THE PERFORMANCE OF SOLAR POWERED AIR CONDITIONING UNIT USING LPG AS REFRIGERANT

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COMMITTEE DECISION

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NOMENCLATURE

COP	: Coefficient of performance
h	: Enthalpy(kJ/kg)
h_m	: Enthalpy of the mixture (kJ/kg)
I	: Current (amp)
$\dot{m}$	: mass flow rate (kg/sec)
P_t	: Total pressure (kPa)
q_e	: Refrigerating Effect (kJ/kg)
Q_e	: Refrigeration Capacity (kW)
T	: Temperature (^{o}C)
T_e	: Evaporation temperature (^{o}C)
T_c	: Condensation temperature (^{o}C)
V	: Volt
W	: Compression work (kJ/kg)
Ø	: Phase angle

SUBSCRIPTS

c	: Condenser
e	: Evaporator
m	: Mixture
t	: Total

ABBREVIATIONS

A/C : Air conditioning

AC : Alternating Current

Ah : Ampere Hour

ASHRAE : American Society of Heating and air conditioning engineers

CFC : Chlorofluorocarbon

DC : Direct current

DOD : Depth of discharge

GWP : Global Warming Potential

HC : Hydrocarbon

HCFC : Hydrochlorofluorocarbon

JD : Jordan Dinar

LPG : Liquefied Petroleum Gas

MPP : Maximum power point

ODP : Ozone Depletion Potential

PV : Photovoltaic cell

SLI : Start Light Ignition

GREEK

η_{vc} : Clearance volumetric efficiency

v_{suc} : Specific volume of vapor entering the compressor (m^3/kg)

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ABSTRACT

The main purpose of this experimental study is to investigate the performance changes of a one ton split air conditioning unit upon replacing R22 with LPG refrigerant and in the same time powered with solar energy instead of mains electricity. It is knowing that A/Cs power consumption have a large share of total building energy sector. The environmental effect of HCFC's on Ozone Depletion necessitates the use of a refrigerant to replace R22.

The performance of one ton split unit powered with solar energy was investigated experimentally. In this work, the refrigerant used first was R22 and then replaced by LPG (a mixture of propane 30% and butane 70%). An inverter using DC from batteries was used to power the usual air conditioning unit. Parameters such as COP, Capacity, mass flow rate of refrigerant and power of the compressor, evaporation temperature $T_{e,}$ and condensing temperature T_c were dependent parameters performance curves for R22 and LPG were presented. Comparisons between those parameters were also made when the solar energy was used as the source of power.

Experimental results show that solar energy system using deep cycle batteries with inverter is an attractive substitute for the mains power; the performance curves indicated an acceptable performance of the unit.

For the high consumption of energy compared with that generated by the 12–PV modules used, cut off and cut in voltage was experienced by the system. Also the results showed that there was no difference in the performance of the unit when using the same refrigerant and changing the source of power from mains to solar power. LPG was found to have lower COP compared to R22 by 40%. The results indicated that using LPG as refrigerant is more suitable than R22 when solar power system is used.

CHAPTER ONE

INTRODUCTION

In 1987, the Montreal Protocol, an international environmental agreement established requirements for the worldwide phase out of ozone depleting HCFCs, so the research in the air conditioning field has been actively engaged to reduce the emission of gases related to the ozone depletion and greenhouse effect and the researchers began to find alternatives refrigerants.

Alternative refrigerants must have suitable physical and thermodynamic properties, chemical and thermal stability, good miscibility with the used lubricant low toxicity and low flammability. Hydrocarbon refrigerants are considered as a good alternative to replace R22.

Many experimental studies were conducted to investigate the performance of HC refrigerants in refrigerators, A/Cs and heat pump systems, and they found that using a mixture of propane (R290) and butane (R600) is the best alternative to replace R22. The only problem is flammability of HC and this may be ignoring when the amount of charge of HC in the system is so small.

This work studies the performance of an air conditioning split unit with one ton capacity when it is powered by solar energy and replacing the refrigerant R22 with a mixture of propane (R290) and butane (R600) called LPG experimentally and compares it with the performance of the split unit when using R22 under same conditions. The optimum amount of charge of LPG for a one ton of refrigeration A/C unit was found experimentally. The effect of the variation of power from solar energy on using R22 and HCs mixtures was investigated. The dependent variable were listed as: cooling capacity, refrigeration effect, power, compressor exit temperature, mass flow rate of refrigerant, and COP. Air supply temperature, the evaporation temperature (T_e), condensing temperature (T_c), room temperature and ambient temperature were used as independent variables.

