was measured by ampere clamp meter model (TES 3010) with an accuracy of 0.01 Amperes.

(5) **Refrigerant mass measurement**:

The mass of the refrigerants used in the experiments was measured by using an electronic balance of 5-g accuracy. It is used to determine the quantity of R22 and R134a charged into the air conditioning unit. Three different charge quantities of R134a were used in the experiments.

(6) **Time measurement**:

Time was measured using a stopwatch of 0.1-second accuracy to determine the power consumption and the time needed to cool the space.

4.3 Refrigerant Mass Used In the Experiment:

Refrigerants masses used in the air conditioning unit are as follows:

- R22: - The original refrigerant, with a mass of 0.965 kg.
- R134a: - The replacement refrigerant, with masses of 0.550 kg, 0.660 kg, and 0.770 kg. R134a is locally available in containers like

those of R22, with a relative price of about 3-5 times that of R22 as shown in Table 2.2.

4.4 **Experimental Precautions**:

Before starting the experiments, the following precautions have to be taken into consideration.

1. All the electrical connections must be well connected. The air conditioning unit must be connected to the earth line and to a fuse of 20 ampere time delay or a circuit breaker must be used.
2. A fire extinguisher, which contains carbon dioxide must be available in the site of the experiment.
3. All the components of the air conditioning unit have to work effectively. The compressor performance was tested according to the British Standard BS3122/1977, while the condenser was tested according to BS 1586/1964.
4. The amount of R22 must be same as labeled on the air conditioning unit. Otherwise it has to be evacuated and then filled with the specified quantity.
5. During the experiment of increasing the evaporator temperature, direct heating of the evaporator pipes, at which a thermocouple is fixed, must be avoided to obtain the correct temperature of the refrigerant inside pipes.

6. The exit air of the evaporator must be separated from the inlet air, where a heat source is applied.
7. The end of thermocouple joint that is fixed to the pipe must be insulated, so that the surrounding air temperature will not affect its reading.

4.5 **Test Procedure**:

Two stages of the experimental work had been performed as follows;

(1) **First stage test**:

The original refrigerant, R22 was used in this test stage. To be sure that the amount of R22 in the air conditioning unit is the same as that labeled, it was evacuated and then filled with the specified quantity of R22 (0.965 kg). At the beginning of the test, all measurements were taken at the normal evaporator temperature. Then, the evaporator temperature was varied four to six times using a heat source applied to the air entering the evaporator, while holding the condenser temperature constant. This procedure was repeated for another condenser temperature. The same procedure was also repeated for varied condenser and constant evaporator temperatures. All measurements were taken for each set of different values of Te and Tc.

(2) **Second stage test**:

In this stage the air conditioning unit was evacuated from R22 using a vacuum pump. The old lubricant oil that was used with R22 was also drained out of the system and was replaced by new ester- lubrication oil. Then the unit was charged with 550, 660, and 770 g of R134a. For each charge; all measurements were taken at different values of Te and Tc.

4.6 **Data Tables**:

The previous measurements for the two test stages are given in appendix tables A.1 through A.13. Tables A.1 through A.5 were assigned for the first stage test measurements, while Tables A.6 through A.13 give the experimental data for the second stage test measurements using 550, 660, and 770 g charge quantities.

CHAPTER FIVE

RESULTS AND DISCUSSION

All performance parameters for the original and alternative refrigerants are plotted versus variable values of the evaporating and condensing temperatures, Te and Tc, respectively. The performance parameters investigated in the present work are: cooling effect, work of compression, coefficient of performance, mass flow rate per kilowatt of cooling capacity, cooling capacity, and evaporator air outlet or supply temperature. These parameters are also plotted versus the charge quantity of R134a to decide upon that the optimum charge quantity to be used in the air conditioning unit.

5.1 **Cooling Effect**:

Fig. 5.1 represents the cooling effect, qe , kJ/kg, for 965 g of R22 with respect to the evaporating temperature, Te, °C, at constant condensing temperature, Tc, °C, of 40°C. It can be seen that when the evaporator temperature increases, the cooling effect increases, because when Te increases at constant Tc; h1 increases while h4 which equals to h3 (equation 3.3) remains constant, then from equation 3.5 qe will be increased.

Fig. 5.2 represents the cooling effect, qe, kJ/kg, for 965 g of R22 with respect to the condensing temperature, Tc, °C, at constant evaporating temperature, Te, °C, of 6 °C. It can be seen that when the condenser temperature increases, the cooling effect decreases, because when Tc increases at constant Te, h4 which equals to h3 increases while h1 remains constant. So, from equation 3.5 qe will be decreased.

In general the scattering seen in the data happened at low Te values (Te below 7.5 °C), because of the influence of hot ambient temperature on the wiring and connections of measuring devices and therefore on the measured data. So, to eliminate this problem only few measured data were taken at temperatures below 7.5 °C.

Fig. 5.3 shows the cooling effect with respect to the R134a charge quantity, at constant evaporating temperature. There are three charge quantities 550 g, 660 g, and 770 g. Because of the compressor overheating these three charges can only be taken. The optimum difference between the charges is found to be about 110 g; since there is no obvious change in the pressure and temperature readings at differences smaller than this. It is shown that the highest value of cooling effect was found at the charge quantity around 660 g of R134a.

Fig. 5.4 shows the cooling effect with respect to the R134a charge quantities, at constant condensing temperature. It is also shown that the charge quantity around 660 g of R134a has the highest value of cooling effect.

Fig.5.5 represents the cooling effect, qe, kJ/kg, for the optimum R134a charge quantity with respect to the evaporating temperature, Te, at two different constant condensing temperatures, Tc, of 30 and 40 °C. It is shown that the cooling effect increases with the increase of the evaporator temperature, and the higher values of the cooling effect are obtained at lower condenser temperatures.

Fig.5.6 represents the cooling effect, qe, kJ/kg, for the optimum R134a charge with respect to the condensing temperature, Tc, at two different constant evaporating temperatures, Te, of 10 and 15 °C. It is shown that the cooling effect decreases with the increase of the condenser temperature with higher values of cooling effect correspond to higher evaporator temperatures.

Fig. 5.7 shows the cooling effect for R22 and R134a with respect to the evaporator temperature, at constant condenser temperature of 40 °C. it is shown that as the evaporator temperature increases; the cooling effect increases, with higher values of the cooling effect correspond to R22.

Fig. 5.8 shows the cooling effect for R22 and R134a with respect to the condenser temperature, at constant evaporator temperature of 10 °C. it is shown that as the condenser temperature increases; the cooling effect decreases, with higher values of the cooling effect correspond to R22. It is shown from the above two figures that the average value of the cooling effect is decreased by about 5% when R22 was replaced by 660 g of R134a.

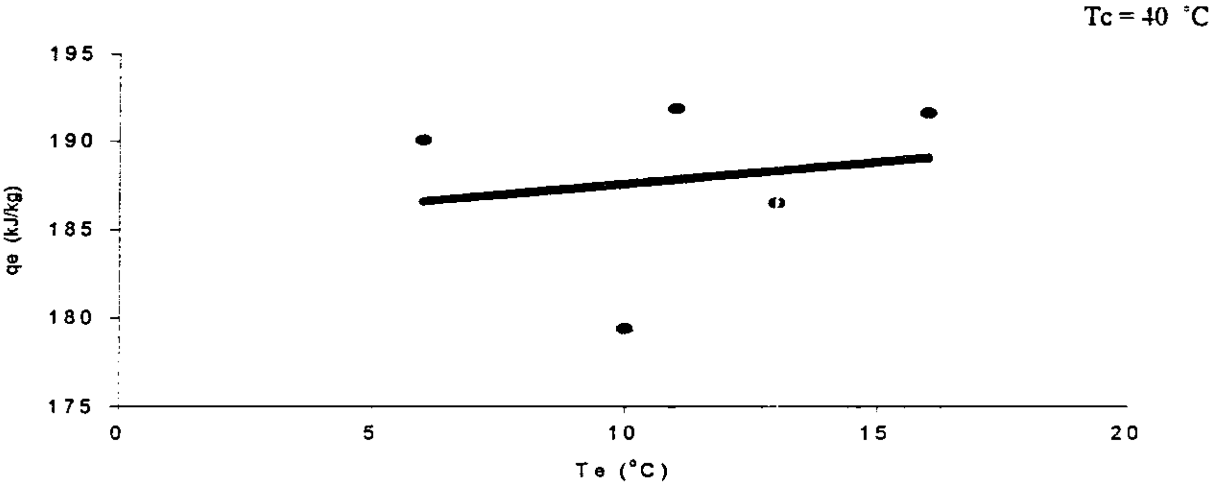


Fig. 5.1 Cooling Effect vs. Evaporator Temperature for 965 g of R22

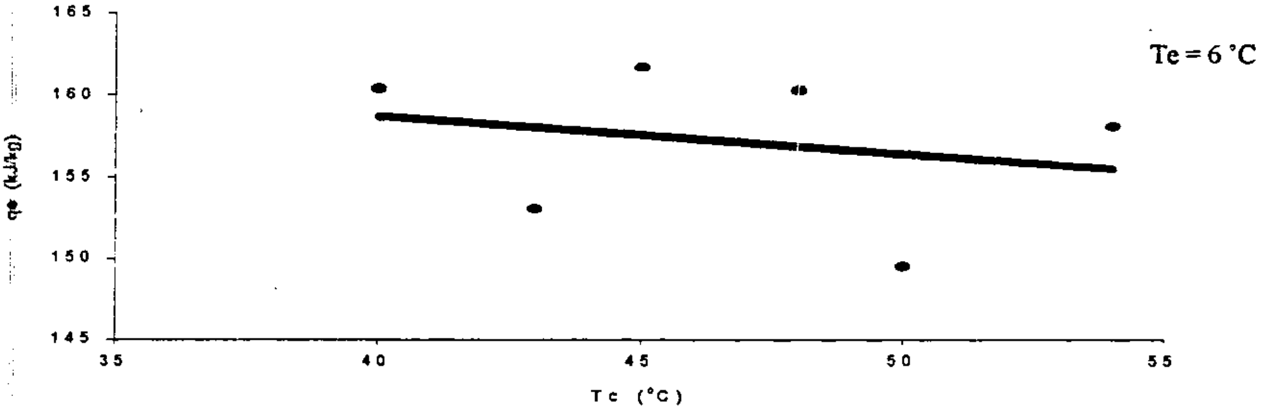


Fig. 5.2 Cooling Effect vs. Condenser Temperature for 965 g of R22

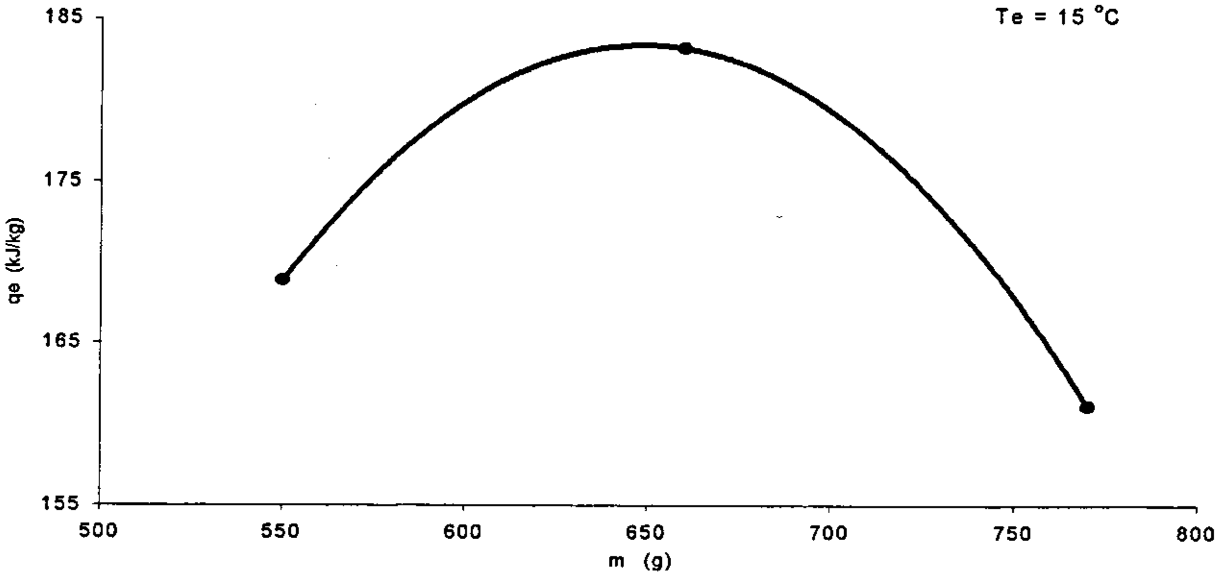


Fig. 5.3 Cooling Effect vs. R134a Charge Quantity

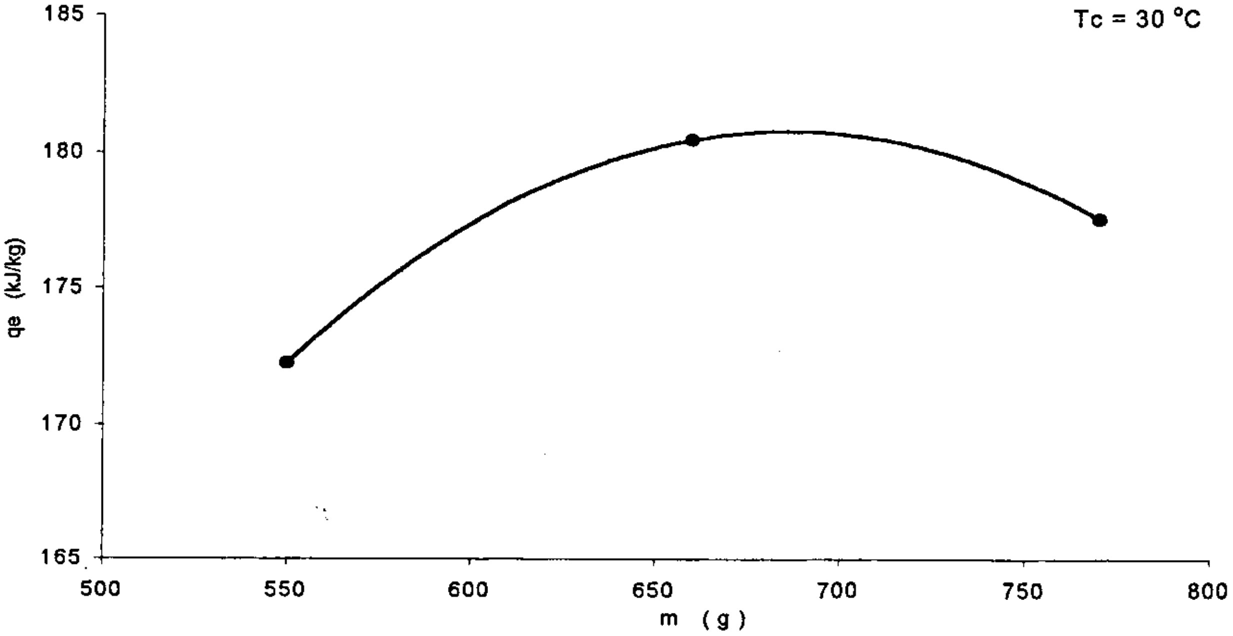


Fig. 5.4 Cooling Effect vs. R134a Charge Quantity

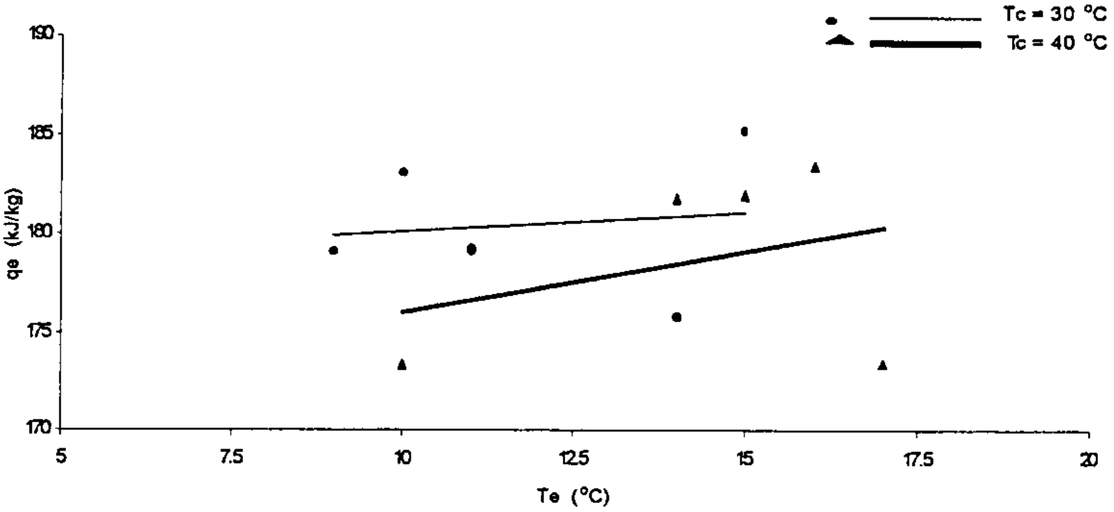


Fig. 5.5 Cooling Effect vs. Evaporator Temperature for 660 g of R134a

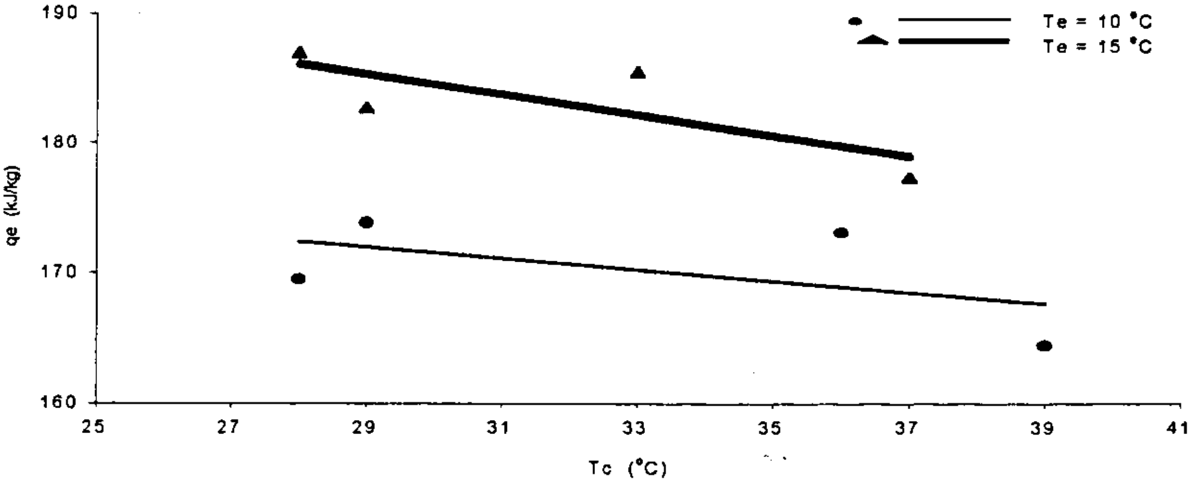


Fig. 5.6 Cooling Effect vs. Condenser Temperature for 660 g of R134a

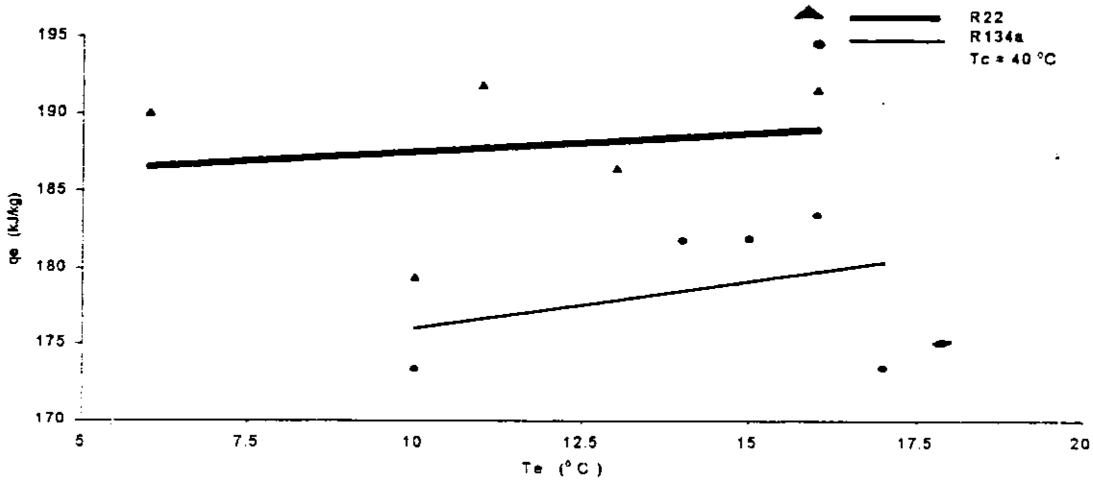


Fig. 5.7 Cooling Effect vs. Evaporator Temperature for R22 and R134a

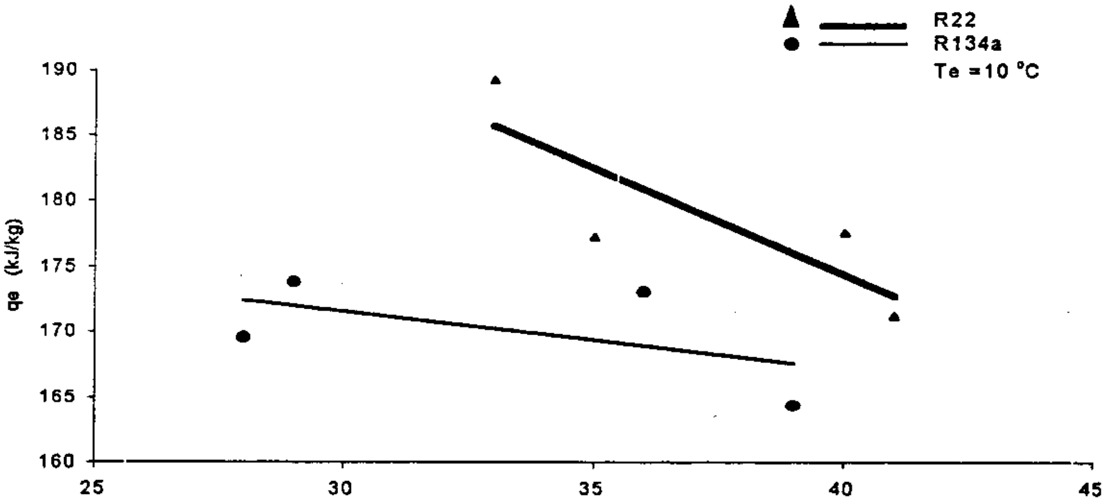


Fig. 5.8 Cooling Effect vs. Condenser Temperature for R22 and R134a

5.2 Work of Compression:

As the evaporating temperature increases, the enthalpy values of the refrigerant entering the compressor increases while keeping that coming out of the compressor constant. According to equation 3.1 this results in decreasing the specific work of the compression, *w*, kJ/kg, as shown in figures 5.9 for R22 and 5.13 for the optimum charge quantity of R134a. On the other hand, increasing the condensing temperature while keeping the evaporating temperature constant; means that, the exit temperature of the compressor will be increased, and hence, the enthalpy values of the refrigerant coming out of the compressor is increased while keeping that coming into the compressor constant. This results in increasing work of compression as shown in figures 5.10 for R22 and 5.14 for the optimum charge quantity of R134a.

Figures 5.11 and 5.12 show the relation between *w* and R134a charge quantity, m, g. it is shown that the minimum values of *w* are obtained at approximate 660-g charge quantity of R134a. So as mentioned earlier this charge quantity is the optimum to be used in the air conditioning unit.

Figures 5.13, and 5.14 show the effect of changing Te and Tc on *w* for the optimum charge of R134a. It is shown that *w* decreases as Te increases or Tc decreases.

Figures 5.15 and 5.16 show that the average *w* value is increased by 5% when R22 was replaced by the 660-g charge of R134a at the same conditions.