CHAPTER 2

LITERATURE REVIEW

CFCs and HCFCs are widely used as refrigerants in air conditioning and refrigeration system. They provide the characteristics and properties need for good performance. However they are not environmentally friendly as they have a damaging effect on stratosphere ozone layer. This damaging effect was the incentive for scientists and engineers to search for substitutes that do not have those bad effects on environment.

During the last few years several research works have been conducted to study the physical and thermodynamic properties, system performance and environmental effect for different alternative refrigerants.

Here the work of some researchers on the subject of refrigeration and air conditioning and their efforts to find the environmentally safe alternative refrigerants for the used refrigerants will be shown.

Abuzahra (1994) investigated experimentally the performance parameters of methane gas when it replaces R22 in a window-type air conditioning unit of 17000 Btu/h (1.4 ton).The performance parameters investigated in the work are cooling effect, COP, work of compression, mass flow rate per kilowatt of cooling capacity, cooling capacity and the evaporator air outlet temperature. All parameters for the refrigerants used are plotted versus variable values of evaporating temperature and the charge quantity of LPG at constant condenser temperature of 35 ^{o}C. Then these parameters are compared with those of the original refrigerant R22 to decide if it is suitable or not. The unit was charged with 120 g of methane. All measurements were taken at seven different values of T_e. The methane cycle used in that work did not reach the saturation region; it cooled and heated the superheated gas. The results of the work indicated that methane gas cannot be used as alternative refrigerant for R22 in this type of air conditioning units due to compressor overheating which makes the work of compression very high while the cooling effect is very small. This results in a very small value of the coefficient of performance. The liquefied petroleum gas, LPG, is also used in the work as replacement of R22. Six different charge quantities of the LPG were used in the work with 300,400,450,500,550and 600 g for each charge; all measurements were taken at different values of T_e. He concluded that the optimum charge quantity of the LPG is 500 g at which the coefficient of performance is the best and the air temperature coming out from the evaporator is the nearest to that when R22 is used, also as T_e increase the values of q, COP, Q and T_o increase while the value of W and $\dot{m}$ decrease either when R22 or LPG is used.

Purkayastha and Bansal (1997) studied experimentally the performance of hydrocarbon refrigerants propane and liquefied petroleum gas (LPG) mix as suitable replacements for refrigerant R22. Experiments were carried out in a laboratory heat pump refrigeration test apparatus with maximum heating capacity of approximately 15kW. It consists of semi-hermetic compressor, thermostatic expansion valve, a receiver and accumulator. The secondary heat transfer fluid was water in the condenser and glycol-water mixture in the evaporator. The experiments were carried out with R22, HC-290, and LPG mix using the test facility as heat pump varying the evaporating temperature

(-15 to +15 ^{o}C) while maintaining a constant condensing temperature at 35, 45 or 55 ^{o}C. The test data were recorded for each condensing temperature and corresponding evaporator temperature. In the case of a mixture the condensing or evaporating temperature was calculated by averaging the bubble point and dew point temperatures. Their investigated parameters including the COP, volumetric refrigeration capacity, condenser capacity, discharge temperature, power input to the compressor and the mass flow rate of the refrigerant. They found that COP with hydrocarbon refrigerants (HC-290 and the LPG mix) is higher than R22 about 18% and 12% at T_c = 35 ^{o}C and T_e = 3^{o}C, for volumetric refrigeration capacity R22 offer higher volumetric capacity than HC refrigeration, the volumetric capacity of the LPG is higher than HC290 but for condenser capacity HC290 is seen to offer lower condenser capacity than R22 and the LPG mix. Also they found that the discharge temperature with HC-290 and LPG mix was much lower than with R22 over the entire range of operation, for the mass flow rate the refrigerant R22 was higher for about 50% and 44% than HC-290 and the LPG mix. They concluded that HC refrigerants performed better than HCF22 but with small loss of condenser capacity, also they found that the performance of the specific LPG mix was better than HC290 at higher condensing temperature but poorer at a lower condensing temperature. The study reveals that LPG (mixture of propane, ethane and iso-butane) can be a good refrigerant in heat pump refrigeration application.

Hammad and Alsaad (1998) studied experimentally the performances of domestic refrigerator when four ratios of propane, butane and isobutene are used as possible alternative replacements to the traditional R-12 refrigerant. They used domestic refrigerator with capacity 320 l, the compressor used is of reciprocating, hermetically sealed type with displacement volume of 8 cm^{3}. Three type of experiments were performed, the evaporator temperature variation test, the condenser temperature variation test and the cooling rate test. The refrigerator was charged and tested with each of four hydrocarbon mixtures that consist of 100% propane, 75%propane-19.1%butane- 5.9%isobutane, 50% propane -38.3%butane-11.7% isobutene and 25% propane – 57.5% butane- 17.5% isobutene. They investigated the evaporator capacity, the compressor power, the COP and cooling rate characteristics. They found that the hydrocarbon mixture with 50% propane - 38.3% butane - 11.7 % isobutane is the most suitable alternative refrigerant with the best performance among all other hydrocarbon mixtures investigated. Also results show that refrigeration's capacity, mass flow rate, compressor power and COP increase when T_e increases for all mixtures. They concluded that 100% propane mixture has the highest COP values among all hydrocarbons tested; no problems have been encountered with the compressor. Also no degradation of lubricating oil could be detected after the refrigerator worked for about 4000 h using the same oil.

Chang and Kim (1999) investigated experimentally the performance of heat pump system using hydrocarbon refrigerants, single component hydrocarbon refrigerants (propane, isobutene, butane and propylene) and binary mixtures of propane/isobutene and propane/butane are considered as working fluids in a heat pump system and compared with that of R22. They used for the experiment an apparatus which is composed of major components; compressor, condenser, expansion valve and evaporator and auxiliary devices for circulating and controlling the temperature of the secondary heat transfer fluids. The cooling capacity and (COP) at several compressor speeds and as a function of condenser inlet temperatures of the secondary heat transfer fluid are presented. The experimental work showed that cooling capacity increase with increasing the compressor speed while COP decrease, also R1270 has a comparable cooling capacity to R22 and the cooling capacity of R290 is 14% less than that of R22 at a compressor speed of 1100 rpm. R1270 and R290 have a slightly higher COP than R22 while R600a and R600 show lower cooling capacity and COP than R22 with variation of compressor speed. When they represented cooling capacity and COP with condenser inlet temperature they found as the temperature increase the cooling capacity and COP decrease and R1270 and R290 have higher COP than R22 but its lower for R600 and R600a compared of R22. For refrigerant mixtures they found as the concentration of R290 increases the cooling and heating capacity increase. For mass percentage of 50% of R290 in R290/600a mixture the cooling COP is enhanced by about 7% and the maximum increase occur with 11% for R290/600 at composition of 75/25 by mass percentage. They concluded that capacity and COP of R1270 are slightly greater than that of R22 which is an indication of a possible alternative for air conditioning and heat pump application.

Hammad and Tarawnah (2000) studied the performance of 2.5 ton split air conditioning unit when it replaces R22 with mixture of both butane and propane with different ratios. The percentage of propane was used as a variable, COP compressor exit temperature and evaporator pressure were taken as dependent variable. The unit was replaced by five different hydrocarbon mixtures which are 100%, 90%, 70%, 50%, and 40% of propane with percent of butane .The mineral oil, naphthalene based oil, which was used with R22, was also used with the hydrocarbon mixtures. All experiments were performed for the purpose of comparison at constant evaporating temperature around 1 ^{o}C. They found that the mixture of 90% propane gives equal pressure as R22 with higher COP while the mixture of about 60% propane gives equal COP, but lower pressure. The capacity and compressor work decrease with propane percentage increase. Also they investigated that the evaporation pressure increases with the increase of the propane percentage in the mixture, while the R22 evaporation pressure coincides with that of 90% propane mixture. They concluded that all mixtures of propane and butane can be used as possible alternative refrigerants to R22 and 100% propane mixture has the highest COP values among all hydrocarbons. They selected 90% propane mixture to be the most suitable alternative refrigerant to R22 based in both higher COP and equal saturated pressure match without any modifications or adjustments were made to the A/C.