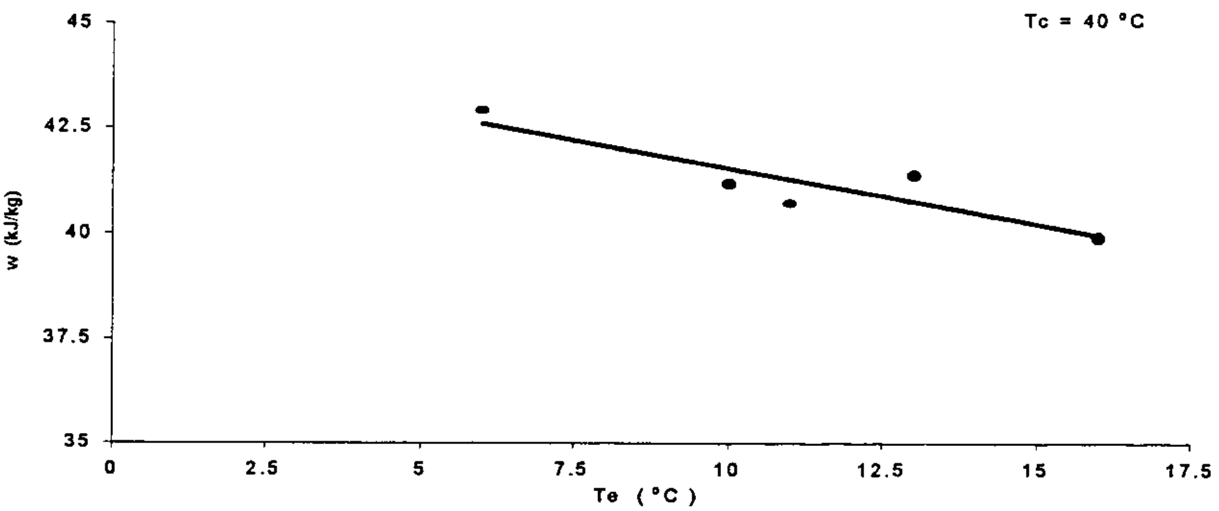


Fig. 5.9 Work of Compressor vs. Evaporator Temperature for 965 g of R22

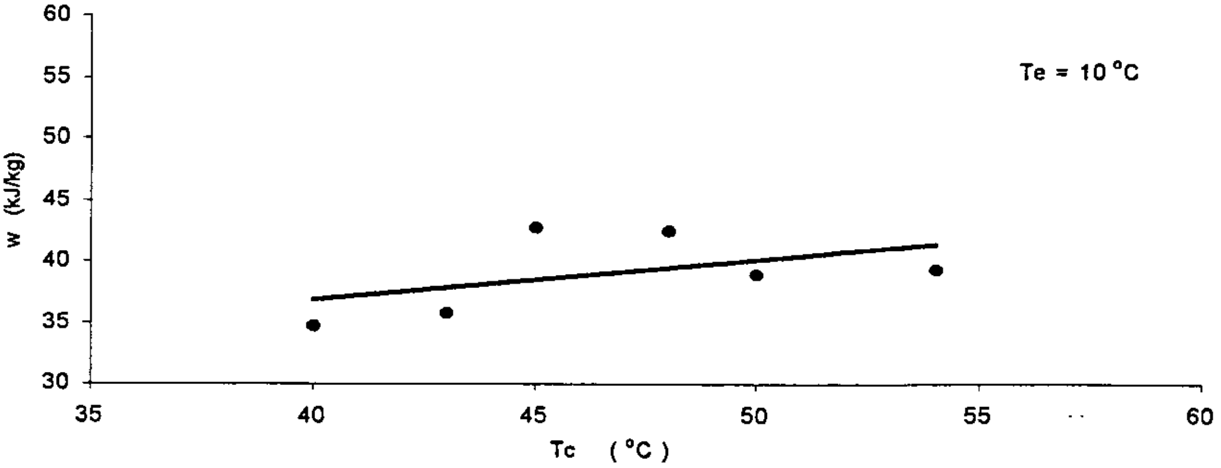


Fig. 5.10 Work of Compressor vs. Condenser Temperature for 965 g of R22

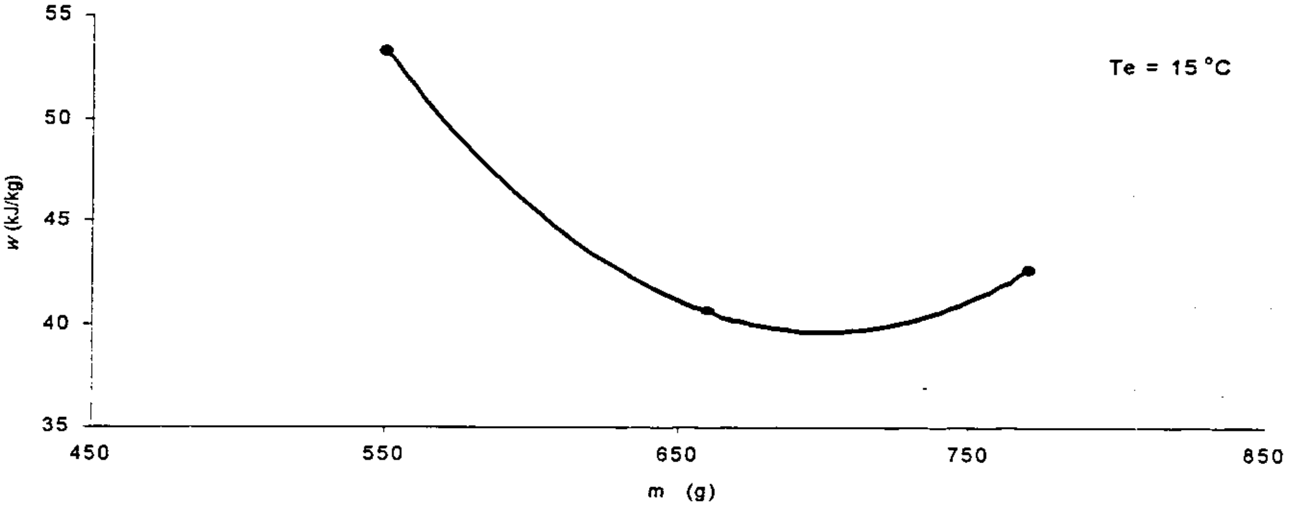


Fig 5.11 Work of Compressor vs. R134a Charge Quantity

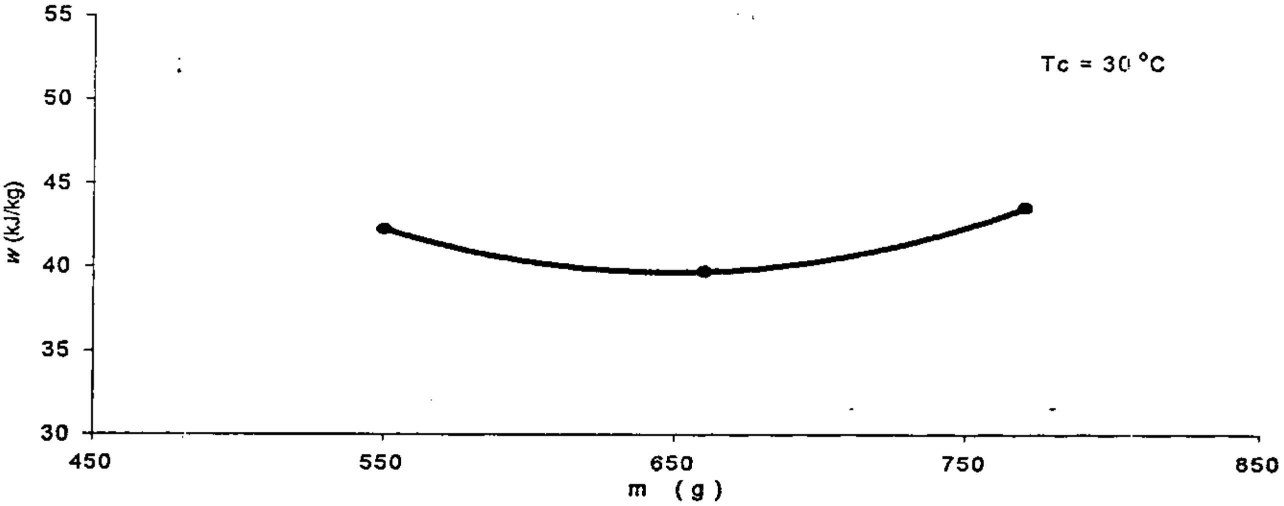


Fig. 5.12 Work of Compressor vs. R134a Charge Quantity

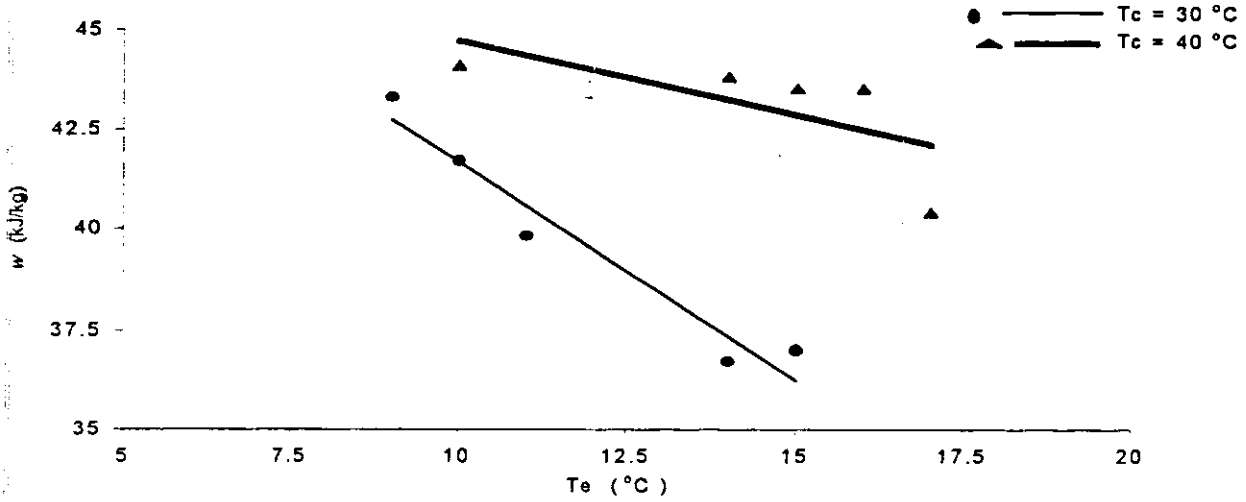


Fig. 513 Work of Compressor vs. Evaporator Temperature for 660 g of R134a

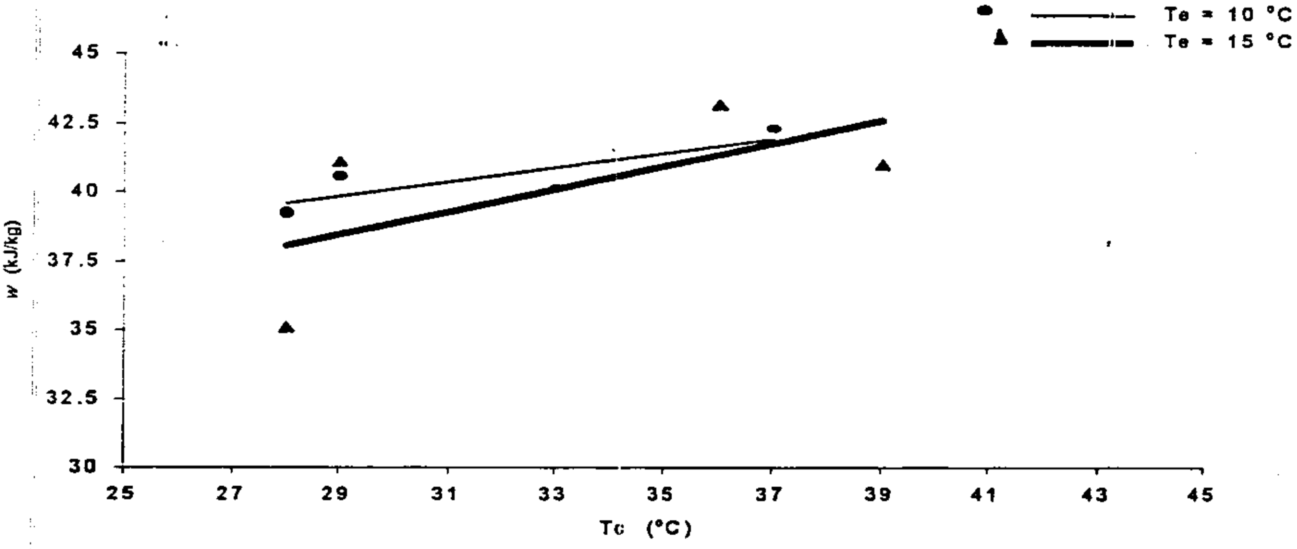


Fig. 5.14 Work of Compressor vs. Condenser Temperature for 660 g of R134a

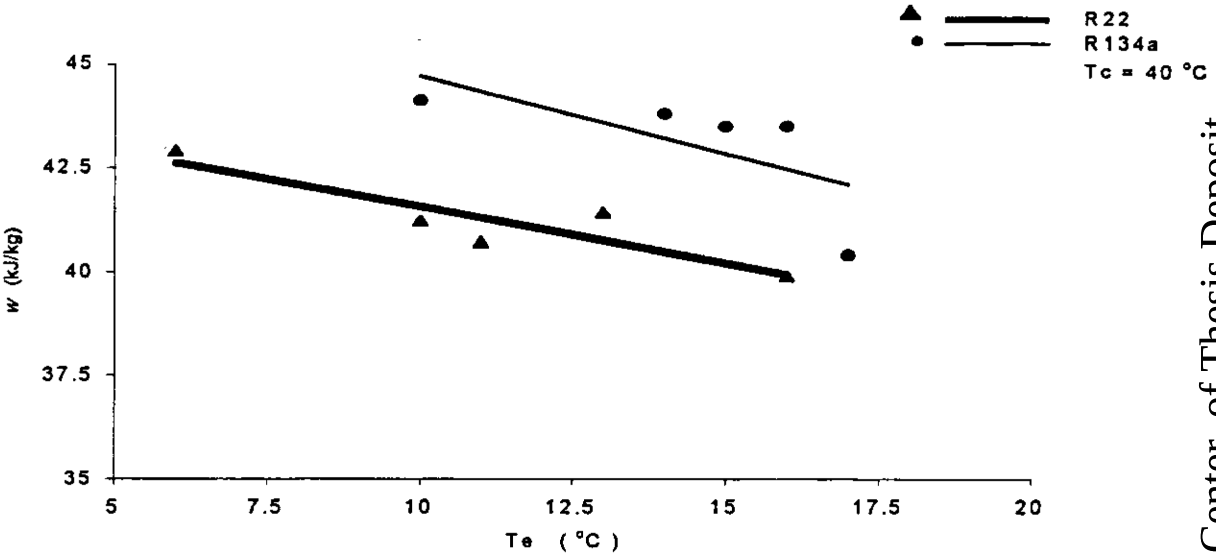


Fig. 5.15 Work of Compressor vs. Evaporator Temperature for R22 and R134a

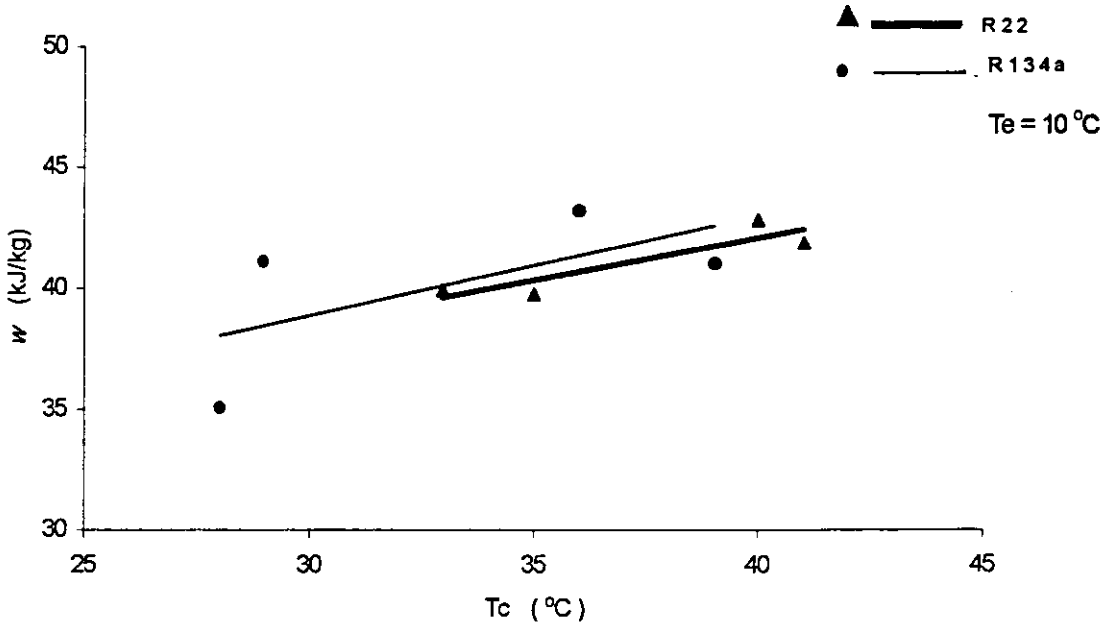


Fig.5.16 Work of Compressor vs. Condenser Temperature for R22 and R134a

5.3 Coefficient of Performance:

The coefficient of performance, COP, was plotted against Te and Tc for R22 and R134a as shown in figures 5.17, 5.18, 5.21, and 5.22, respectively. The COP increases when Te increases or Tc decreases. As discussed earlier as Te increases or Tc decreases, qe accordingly increases and *w* decreases; from equation 3.7 COP will be increased. Figures 5.19 and 5.20 show the relation between COP and R134a charge quantity, m, g. it is shown that the maximum values of COP are obtained at approximately 660-g charge quantity of R134a. Figures 5.21, and 5.22 show the effect of changing both Te and Tc on the COP values for the optimum charge quantity of R134a. It is shown from the figures that the COP increases when Te increases and Tc decreases.

Figures 5.23 and 5.24 show that the average COP values are decreased by 10% when R22 was replaced by about 660-g charge of R134a.

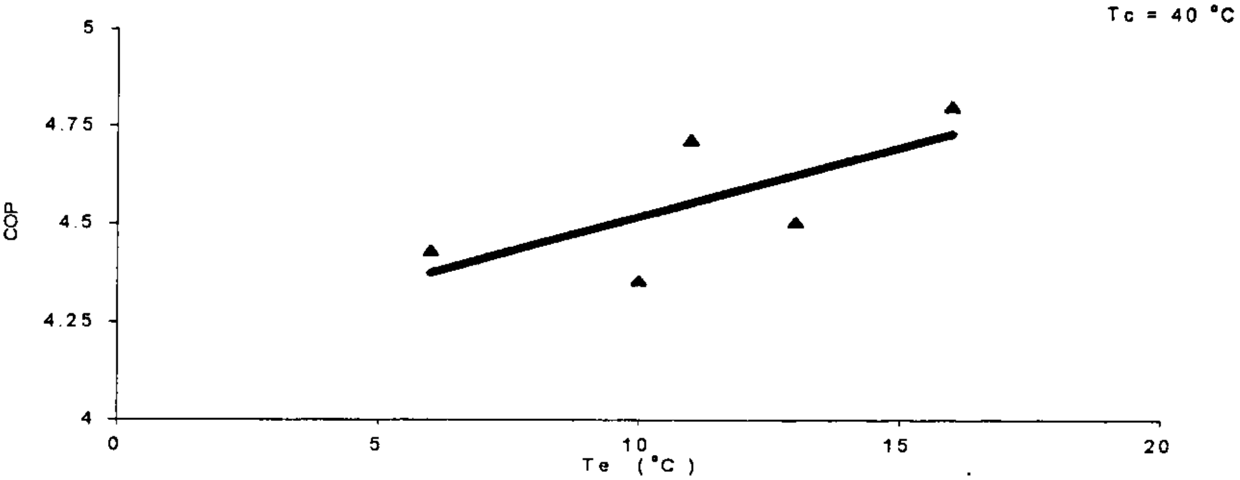


Fig. 5.17 Coefficient of Performance vs. Evaporator Temperature for 965 g of R22

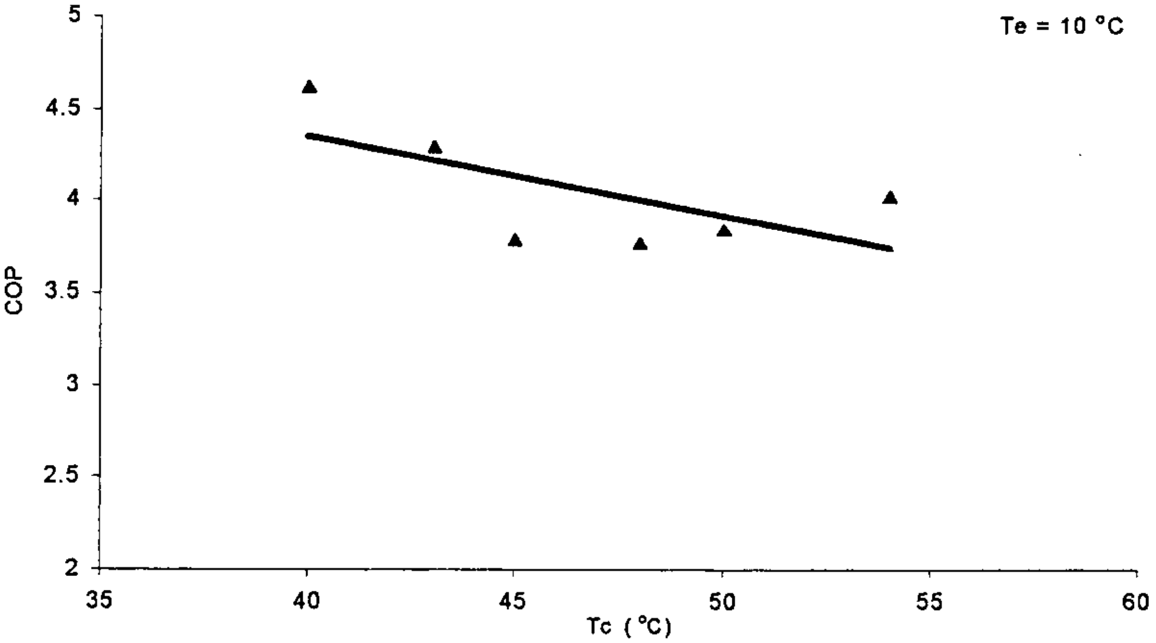


Fig.5.18 Coefficient of Performance vs. Condenser Temperature for 965g of R22

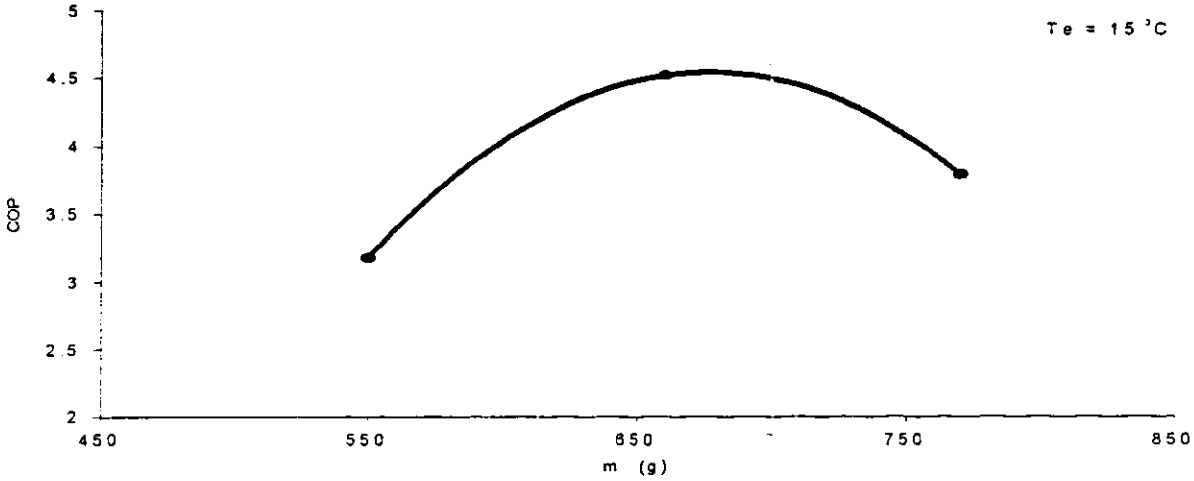


Fig. 5.19 Coefficient of Performance vs. R134a Charge Quantity

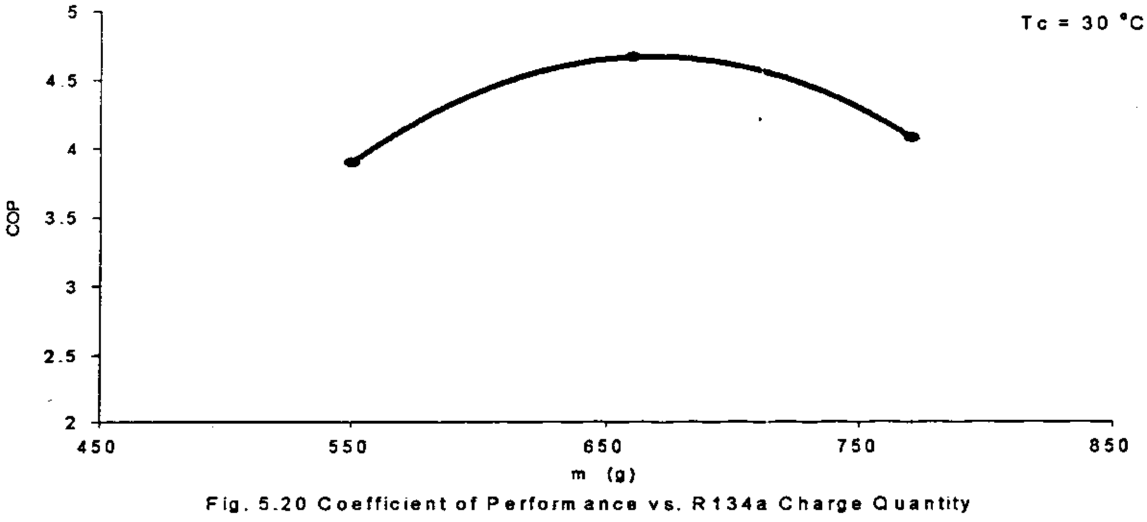


Fig. 5.20 Coefficient of Performance vs. R134a Charge Quantity

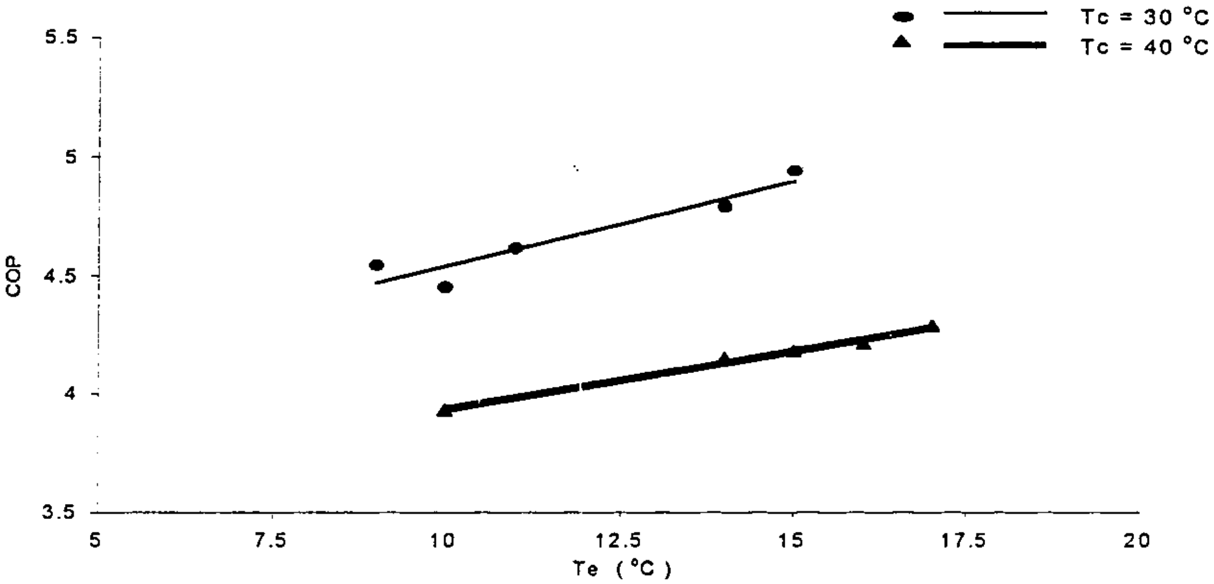


Fig. 5.21 Coefficient of Performance vs. Evaporator Temperature for 660 g of R134a

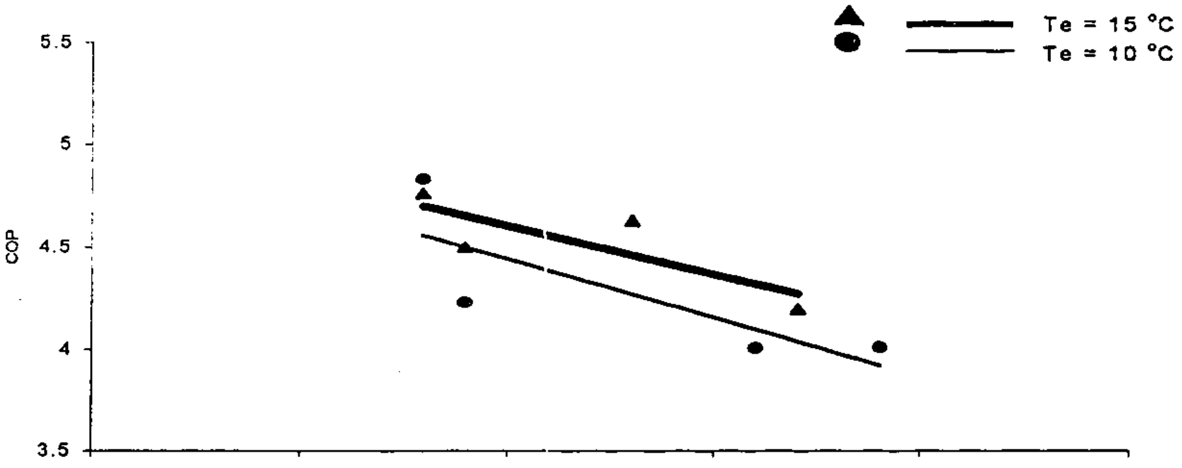


Fig. 5.22 Coefficient of Performance vs. Condenser Temperature for 660 g of R134a

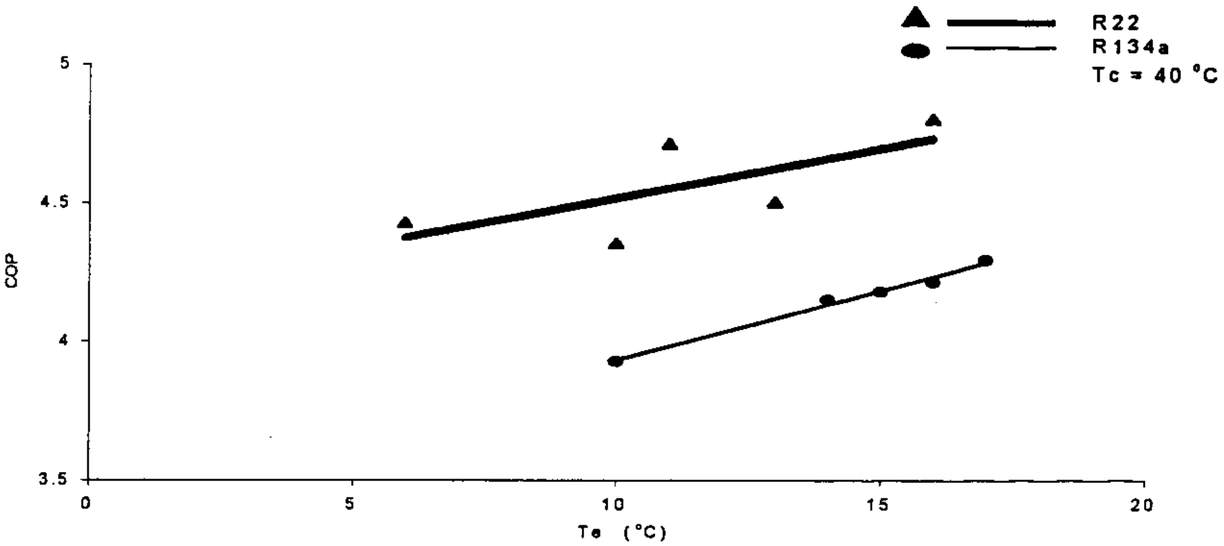


Fig. 5.23 Coefficient of Performance vs. Evaporator Temperature for R22 and R134a

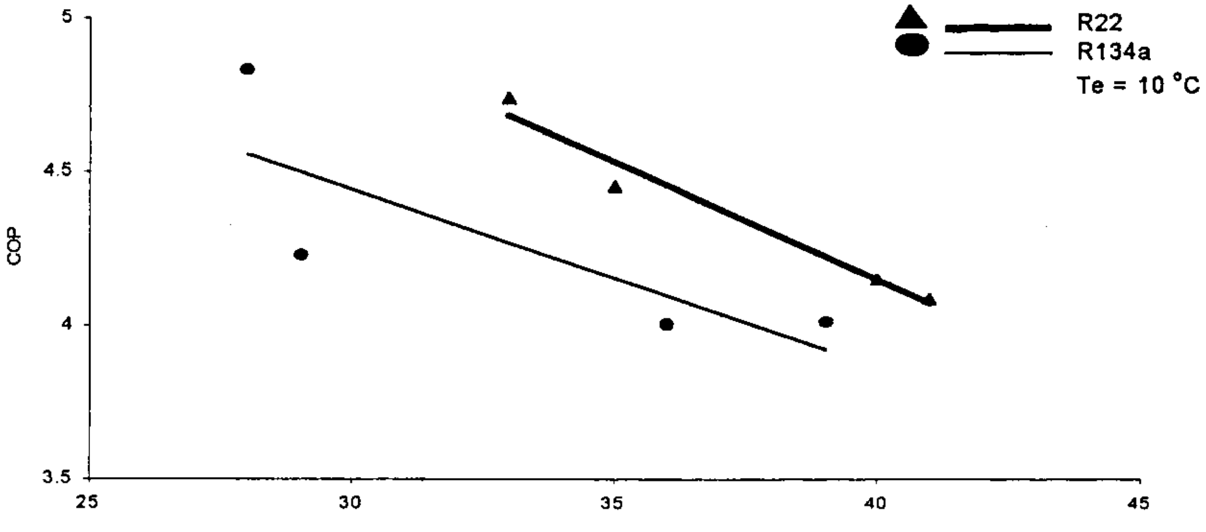


Fig. 5.24 Coefficient of Performance vs. Condenser Temperature for R22 and R134a

5.4 Mass Flow Rate per Kilowatt of Cooling Capacity:

The mass flow rate per kW of cooling capacity, $\dot{m}$, g/s/kW, was plotted against Te and Tc for R22 and R134a as shown in figures 5.25, 5.26, 5.29, and 5.30, respectively. The $\dot{m}$ for both R22 and R134a decreases when Te increases or Tc decreases, because as Te increases or Tc decreases, qe decreases, then from equation 3.8 $\dot{m}$ will be decreased.

Figures 5.27, and 5.28 show that the minimum values of $\dot{m}$ are obtained around 660-g charge quantity of R134a.

Figures 5.29, and 5.30 show the effect of changing Te and Tc on $\dot{m}$ for the optimum charge quantity of R134a. It is shown that $\dot{m}$ decreases as Te increases or Tc decreases.

Figures 5.31 and 5.32 show that the average $\dot{m}$ value is increased by 6% when R22 was replaced by about 660-g charge of R134a.

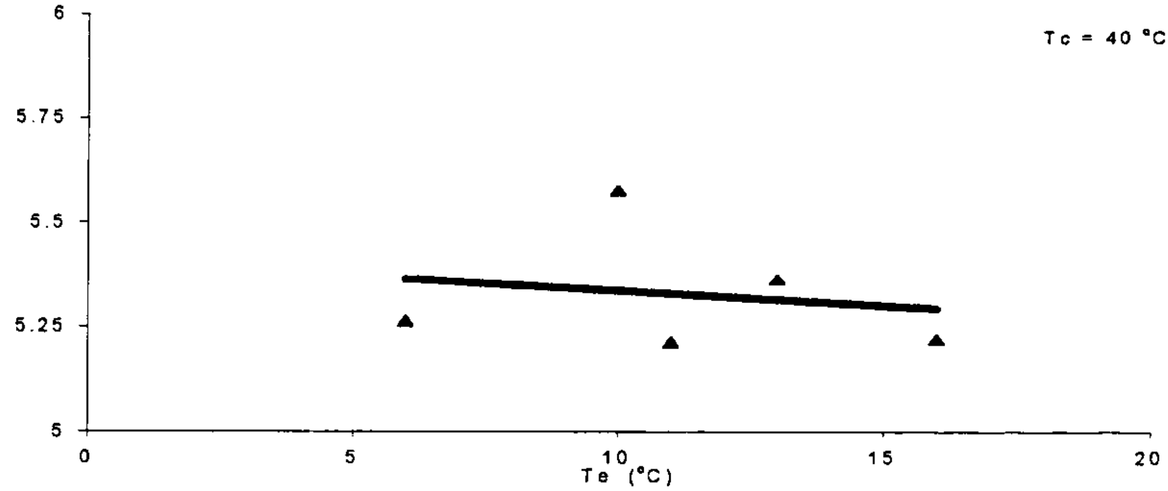


Fig. 5.25 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Evaporator Temperature for 965 g of R22

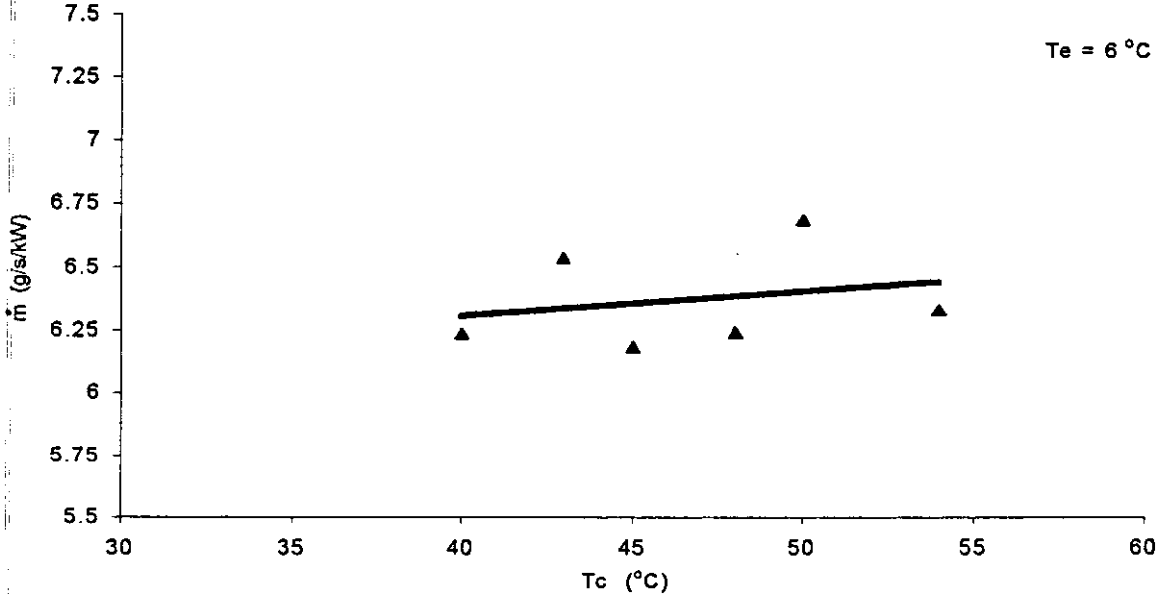


Fig. 5.26 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Condenser Temperature for 965 g of R22

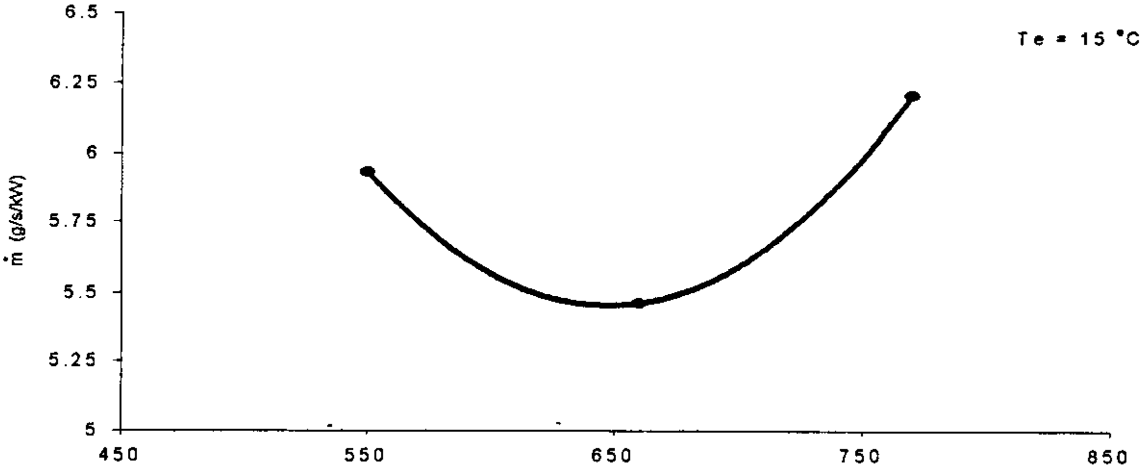


Fig. 5.27 Mass Flow Rate per Kilowatt of Cooling Capacityvs. R134a Charge Quantity

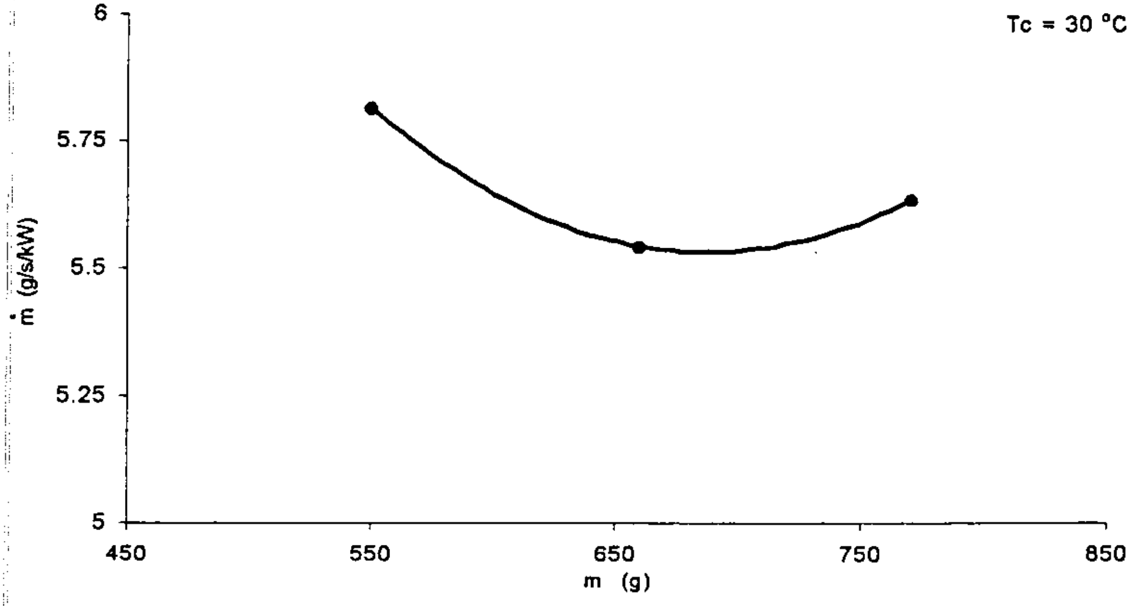


Fig. 5.28 Mass Flow Rate per Kilowatt of Cooling Capacity vs. R134a Charge Quantity

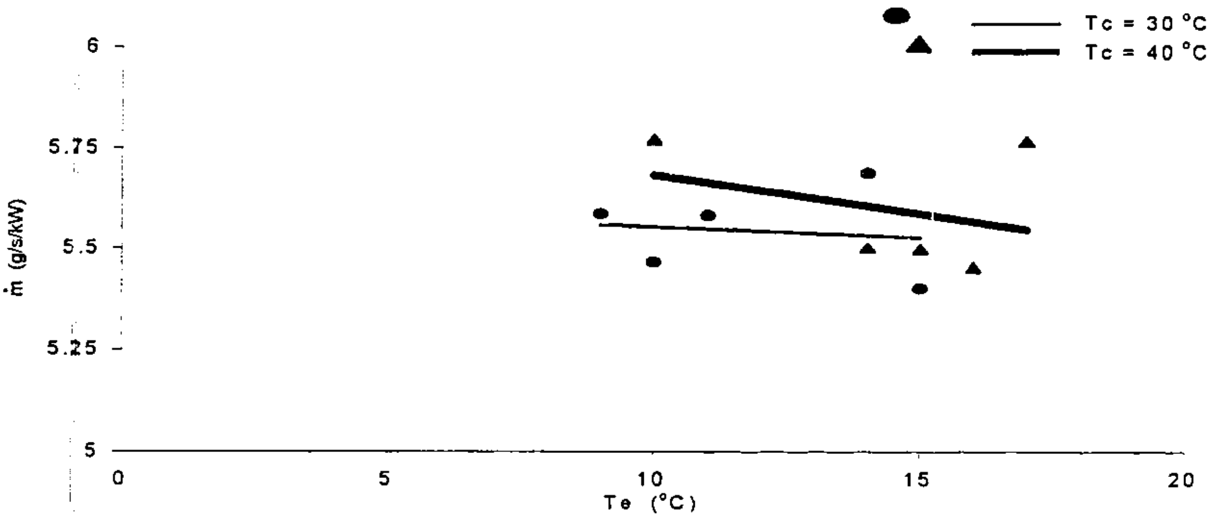


Fig. 5.29 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Evaporator Temperature for 660 g of R134a

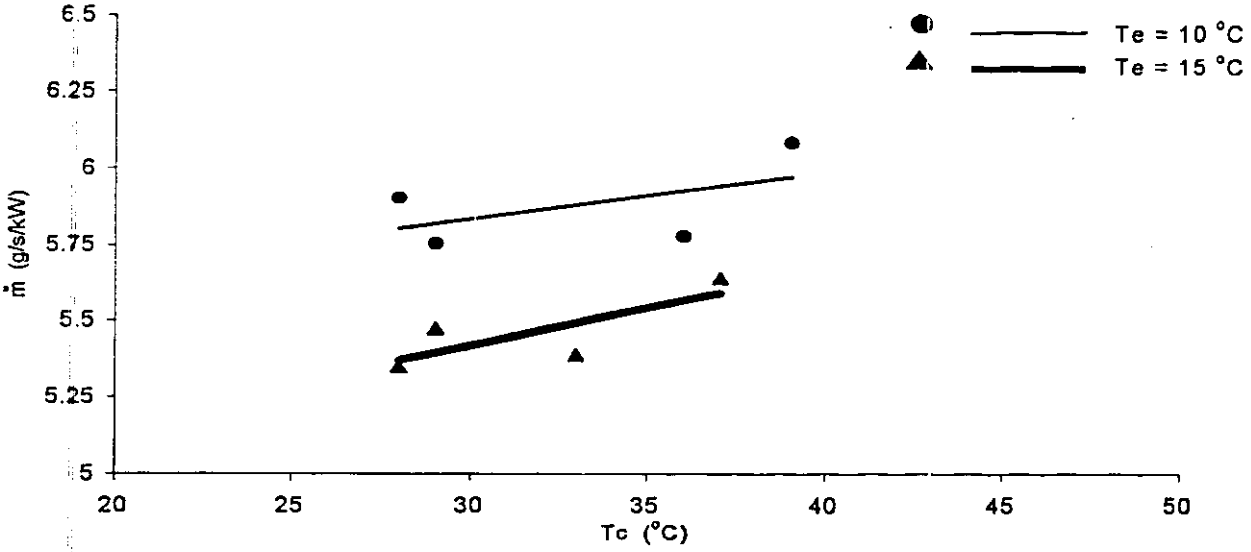


Fig. 5.30 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Condenser Temperature for 660 g of R134a

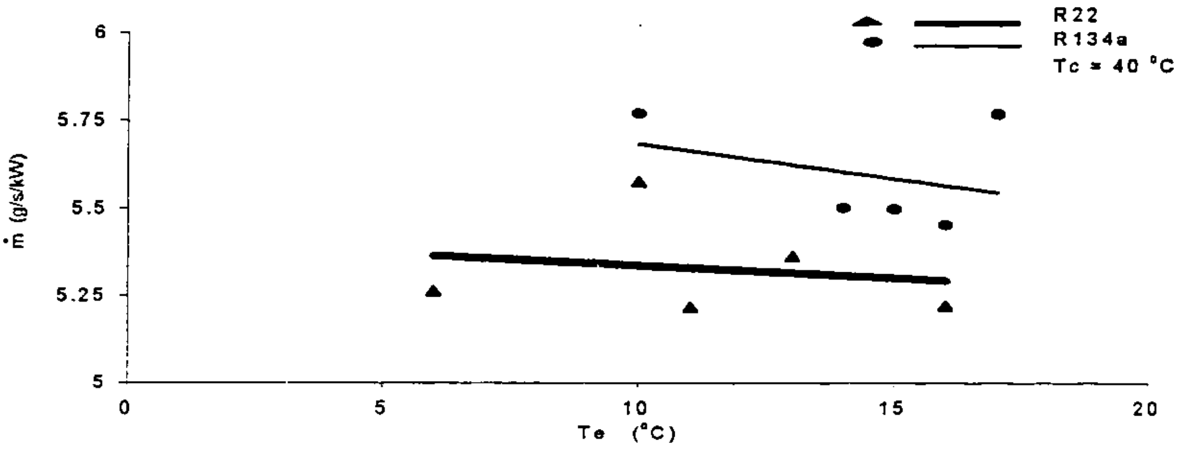


Fig. 5.31 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Evaporator Temperature for R22 and R134a

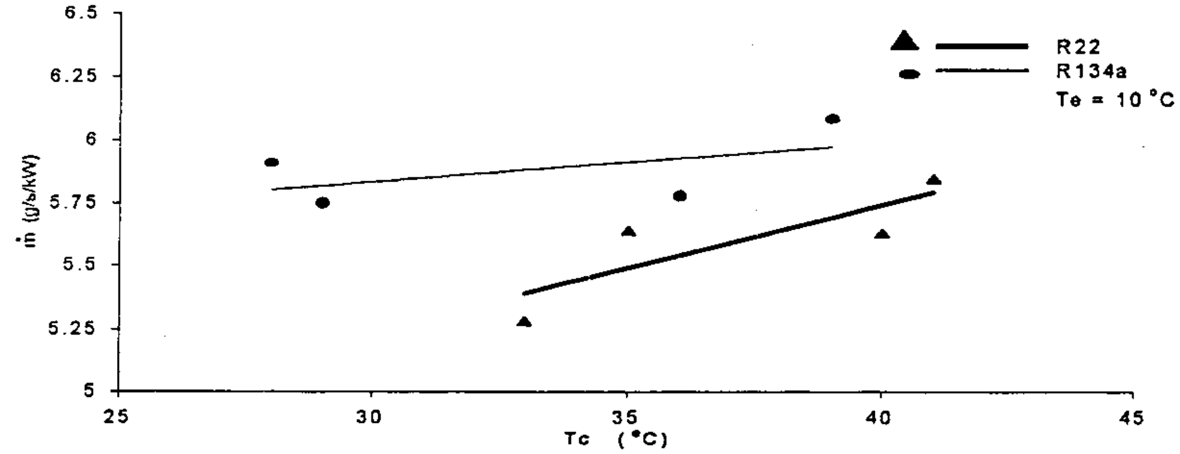


Fig. 5.32 Mass Flow Rate per Kilowatt of Cooling Capacity vs. Condenser Temperature for R22 and R134a

5.5 Cooling Capacity:

The cooling capacity, Q, kW, was plotted against Te and Tc for R22 and R134a as shown in figures 5.33, 5.34, 5.37, and 5.38, respectively. The Q for both R22 and R134a increases when Te increases or Tc decreases. This can be explained by returning to equation 3.6, since qe increases, then Q will be increased.

Figures 5.35, and 5.36 illustrate the relation between R134a charge quantity and the cooling capacity. The maximum value of Q was obtained at about 660-g charge regardless of the constant or variable temperature.

Figures 5.37, and 5.38 show the effect of changing Te and Tc on Q for the optimum charge of R134a. It is shown that Q increases as Te increases or Tc decreases.

Figures 5.39 and 5.40 show that the average Q values are decreased by 35% when R22 was replaced by approximate 660-g charge of R134a.