Jawad (2000) studied the performance of domestic refrigerator when R12 was replaced with mixture of propane /butane (50%/50%). The refrigerator was charged with four different charge amounts of the mixture. The performance of the best charge quantity was compared with that for R12. The results showed that the best performance was for 90g charge mass and it gave 15% saving in input power. COP of 4.75 at T_c of 33 ^oC, T_e of -15 ^oC and T_a of 18 ^oC was obtained which is higher than that of R12 by 10.2%. He concluded that hydrocarbon blend of propane/butane (50/50) is an attractive substitute for R12.

Sleiti (2001) developed a computer algorithm to study the performance of two ton split A/C unit working on R407C. The algorithm covered both theoretical and actual vapour-compression cycles. He used Matlab software version 5.1 to build the equations for the following properties, enthalpy, entropy and specific volume in liquid and vapor phases as function of pressure or temperature for saturated properties and as function of pressure and temperature for the superheated properties of the refrigerant. Polynomial of the third order was used for saturation and superheated properties, while a second order polynomial was used to represent the superheated enthalpy. He compared between the theoretical vapor- compression cycles and the actual cycle. Volumetric efficiency, mass flow rate, compressor discharge temperature, refrigeration capacity, compressor, heat rejection rate and COP the parameters were investigated and compared for theoretical and actual cycle. The results shows that the volumetric efficiency increases as T_e increases for constant T_c and decrease as T_c increase for constant T_e and there is a slight difference between the volumetric efficiency of theoretical and actual cycles. Mass flow rate, compressor power, capacity, heat reject and COP increase with increasing T_e but exit temperature reduce. Also exit temperature, compressor power increase with increasing T_c but mass flow rate, capacity, heat rejected and COP decrease as T_c increasing. He concluded that the computational model can be helpful in testing the refrigeration systems using the mixture, the COP trend the same for theoretical and actual cycle with a deviation ranged from 3% to 18% and results indicated that the refrigerant R407C is a suitable replacement for R22 in A/C split unit.

Nofal (2004) studied the performance of chest freezer when a propane/butane mixture is used as substitute refrigerant to R-134a. The best charge quantity is determined and it performance was compared to that of R-134a. The results showed that LPG refrigerant has higher COP than R-134a by 20%, lower refrigeration capacity and slightly lower power consumption. He concluded that it is successful use of LPG mixture as an alternative refrigerant to R-134a in chest freezer.

Devotta et al (2005) studied the performance of a 5.13 kW window air conditioner designed for R22 when it replaced with R-290 (propane). The performance of air conditioner with R-290 is compared with the performance of R22. The air conditioner was tested in a chamber consists of two rooms of equal size, one on evaporator side and the other on condenser side. The conditions of the air in both rooms were done using the dehumidifiers, air heaters and humidifiers for operating in lower and higher conditions. The A/C was charged with R-290 without changing oil in the compressor. Also simulation of computer model "EVAP-COND" was used to determine the capacities of the evaporators and the condenser with R22 and R-290. They concluded that R22 gave a cooling capacity of 5.085 kW for the lower operating conditions and 4.111 kW for the higher operating conditions. For R-290 it was 6.6% lower cooling capacity for the lower operating conditions and 9.7% lower for the higher operating conditions with respect to R-290 .The energy consumed by the system with R-290 was lower for all operation conditions than R22 because of lower pressure ratios for R-290 than R22. The coefficient of performance for R-290 was 7.9% higher for the lower operation conditions and 2.8% higher for the higher operating conditions. The decrease in COP at higher operating conditions is due to decrease in heat transfer rates in the condenser and the compressor performances.R-290 had lower discharge pressures than R22 in the range 13.7-18.2% for all operation conditions and pressure drops of R-290 were lower than R22 for all tests .Also simulation results gave R-290 had lower cooling capacity with range 7.2-13% for all operation conditions and evaporating pressures for R-290 are lower in the range 2.1-3.3% than R22.

Park and Jung (2006) studied the thermodynamic performance of two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), HFC152a and (RE170, DME) in residential air- conditioners. These fluids all have no ozone depletion potential and also offer relatively low GWPs of less than 60 and hence can be used as long term candidates. Heat pump with capacity of 3.5 kW was used in the experiment; the evaporator and condenser were manufactured by connecting eight pieces of pre- manufactured double tube commercial pipes in series. Both evaporator and condenser were designed to be passed through the inner tube while the refrigerant flowed through the annulus; water was used as the secondary fluid for both evaporator and condenser. Various performance characteristics of the refrigerants were measured. Experimental results showed that COPs of all alternative refrigerants are up to 5.7% higher than that of R22 except that the COP of R1270 is 0.7% lower than of R22. Propane showed 11.5% decrease in capacity as compared to R22 while R1270 showed 5.8% increase in capacity. 50%R1270/50%R290 and 60%R290/40%R152a showed almost the same capacity as that of R22.All alternative fluids tested in the study showed 11-17 ^{o}C decrease in compressor discharge temperature and about 55% decrease in charge compared to R22.

Jabaraj et al (2006) studied the possibility of using HFC407C/HC290/HC600a refrigerant mixture as a substitute for R22 in a window air conditioner and to evolve an optimal composition for the mixture. HC blend considered of 45.2% of HC290 and 54.8% of HC600a. They conducted experiments for the mixtures containing 10, 15, 20, and25% HC blend by weight in HFC407C and they referred as M10, M15, M20 and M25. The experimental setup consists of a room calorimeter, a window air conditioner of 1050 W capacity and instruments. The walls of room calorimeter were insulated with glass wool; in order ton maintain the heat infiltration to be less than 5% and inside the room there was a heater with 2 kW capacity to be as source for cooling load . The condenser surface area was increased by 19% for the mixtures to control the increase in discharge pressure and maintained it within 27 bar. The charge quantity, the capillary length and diameter, the mixture composition and the condenser length were the variables in the experiment. The condenser inlet air temperature was varied from 30 ^{o}C to 45 ^{o}C in step of 5 ^{o}C whereas evaporator inlet air temperature was varied from 21 ^{o}C to 29 ^{o}C in step of 2 ^{o}C for each condensing temperature. Firstly the optimal capillary and optimal charge were found for R22 and then the performance study of the system was carried out for various sets of condenser and evaporator inlet air temperatures, secondly the optimal capillary and charge were carried for the mixtures and also the system performance study were repeated with mixtures M10, M15, M20 and M25 . They concluded that COP of M20 is 8.19 to 11.15% higher than that of HCFC22 at various condenser inlet air temperatures and the power consumption of M20 was 2.34 to 10.45% higher than that of R22 also the oil miscibility of M20 with mineral oil is ascertained. So among the mixtures considered M20 would be the best choice for R22 window air conditioners without changing the mineral oil.

This work will concentrate on using solar energy as a source of power to compare the performance of R22 and LPG, an optimum amount of charge of LPG (propane and butane) at 30%, 70% respectively for a 1 Ton of refrigeration A/C unit without modification will be found. The effect of variation of power from solar energy on using R22 and LPG will be investigated. The variation of refrigeration effect, cooling capacity, compressor power, compressor exit temperature, COP, mass flow rate of refrigerant and heat reject with the evaporation temperature and condensing temperature will be investigated

CHAPTER THREE

PHOTOVOLTAIC SYSTEM

3.1 Solar Energy

Solar energy is classified as most important source of renewable energy, while solar energy is not being used as a primary source of fuel energy at the present time, a large research and development were made to develop economical system to harness solar energy and make it a major source of fuel energy, particularly for the heating and cooling of buildings.

3.2 Conversion of Solar Energy

Solar energy can be converted directly into other two forms of energy:

- Thermal process (absorption of solar radiation and conversion of this energy into thermal energy)
- Electrical process (production of electricity by photovoltaic or solar cell)

3.3 Solar Air Conditioning

Solar air conditioning refers to any air conditioning (cooling) system that uses solar power. This can be done through passive solar and active solar such as photovoltaic conversion (sun to electricity), or solar thermal energy conversion

3.4 Solar Collectors

Type of solar energy collection system can classified as:

1) Solar cell that produces DC electricity directly from the electromagnetic energy of the sun
2) The system that produces low temperature thermal energy
3) The system produces high temperature thermal energy to generate electrical energy.

First system was used in this experiment to give the air condition its power, this power is not constant and it changes over the day.