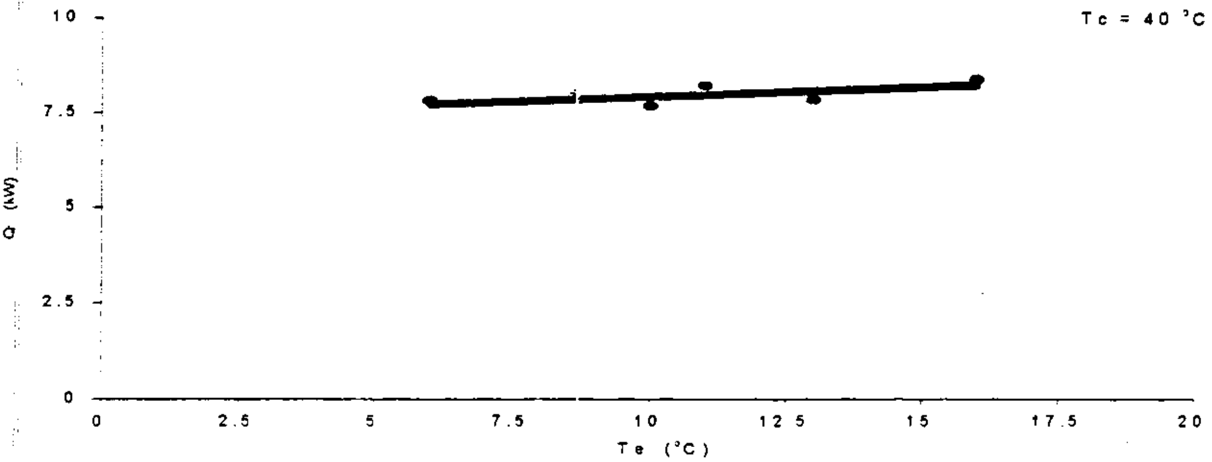


Fig. 5.33 Cooling Capacity vs. Evaporator Temperature for 965 g of R22

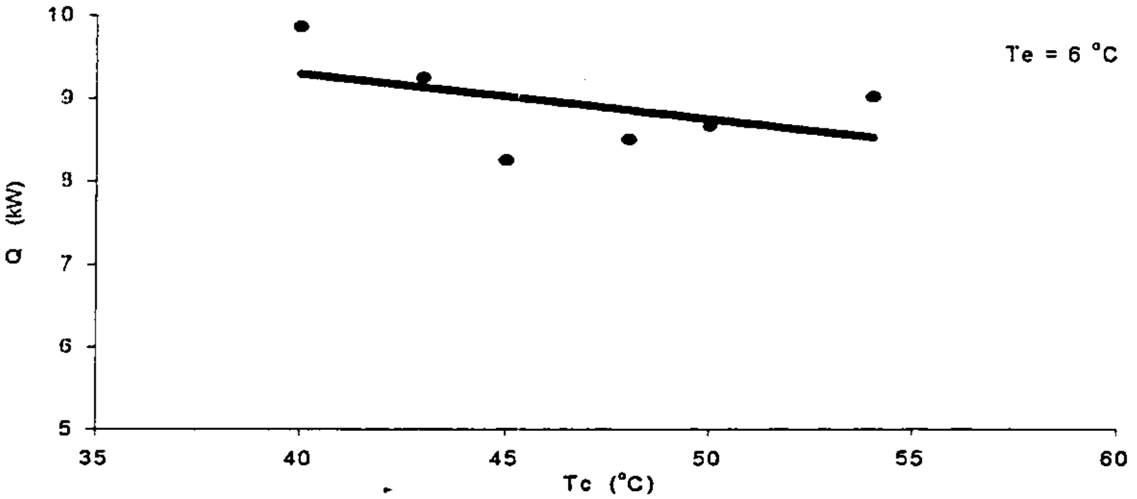


Fig. 5.34 Cooling Capacity vs. Condenser Temperature for 965 g of R22

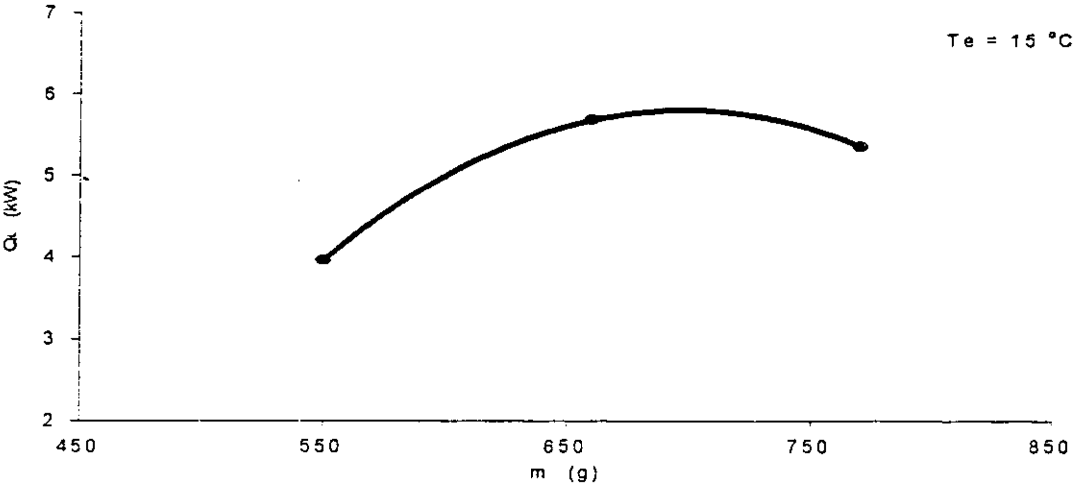


Fig. 535 Cooling Capacity vs. R134a Charge Quantity

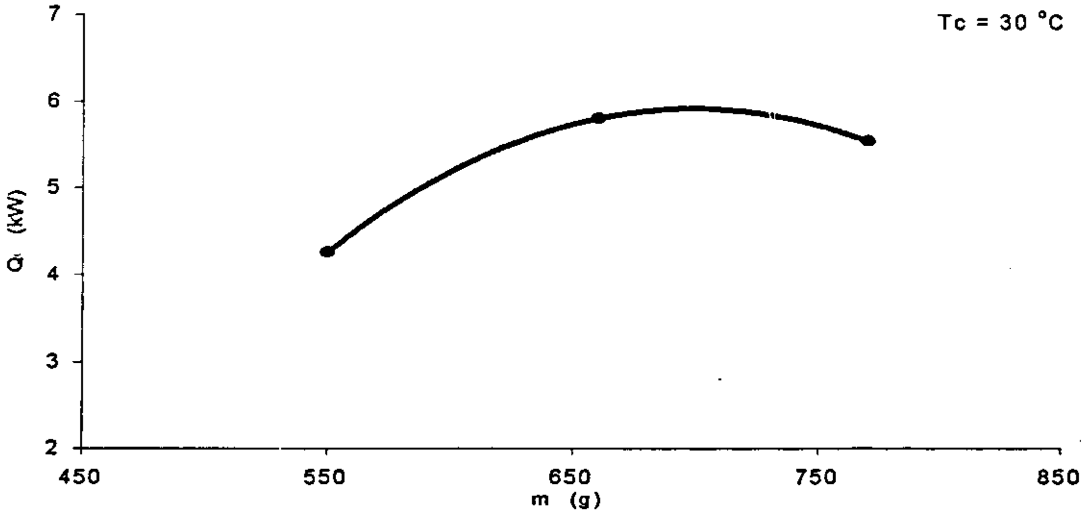


Fig. 5.36 Cooling Capacity vs. R134a Charge Quantity

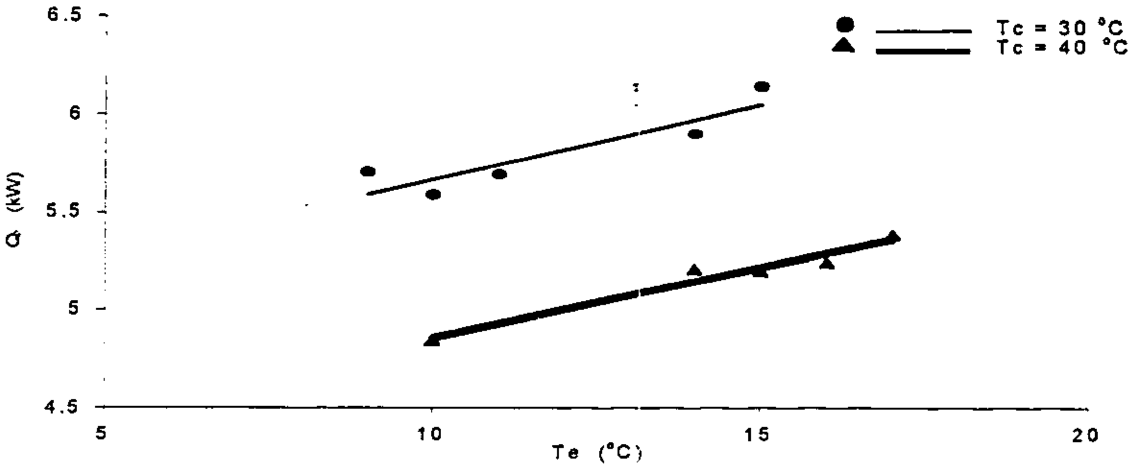


Fig. 5.37 Cooling Capacity vs. Evaporator Temperature for 660 g of R134a

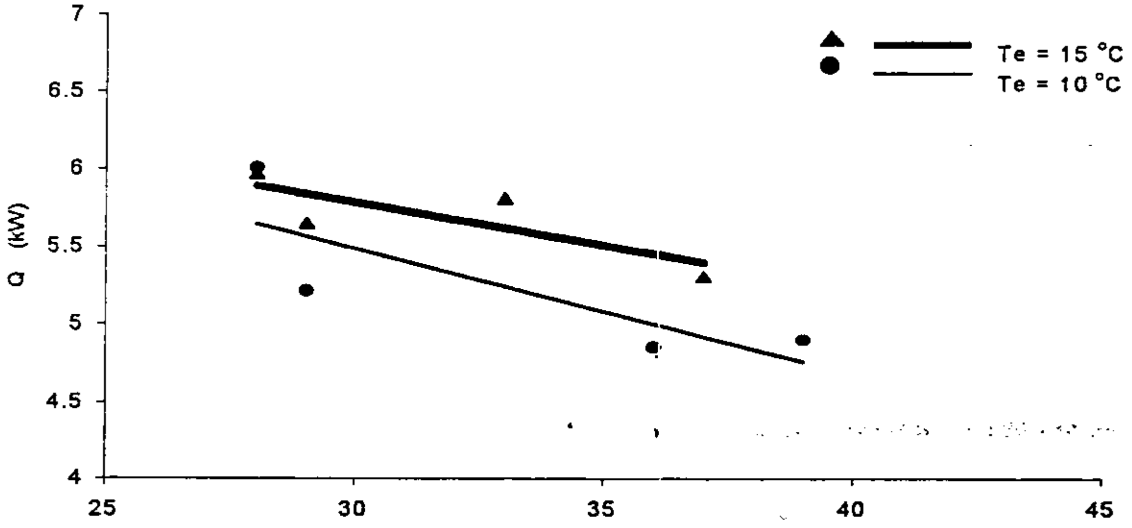


Fig. 5.38 Cooling Capacity vs. Condenser Temperature for 660 g of R134a

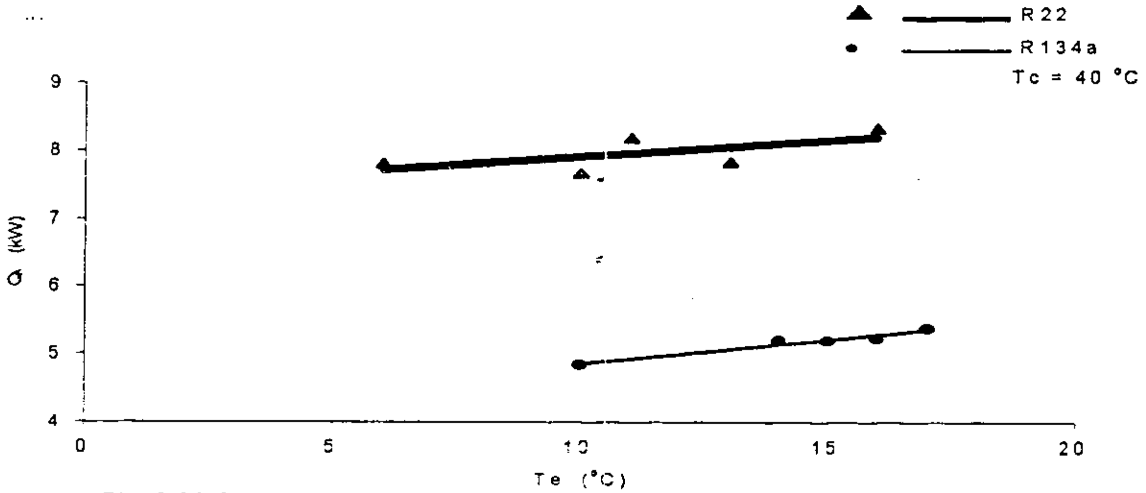


Fig. 5.39 Cooling Capacity vs. Evaporator Temperature for R22 and R134a

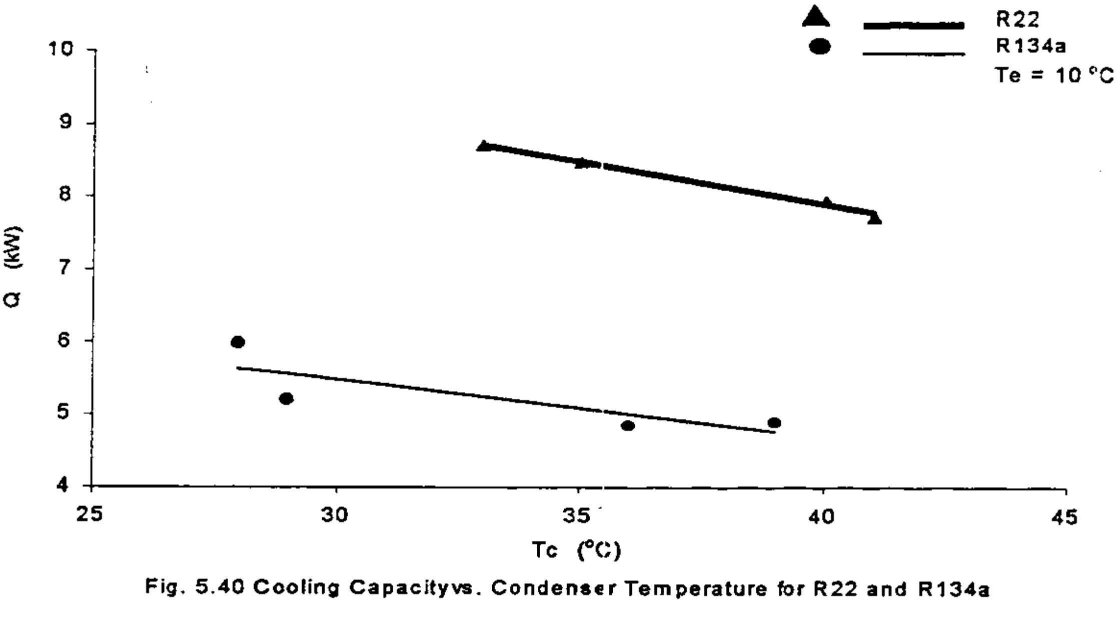


Fig. 5.40 Cooling Capacityvs. Condenser Temperature for R22 and R134a

5.6 Supply Temperature:

Supply temperature, or the temperature coming out of the evaporator to the conditioned space, Ts, °C, must be suitable and comfortable for human being. It increases as Te increases and slightly decreases as Tc increases as shown in figures 5.41, and 5.42 for R22 and figures 5.45, and 5.46 for the optimum charge quantity of R134a. Also these figures show the effect of changing Te and Tc on Ts. It is shown that Ts increases as Te increases, which is sensible, since the air coming out of the air conditioning unit passes through the evaporator tubes.

Figures 5.43, and 5.44 illustrate the relation between R134a charge quantity and Ts. The minimum average value of Ts was obtained at approximate 660-g charge regardless of the constant or variable temperature.

Figures 5.47and 5.48 show that the average Ts value is increased by 10% when R22 was replaced by about 660-g charge of R134a.

Fig. 5.49 and 5.50 show comparison between compressor exit temperatures T_2, for R22 and R134a with respect to Te and Tc, respectively. It is shown that as Te increases at constant Tc T_2 decreases, while it increases with increasing Tc at constant Te. R134a has average T_2 value lower than that of R22 by about 22 %.

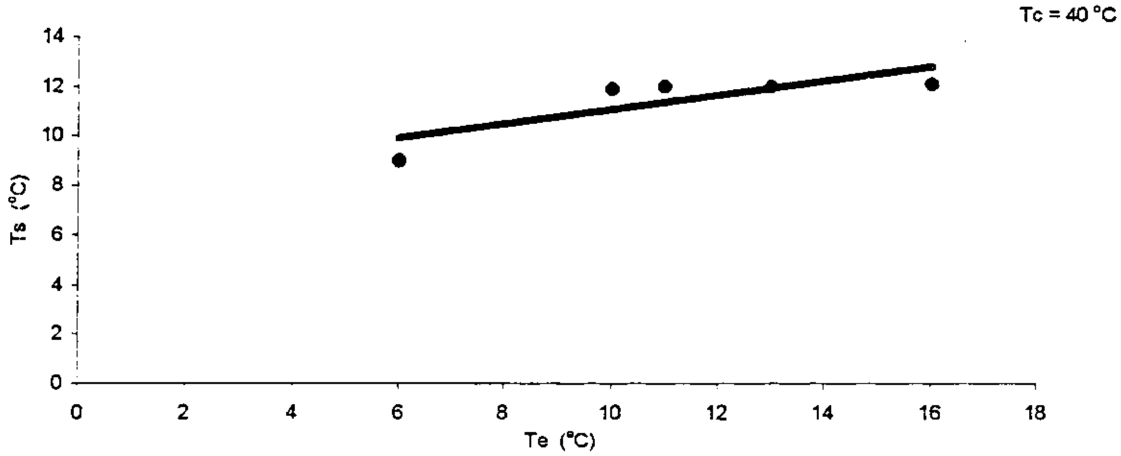


Fig. 5.41 Supply Temperature vs. Evaporator Temperature for 965 g of R22

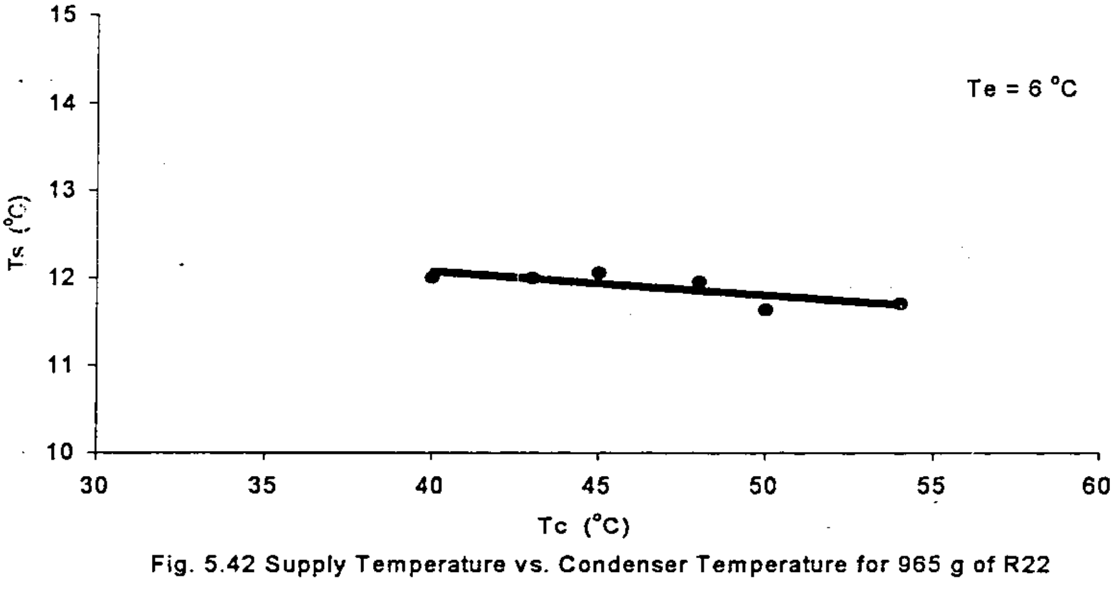


Fig. 5.42 Supply Temperature vs. Condenser Temperature for 965 g of R22

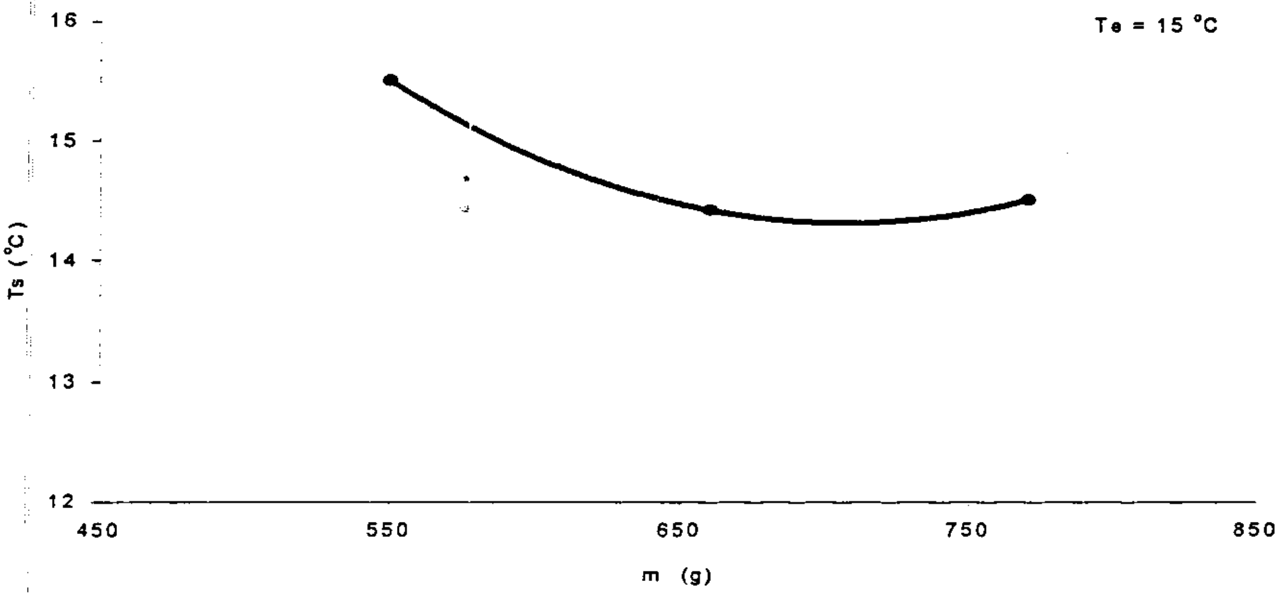


Fig. 5.43 Supply Temperature vs. R134a Charge Quantity

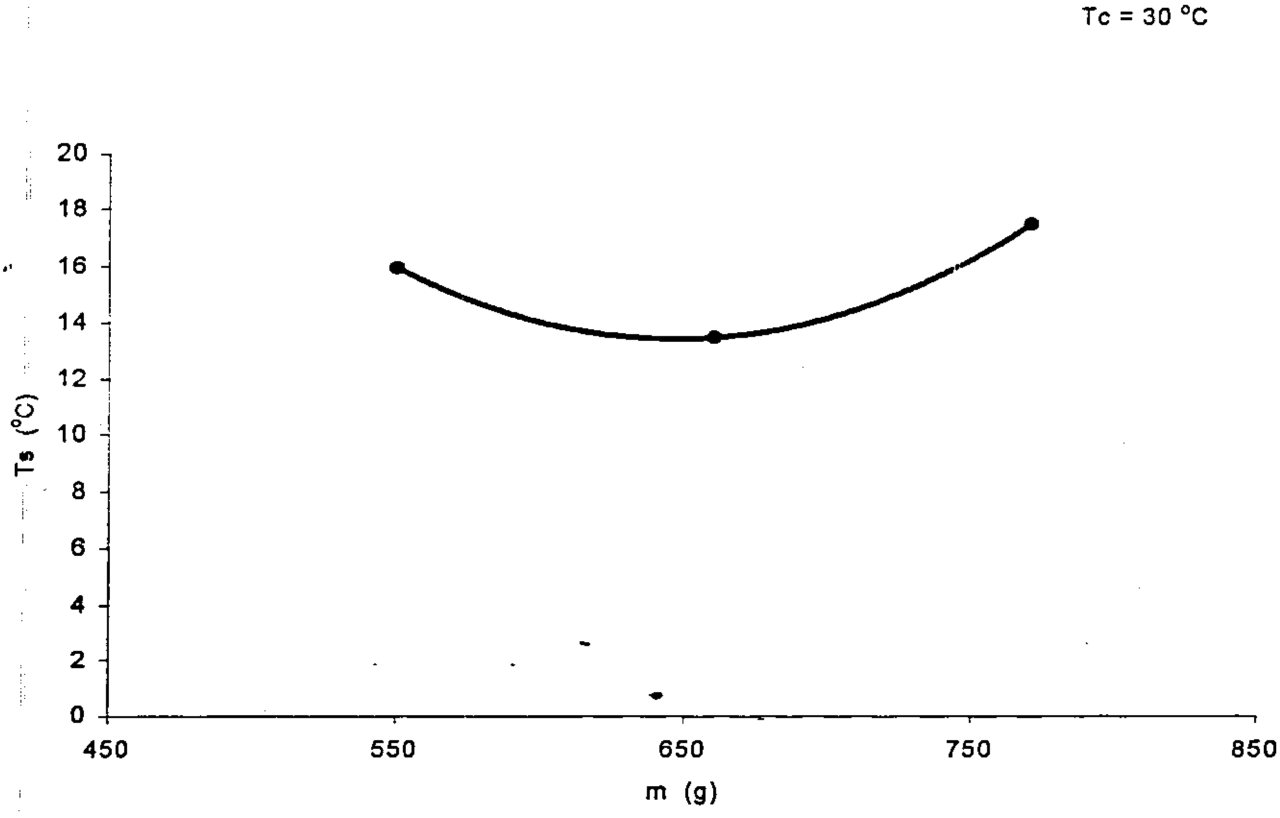


Fig. 5.44 Supply Temperature vs. R134a Charge Quantity

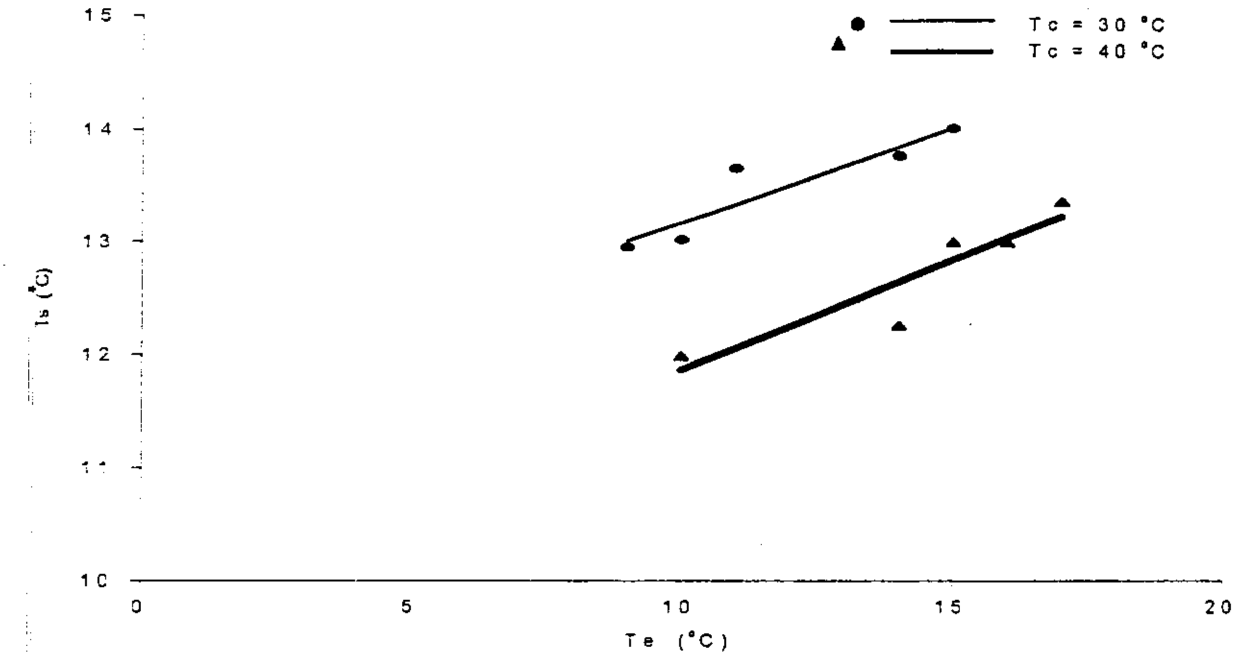


Fig. 5.45 Supply Temperature vs. Evaporator Temperature for 660 g of R134a

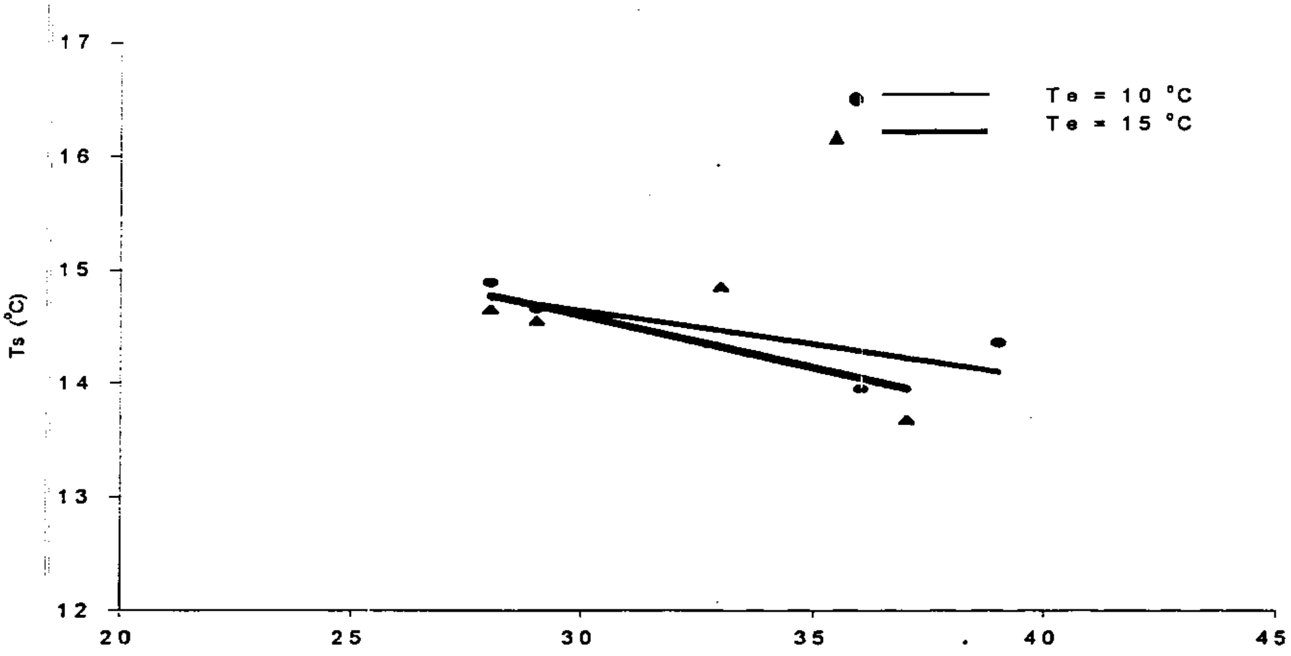


Fig. 5.46 Supply Temperature vs. Condenser Temperature for 660 g of R134a

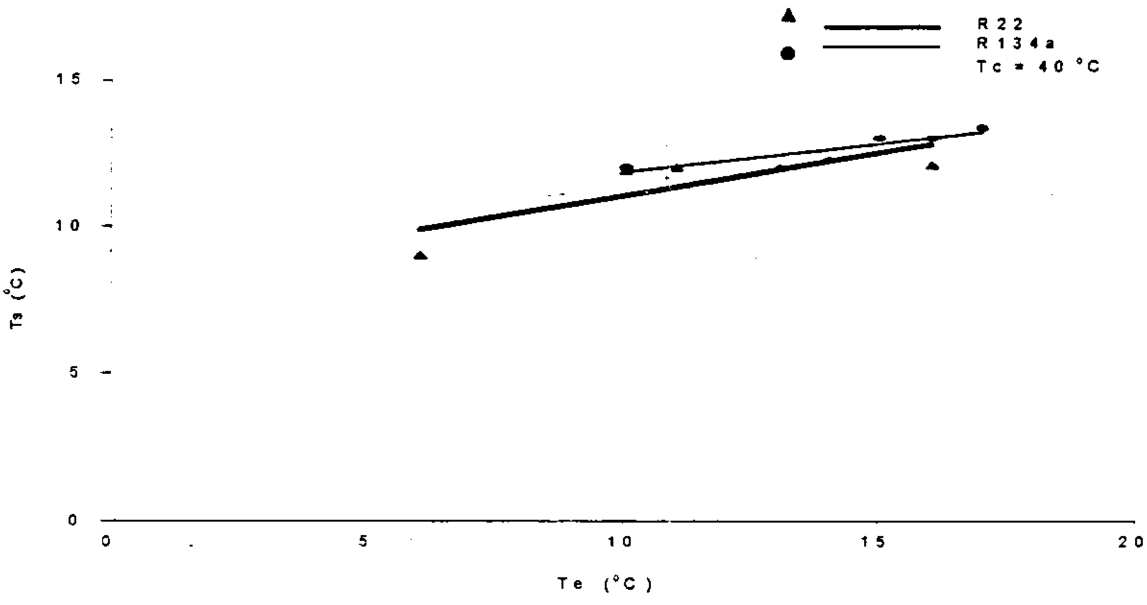


Fig. 5.47 Supply Temperature vs. Evaporator Temperature for R22 and R134a

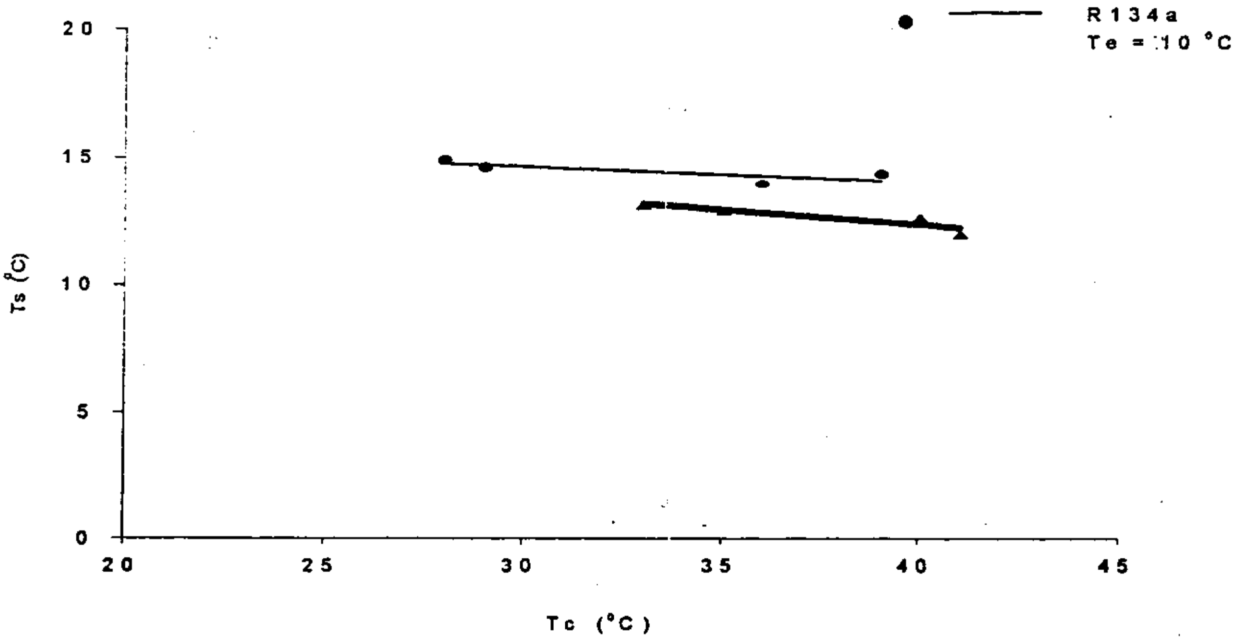


Fig. 5.48 Supply Temperature vs. Condenser Temperature for R22 and R134a

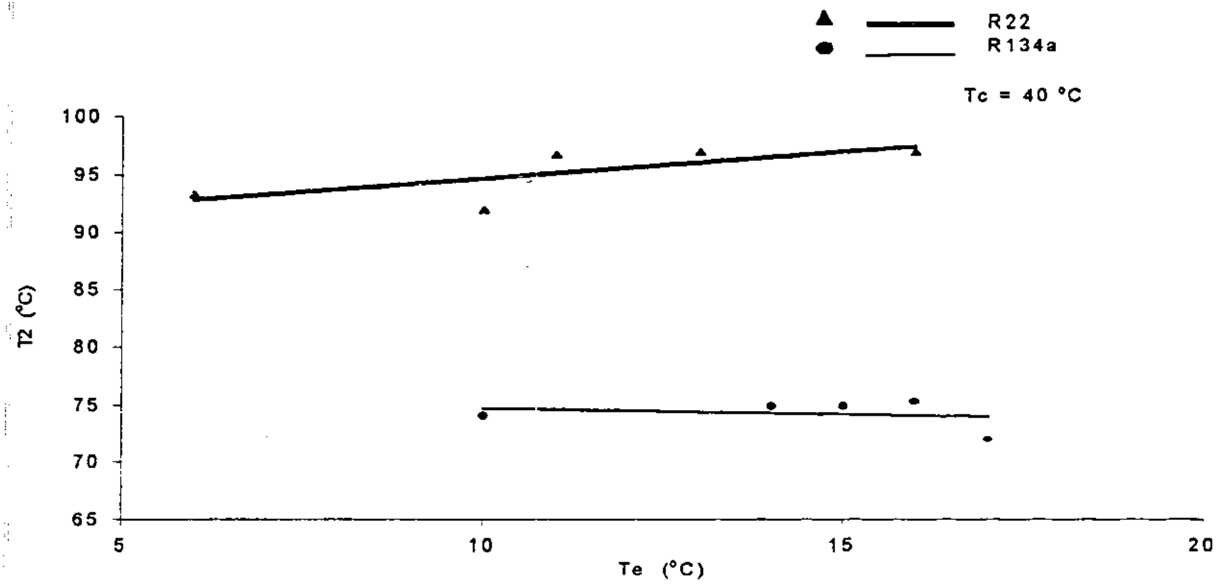


Fig. 5.49 Compressor Exit Temperature vs. Evaporator Temperature for R22 and R134a