3.5 Types of Solar Cooling

- **Absorption cooling**

  It was the first type of air conditioning used to adjust the indoor climate; it's driven by heat rather than electricity. Absorption is the process of attracting and holding moisture by substances called desiccants. The Desiccant removes most of air's moisture making it seems cooler.

- **Heat engine cooling**

  In this system solar collector are used to heat the working fluid and the working fluid can be used to drive a Rankine cycle heat engine. The system has to be relative large in order to provide a useful amount of cooling

- **Photovoltaic powered cooling**

  In this method, PV is used to generate power for air conditioning systems

3.9 Stand Alone PV systems

Stand alone PV systems are also known as autonomous system. In a typical stand alone PV system the DC electricity produced by the modules is used to charge batteries via solar change controller. If AC mains voltage appliances are to be powered, this is done via an inverter connected directly to the batteries. The inverter used in stand alone systems convert DC electricity to AC

3.9.1 Stand Alone PV system components

- **Modules and arrays**

The PV modules in a stand alone PV system must produce enough electrical energy to power all the electrical appliances system. The PV modules need to be configured to match the system DC voltage, which is determined by the battery. System voltages are usually 12 VDC or 24VDC and on large system 48VDC. The operation voltage of the PV modules in stand alone PV system must be high enough to charge the batteries. A 12 V battery needs a voltage of 14.4 V to charge it. The PV modules must deliver this voltage to the battery after power losses/ voltage drop incurred in cables and across charge controller. For a 12 V battery this is 36 crystalline silicon solar cells and for a 24 V battery this is 72 cells (or 2*36 cell module connected in series) with knowing that each silicon cell produced approximately 0.5-0.6 VDC.

- **Charge Controller**

The function of the charge controller is to protect the battery and ensure that is that it has as long a working life as possible. Batteries are very sensitive to being over discharge and over charging. The main functions of charge controller are to:

1) protect battery from over discharge usually a low voltage disconnect (LVD) disconnect the battery from the loads when battery voltage reaches a level which indicates it has reached a certain depth of discharge
2) Protect the battery from over charging.
3) Prevent current flowing into PV array at night

Charge controllers are rated and sized by the array current and system voltage, so if we have modules produce total current 20 amp to 24 V system we increase the controller amperage by a minimum of 25% because of light reflection and the edge of cloud effect to be the best choosing is 25 amp and 24 volt charge controller. There is no problem going with a 30-amp or larger charge controller but with 24 V controller.

- **Batteries**

The rechargeable batteries in stand alone PV systems need to have large capacity to insure long working lives under conditions of daily charging and dicharging batteries which can do this are known as deep cycle batteries. Several batteries together are usually reffered to as a battery bank

Major Batteries type by application

- SLI or automotive are desighned to deliver heavy starting currents for a short period of time not for the cycle regime of stand alone PV system or deep cycle use so are not suitable. SLI batteries have many very thin plates with a large surface area densign to be discharge no more than 1 to 5% from full charge. Starting batteries are uaually rated at "CCA" or cold cranking amps, this mean they are not deep cycle batteries.

- Deep cycle batteries which design to put 80% of their capacity time after time without damage and have much thicker plate than SLI batteries. Automotive batteries (SLI) can be severely damaged if heavily discharge after time. Industrial deep cycle batteries called fork lift
- Marine deep cycle batteries are actually hybrid and fall between deep cycle and SLI

Also batteries can be divided by construction to:

- Flooded, these batteries may be standard or the so called maintance free
- Gelled, it contains acid that has been gelled. The avdantage of these batteries is that it is imbossible to spill acid even if they are broken-the disadvantage is that they must be charged at a slower rate and the current must be limited to the manufacturer's specifications.
- AGM (Absorbed Glass Mat). AGM batteries are also sometimes called dry. These type of batteries act just like gelled, but can take much more abuse and have several advantages over both gelled and flooded. They cost 2 to 3 times as much as flooded batteries of same capacity.

Capacity of Deep Cycle Batteries

The electrical storage capacity of a battery is measured in amp-hours(Ah). This indicates how many hours a specific current can be delivered by fully charged battery before it is discharged. This can be converted into watt –hour by multiplting the battery AH by its voltage. This because at low discharge currents more electricity can be delivered by battery than at high discharge currents.