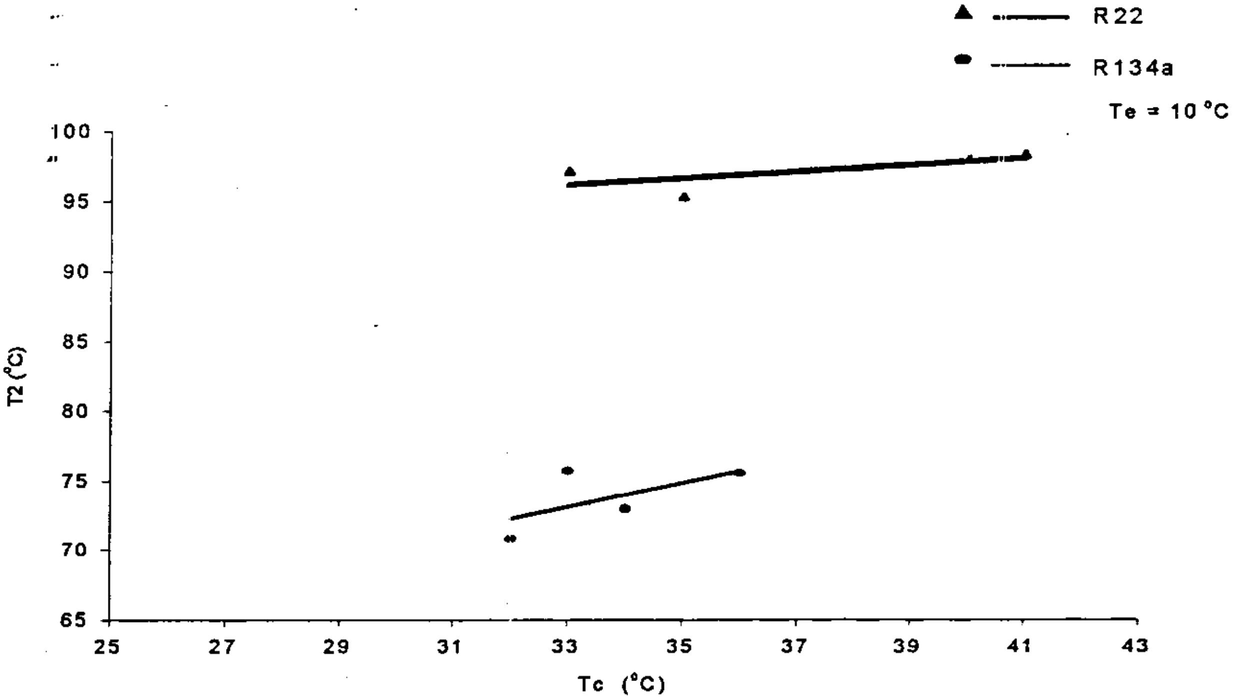


Fig. 5.50 Compressor Exit Temperature vs. Condenser Temperature for R22 and R134a

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

In this experimental study, a window-type air conditioning unit was used to test its performance when using R134a as a possible replacement refrigerant. The performance parameters obtained were compared with that of the original designed refrigerant, R22.

6.1 **Conclusions**:

The following conclusions are obtained from the results:

1- R134a gas can be used in the 5-kW air conditioning unit with less capacity.

2- As Te increases and Tc decreases, the values of qe, COP, Q, and Ts increase, while the values of *w* and $\dot{m}$ decrease either when R22 or R134a is used.

3- The maximum values of qe, COP, and Q; and the minimum values of *w*, $\dot{m}$, and Ts were obtained at approximate 660-g charge of R134a. So this charge quantity was considered the base of comparison with the original refrigerant, R22.

4- When R22 was replaced by approximate 660-g of R134a, qe decreased by 5%, *w* increased by 5%, COP decreased by 10%, $\dot{m}$ increased by 5%, Q decreased by 35%, and Ts increased by 10%.

6.2 **Recommendations**:

R134a can be used in the 5-kW refrigeration unit, but with less capacity. This situation may continue until phase out date is reached. So more researches are needed to find along-term alternative for R22 better than R134a.

REFERENCES

Abu-Zahra, H. *Performance of Methane Gas as a Replacement for Small Air Conditioning Units*. Msc. Thesis, University of Jordan, Amman, Jordan.

American Society of Heating, Refrigerating, and Air Conditioning Engineers: ASHREAE Handbook of Fundamentals, Atlanta, GA, 1997.

Atwood, Th. 1991. Refrigerants of the Future. *ASHRAE Jour.*, 33 (2): 30-35.

BITZER Kuhlmaschinenbau GmbH & Co. KG, Substitutes for R22 A-505-3, Sindelfingen, 1996.

British Standard for Refrigerant Compressors: Methods of Test for Performance, BS 3122, 1977.

Carpenter, N. E. 1992. Retrofitting HFC134a into Existing CFC12 Systems. *Int. Jour. Refrig.*, 15 (6): 332-339.

Carrington, C. G. Bannister, P. and Liu, Q. 1995. Performance Analysis of a Dehumidifier Using HFC134a. *Int. Jour. Refrig.*, 18 (7): 477-485.

Eckels, S. J. and Pate, M.B. 1991. An Experimental Comparison of Evaporation and Condensation Heat Transfer Coefficients for HFC134a and CFC12. *Int. Jour. Refrig.*, 14 (2): 70-77.

Feng, X. Yu, Y. and Zhou, L. 1994. A Study on the Alternative Refrigerants for HCFC22. *Proc. The Day After Conference*, Padova, Italy.

Fischer, S. K. 1993. Total Equivalent Warming Impact: A Measure of the Global Warming Impact of CFC Alternatives in Refrigerating Equipment. *Int. Jour. Refrig.*, 16 (6): 423-428.

Hainbach, Chr. and Steimle, F. 1994. Experimental and Theoretical Investigation of the Alternate Refrigerants R290 and R134a in consideration of the Behavior of a Reciprocating Compressor. *Proc. Of New Application of Fluid in Refrigeration and Air Conditioning*, Hannover.

Hodgkinson, N. 1990. Alternatives to Halocarbon in Air Conditioning Refrigeration and Fire Protection. *Aust. Refrig. Air Cond.* Heat, 44 (7): 42.

Jennings, B. H. 1978. *The Thermal Environment Conditioning and Control, 2nd edition*. Harper & Row Publishers, New York.

Jung, D. Park, Ch. and Park, B. 1999. Capillary Tube Selection for HCFC22 Alternatives. *Int. Jour. Refrig.*, 22 (8): 604-614.

Lorentzen, G. 1994. Revival of Carbon Dioxide as a Refrigerant. *Int. Jour. Refrig.*, 17 (5): 292-301.

Lorentzen, G. 1995. The Use of Natural Refrigerant: A Complete Solution to the CFC/HCFC Predicament. *Int. Jour. Refrig.*, 18 (3): 190-197.

Melo, C. Ferreira, R. T. S. Boabaid Neto, C. Goncalves, J. M. Pereira, R. H. and Thiessen, M. R. 1994. Evaluation of HC600a, HFC134a, and CFC12 Mass Flow Rate Through Capillary Tubes. Proc. *Of New Application of Fluid in Refrigeration and Air Conditioning*, Hannover.

Melzer, J. 1996. HFC134a and Hydrocarbon Appliances in Domestic Refrigeration: Market Trends, Conversion. *Proc. Of the Conference on Hydrocarbon Fluid in Domestic and Conerical Refrigeration Applience*, New Delhi.

Preisegger, E. and Henrici, R. 1992. Refrigerant R134a: The First Step into a New Age of Refrigerants. *Int. Jour. Refrig.*, 15 (6): 326-331.

Salsbury, J. K. 1950. *Kent's Mechanical Engineers' Handbook, Power Volume, 12th edition*. John Wiley & sons., New- York.

Sicars, S. and Tiedeman, Th. 1996. Synthetic and Natural Fluids in Commercial Refrigeration Applications. *Proc. Of the Conference on Hydrocarbon Fluid in Domestic and Conerical Refrigeration Applience*, New Delhi.

Statt, T. 1990. Potential Ozone-Safe Refrigerants for Centrifugal Chillers. *ASHRAE Jour.*, 32 (9).

Wuebbles, D. J. 1994. The Role of Refrigerants in Climate Change. *Int. Jour. Refrig.*, 17 (1): 7-17.

APPENDIX A

DATA TABLES

Table A.1 Measured Data for 965 g of R22 at Constant

T1°C	T2°C	T3°C	T4°C	T5°C	T6°C	T7°C	T8°C	T9°C	T10°C			
12.91	85	38.75	0	5.5	40	21	12	52	32			
14	87	41.95	0	6.15	43	21.47	11.99	52	33	22	0.517	2.17
7.63	90.1	38	3	5.85	45	20	12.05	55	38	20	0.514	2.21
8.2	90	38.93	1	6.01	48	21	11.85	55.3	35	21.01	0.541	2.24
15	92	50.9	2	6.25	51	20	11.35	56	42	22.15	0.524	2.24
8.4	87.15	41	1	6.5	54	21.5	12	56	44	21.3	0.524	2.24

Table A.2 Measured Data for 965 g of R22 at Constant Te = 10 °C

T1°C	T2°C	T3°C	T4°C	T5°C	T6°C	T7°C	T8°C	T9°C	T10°C	T11°C	P1 MPa	P2 MPa
22	97.15	26	-2	9.95	33	23	13	46	28	20.15	0.431	2.06
17.9	95.3	32.9	-1	10.15	35	24	12.75	47	34	19.5	0.44	2.12
16.89	98	32	3	10.1	40	27	12.65	48	36	20	0.445	2.12
18.79	98.35	38	-2	9.75	41	30	12.01	48	39	19.79	0.448	2.13

Table A.3 Measured Data for 965 g of R22 at Constant Te = 15 °C

T1°C	T2°C	T3°C	T4°C	T5°C	T6°C	T7°C	T8°C	T9°C	T10°C	T11°C	P1 MPa	P2 MPa
23.9	104.1	26	4	14.37	36	35	13.26	46	26	20	0.427	2.05
20	104	34	3	14	38	36	13.15	45.97	30	20.15	0.43	2.06
22	104.3	32.1	0	15.96	40	39	13.01	47	37	21	0.44	2.12
22.95	104.4	27	3	15.34	42	31	12.99	48	36	20.9	0.445	2.123
23	106	27.15	2	15	44	33	12.85	49	38	20	0.448	2.137
20	104.6	27.1	2	14.5	46	36	12.75	48	36	21	0.441	2.12

Table A.4 Measured Data for 965 g of R22 at Constant Tc = 40 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2MPa
14.86	93.25	30	0	6	39.9	30	9	45	35	20.15	0.41	1.98
15	92	22.1	0	10	40	29	11.9	45	36	20	0.407	1.98
19.65	96.75	23	-1	11	40.01	34	12	45.97	36.15	21	0.403	1.98
19	97	27	-3	13	40	35	11.99	48	36.25	21.16	0.393	1.97
17	97	22.9	-2	16	40.5	39	12.09	49	37	19.76	0.4	1.97

Table A.5 Measured Data for 965 g of R22 at Constant Tc = 42 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2MPa
19.91	98.89	30	0	9	42	27	11.91	45	35	21.15	0.42	2.04
22.9	100	29.1	3	13	41.9	32	12	46	36	20.9	0.43	2.08
18	100	26	3	15	42	35	12.1	48	36	20.79	0.44	2.096
19	102.2	26.2	5	17	43	42	13	48	36.3	21	0.445	2.12
19	103.5	27	7	19	40.9	42.69	13.25	49	35.9	21	0.448	2.13

Table A.6 Measured Data for 550 g of R134a at Constant Te = 15 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2MPa
23.92	86	29	0	15	29	19	16.85	36	24	23	0.189	0.758
22	94	32.35	0	14.96	32	20	16.76	39	31	22	0.214	0.81
23	95	39	1	15	40	19	16.67	38	35	23.65	0.117	1.2
25	94	42	2	15.1	42	20	16.01	40	35	22.1	0.11	1.2
26	90	42.3	4	14.5	45	20.3	16	40	34	23	0.1	1.2

Table A.7 Measured Data for 550 g of R134a at Constant Tc = 42 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2 MPa
26	91.1	41	0	9	42.3	28	15.36	34	25	24	0.082	1.089
25	91	39	0	13	41.9	35	16	35	25	24.3	0.082	1.096
25.1	90.26	29	1	19	41.86	39	16.5	34	25	23	0.082	1.096

Table A.8 Measured Data for 660 g of R134a at Constant Te = 10 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2 MPa
16.59	70.91	31.89	2	9.67	32	37	14.89	37	25	21.67	0.165	1.17
15.22	75.75	28	0	10.25	33	37	14.65	39	32	21.75	0.171	1.21
12.62	75.61	27	1	10	36	33	13.95	39	34	22	0.176	1.22
11.65	73	32	2	9.5	34	34	14.35	39	35	21.35	0.169	1.22

Table A.9 Measured Data for 660 g of R134a at Constant Te = 15 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1MPa	P_2 MPa
18.98	76.75	21	1	14.9	28	28	15	37	28	21	0.172	1.186
18.99	78.35	22	0	15	29	27	14.65	39	31	21.65	0.178	1.22
18.99	77.99	24	1	15.12	33	29	14.85	39	33	22	0.179	1.227
13	74.89	32	4	15.1	37	28	13.67	38	29	22	0.174	1.2

Table A.10 Measured Data for 660 g of R134a at Constant Tc = 30 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1 MPa	P_2 MPa
12	71.45	22	4	9	29.5	28	12.95	40	31	20	0.191	1.227
14.99	76	21	0	10	29.95	32	13.01	39	30	20.9	0.198	1.24
12	71.11	22	0	11	30	37	13.65	38	30	21	0.187	1.23
17.97	73.91	28	-2	14	31	38	13.67	39	30.15	21.3	0.189	1.23
18.96	75.45	22	-2	15	29	39	14	40	30.67	21.5	0.193	1.24

Table A.11 Measured Data for 660 g of R134a at Constant Tc = 40 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1 MPa	P_2 MPa
11	74.1	26	0	10	40	21	11.95	38	24	20.3	0.165	1.12
12	75	20	-3	14	39.91	33	12.26	38	24	20.76	0.196	1.2
1195	75	20	-2	15	39.95	28	13	38	23	21.01	0.189	1.21
13.83	75.3	20.15	0	16	40	31	12.99	39	24	21	0.151	1.13
12	72	26	-2	17	40.1	41	13.36	39.56	24	21.5	0.193	1.2

Table A.12 Measured Data for 770 g of R134a at Constant Te = 15 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1 MPa	P_2 MPa
24	82	41.65	0	16.5	42	19	15.01	37	24	20.6	0.154	1.151
24	84	42.3	3	15.15	43.5	19.45	15.25	39	31	21	0.151	1.255
23.99	85	40.15	4	14.64	44.65	20.36	14.96	41	34	22	0.156	1.296
21.67	85	41	1	14.95	45	20	14.75	42	40	22.67	0.152	1.296

Table A.13 Measured Data for 770 g of R134a at Constant Tc = 30 °C

T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	T_6°C	T_7°C	T_8°C	T_9°C	T_{10}°C	T_{11}°C	P_1 MPa	P_2 MPa
21	85	29	0	5	30	20	14	38	25	23	0.138	1.151
20	84	31	-3	6	32	22	15.36	37	25	23.3	0.139	1.151
24	85	31	-4	9	32.5	24	16	37	25	23.67	0.139	1.155
24	85	31	-3	11	29.9	28	17	37.01	24.67	23	0.138	1.158
25	84	25.25	-4	13	28	32	19	37.15	25.55	23.69	0.14	1.158
25	84	36	-3	15	32	35	21	37.5	25	25	0.143	1.158
25	85	33	-2	16	30	39	20	28	24.01	24.01	0.145	1.16

APPENDIX B
REFRIGERANT PROPERTIES TABLES AND CHARTS

Table B.1 Refrigerant 22 (Chlorodifluoromethane) Properties of Saturated Liquid and Saturated Vapor**

Temp,* °C	Absolute Pressure, MPa	Density, kg/m³	Volume, m³/kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c_p, kJ/(kg·K)		c_p/c_v	Velocity of Sound, m/s		Viscosity, μPa·s		Thermal Cond. mW/(m·K)		Surface Tension, mN/m	Temp,* °C
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
-150.00	-	1701.5	-	26.31	335.85	0.0566	2.5752	-	0.434	1.285	-	123.	-	-	-	-	37.59	-150.00
-140.00	-	1675.3	-	43.84	340.24	0.1961	2.4222	-	0.445	1.275	-	128.	-	-	-	-	35.70	-140.00
-130.00	0.00006	1649.7	229.29	57.00	344.75	0.2916	2.3017	-	0.458	1.266	-	132.	-	-	-	-	33.84	-130.00
-120.00	0.00023	1624.0	63.648	68.51	349.38	0.3694	2.2033	-	0.470	1.258	-	136.	-	-	-	-	32.00	-120.00
-110.00	0.00074	1598.0	21.311	79.47	354.11	0.4386	2.1220	-	0.483	1.250	-	140.	-	-	-	-	30.17	-110.00
-100.00	0.00200	1571.7	8.2980	90.24	358.93	0.5027	2.0545	-	0.497	1.243	-	144.	-	-	-	-	28.37	-100.00
-90.00	0.00480	1545.1	3.6548	100.95	363.82	0.5629	1.9982	1.070	0.511	1.237	1094.	147.	-	-	-	-	26.59	-90.00
-80.00	0.01035	1518.3	1.7816	111.66	368.75	0.6197	1.9508	1.070	0.527	1.233	1037.	150.	-	-	-	-	24.83	-80.00
-70.00	0.02044	1491.1	0.94476	122.36	373.68	0.6738	1.9109	1.072	0.544	1.231	986.	153.	-	-	128.0	-	23.10	-70.00
-60.00	0.03747	1463.6	0.53734	133.11	378.58	0.7253	1.8770	1.076	0.563	1.231	937.	156.	-	-	125.1	5.61	21.39	-60.00
-50.00	0.06449	1435.5	0.32405	143.91	383.39	0.7748	1.8480	1.083	0.584	1.233	890.	158.	-	-	118.4	6.31	19.70	-50.00
-48.00	0.07140	1429.8	0.29469	146.08	384.35	0.7844	1.8427	1.085	0.589	1.233	881.	159.	-	-	117.5	6.44	19.37	-48.00
-46.00	0.07890	1424.1	0.26849	148.25	385.29	0.7940	1.8376	1.087	0.594	1.234	871.	159.	-	-	116.5	6.58	19.04	-46.00
-44.00	0.08700	1418.4	0.24507	150.43	386.23	0.8035	1.8326	1.089	0.598	1.235	862.	160.	-	-	115.6	6.71	18.70	-44.00
-42.00	0.09575	1412.6	0.22410	152.61	387.17	0.8130	1.8277	1.091	0.603	1.236	853.	160.	-	-	114.7	6.85	18.37	-42.00
-40.80b	0.10132	1409.1	0.21256	153.93	387.72	0.8186	1.8249	1.092	0.606	1.237	847.	160.	-	-	114.1	6.93	18.18	-40.80
-40.00	0.10518	1406.8	0.20526	154.80	388.09	0.8224	1.8230	1.093	0.608	1.237	844.	160.	-	-	113.8	6.98	18.05	-40.00
-38.00	0.11533	1401.0	0.18832	156.99	389.01	0.8317	1.8184	1.096	0.614	1.239	834.	161.	-	-	112.9	7.11	17.72	-38.00
-36.00	0.12623	1395.1	0.17306	159.19	389.93	0.8410	1.8140	1.098	0.619	1.240	825.	161.	-	-	112.0	7.24	17.39	-36.00
-34.00	0.13793	1389.2	0.15927	161.40	390.84	0.8502	1.8096	1.101	0.624	1.242	816.	161.	-	-	111.1	7.37	17.07	-34.00
-32.00	0.15045	1383.3	0.14680	163.61	391.74	0.8594	1.8054	1.104	0.630	1.243	807.	161.	-	-	110.1	7.50	16.74	-32.00
-30.00	0.16384	1377.3	0.13551	165.82	392.63	0.8685	1.8013	1.107	0.636	1.245	797.	162.	-	-	109.2	7.63	16.42	-30.00
-28.00	0.17815	1371.3	0.12525	168.04	393.52	0.8776	1.7973	1.110	0.642	1.247	788.	162.	-	-	108.4	7.76	16.10	-28.00
-26.00	0.19340	1365.2	0.11593	170.27	394.39	0.8866	1.7934	1.114	0.648	1.249	779.	162.	-	-	107.5	7.89	15.77	-26.00
-24.00	0.20965	1359.1	0.10744	172.51	395.26	0.8955	1.7896	1.117	0.654	1.252	770.	162.	-	-	106.6	8.02	-	-24.00
-22.00	0.22693	1352.9	0.09970	174.75	396.12	0.9044	1.7859	1.121	0.660	1.254	760.	163.	-	-	105.7	8.14	-	-22.00
-20.00	0.24529	1346.8	0.09262	177.00	396.97	0.9133	1.7822	1.125	0.667	1.257	751.	163.	260.1	-	104.8	8.27	-	-20.00
-18.00	0.26477	1340.5	0.08615	179.26	397.81	0.9222	1.7787	1.129	0.674	1.260	742.	163.	251.7	11.08	103.9	8.40	-	-18.00
-16.00	0.28542	1334.2	0.08023	181.53	398.64	0.9309	1.7752	1.133	0.681	1.263	733.	163.	249.4	11.16	103.1	8.52	-	-16.00
-14.00	0.30728	1327.9	0.07479	183.81	399.46	0.9397	1.7719	1.137	0.688	1.266	723.	163.	244.2	11.24	102.2	8.64	-	-14.00
-12.00	0.33040	1321.5	0.06979	186.09	400.27	0.9484	1.7686	1.141	0.695	1.269	714.	163.	239.1	11.32	101.3	8.77	-	-12.00
-10.00	0.35482	1315.0	0.06520	188.38	401.07	0.9571	1.7653	1.146	0.703	1.273	705.	163.	234.1	11.40	100.4	8.89	-	-10.00
-8.00	0.38059	1308.5	0.06096	190.69	401.85	0.9657	1.7621	1.151	0.710	1.277	696.	163.	229.1	11.48	99.6	9.02	-	-8.00
-6.00	0.40775	1301.9	0.05706	193.00	402.63	0.9743	1.7590	1.156	0.718	1.281	686.	163.	224.2	11.56	98.7	9.14	-	-6.00
-4.00	0.43636	1295.3	0.05345	195.32	403.39	0.9829	1.7560	1.161	0.727	1.285	677.	163.	219.4	11.64	97.9	9.26	-	-4.00
-2.00	0.46646	1288.6	0.05012	197.66	404.14	0.9915	1.7530	1.166	0.735	1.289	668.	163.	214.7	11.72	97.0	9.38	-	-2.00
0.00	0.49811	1281.8	0.04703	200.00	404.87	1.0000	1.7500	1.171	0.744	1.294	658.	163.	210.1	11.80	96.2	9.50	-	0.00
2.00	0.53134	1275.0	0.04417	202.35	405.59	1.0085	1.7471	1.177	0.753	1.299	649.	163.	205.6	11.88	95.3	9.63	-	2.00
4.00	0.56622	1268.1	0.04152	204.72	406.30	1.0170	1.7443	1.183	0.762	1.305	640.	163.	201.2	11.96	94.5	9.75	-	4.00
6.00	0.60279	1261.1	0.03906	207.10	406.99	1.0254	1.7415	1.189	0.772	1.310	630.	163.	196.9	12.04	93.6	9.87	-	6.00
8.00	0.64109	1254.0	0.03676	209.49	407.67	1.0338	1.7387	1.195	0.782	1.316	621.	163.	192.6	12.12	92.8	9.99	-	8.00
10.00	0.68119	1246.9	0.03463	211.89	408.33	1.0422	1.7360	1.202	0.792	1.323	611.	163.	188.5	12.20	92.0	10.11	-	10.00
12.00	0.72314	1239.7	0.03265	214.31	408.97	1.0506	1.7333	1.208	0.802	1.330	602.	162.	184.4	12.28	91.1	10.23	-	12.00
14.00	0.76698	1232.4	0.03079	216.74	409.60	1.0590	1.7306	1.215	0.813	1.337	592.	162.	180.5	12.36	90.3	10.35	-	14.00
16.00	0.81277	1225.0	0.02906	219.18	410.21	1.0673	1.7280	1.223	0.825	1.345	583.	162.	176.6	12.44	89.5	10.47	-	16.00
18.00	0.86056	1217.6	0.02744	221.63	410.80	1.0756	1.7254	1.230	0.837	1.353	573.	162.	172.8	12.52	88.7	10.59	-	18.00
20.00	0.91041	1210.0	0.02593	224.10	411.38	1.0840	1.7228	1.238	0.849	1.361	564.	161.	169.1	-	87.8	10.71	-	20.00
22.00	0.96236	1202.4	0.02451	226.59	411.93	1.0923	1.7202	1.246	0.862	1.370	554.	161.	165.4	-	87.0	10.82	-	22.00
24.00	1.0165	1194.6	0.02319	229.09	412.46	1.1006	1.7177	1.254	0.875	1.380	544.	160.	161.9	-	86.2	10.94	-	24.00
26.00	1.0728	1186.8	0.02194	231.60	412.98	1.1088	1.7151	1.263	0.889	1.391	535.	160.	158.4	-	85.4	11.06	-	26.00
28.00	1.1314	1178.8	0.02077	234.14	413.46	1.1171	1.7126	1.272	0.904	1.402	525.	160.	155.0	-	84.6	11.18	-	28.00
30.00	1.1924	1170.7	0.01968	236.69	413.93	1.1254	1.7101	1.282	0.919	1.413	515.	159.	151.7	-	83.8	11.30	-	30.00
32.00	1.2557	1162.5	0.01864	239.25	414.37	1.1336	1.7075	1.292	0.935	1.426	506.	159.	148.5	-	83.0	11.42	-	32.00
34.00	1.3215	1154.2	0.01767	241.84	414.79	1.1419	1.7050	1.302	0.952	1.440	496.	158.	145.4	-	82.2	11.54	-	34.00
36.00	1.3898	1145.7	0.01675	244.44	415.18	1.1501	1.7024	1.313	0.970	1.454	486.	158.	142.3	-	81.4	11.66	-	36.00
38.00	1.4606	1137.1	0.01589	247.06	415.54	1.1584	1.6999	1.325	0.989	1.470	476.	157.	139.3	-	80.6	11.78	-	38.00
40.00	1.5341	1128.4	0.01507	249.71	415.87	1.1667	1.6973	1.338	1.009	1.486	466.	156.	136.3	-	79.8	11.90	-	40.00
42.00	1.6103	1119.5	0.01430	252.37	416.17	1.1749	1.6947	1.351	1.030	1.504	456.	156.	-	-	79.0	12.02	-	42.00
44.00	1.6892	1110.4	0.01357	255.06	416.44	1.1832	1.6921	1.365	1.052	1.524	446.	155.	-	-	78.2	12.14	-	44.00
46.00	1.7709	1101.2	0.01288	257.77	416.68	1.1915	1.6894	1.380	1.076	1.545	436.	154.	-	-	77.4	12.26	-	46.00
48.00	1.8555	1091.8	0.01223	260.51	416.87	1.1998	1.6867	1.396	1.102	1.568	426.	153.	-	-	76.6	12.38	-	48.00
50.00	1.9431	1082.1	0.01161	263.27	417.03	1.2081	1.6840	1.414	1.129	1.593	415.	153.	-	-	-	-	-	50.00
55.00	2.1753	1057.1	0.01020	270.31	417.24	1.2291	1.6768	1.464	1.209	1.667	389.	150.	-	-	-	-	-	55.00
60.00	2.4274	1030.5	0.00895	277.56	417.14	1.2503	1.6692	1.528	1.307	1.762	362.	148.	-	-	-	-	-	60.00
65.00	2.7008	1001.8	0.00784	285.06	416.65	1.2718	1.6610	1.611	1.435	1.888	335.	145.	-	-	-	-	-	65.00
70.00	2.9967	970.4	0.00684	292.90	415.69	1.2940	1.6518	1.726	1.609	2.064	306.	142.	-	-	-	-	-	70.00
75.00	3.3168	935.3	0.00594	301.18	414.09	1.3169	1.6413	1.896	1.862	2.324	276.	138.	-	-	-	-	-	75.00
80.00	3.6627	894.8	0.00511	310.10	411.60	1.3413	1.6287	2.176	2.268	2.748	244.	134.	-	-	-	-	-	80.00
85.00	4.0368	845.1	0.00433	320.05	407.72	1.3680	1.6128	2.735	3.039	3.555	209.	129.	-	-	-	-	-	85.00
90.00	4.4416	777.5	0.00355	331.98	401.33	1.3998	1.5907	4.186	5.041	5.643	170.	124.	-	-	-	-	-	90.00
95.00	4.8820	665.4	0.00264	348.86	387.46	1.4442	1.5491	-	-	-	-	-	-	-	-	-	-	95.00
96.14c	4.9900	523.8	0.00191	366.59	366.59	1.4918	1.4918	-	-	-	0.	0.	-	-	-	-	0.00	96.14

*temperatures are on the ITS–90 scale

b = normal boiling point

c = critical point

** (ASHRAE, 1997)

Table B.2 Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor**

Temp,* °C	Absolute Pressure, MPa	Density, kg/m³ Liquid	Volume, m³/kg Vapor	Enthalpy, kJ/kg Liquid	Enthalpy, kJ/kg Vapor	Entropy, kJ/(kg·K) Liquid	Entropy, kJ/(kg·K) Vapor	Specific Heat c_p, kJ/(kg·K) Liquid	Specific Heat c_p, kJ/(kg·K) Vapor	c_p/c_v Vapor	Velocity of Sound, m/s Liquid	Velocity of Sound, m/s Vapor	Viscosity, µPa·s Liquid	Viscosity, µPa·s Vapor	Thermal Cond., mW/(m·K) Liquid	Thermal Cond., mW/(m·K) Vapor	Surface Tension, mN/m	Temp,* °C
−103.30a	0.00039	1591.2	35.263	71.89	335.07	0.4143	1.9638	1.147	0.585	1.163	1135.	127.	2186.6	6.63	—	—	28.15	−103.30
−100.00	0.00056	1581.9	25.039	75.71	337.00	0.4366	1.9456	1.168	0.592	1.161	1111.	128.	1958.2	6.76	—	—	27.56	−100.00
−90.00	0.00153	1553.9	9.7191	87.59	342.94	0.5032	1.8975	1.201	0.614	1.155	1051.	131.	1445.6	7.16	—	—	25.81	−90.00
−80.00	0.00369	1525.2	4.2504	99.65	349.03	0.5674	1.8585	1.211	0.637	1.151	999.	134.	1109.9	7.57	—	—	24.11	−80.00
−70.00	0.00801	1493.6	2.0528	111.78	355.23	0.6286	1.8269	1.215	0.660	1.148	951.	137.	879.6	7.97	125.8	—	22.44	−70.00
−60.00	0.01594	1471.0	1.0770	123.96	361.51	0.6871	1.8016	1.220	0.685	1.146	904.	139.	715.4	8.38	121.1	—	20.81	−60.00
−50.00	0.02948	1443.1	0.60560	136.21	367.83	0.7432	1.7812	1.229	0.712	1.146	858.	142.	594.3	8.79	116.5	7.12	19.22	−50.00
−40.00	0.05122	1414.8	0.36095	148.57	374.16	0.7973	1.7649	1.243	0.740	1.148	812.	144.	502.2	9.20	111.9	8.19	17.66	−40.00
−30.00	0.08436	1385.9	0.22596	161.10	380.45	0.8498	1.7519	1.260	0.771	1.152	765.	145.	430.4	9.62	107.3	9.16	16.13	−30.00
−28.00	0.09268	1380.0	0.20682	163.62	381.70	0.8601	1.7497	1.264	0.778	1.153	756.	145.	418.0	9.71	106.3	9.35	15.83	−28.00
−26.07b	0.10132	1374.3	0.19016	166.07	382.90	0.8701	1.7476	1.268	0.784	1.154	747.	146.	406.4	9.79	105.4	9.52	15.54	−26.07
−26.00	0.10164	1374.1	0.18961	166.16	382.94	0.8704	1.7476	1.268	0.785	1.154	747.	146.	406.0	9.79	105.4	9.53	15.53	−26.00
−24.00	0.11127	1368.2	0.17410	168.70	384.19	0.8806	1.7455	1.273	0.791	1.155	738.	146.	394.6	9.88	104.5	9.71	15.23	−24.00
−22.00	0.12160	1362.2	0.16010	171.26	385.43	0.8908	1.7436	1.277	0.798	1.156	728.	146.	383.6	9.96	103.6	9.89	14.93	−22.00
−20.00	0.13268	1356.2	0.14744	173.82	386.66	0.9009	1.7417	1.282	0.805	1.157	719.	146.	373.1	10.05	102.6	10.07	14.63	−20.00
−18.00	0.14454	1350.2	0.13597	176.39	387.89	0.9110	1.7399	1.286	0.812	1.159	710.	146.	363.0	10.14	101.7	10.24	14.33	−18.00
−16.00	0.15721	1344.1	0.12556	178.97	389.11	0.9211	1.7383	1.291	0.820	1.160	700.	147.	353.3	10.22	100.8	10.42	14.04	−16.00
−14.00	0.17074	1338.0	0.11610	181.56	390.33	0.9311	1.7367	1.296	0.827	1.162	691.	147.	344.0	10.31	99.9	10.59	13.74	−14.00
−12.00	0.18516	1331.8	0.10749	184.16	391.55	0.9410	1.7351	1.301	0.835	1.164	682.	147.	335.0	10.40	99.0	10.76	13.45	−12.00
−10.00	0.20052	1325.6	0.09963	186.78	392.75	0.9509	1.7337	1.306	0.842	1.166	672.	147.	326.3	10.49	98.0	10.93	13.16	−10.00
−8.00	0.21684	1319.3	0.09246	189.40	393.95	0.9608	1.7323	1.312	0.850	1.168	663.	147.	318.0	10.58	97.1	11.10	12.87	−8.00
−6.00	0.23418	1313.0	0.08591	192.03	395.15	0.9707	1.7310	1.317	0.858	1.170	654.	147.	309.9	10.67	96.2	11.28	12.58	−6.00
−4.00	0.25257	1305.6	0.07991	194.68	396.33	0.9805	1.7297	1.323	0.866	1.172	644.	147.	302.2	10.76	95.3	11.45	12.29	−4.00
−2.00	0.27206	1300.2	0.07440	197.33	397.51	0.9903	1.7285	1.329	0.875	1.175	635.	147.	294.7	10.85	94.3	11.62	12.00	−2.00
0.00	0.29269	1293.7	0.06935	200.00	398.68	1.0000	1.7274	1.335	0.883	1.178	626.	147.	287.4	10.94	93.4	11.79	11.71	0.00
2.00	0.31450	1287.1	0.06470	202.68	399.84	1.0097	1.7263	1.341	0.892	1.180	616.	147.	280.4	11.03	92.5	11.96	11.43	2.00
4.00	0.33755	1280.5	0.06042	205.37	401.00	1.0194	1.7252	1.347	0.901	1.183	607.	147.	273.6	11.13	91.6	12.13	11.14	4.00
6.00	0.36186	1273.8	0.05648	208.08	402.14	1.0291	1.7242	1.353	0.910	1.187	598.	147.	267.0	11.22	90.7	12.31	10.86	6.00
8.00	0.38749	1267.0	0.05284	210.80	403.27	1.0387	1.7233	1.360	0.920	1.190	588.	147.	260.6	11.32	89.7	12.48	10.58	8.00
10.00	0.41449	1260.2	0.04948	213.53	404.40	1.0483	1.7224	1.367	0.930	1.193	579.	146.	254.3	11.42	88.8	12.66	10.30	10.00
12.00	0.44289	1253.3	0.04636	216.27	405.51	1.0579	1.7215	1.374	0.939	1.197	569.	146.	248.3	11.52	87.9	12.84	10.02	12.00
14.00	0.47276	1246.3	0.04348	219.03	406.61	1.0674	1.7207	1.381	0.950	1.201	560.	146.	242.5	11.62	87.0	13.02	9.74	14.00
16.00	0.50413	1239.3	0.04081	221.80	407.70	1.0770	1.7199	1.388	0.960	1.206	550.	146.	236.8	11.72	86.0	13.20	9.47	16.00
18.00	0.53706	1232.1	0.03833	224.59	408.78	1.0865	1.7191	1.396	0.971	1.210	541.	146.	231.2	11.82	85.1	13.39	9.19	18.00
20.00	0.57159	1224.9	0.03603	227.40	409.84	1.0960	1.7183	1.404	0.982	1.215	532.	145.	225.8	11.92	84.2	13.57	8.92	20.00
22.00	0.60777	1217.5	0.03388	230.21	410.89	1.1055	1.7176	1.412	0.994	1.220	522.	145.	220.5	12.03	83.3	13.76	8.65	22.00
24.00	0.64566	1210.1	0.03189	233.05	411.93	1.1149	1.7169	1.420	1.006	1.226	512.	145.	215.4	12.14	82.4	13.96	8.38	24.00
26.00	0.68531	1202.6	0.03003	235.90	412.95	1.1244	1.7162	1.429	1.018	1.231	503.	144.	210.4	12.25	81.4	14.15	8.11	26.00
28.00	0.72676	1194.9	0.02829	238.77	413.95	1.1338	1.7155	1.438	1.031	1.238	493.	144.	205.5	12.36	80.5	14.35	7.84	28.00
30.00	0.77008	1187.2	0.02667	241.65	414.94	1.1432	1.7149	1.447	1.044	1.244	484.	143.	200.7	12.48	79.6	14.56	7.57	30.00
32.00	0.81530	1179.3	0.02516	244.55	415.90	1.1527	1.7142	1.457	1.058	1.251	474.	143.	196.0	12.60	78.7	14.76	7.31	32.00
34.00	0.86250	1171.3	0.02374	247.47	416.85	1.1621	1.7135	1.467	1.073	1.259	465.	142.	191.4	12.72	77.7	14.97	7.05	34.00
36.00	0.91172	1163.2	0.02241	250.41	417.78	1.1715	1.7129	1.478	1.088	1.267	455.	142.	186.9	12.84	76.8	15.19	6.78	36.00
38.00	0.96301	1154.9	0.02116	253.37	418.69	1.1809	1.7122	1.489	1.104	1.276	445.	141.	182.5	12.97	75.9	15.41	6.52	38.00
40.00	1.0165	1146.5	0.01999	256.35	419.58	1.1903	1.7115	1.500	1.120	1.285	436.	140.	178.2	13.10	75.0	15.64	6.27	40.00
42.00	1.0721	1137.9	0.01890	259.35	420.44	1.1997	1.7108	1.513	1.138	1.295	426.	140.	174.0	13.24	74.1	15.86	6.01	42.00
44.00	1.1300	1129.2	0.01786	262.38	421.28	1.2091	1.7101	1.525	1.156	1.306	416.	139.	169.8	13.38	73.1	16.10	5.76	44.00
46.00	1.1901	1120.3	0.01689	265.42	422.09	1.2185	1.7094	1.539	1.175	1.318	407.	138.	165.7	13.52	72.2	16.34	5.51	46.00
48.00	1.2527	1111.3	0.01598	268.49	422.88	1.2279	1.7086	1.553	1.196	1.331	397.	137.	161.7	13.67	71.3	16.59	5.26	48.00
50.00	1.3177	1102.0	0.01511	271.59	423.63	1.2373	1.7078	1.569	1.218	1.345	387.	137.	157.7	13.83	70.4	16.84	5.01	50.00
52.00	1.3852	1092.6	0.01430	274.71	424.35	1.2468	1.7070	1.585	1.241	1.360	377.	136.	153.8	13.99	69.5	17.10	4.76	52.00
54.00	1.4553	1082.9	0.01353	277.86	425.03	1.2562	1.7061	1.602	1.266	1.377	367.	135.	149.9	14.16	68.5	17.36	4.52	54.00
56.00	1.5280	1073.0	0.01280	281.04	425.68	1.2657	1.7051	1.621	1.293	1.395	358.	134.	146.1	14.33	67.6	17.63	4.28	56.00
58.00	1.6033	1062.8	0.01212	284.25	426.29	1.2752	1.7041	1.641	1.322	1.416	348.	133.	142.3	14.51	66.7	17.91	4.04	58.00
60.00	1.6815	1052.4	0.01146	287.49	426.86	1.2847	1.7031	1.663	1.354	1.438	338.	132.	138.6	14.71	65.8	18.19	3.81	60.00
62.00	1.7625	1041.7	0.01085	290.77	427.37	1.2943	1.7019	1.686	1.388	1.463	328.	131.	134.9	14.91	64.9	18.48	3.57	62.00
64.00	1.8464	1030.7	0.01026	294.08	427.84	1.3039	1.7007	1.712	1.426	1.490	318.	129.	131.2	15.12	63.9	18.79	3.34	64.00
66.00	1.9334	1019.4	0.00970	297.44	428.25	1.3136	1.6993	1.740	1.468	1.522	308.	128.	127.5	15.35	63.0	19.09	3.12	66.00
68.00	2.0234	1007.7	0.00917	300.84	428.61	1.3234	1.6979	1.772	1.515	1.557	298.	127.	123.9	15.59	62.1	19.40	2.89	68.00
70.00	2.1165	995.6	0.00867	304.29	428.89	1.3332	1.6963	1.806	1.567	1.597	287.	126.	120.3	15.85	61.2	19.72	2.67	70.00
72.00	2.2130	983.1	0.00818	307.79	429.10	1.3430	1.6945	1.846	1.626	1.642	277.	124.	116.7	16.12	60.3	20.05	2.46	72.00
74.00	2.3127	970.0	0.00772	311.34	429.23	1.3530	1.6925	1.890	1.693	1.695	267.	123.	113.1	16.41	59.3	20.39	2.24	74.00
76.00	2.4159	956.5	0.00728	314.96	429.27	1.3631	1.6905	1.941	1.770	1.757	256.	121.	109.4	16.73	58.4	20.74	2.03	76.00
78.00	2.5227	942.3	0.00686	318.65	429.20	1.3733	1.6881	2.000	1.861	1.830	246.	120.	105.8	17.08	57.5	21.09	1.83	78.00
80.00	2.6331	927.4	0.00646	322.41	429.02	1.3837	1.6855	2.069	1.967	1.917	235.	118.	102.1	17.46	56.6	21.46	1.63	80.00
85.00	2.9259	886.2	0.00550	332.27	427.91	1.4105	1.6775	2.313	2.348	2.231	207.	113.	92.7	18.59	54.3	22.41	1.15	85.00
90.00	3.2445	836.9	0.00461	343.01	425.48	1.4392	1.6663	2.766	3.064	2.832	178.	108.	82.6	20.15	—	—	0.72	90.00
95.00	3.5916	771.6	0.00374	355.43	420.60	1.4720	1.6490	3.961	4.942	4.424	145.	102.	70.9	22.59	—	—	0.33	95.00
100.00	3.9721	646.7	0.00265	374.02	407.08	1.5207	1.6093	—	—	—	105.	94.	53.0	28.86	—	—	0.03	100.00
101.03c	4.0560	513.3	0.00195	389.79	389.79	1.5593	1.5593	∞	∞	∞	0	0	—	—	—	—	0	101.03

*Temperatures are on the ITS–90 scale

a = triple point

b = normal boiling point

c = critical point

** (ASHRAE, 1997)

Table B.3 Refrigerant 134a Properties of Superheated Vapor **

Pressure = 0.101325 MPa
Saturation temperature = −26.07°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1374.34	166.07	0.8701	747.1
Vapor	5.26	382.90	1.7476	145.7
−20.00	5.11	387.68	1.7667	147.8
−10.00	4.89	395.65	1.7976	151.0
0.00	4.69	403.74	1.8278	154.2
10.00	4.50	411.97	1.8574	157.2
20.00	4.34	420.34	1.8864	160.1
30.00	4.18	428.85	1.9150	162.9
40.00	4.04	437.52	1.9431	165.7
50.00	3.91	446.33	1.9708	168.4
60.00	3.78	455.30	1.9981	171.0
70.00	3.67	464.43	2.0251	173.6
80.00	3.56	473.70	2.0518	176.1
90.00	3.46	483.13	2.0781	178.6
100.00	3.36	492.71	2.1041	181.0
110.00	3.27	502.44	2.1298	183.4
120.00	3.19	512.32	2.1553	185.7
130.00	3.11	522.35	2.1805	188.1
140.00	3.03	532.52	2.2054	190.3
150.00	2.96	542.83	2.2301	192.6

Pressure = 0.200 MPa
Saturation temperature = −10.07°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1325.78	186.69	0.9506	672.8
Vapor	10.01	392.71	1.7337	146.9
−10.00	10.01	392.77	1.7339	147.0
0.00	9.54	401.21	1.7654	150.6
10.00	9.13	409.73	1.7961	154.0
20.00	8.76	418.35	1.8260	157.3
30.00	8.42	427.07	1.8552	160.4
40.00	8.12	435.90	1.8839	163.4
50.00	7.83	444.87	1.9121	166.3
60.00	7.57	453.97	1.9398	169.2
70.00	7.33	463.20	1.9671	171.9
80.00	7.11	472.57	1.9940	174.6
90.00	6.89	482.08	2.0206	177.2
100.00	6.70	491.74	2.0468	179.7
110.00	6.51	501.53	2.0727	182.2
120.00	6.34	511.47	2.0983	184.7
130.00	6.17	521.55	2.1236	187.1
140.00	6.01	531.76	2.1486	189.4
150.00	5.87	542.12	2.1734	191.7

Pressure = 0.400 MPa
Saturation temperature = 8.94°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1263.84	212.08	1.0432	583.8
Vapor	19.52	403.80	1.7229	146.6
10.00	19.41	404.78	1.7263	147.0
20.00	18.45	414.00	1.7583	151.2
30.00	17.61	423.21	1.7892	155.0
40.00	16.87	432.46	1.8192	158.6
50.00	16.20	441.76	1.8485	162.0
60.00	15.60	451.15	1.8771	165.3
70.00	15.05	460.63	1.9051	168.4
80.00	14.54	470.21	1.9326	171.4
90.00	14.08	479.91	1.9597	174.3
100.00	13.65	489.72	1.9864	177.1
110.00	13.24	499.65	2.0126	179.8
120.00	12.87	509.71	2.0386	182.4
130.00	12.51	519.90	2.0641	185.0
140.00	12.18	530.21	2.0894	187.5
150.00	11.87	540.66	2.1144	190.0

Pressure = 0.600 MPa
Saturation temperature = 21.58°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1219.08	229.62	1.1035	524.0
Vapor	29.13	410.67	1.7178	145.0
30.00	27.79	418.97	1.7455	149.0
40.00	26.41	428.72	1.7772	153.4
50.00	25.21	438.44	1.8077	157.4
60.00	24.16	448.16	1.8374	161.2
70.00	23.22	457.93	1.8662	164.7
80.00	22.37	467.75	1.8944	168.0
90.00	21.59	477.65	1.9221	171.2
100.00	20.88	487.64	1.9492	174.3
110.00	20.22	497.72	1.9759	177.3
120.00	19.61	507.92	2.0022	180.1
130.00	19.04	518.22	2.0280	182.9
140.00	18.51	528.63	2.0536	185.6
150.00	18.01	539.17	2.0787	188.2
160.00	17.54	549.82	2.1036	190.8
170.00	17.10	560.59	2.1282	193.3
180.00	16.68	571.48	2.1525	195.8
190.00	16.29	582.50	2.1766	198.2
200.00	15.91	593.63	2.2003	200.6

Pressure = 0.800 MPa
Saturation temperature = 31.33°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1181.92	243.58	1.1495	477.4
Vapor	38.99	415.58	1.7144	142.9
40.00	36.98	424.61	1.7437	147.6
50.00	35.03	434.85	1.7758	152.4
60.00	33.36	444.98	1.8067	156.8
70.00	31.90	455.08	1.8366	160.8
80.00	30.62	465.17	1.8656	164.6
90.00	29.46	475.30	1.8939	168.1
100.00	28.41	485.49	1.9215	171.5
110.00	27.46	495.74	1.9486	174.7
120.00	26.58	506.07	1.9753	177.8
130.00	25.77	516.50	2.0015	180.8
140.00	25.01	527.03	2.0272	183.7
150.00	24.31	537.66	2.0527	186.4
160.00	23.65	548.40	2.0777	189.2
170.00	23.03	559.24	2.1025	191.8
180.00	22.45	570.20	2.1270	194.4
190.00	21.89	581.28	2.1511	196.9
200.00	21.37	592.46	2.1750	199.4

Pressure = 1.000 MPa
Saturation temperature = 39.39°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1149.06	255.44	1.1874	438.6
Vapor	49.16	419.31	1.7117	140.6
40.00	48.95	419.99	1.7139	141.0
50.00	45.86	430.91	1.7482	146.9
60.00	43.34	441.56	1.7807	152.0
70.00	41.21	452.05	1.8117	156.7
80.00	39.36	462.47	1.8416	160.9
90.00	37.74	472.86	1.8706	164.9
100.00	36.29	483.26	1.8989	168.6
110.00	34.99	493.69	1.9265	172.1
120.00	33.80	504.19	1.9535	175.4
130.00	32.71	514.75	1.9800	178.6
140.00	31.70	525.39	2.0061	181.7
150.00	30.76	536.12	2.0318	184.6
160.00	29.90	546.95	2.0571	187.5
170.00	29.08	557.88	2.0820	190.3
180.00	28.32	568.91	2.1066	193.0
190.00	27.60	580.05	2.1309	195.6
200.00	26.92	591.29	2.1550	198.2

Pressure = 1.200 MPa
Saturation temperature = 46.32°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1118.89	265.91	1.2200	405.0
Vapor	59.73	422.22	1.7092	138.2
50.00	58.09	426.51	1.7226	140.7
60.00	54.32	437.83	1.7571	146.9
70.00	51.26	448.81	1.7896	152.3
80.00	48.69	459.61	1.8206	157.1
90.00	46.49	470.30	1.8504	161.9
100.00	44.55	480.94	1.8794	165.6
110.00	42.83	491.58	1.9075	169.4
120.00	41.28	502.25	1.9350	173.0
130.00	39.87	512.95	1.9619	176.4
140.00	38.58	523.72	1.9882	179.7
150.00	37.39	534.56	2.0142	182.8
160.00	36.29	545.48	2.0397	185.8
170.00	35.26	556.50	2.0648	188.8
180.00	34.31	567.60	2.0896	191.6
190.00	33.40	578.80	2.1141	194.4
200.00	32.56	590.11	2.1382	197.1
210.00	31.76	601.51	2.1621	199.7
220.00	31.01	613.02	2.1856	202.3
230.00	30.29	624.64	2.2090	204.8
240.00	29.61	636.36	2.2320	207.2
250.00	28.96	648.18	2.2548	209.7

Pressure = 1.400 MPa
Saturation temperature = 52.43°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1090.50	275.38	1.2488	375.1
Vapor	70.76	424.50	1.7068	135.6
60.00	66.61	433.69	1.7347	141.2
70.00	62.25	445.31	1.7691	147.5
80.00	58.74	456.56	1.8014	153.0
90.00	55.79	467.60	1.8322	158.0
100.00	53.24	478.53	1.8619	162.5
110.00	51.03	489.39	1.8906	166.6
120.00	49.05	500.25	1.9186	170.5
130.00	47.28	511.11	1.9459	174.2
140.00	45.67	522.02	1.9726	177.7
150.00	44.19	532.97	1.9988	181.0
160.00	42.83	544.00	2.0246	184.2
170.00	41.57	555.10	2.0499	187.2
180.00	40.41	566.28	2.0748	190.2
190.00	39.31	577.55	2.0994	193.1
200.00	38.28	588.92	2.1237	195.9
210.00	37.32	600.38	2.1477	198.6
220.00	36.41	611.94	2.1714	201.3
230.00	35.55	623.60	2.1948	203.9
240.00	34.73	635.35	2.2179	206.4
250.00	33.96	647.22	2.2408	208.9

Pressure = 1.600 MPa
Saturation temperature = 57.91°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1063.28	284.11	1.2748	348.1
Vapor	82.34	426.27	1.7042	132.9
60.00	80.74	428.99	1.7124	134.7
70.00	74.43	441.47	1.7493	142.3
80.00	69.61	453.30	1.7833	148.7
90.00	65.71	464.76	1.8153	154.2
100.00	62.43	476.01	1.8458	159.2
110.00	59.62	487.13	1.8753	163.8
120.00	57.14	498.19	1.9038	168.0
130.00	54.95	509.23	1.9315	171.9
140.00	52.98	520.28	1.9586	175.6
150.00	51.18	531.36	1.9851	179.1
160.00	49.54	542.49	2.0111	182.5
170.00	48.03	553.68	2.0366	185.7
180.00	46.63	564.94	2.0617	188.6
190.00	45.32	576.29	2.0865	191.6
200.00	44.10	587.71	2.1109	194.7
210.00	42.96	599.23	2.1350	197.6
220.00	41.88	610.84	2.1588	200.3
230.00	40.87	622.55	2.1823	203.0
240.00	39.91	634.35	2.2055	205.6
250.00	39.00	646.25	2.2285	208.2

*temperatures are on the ITS-90 scale

** (ASHRAE, 1997)

Table B.3 Refrigerant 134a Properties of Superheated Vapor (*Concluded*)

Pressure = 1.800 MPa
Saturation temperature = 62.90°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1036.81	292.26	1.2987	323.2
Vapor	94.53	427.59	1.7014	130.1
70.00	88.23	437.17	1.7296	136.5
80.00	81.54	449.76	1.7657	144.0
90.00	76.38	461.74	1.7992	150.3
100.00	72.17	473.36	1.8308	155.9
110.00	68.64	484.78	1.8610	160.8
120.00	65.60	496.06	1.8900	165.4
130.00	62.91	507.29	1.9183	169.6
140.00	60.53	518.50	1.9457	173.5
150.00	58.37	529.71	1.9725	177.3
160.00	56.42	540.95	1.9988	180.8
170.00	54.62	552.24	2.0246	184.2
180.00	52.97	563.59	2.0499	187.4
190.00	51.44	575.01	2.0748	190.6
200.00	50.01	586.50	2.0995	193.6
210.00	48.68	598.08	2.1236	196.5
220.00	47.43	609.74	2.1475	199.4
230.00	46.25	621.50	2.1710	202.1
240.00	45.14	633.34	2.1944	204.9
250.00	44.09	645.29	2.2174	207.5

Pressure = 2.000 MPa
Saturation temperature = 67.49°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	1010.74	299.96	1.3209	300.1
Vapor	107.46	428.52	1.6983	127.2
70.00	104.37	432.22	1.7091	129.9
80.00	94.85	445.86	1.7483	138.9
90.00	87.97	458.49	1.7835	146.2
100.00	82.58	470.57	1.8164	152.4
110.00	78.17	482.32	1.8474	157.8
120.00	74.44	493.86	1.8772	162.7
130.00	71.18	505.30	1.9059	167.2
140.00	68.33	516.68	1.9338	171.4
150.00	65.78	528.03	1.9609	175.4
160.00	63.47	539.39	1.9875	179.1
170.00	61.57	550.79	2.0135	182.6
180.00	59.45	562.23	2.0390	186.0
190.00	57.67	573.72	2.0641	189.3
200.00	56.02	585.28	2.0888	192.4
210.00	54.49	596.92	2.1131	195.5
220.00	53.05	608.64	2.1371	198.4
230.00	51.70	620.44	2.1608	201.3
240.00	50.43	632.33	2.1842	204.1
250.00	49.23	644.30	2.2073	206.8

Pressure = 2.200 MPa
Saturation temperature = 71.74°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	984.76	307.32	1.3417	278.4
Vapor	121.25	429.08	1.6948	124.3
80.00	110.03	441.49	1.7303	133.3
90.00	100.70	454.98	1.7680	141.8
100.00	93.78	467.61	1.8023	148.7
110.00	88.25	479.73	1.8344	154.7
120.00	83.70	491.59	1.8649	160.0
130.00	79.79	503.25	1.8942	164.9
140.00	76.41	514.81	1.9226	169.3
150.00	73.40	526.32	1.9501	173.5
160.00	70.71	537.81	1.9769	177.4
170.00	68.28	549.31	2.0032	181.1
180.00	66.06	560.84	2.0289	184.6
190.00	64.02	572.12	2.0542	188.0
200.00	62.13	584.06	2.0790	191.3
210.00	60.38	595.76	2.1035	194.4
220.00	58.74	607.53	2.1276	197.5
230.00	57.21	619.38	2.1514	200.4
240.00	55.77	631.31	2.1749	203.3
250.00	54.42	643.33	2.1981	206.1

Pressure = 2.400 MPa
Saturation temperature = 75.70°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	958.58	314.40	1.3616	257.9
Vapor	136.07	429.27	1.6908	121.4
80.00	127.96	436.42	1.7112	126.9
90.00	114.90	451.12	1.7523	137.0
100.00	105.89	464.44	1.7885	144.8
110.00	99.00	477.04	1.8218	151.5
120.00	93.44	489.22	1.8532	157.2
130.00	88.79	501.14	1.8831	162.4
140.00	84.77	512.90	1.9119	167.2
150.00	81.27	524.57	1.9398	171.6
160.00	78.15	536.20	1.9670	175.7
170.00	75.35	547.82	1.9935	179.6
180.00	72.81	559.45	2.0195	183.3
190.00	70.48	571.11	2.0449	186.8
200.00	68.34	582.82	2.0699	190.2
210.00	66.36	594.58	2.0945	193.4
220.00	64.51	606.41	2.1188	196.6
230.00	62.79	618.31	2.1427	199.6
240.00	61.18	630.29	2.1662	202.5
250.00	59.66	642.35	2.1895	205.4

Pressure = 2.600 MPa
Saturation temperature = 79.41°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	931.88	321.29	1.3806	238.2
Vapor	152.12	429.08	1.6863	118.3
80.00	150.48	430.22	1.6895	119.3
90.00	131.08	446.81	1.7359	131.7
100.00	119.15	461.03	1.7745	140.8
110.00	110.50	474.19	1.8093	148.1
120.00	103.72	486.75	1.8417	154.4
130.00	98.17	498.96	1.8724	160.0
140.00	93.46	510.94	1.9017	165.0
150.00	89.39	522.79	1.9301	169.7
160.00	85.80	534.57	1.9576	174.0
170.00	82.59	546.30	1.9844	178.1
180.00	79.70	558.04	2.0106	181.9
190.00	77.07	569.79	2.0362	185.5
200.00	74.65	581.57	2.0614	189.0
210.00	72.43	593.40	2.0861	192.4
220.00	70.36	605.29	2.1105	195.6
230.00	68.44	617.24	2.1345	198.8
240.00	66.64	629.27	2.1581	201.8
250.00	64.95	641.37	2.1815	204.8

Pressure = 2.800 MPa
Saturation temperature = 82.90°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	904.29	328.05	1.3990	219.1
Vapor	169.71	428.50	1.6812	115.3
90.00	150.13	441.84	1.7183	125.9
100.00	133.85	457.33	1.7603	136.4
110.00	122.89	471.16	1.7970	144.6
120.00	114.63	484.17	1.8305	151.5
130.00	108.00	496.70	1.8620	157.5
140.00	102.49	508.93	1.8919	162.9
150.00	97.78	520.97	1.9207	167.8
160.00	93.66	532.90	1.9486	172.3
170.00	90.01	544.77	1.9757	176.5
180.00	86.74	556.61	2.0021	180.5
190.00	83.78	568.45	2.0279	184.3
200.00	81.08	580.31	2.0533	187.9
210.00	78.59	592.21	2.0782	191.4
220.00	76.29	604.16	2.1027	194.7
230.00	74.15	616.17	2.1268	198.0
240.00	72.16	628.25	2.1505	201.1
250.00	70.30	640.59	2.1740	204.1

Pressure = 3.000 MPa
Saturation temperatue = 86.20°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	875.30	334.75	1.4171	200.4
Vapor	189.25	427.47	1.6752	112.2
90.00	173.82	435.84	1.6983	119.1
100.00	150.47	453.20	1.7455	131.8
110.00	136.36	467.93	1.7845	141.0
120.00	126.23	481.47	1.8191	148.5
130.00	118.34	494.36	1.8518	155.0
140.00	111.89	506.86	1.8824	160.7
150.00	106.45	519.11	1.9117	165.9
160.00	101.75	531.21	1.9399	170.6
170.00	97.62	543.21	1.9673	175.0
180.00	93.94	555.16	1.9940	179.2
190.00	90.62	567.10	2.0201	183.1
200.00	87.61	579.05	2.0456	186.8
210.00	84.84	591.02	2.0706	190.4
220.00	82.30	603.03	2.0953	193.8
230.00	79.94	615.10	2.1195	197.2
240.00	77.74	627.22	2.1433	200.4
250.00	75.69	639.41	2.1668	203.4
260.00	73.77	651.66	2.1900	206.5
270.00	71.96	664.00	2.2130	209.4
280.00	70.25	676.41	2.2356	212.2
290.00	68.63	688.89	2.2580	215.0
300.00	67.10	701.46	2.2801	217.8

Pressure = 4.000 MPa
Saturation temperature = 100.35°C

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
Saturated				
Liquid	626.95	376.48	1.5272	101.3
Vapor	396.29	404.57	1.6024	93.4
110.00	233.68	446.28	1.7131	119.8
120.00	199.79	465.29	1.7621	132.5
130.00	179.83	481.11	1.8018	142.0
140.00	165.73	495.51	1.8371	149.7
150.00	154.89	509.13	1.8697	156.4
160.00	146.10	522.25	1.9004	162.4
170.00	138.74	535.07	1.9296	167.8
180.00	132.41	547.69	1.9578	172.7
190.00	126.88	560.17	1.9850	177.4
200.00	121.97	572.58	2.0115	181.7
210.00	117.55	584.95	2.0374	185.8
220.00	113.56	597.30	2.0627	189.7
230.00	109.90	609.66	2.0875	193.4
240.00	106.55	622.05	2.1119	197.0
250.00	103.44	634.47	2.1359	200.5
260.00	100.56	646.93	2.1595	203.8
270.00	97.87	659.45	2.1827	207.1
280.00	95.35	672.03	2.2057	210.2
290.00	92.98	684.67	2.2283	213.3
300.00	90.75	697.38	2.2507	216.2

Pressure = 6.00 MPa
Saturation temperature = n/a (supercritical)

Temp,* °C	Density, kg/m³	Enthalpy, kJ/kg	Entropy, kJ/(kg·K)	Vel. Sound, m/s
110.00	762.66	375.61	1.5174	173.8
120.00	591.77	405.75	1.5950	127.4
130.00	418.90	439.87	1.6807	120.4
140.00	333.91	465.19	1.7428	130.1
150.00	289.37	484.69	1.7894	139.9
160.00	260.70	501.52	1.8288	148.3
170.00	239.96	516.92	1.8639	155.7
180.00	223.87	531.45	1.8963	162.2
190.00	210.82	545.43	1.9269	168.1
200.00	199.88	559.04	1.9559	173.6
210.00	190.50	572.39	1.9839	178.6
220.00	182.31	585.57	2.0109	183.4
230.00	175.06	598.64	2.0371	187.8
240.00	168.56	611.63	2.0626	192.1
250.00	162.68	624.57	2.0876	196.2
260.00	157.33	637.50	2.1121	200.0
270.00	152.41	650.45	2.1361	203.8
280.00	147.88	663.38	2.1598	207.4
290.00	143.67	676.35	2.1830	210.9
300.00	139.75	689.36	2.2059	214.3

*Temperatures are on the ITS-90 scale

Table B.4 Standard Designation of Refrigerants (ASHRAE *Standard* 34)**

Refrigerant Number	Chemical Name or Composition (% by mass)	Chemical Formula
Methane Series		
10	tetrachloromethane (carbon tetrachloride)	CCl_4
11	trichlorofluoromethane	CCl_3F
12	dichlorodifluoromethane	CCl_2F_2
12B1	bromochlorodifluoromethane	$CBrClF_2$
12B2	dibromodifluoromethane	CBr_2F_2
13	chlorotrifluoromethane	$CClF_3$
13B1	bromotrifluoromethane	$CBrF_3$
14	tetrafluoromethane (carbon tetrafluoride)	CF_4
20	trichloromethane (chloroform)	$CHCl_3$
21	dichlorofluoromethane	$CHCl_2F$
22	chlorodifluoromethane	$CHClF_2$
22B1	bromodifluoromethane	$CHBrF_2$
23	trifluoromethane	CHF_3
30	dichloromethane (methylene chloride)	CH_2Cl_2
31	chlorofluoromethane	CH_2ClF
32	difluoromethane (methylene fluoride)	CH_2F_2
40	chloromethane (methyl chloride)	CH_3Cl
41	fluoromethane (methyl fluoride)	CH_3F
50	methane	CH_4
Ethane Series		
110	hexachloroethane	CCl_3CCl_3
111	pentachlorofluoroethane	CCl_3CCl_2F
112	1,1,2,2-tetrachloro-1,2-difluoroethane	CCl_2FCCl_2F
112a	1,1,1,2-tetrachloro-2,2-difluoroethane	CCl_3CClF_2
113	1,1,2-trichloro-1,2,2-trifluoroethane	CCl_2FCClF_2
113a	1,1,1-trichloro-2,2,2-trifluoroethane	CCl_3CF_3
114	1,2-dichloro-1,1,2,2-tetrafluoroethane	$CClF_2CClF_2$
114a	1,1-dichloro-1,2,2,2-tetrafluoroethane	CCl_2FCF_3
114B2	1,2-dibromo-1,1,2,2-tetrafluoroethane	$CBrF_2CBrF_2$
115	chloropentafluoroethane	$CClF_2CF_3$
116	hexafluoroethane	CF_3CF_3
120	pentachloroethane	$CHCl_2CCl_3$
123	2,2-dichloro-1,1,1-trifluoroethane	$CHCl_2CF_3$
123a	1,2-dichloro-1,1,2-trifluoroethane	$CHClFCClF_2$
124	2-chloro-1,1,1,2-tetrafluoroethane	$CHClFCF_3$
124a	1-chloro-1,1,2,2-tetrafluoroethane	CHF_2CClF_2
125	pentafluoroethane	CHF_2CF_3
133a	2-chloro-1,1,1-trifluoroethane	CH_2ClCF_3
134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3
140a	1,1,1-trichloroethane (methyl chloroform)	CH_3CCl_3
141b	1,1-dichloro-1-fluoroethane	CCl_2FCH_3
142b	1-chloro-1,1-difluoroethane	$CClF_2CH_3$
143a	1,1,1-trifluoroethane	CF_3CH_3
150a	1,1-dichloroethane	$CHCl_2CH_3$
152a	1,1-difluoroethane	CHF_2CH_3
160	chloroethane (ethyl chloride)	CH_3CH_2Cl
170	ethane	CH_3CH_3
Propane Series		
216ca	1,3-dichloro-1,1,2,2,3,3-hexafluoropropane	$CClF_2CF_2CClF_2$
218	octafluoropropane	$CF_3CF_2CF_3$
245cb	1,1,1,2,2-pentafluoropropane	$CF_3CF_2CH_3$
290	propane	$CH_3CH_2CH_3$
Cyclic Organic Compounds		
C316	1,2-dichloro-1,2,3,3,4,4-hexafluorocyclobutane	$C_4Cl_2F_6$
C317	chloroheptafluorocyclobutane	C_4ClF_7
C318	octafluorocyclobutane	C_4F_8
Zeotropic Blends (% by mass)		
400	R-12/114 (must be specified)	
401A	R-22/152a/124 (53/13/34)	
401B	R-22/152a/124 (61/11/28)	
401C	R-22/152a/124 (33/15/52)	
402A	R-125/290/22 (60/2/38)	
402B	R-125/290/22 (38/2/60)	
Zeotropes (*Continued*)		
403A	R-290/22/218 (5/75/20)	
403B	R-290/22/218 (5/56/39)	
404A	R-125/143a/134a (44/52/4)	
405A	R-22/152a/142b/C318 (45/7/5.5/42.5)	
406A	R-22/600a/142b (55/4/41)	
407A	R-32/125/134a (20/40/40)	
407B	R-32/125/134a (10/70/20)	
407C	R-32/125/134a (23/25/52)	
407D	R-32/125/134a (15/15/70)	
408A	R-125/143a/22 (7/46/47)	
409A	R-22/124/142b (60/25/15)	
409B	R-22/124/142b (65/25/10)	
410A	R-32/125 (50/50)	
410B	R-32/125 (45/55)	
411A	R-1270/22/152a (1.5/87.5/11.0)	
411B	R-1270/22/152a (3/94/3)	
412A	R-22/218/142b (70/5/25)	
Azeotropic Blends (% by mass)		
500	R-12/152a (73.8/26.2)	
501	R-22/12 (75.0/25.0)*	
502	R-22/115 (48.8/51.2)	
503	R-23/13 (40.1/59.9)	
504	R-32/115 (48.2/51.8)	
505	R-12/31 (78.0/22.0)*	
506	R-31/114 (55.1/44.9)	
507A	R-125/143a (50/50)	
508A	R-23/116 (39/61)	
508B	R-23/116 (46/54)	
509A	R-22/218 (44/56)	
Miscellaneous Organic Compounds		
Hydrocarbons		
600	butane	$CH_3CH_2CH_2CH_3$
600a	2-methyl propane (isobutane)	$CH(CH_3)_3$
Oxygen Compounds		
610	ethyl ether	$C_2H_5OC_2H_5$
611	methyl formate	$HCOOCH_3$
Sulfur Compounds		
620	(Reserved for future assignment)	
Nitrogen Compounds		
630	methyl amine	CH_3NH_2
631	ethyl amine	$C_2H_5NH_2$
Inorganic Compounds		
702	hydrogen	H_2
704	helium	He
717	ammonia	NH_3
718	water	H_2O
720	neon	Ne
728	nitrogen	N_2
732	oxygen	O_2
740	argon	Ar
744	carbon dioxide	CO_2
744A	nitrous oxide	N_2O
764	sulfur dioxide	SO_2
Unsaturated Organic Compounds		
1112a	1,1-dichloro-2,2-difluoroethene	$CCl_2{=}CF_2$
1113	1-chloro-1,2,2-trifluoroethene	$CClF{=}CF_2$
1114	tetrafluoroethene	$CF_2{=}CF_2$
1120	trichloroethene	$CHCl{=}CCl_2$
1130	1,2-dichloroethene (trans)	$CHCl{=}CHCl$
1132a	1,1 difluoroethene (vinylidene fluoride)	$CF_2{=}CH_2$
1140	1-chloroethene (vinyl chloride)	$CHCl{=}CH_2$
1141	1-fluoroethene (vinyl fluoride)	$CHF{=}CH_2$
1150	ethene (ethylene)	$CH_2{=}CH_2$
1270	propene (propylene)	$CH_3CH{=}CH_2$

*The exact composition of this azeotrope is in question

** (ASHRAE, 1997)

Table B.5Physical Propert es of Selected Refrigerants[a] **

Refrigerant		Chemical Formula	Molecular Mass	Boiling Pt. (NBP) at 101.325 kPa, °C	Freezing Point, °C	Critical Temperature, °C	Critical Pressure, kPa	Critical Volume, L/kg	Refractive Index of Liquid[b,c]
No.	Chemical Name or Composition (% by mass)								
704	Helium	He	4.0026	−268.9	None	−267.9	228.8	14.43	1.021 (NBP) 546.1 nm
702p	Hydrogen, para	H_2	2.0159	−252.9	−259.3	−240.2	1292	31.82	1.09 (NBP)[f]
702n	Hydrogen, normal	H_2	2.0159	−252.8	−259.2	−239.9	1315	33.21	1.097 (NBP) 579.1 nm
720	Neon	Ne	20.183	−246.1	−248.6	−228.7	3397	2.070	—
728	Nitrogen	N_2	28.013	−195.8	−210	−146.9	3396	3.179	1.205 (83 K) 589.3 nm
729	Air	—	28.97	−194.3	—	−140.53 −140.6	3785 3764	3.31 3.126	
740	Argon	Ar	39.948	−185.86	−189.3	−122.49	4860	1.88	1.233 (84 K) 589.3 nm
732	Oxygen	O_2	31.9988	−182.962	−218.8	−118.569	5042.9	2.293	1.221 (92 K) 589.3 nm
50	Methane	CH_4	16.04	−161.5	−182.2	−82.5	4638	6.181	
14	Tetrafluoromethane	CF_4	88.01	−127.9	−184.9	−45.7	3741	1.598	
1150	Ethylene	C_2H_4	28.05	−103.7	−169	9.3	5114	4.37	1.363 (−100)[1]
744A[2]	Nitrous oxide	N_2O	44.02	−89.5	−102	36.5	7221	2.216	
170	Ethane	C_2H_6	30.07	−88.8	−183	32.2	4891	5.182	
503	R-23/13 (40.1/59.9)	—	87.5	−88.7	—	19.5	4182	2.035	
23	Trifluoromethane	CHF_3	70.02	−82.1	−155	25.6	4833	1.942	
13	Chlorotrifluoromethane	$CClF_3$	104.47	−81.4	−181	28.8	3865	1.729	1.146 (25)[4]
744	Carbon dioxide	CO_2	44.01	−78.4[d]	−56.6[e]	31.1	7372	2.135	1.195 (15)
13B1	Bromotrifluoromethane	$CBrF_3$	148.93	−57.75	−168	67.0	3962	1.342	1.239 (25)[4]
504	R-32/115 (48.2/51.8)	—	79.2	−57.2	—	66.4	4758	2.023	
32	Difluoromethane	CH_2F_2	52.02	−51.8	−136	78.4	5830	2.326	
125	Pentafluoroethane	C_2HF_5	120.03	−48.57	−103.15	66.3	3630.6	—	—
1270	Propylene	C_3H_6	42.09	−47.7	−185	91.8	4618	4.495	1.3640 (−50)[1]
502[5]	R-22/115 (48.8/51.2)	—	111.63	−45.4	—	82.2	4075	1.785	
290	Propane	C_3H_8	44.10	−42.09	−187.7	96.70	4248	4.53	1.3397 (−42)
22	Chlorodifluoromethane	$CHClF_2$	86.48	−40.76	−160	96.0	4974	1.904	1.234 (25)[4]
115	Chloropentafluoroethane	$CClF_2CF_3$	154.48	−39.1	−106	79.9	3153	1.629	1.221 (25)[4]
500	R-12/152a (73.8/26.2)	—	99.31	−33.5	−159	105.5	4423	2.016	
717	Ammonia	NH_3	17.03	−33.3	−77.7	133.0	11417	4.245[d]	1.325 (16.5)
12	Dichlorodifluoromethane	CCl_2F_2	120.93	−29.79	−158	112.0	4113	1.792	1.288 (25)[4]
134a	Tetrafluoroethane	CF_3CH_2F	102.03	−26.16	−96.6	101.1	4067	1.81	—
152a	Difluoroethane	CHF_2CH_3	66.05	−25.0	−117	113.5	4492	2.741	
40[2]	Methyl chloride	CH_3Cl	50.49	−12.4	−97.8	143.1	6674	2.834	
124	Chlorotetrafluoroethane	$CHClFCF_3$	136.47	−13.19	−199.15	122.5	3660	—	—
600a	Isobutane	C_4H_{10}	58.13	−11.73	−160	135.0	3645	4.526	1.3514 (−25)[1]
764[6]	Sulfur dioxide	SO_2	64.07	−10.0	−75.5	157.5	7875	1.910	
142b	Chlorodifluoroethane	$CClF_2CH_3$	100.5	−9.8	−131	137.1	4120	2.297	
630[6]	Methyl amine	CH_3NH_2	31.06	−6.7	−92.5	156.9	7455		1.432 (17.5)
C318	Octafluorocyclobutane	C_4F_8	200.04	−5.8	−41.4	115.3	2781	1.611	
600	Butane	C_4H_{10}	58.13	−0.5	−138.5	152.0	3794	4.383	1.3562 (−15)[1]
114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	170.94	3.8	−94	145.7	3259	1.717	1.294 (25)
21[7]	Dichlorofluoromethane	$CHCl_2F$	102.92	8.9	−135	178.5	5168	1.917	1.332 (25)[4]
160[2]	Ethyl chloride	C_2H_5Cl	64.52	12.4	−138.3	187.2	5267	3.028	
631[6]	Ethyl amine	$C_2H_5NH_2$	45.08	16.6	−80.6	183.0	5619		
11	Trichlorofluoromethane	CCl_3F	137.38	23.82	−111	198.0	4406	1.804	1.362 (25)[4]
123	Dichlorotrifluoroethane	$CHCl_2CF_3$	152.93	27.87	−107.15	183.79	3674	—	—
611[6]	Methyl formate	$C_2H_4O_2$	60.05	31.8	−99	214.0	5994	2.866	
141b	Dichlorofluoroethane	CCl_2FCH_3	116.95	32	—	204.2	4250	—	
610[6]	Ethyl ether	$C_4H_{10}O$	74.12	34.6	−116.3	194.0	3603	3.790	1.3526 (20)
216ca	Dichlorohexafluoropropane	$C_3Cl_2F_6$	220.93	35.69	−125.4	180.0	2753	1.742	
30[6]	Methylene chloride	CH_2Cl_2	84.93	40.2	−97	237.0	6077		1.4244 (20)[3]
113	Trichlorotrifluoroethane	CCl_2FCClF_2	187.39	47.57	−35	214.1	3437	1.736	1.357 (25)[4]
1130[6]	Dichloroethylene	$CHCl{=}CHCl$	96.95	47.8	−50	243.3	5478		
1120[6]	Trichloroethylene	$CHCl{=}CCl_2$	131.39	87.2	−73	271.1	5016		1.4782 (20)[3]
718[6]	Water	H_2O	18.02	100	0	373.99	22064	3.11	

Notes:

[a] Data from ASHRAE *Thermodynamic Properties of Refrigerants* (Stewart et al. 1986) or from McLinden (1990), unless otherwise noted.

[b] Temperature of measurement (Celsius, unless kelvin is noted) is shown in parentheses. Data from CRC *Handbook of Chemistry and Physics* (CRC 1987), unless otherwise noted.

[c] For the sodium D line.

[d] Sublimes.

[e] At 527 kPa.

[f] Dielectric constant data.

** (ASHRAE, 1997)

References:

[1] Kirk and Othmer (1956).

[2] *Matheson Gas Data Book* (1966).

[3] Electrochemicals Department, E.I. duPont de Nemours & Co.

[4] *Bulletin* B-32A (duPont).

[5] *Bulletin* T-502 (duPont 1980).

[6] *Handbook of Chemistry* (1967).

[7] *Bulletin* G-1 (duPont).

[8] CRC *Handbook of Chemistry and Physics* (CRC 1987).

Table B.6 Velocity of sound in Refrigerant Vapors[a]**

Refrigerant	Pressure, kPa	Temperature, ° C		
		10	50	100
		Velocity of Sound, m/s		
11	100	b	144	156
12	100	144	155	167
22	100	176	188	201
113	100	b	120	130
114	100	118	127	137
502	100	151	162	173
123	100	b	134	145
124	100	134	144	155
125	100	145	155	166
134a	100	157	169	181
12	1000	b	138	156
22	1000	b	173	193
502	1000	129	148	166
124	1000	b	b	140
125	1000	b	141	159
134a	1000	b	149	170
12	1500	b	b	148
22	1500	b	164	187
502	1500	b	138	159
125	1500	b	133	155
134a	1500	b	b	163

[a] Below saturation temperature

** (ASHRAE, 1997)

Table B.7 Latent Heat of Vaporization Versus Boiling Point**

Refrigerant No.	Refrigerant Chemical Name or Composition (% by mass)	Normal Boiling Pt., °C	Latent Heat λ at NBP, kJ/kg·mol	Trouton Constant λ/K^b	Ref.
717	Ammonia	−33.3	23 343	97.32	1
630	Methyl amine^a	−5.0	25 914	96.64	4
764	Sulfur dioxide	−10.2	24 900	94.69	2
631	Ethyl amine	20.0	27 086	92.40	4
611	Methyl formate^a	37.8	28 131	90.47	4
134a	Tetrafluoroethane	−26.15	22 160	89.77	5
504	R-32/115 (48.2/51.8)	−57.2	19 264	89.21	1
23	Trifluoromethane	−82.1	17 039	89.19	1
124	Chlorotetrafluoroethane	−13.19	22 654	87.14	5
C318	Octafluorocyclobutane	−5.8	23 298	87.14	1
21	Dichlorofluoromethane	8.8	24 556	87.09	3
22	Chlorodifluoromethane	−40.8	20 207	86.97	1
40	Methyl chloride	−23.8	21 644	86.80	3
123	Dichlorotrifluoroethane	27.87	26 005	86.43	5
506	R-31/114 (55.1/44.9)	−12.3	22 431	85.99	3
125	Pentafluoroethane	−48.57	19 276	85.89	5
113	Trichlorotrifluoroethane	47.6	27 513	85.78	1
152a	Difluoroethane	−25.0	21 039	84.78	1
502	R-22/115 (48.8/51.2)	−45.5	19 258	84.59	1
114	Dichlorotetrafluoroethane	3.8	23 273	84.03	1
216ca	Dichlorohexafluoropropane	35.7	25 943	84.00	1
505	R-12/31 (78.0/22.0)^c	−29.9	20 319	83.53	3
11	Trichlorofluoromethane	23.8	24 768	83.41	1
500	R-12/152a (73.8/26.2)	−33.5	19 975	83.35	1
14	Tetrafluoromethane	−127.9	11 969	82.40	1
30	Methylene chloride^a	48.9	26 511	82.32	4
600	Butane	−0.5	22 425	82.25	1
13B1	Bromotrifluoromethane	−57.8	17 695	82.17	1
12	Dichlorodifluoromethane	−29.8	19 982	82.11	1
142b	Chlorodifluoroethane	−9.8	21 624	82.11	1
115	Chloropentafluoroethane	−39.1	19 178	81.94	1
1270	Propylene	−47.7	18 448	81.83	1
503	R-23/13 (40.1/59.9)	−87.8	15 080	81.36	1
600a	Isobutane	−11.7	21 174	80.99	1
13	Chlorotrifluoromethane	−81.4	15 515	80.9[illegible]	1
290	Propane	−42.1	18 669	80.80	1
1150	Ethylene	−103.7	13 475	79.52	1
170	Ethane	−88.8	14 645	79.44	1
50	Methane	−161.5	8 191	73.36	1

Notes:

[a] Not at normal atmospheric pressure.

[b] Normal boiling temperatures.

[c] The exact composition of this azeotrope is in question.

References:

1 ASHRAE *Thermodynamic Properties of Refrigerants* (Stewart et al. 1986)
2 CRC *Handbook of Chemistry and Physics* (CRC 1967).
3 ASHRAE (1977).
4 *Chemical Engineer's Handbook* (1973).
5 NIST Standard Reference Database 23.

** (ASHRAE, 1997)

Table B.8Comparative Refrigerant Performance per Kilowatt of Refrigeration[a] **

Refrigerant No.	Chemical Name or Composition (% by mass)	Evaporator Pressure, MPa	Condenser Pressure, MPa	Compression Ratio	Net Refrigerating Effect, kJ/kg	Refrigerant Circulated, kg/s	Liquid Circulated, L/s	Specific Volume of Suction Gas, m³/kg	Compressor Displacement, L/s	Power Consumption, kW	Coefficient of Performance	Comp. Discharge Temp., K
170	Ethane	1.623	4.637	2.86	162.44	0.00616	0.0232	0.0335	0.206	0.364	2.74	324
744	Carbon dioxide	2.291	7.208	3.15	134.24	0.00745	0.0123	0.0087	0.065	0.338	2.96	343
13B1	Bromotrifluoromethane	0.536	1.821	3.39	66.14	0.01512	0.0101	0.0237	0.358	0.274	3.65	313
125	Pentafluoroethane	0.400	1.570	3.93	87.76	0.01139	0.0098	0.0394	0.449	0.272	3.68	315
1270	Propylene	0.362	1.304	3.60	286.48	0.00349	0.0070	0.1285	0.449	0.197	5.07	354
290	Propane	0.291	1.077	3.71	279.88	0.00357	0.0074	0.1542	0.551	0.211	4.74	320
502	R-22/115 (48.8/51.2)	0.349	1.319	3.78	104.39	0.00958	0.0080	0.0500	0.479	0.226	4.43	310
22	Chlorodifluoromethane	0.296	1.192	4.03	162.46	0.00616	0.0053	0.0774	0.476	0.210	4.75	326
717	Ammonia	0.236	1.164	4.94	1102.23	0.00091	0.0015	0.5106	0.463	0.207	4.84	371
500	R-12/152a (73.8/26.2)	0.214	0.879	4.11	140.95	0.00709	0.0062	0.0938	0.665	0.213	4.69	314
12	Dichlorodifluoromethane	0.183	0.745	4.07	116.58	0.00858	0.0066	0.0914	0.784	0.213	4.69	311
134a	Tetrafluoroethane	0.160	0.770	4.81	150.71	0.00664	0.0056	0.1224	0.812	0.226	4.42	316
124	Chlorotetrafluoroethane	0.090	0.440	4.89	118.49	0.00844	0.0063	0.1705	1.439	0.224	4.47	305
600a	Isobutane	0.089	0.407	4.60	262.84	0.00380	0.0070	0.4029	1.533	0.220	4.55	318
600	Butane	0.056	0.283	5.05	292.01	0.00342	0.0060	0.6641	2.274	0.214	4.68	318
114	Dichlorotetrafluoroethane[b]	0.047	0.252	5.41	99.19	0.01008	0.0070	0.2700	2.722	0.225	4.44	303
11	Trichlorofluoromethane	0.020	0.126	6.24	156.22	0.00640	0.0044	0.7641	4.891	0.196	5.09	313
123	Dichlorotrifluoroethane	0.016	0.110	5.50	142.30	0.00703	0.0045	0.8853	6.221	0.229	4.36	301
113	Trichlorotrifluoroethane[b]	0.007	0.054	7.84	127.34	0.00785	0.0051	1.6793	13.187	0.173	5.77	303

Notes: [a]Based on 258 K evaporation and 303 K condensation. [b]Saturated suction except R-113 and R-114. Enough superheat was added to give saturated discharge.

** (ASHRAE, 1997)

Table B.9 Comparative Refrigerant Performance per Kilowatt at Various Evaporating and Condensing Temperatures **

Refrigerant No.	Chemical Name or Composition (% by mass)	Suction Temp., K	Evaporator Pressure, MPa	Condenser Pressure, MPa	Compression Ratio	Net Refrigerating Effect, kJ/kg	Refrigerant Circulated, kg/s	Specific Volume of Suction Gas, m³/kg	Compressor Displacement, L/s	Power Consumption, kW
A. 183 K Saturated Evaporating, 0 K Suction Superheat, 233 K Saturated Condensing										
1150	Ethylene	183	0.211	1.446	6.84	330.40	0.00303	0.2422	0.733	0.373
170	Ethane	183	0.093	0.774	8.31	364.21	0.00275	0.5257	1.443	0.347
13	Chlorotrifluoromethane	183	0.062	0.607	9.72	106.49	0.00939	0.2263	2.125	0.358
23	Trifluoromethane	183	0.062	0.706	11.41	184.56	0.00542	0.3438	1.863	0.372
B. 200 K Saturated Evaporating, 0 K Suction Superheat, 238 K Saturated Condensing										
170	Ethane	200	0.212	0.909	4.29	503.14	0.00199	0.2396	0.476	0.168
13	Chlorotrifluoromethane	200	0.156	0.719	4.61	108.17	0.00924	0.0961	0.888	0.237
125	Pentafluoroethane	200	0.026	0.186	7.06	132.08	0.00757	0.5182	3.923	0.226
22	Chlorodifluoromethane	200	0.017	0.132	7.87	211.73	0.00472	1.1347	5.360	0.221
23	Trifluoromethane	200	0.165	0.847	5.13	185.66	0.00539	0.1373	0.740	0.242
C. 213 K Saturated Evaporating, 0 K Suction Superheat, 258 K Saturated Condensing										
1150	Ethylene	213	0.755	2.859	3.79	272.31	0.00367	0.0729	0.268	0.314
170	Ethane	213	0.377	1.623	4.31	322.65	0.00310	0.1430	0.443	0.279
23	Trifluoromethane	213	0.311	1.628	5.23	162.02	0.00617	0.0756	0.467	0.296
13	Chlorotrifluoromethane	213	0.282	1.325	4.70	91.63	0.01091	0.0549	0.600	0.293
13B1	Bromotrifluoromethane	213	0.091	0.536	5.91	87.86	0.01138	0.1269	1.444	0.266
125	Pentafluoroethane	213	0.056	0.404	7.20	117.76	0.00849	0.2561	2.175	0.271
290	Propane	213	0.042	0.291	6.91	342.79	0.00292	0.9343	2.726	0.254
22	Chlorodifluoromethane	213	0.037	0.296	7.90	195.80	0.00511	0.5364	2.740	0.253
717	Ammonia	213	0.022	0.234	10.83	1257.09	0.0028	4.7738	13.367	0.93
12	Dichlorodifluoromethane	213	0.023	0.183	8.09	138.57	0.00722	0.6396	4.615	0.248
134a	Tetrafluoroethane	213	0.016	0.163	10.36	131.64	0.01935	1.0904	21.1	0.881
D. 233 K Saturated Evaporating, 0 K Suction Superheat, 293 K Saturated Condensing										
744	Carbon dioxide	233	1.005	5.726	5.70	179.50	0.00557	0.0383	0.213	0.469
13B1	Bromotrifluoromethane	233	0.220	1.433	6.33	66.97	0.01493	0.0557	0.831	0.394
125	Pentafluoroethane	233	0.150	1.202	8.03	87.16	0.01147	0.1021	1.171	0.416
290	Propane	233	0.110	0.835	7.57	277.61	0.00360	0.3821	1.376	0.354
22	Chlorodifluoromethane	233	0.105	0.910	8.65	164.21	0.00609	0.2048	1.247	0.341
717	Ammonia	233	0.071	0.853	11.99	1131.45	0.0031	1.5860	4.9167	1.175
500	R-12/152a (73.8/26.2)	233	0.076	0.668	8.85	140.03	0.00714	0.2491	1.779	0.336
12	Dichlorodifluoromethane	233	0.064	0.567	8.84	114.91	0.00870	0.2425	2.112	0.339
134a	Tetrafluoroethane	233	0.051	0.569	11.23	146.95	0.02392	0.3645	8.7167	1.191

Table B.10 Comparison of Safety Group Classifications in ASHRAE *Standard* 34-1989 and ASHRAE *Standard* 34-1992 **

Refrigerant Number	Chemical Formula	Safety Group	
		Old	New
10	CCl_4	2	B1
11	CCl_3F	1	A1
12	CCl_2F_2	1	A1
13	$CClF_3$	1	A1
13B1	$CBrF_3$	1	A1
14	CF_4	1	A1
21	$CHCl_2F$	2	B1
22	$CHClF_2$	1	A1
23	CHF_3		A1
30	CH_2Cl_2	2	B2
32	CH_2F_2		A2
40	CH_3Cl	2	B2
50	CH_4	3a	A3
113	CCl_2FCClF_2	1	A1
114	$CClF_2CClF_2$	1	A1
115	$CClF_2CF_3$	1	A1
116	CF_3CF_3		A1
123	$CHCl_2CF_3$		B1
124	$CHClFCF_3$		A1
125	CHF_2CF_3		A1
134a	CF_3CH_2F		A1
142b	$CClF_2CH_3$	3b	A2
143a	CF_3CH_3		A2
152a	CHF_2CH_3	3b	A2
170	CH_3CH_3	3a	A3
218	$CF_3CF_2CF_3$		A1
290	$CH_3CH_2CH_3$	3a	A3
C318	C_4F_8	1	A1
400	R-12/114 (must be specified)	1	A1/A1
500	R-12/152a (73.8/26.2)	1	A1
501	R-22/12 (75.0/25.0)*	1	A1
502	R-22/115 (48.8/51.2)	1	A1
507A	R-125/143a (50/50)		A1
508A	R-23/116 (39/61)		A1
508B	R-23/116 (46/54)		A1/A1
509A	R-22/218 (44/56)		A1
600	$CH_3CH_2CH_2CH_3$	3a	A3
600a	$CH(CH_3)_3$	3a	A3
611	$HCOOCH_3$	2	B2
702	H_2		A3
704	He		A1
717	NH_3	2	B2
718	H_2O		A1
720	Ne		A1
728	N_2		A1
740	Ar		A1
744	CO_2	1	A1
764	SO_2	2	B1
1140	$CHCl=CH_2$		B3
1150	$CH_2=CH_2$	3a	A3
1270	$CH_3CH=CH_2$	3a	A3

*The exact composition of this azeotrope is in question.

** (ASHRAE, 1997)

Table B.9 Comparative Refrigerant Performance per Kilowatt at Various Evaporating and Condensing Temperatures (Conclu

Refrigerant		Suction Temp., K	Evaporator Pressure, MPa	Condenser Pressure, MPa	Compression Ratio	Net Refrigerating Effect, kJ/kg	Refrigerant Circulated, kg/s	Specific Volume of Suction Gas, m³/kg	Compressor Displacement, L/s	Pow Cons tio kW
No.	Chemical Name or Composition (% by mass)									
E. 250 K Saturated Evaporating, 0 K Suction Superheat, 310 K Saturated Condensing										
123	Dichlorotrifluoroethane	250	0.01	0.139	13.5	130.4	0.02695	1.3080	35.25	1.0
11	Trichlorofluoromethane	250	0.013	0.156	11.73	144.62	0.0243	1.1248	27.333	1.0
124	Chlorotetrafluoroethane	250	0.062	0.543	8.74	105.75	0.00946	0.2379	2.250	0.3
134a	Tetrafluoroethane	250	0.115	0.934	8.09	133.	0.0264	0.1678	4.433	1.1
12	Dichlorodifluoromethane	250	0.134	0.891	6.64	105.80	0.00945	0.1221	1.154	0.3
717	Ammonia	250	0.165	1.423	8.63	1077.23	0.00327	0.7245	2.367	1.0
22	Chlorodifluoromethane	250	0.218	1.390	6.37	150.09	0.00666	0.1033	0.688	0.3
502	R-22/115 (48.8/51.2)	250	0.260	1.563	6.01	91.91	0.01088	0.0662	0.720	0.3
125	Pentafluoroethane	250	0.301	1.867	6.21	73.70	0.01357	0.0525	0.712	0.44
F. 250 K Saturated Evaporating, 41 K Suction Superheat (Not Included in Refrigeration Effect), 310 K Saturated Condensing										
123	Dichlorotrifluoroethane	291	0.01	0.139	13.5	130.4	0.02695	1.5306	41.25	1.2
11	Trichlorofluoromethane	291	0.013	0.156	11.73	144.62	0.0243	1.3141	31.933	1.1
124	Chlorotetrafluoroethane	291	0.062	0.543	8.74	105.75	0.00946	0.2800	2.648	0.39
134a	Tetrafluoroethane	291	0.115	0.934	8.09	133.	0.02642	0.2	5.283	1.37
12	Dichlorodifluoromethane	291	0.134	0.891	6.64	105.80	0.00945	0.1451	1.371	0.39
717	Ammonia	291	0.165	1.423	8.63	1077.23	0.00327	0.8469	2.767	1.2
22	Chlorodifluoromethane	291	0.218	1.390	6.37	150.09	0.00666	0.1237	0.824	0.39
502	R-22/115 (48.8/51.2)	291	0.260	1.563	6.01	91.91	0.01088	0.0796	0.866	0.47
125	Pentafluoroethane	291	0.301	1.867	6.21	73.70	0.01357	0.0636	0.863	0.52
G. 250 K Saturated Evaporating, 41 K Suction Superheat (Included in Refrigeration Effect), 310 K Saturated Condensing										
123	Dichlorotrifluoroethane	291	0.01	0.139	13.5	157.07	0.02238	1.5302	34.25	1.01
11	Trichlorofluoromethane	291	0.013	0.158	11.73	167.61	0.02097	1.3140	27.55	1.02
124	Chlorotetrafluoroethane	291	0.062	0.543	8.74	133.95	0.00747	0.2800	2.090	0.312
134a	Tetrafluoroethane	291	0.115	0.934	8.09	166.58	0.0211	0.1998	4.217	1.1
12	Dichlorodifluoromethane	291	0.134	0.891	6.64	130.33	0.00767	0.1451	1.113	0.31
717	Ammonia	291	0.164	1.423	8.63	1162.31	0.00302	0.8508	2.567	1.172
22	Chlorodifluoromethane	291	0.218	1.390	6.37	177.29	0.00564	0.1237	0.698	0.330
502	R-22/115 (48.8/51.2)	291	0.260	1.563	6.01	119.81	0.00835	0.0796	0.665	0.36
125	Pentafluoroethane	291	0.301	1.867	6.21	105.80	0.00945	0.0636	0.601	0.366
H. 266 K Saturated Evaporating, 0 K Suction Superheat, 300 K Saturated Condensing										
125	Pentafluoroethane	266	0.531	1.450	2.73	95.92	0.01043	0.0300	0.313	0.180
290	Propane	266	0.380	1.000	2.63	297.39	0.00336	0.1196	0.402	0.15
22	Chlorodifluoromethane	266	0.394	1.102	2.80	169.42	0.00590	0.0589	0.348	0.15
717	Ammonia	266	0.326	1.061	3.26	1153.86	0.00305	0.3825	1.167	0.51
500	R-12/152a (73.8/26.2)	266	0.286	0.811	2.84	148.54	0.00673	0.0713	0.480	0.15
12	Dichlorodifluoromethane	266	0.244	0.688	2.82	123.22	0.00812	0.0697	0.566	0.15
134a	Tetrafluoroethane	266	0.224	0.703	3.14	157.32	0.02233	0.0896	2.	0.529
124	Chlorotetrafluoroethane	266	0.124	0.405	3.27	126.55	0.00790	0.1249	0.987	0.15
600a	Isobutane	266	0.121	0.374	3.08	281.18	0.00356	0.3008	1.070	0.15
600	Butane	266	0.075	0.258	3.44	310.75	0.00322	0.4701	1.513	0.14
123	Dichlorotrifluoroethane	266	0.024	0.097	4.16	150.04	0.02342	0.6071	14.217	0.5
11	Trichlorofluoromethane	266	0.029	0.112	3.85	161.78	0.02172	0.5434	11.8	0.495
I. 277 K Saturated Evaporating, 0 K Suction Superheat, 310 K Saturated Condensing										
125	Pentafluoroethane	277	0.756	1.867	2.47	87.30	0.01145	0.0211	0.241	0.179
290	Propane	277	0.534	1.275	2.39	281.59	0.00355	0.0461	0.164	0.080
22	Chlorodifluoromethane	277	0.566	1.390	2.46	160.57	0.00623	0.0415	0.258	0.142
717	Ammonia	277	0.494	1.423	2.88	1120.41	0.00313	0.2606	0.817	0.48
500	R-12/152a (73.8/26.2)	277	0.413	1.053	2.55	141.50	0.00707	0.0501	0.354	0.145
12	Dichlorodifluoromethane	277	0.352	0.891	2.53	117.99	0.00848	0.0493	0.417	0.145
134a	Tetrafluoroethane	277	0.336	0.934	2.78	149.15	0.02357	0.0608	1.433	0.5
124	Chlorotetrafluoroethane	277	0.188	0.543	2.89	126.55	0.00790	0.0840	0.663	0.14
600a	Isobutane	277	0.181	0.493	2.73	270.81	0.00369	0.2072	0.765	0.14
600	Butane	277	0.119	0.347	2.91	301.82	0.00331	0.3170	1.050	0.141
11	Trichlorofluoromethane	277	0.047	0.156	3.33	158.67	0.02215	0.3484	7.717	0.46
123	Dichlorotrifluoroethane	277	0.039	0.139	3.57	146.61	0.02397	0.3790	9.083	0.469
113	Trichlorotrifluoroethane	281	0.018	0.070	3.87	118.90	0.00841	0.6785	5.706	0.15

** (ASHRAE, 1997)

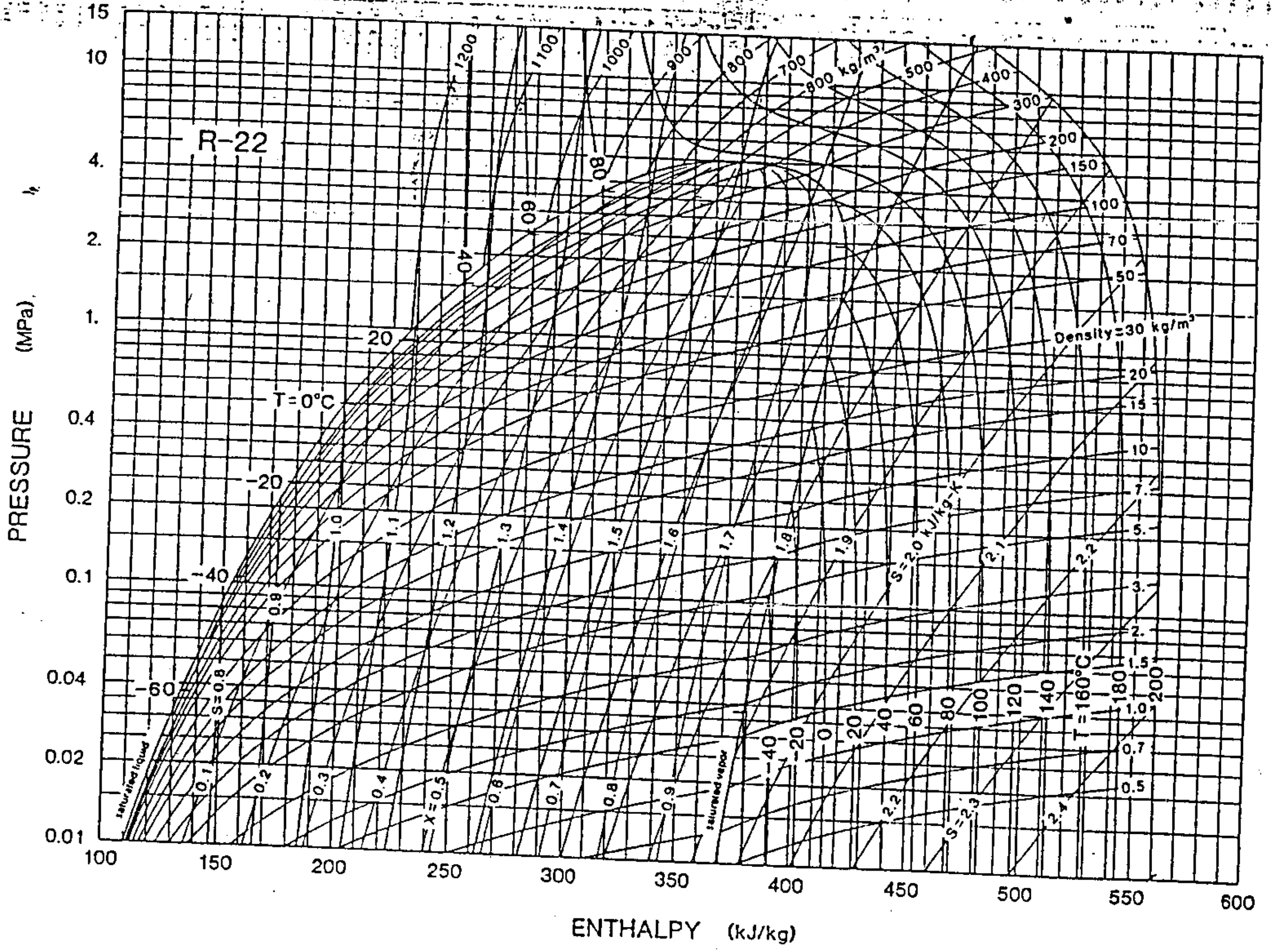
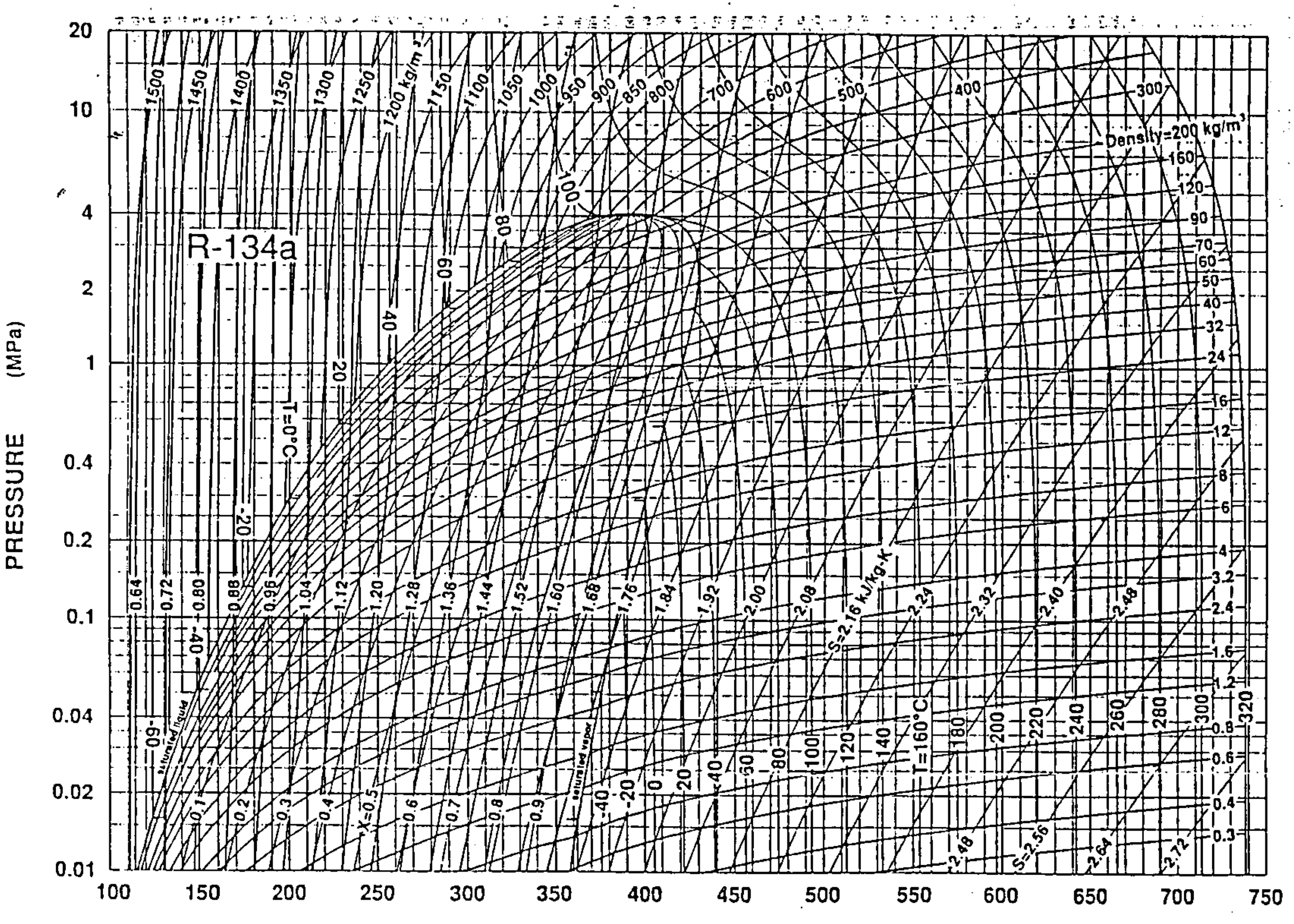


Fig. B.1 Pressure-Enthalpy Diagram for Refrigerant 22**
** (ASHRAE, 1997)



Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho
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Fig. B.2 Pressure–Enthalpy Diagram for Refrigerant 134a**

** (ASHRAE, 1997)

الملخص

دراسة أداء وحدة شباك لتكييف الهواء باستعمال R134a كغاز تبريد بديل

إعداد

خلف الهزل السرحان

اشراف

أ.د. محمد السعد

يهدف هذا البحث بشكل رئيسي إلى فحص عوامل أداء غاز R134a والذي لا يشكل خطرا" على طبقة الأوزون عند استخدامه بديلا" لغاز الفريون ٢٢ في وحدة تكييف قدرة ٥ كيلوواط من نوع النافذة. وتتم مقارنة هذه العوامل بتلك التي للغاز الأصلي لتحديد إمكانية استخدام هذا الغاز بديلا" عن الغاز الأصلي.

تدل نتائج هذا البحث على إمكانية استخدام هذا الغاز بديلا" عن غاز الفريون ٢٢ الأصلي ولحين الموعد المحدد من قبل اعلان مونتريال لوقف انتاج غاز الفريون ٢٢ و لكن بمعامل أداء أقل بحوالي ١٠% و بطاقة تكييف منخفضة بمقدار ٣٥%. حيث تبين أن الشحنة الأفضل تتحقق عند كمية حوالي ٦٦٠ غم من الغاز البديل, حيث يكون عند هذه الشحنة معامل الأداء أفضل ما يمكن وتكون درجات الحرارة الخارجة من المبخر أقرب ما يمكن لتلك الخارجة عند استخدام غاز الفريون٢٢.