Battery Life

Charging and discharging a battery is known as cycling the battery and the number of cycles batteries can withstand is known as the batteries cycle-life. Batteries should never be fully discharged. For a deep cycle battery this is typically 80% depth of discharge. Less depth of discharge means last longer still and more cycle-life for battery.

- **Inverters in stand alone systems**

Inverters are rated in watts and the nominal rated should be sufficient to power all the AC appliances. Inverter must have low power consumption in stand, high efficiency and has a DC input range that takes into account changing battery voltages.

3.9.2 Stand Alone PV Systems Sizing

- **Sizing stand alone PV arrays**

$$W_{PV} = E / (G \times \eta_{sys})$$

Where:

W_{PV} = Peak wattage of the array (Wp)

E = The daily energy requirement in watt-hour (load)

G = Average daily number of peak sun hour in the design month for the inclination and orientation of the PV array.

Total system efficiency can be calculated as follow:

$$\eta_{sys} = \eta_{PV} \times \eta_{PV\text{-}BATT} \times \eta_{CC} \times \eta_{BATT} \times \eta_{DIST} \times \eta_{INV}$$

Where:

η_{PV} = 20% to account for the PV modules not operating at MPP hence 0.8

$\eta_{PV\text{-}BATT}$ = 2% losses due to voltage drop in cables from PV array to battery hence 0.98

η_{CC} = 2% losses in good quality charge controller hence 0.98

η_{BATT} = 10% battery losses hence 0.9

η_{DIST} = 2% losses in distribution cables from PV battery to load hence 0.98

η_{INV} = 10% losses in a good quality inverter hence 0.9

- **Battery Sizing**

The battery need to be sized to store not only daily energy requirement, but also several days extra. This is to provide energy during over cast days. The following formula can be used:

$$Q = (E \times A) / (V \times T \times \eta_{INV} \times \eta_{cable})$$

Q = minimum battery capacity required in amp-hour

E = the daily energy requirement in watt-hour

A = the number of days of storage required

V = the system DC voltage (V)

T = the maximum allowable depth of discharge of the battery

η_{INV} = inverter efficiency

η_{cable} = the efficiency of the cables delivering the power from battery to loads

If there is an electrical appliance with rating power consumption of 1000 W

So for four hour, then the daily energy consumption = 4 × 1000 = 4000 W

A= 1 for one day

V= 24 V

T = 0.9 the depth of discharge of the battery

η_{INV} = 0.9

$\eta_{cable} = 0.97$

$Q = (4000 \times 1)/ (24\times0.9\times0.9 \times0.97) = 212$ Ah

Battery with 212 Ah at 4 hour rate is selected and here because of 24 V systems, two batteries 12 V were used. Each battery has relationship between discharge time and the nominal capacity ampere hour, this explains in catalogue of battery as figure or tables. If four batteries is used then 106 Ah at 4 hour rate is selected to give 24 V systems.

CHAPTER FOUR

EXPERIMENTAL SETUP AND EXPERIMENTAL WORK PROCUDRE

4.0 Introduction

Experimental work was divided into three parts and here below the details of these parts of experiments.

4.1 First Part

In this part mains electrical power and R22 as refrigerant were used to study the performance of the split air conditioner, it was charged with 960g as mentioned with manufacture, all performance parameters such as: capacity, refrigeration effect, power, mass flow rate and COP were studied as dependant variables. Time from 10:00 AM to 5:00 PM evaporation temperature (T_e) and condensing temperature (T_c) variation test were considered.

4.1.1 Specification of the Air Conditioning Unit

Table (4.1) below shows the specification of the air conditioning unit used as supplied by the manufacturer.

Table (4.1) Specification of air conditioning unit

Type	Split unit (CHIGO)
Model	KF-32GW/Ac
Voltage	220-240/50/1
Capacity	12000 BTU (3.5kW)
Power input	1250 W (cooling mode)
Operating current	5.6 Amp
Refrigerant	R22
Indoor unit	Three speed fan
Air flow	550 m^3/h

4.2 Second part

Here the usual split air conditioning unit was used without modification. Figure (4.1) shows the solar system used to feed the air conditioning unit with power; Inverter, batteries and charge controller were used in this system to store the DC energy from modules in the batteries and then to invert it to AC power by inverter. R22 was used in this part as a refrigerant, all performance parameters were conducted with variation of time, T_e and T_c variation test.

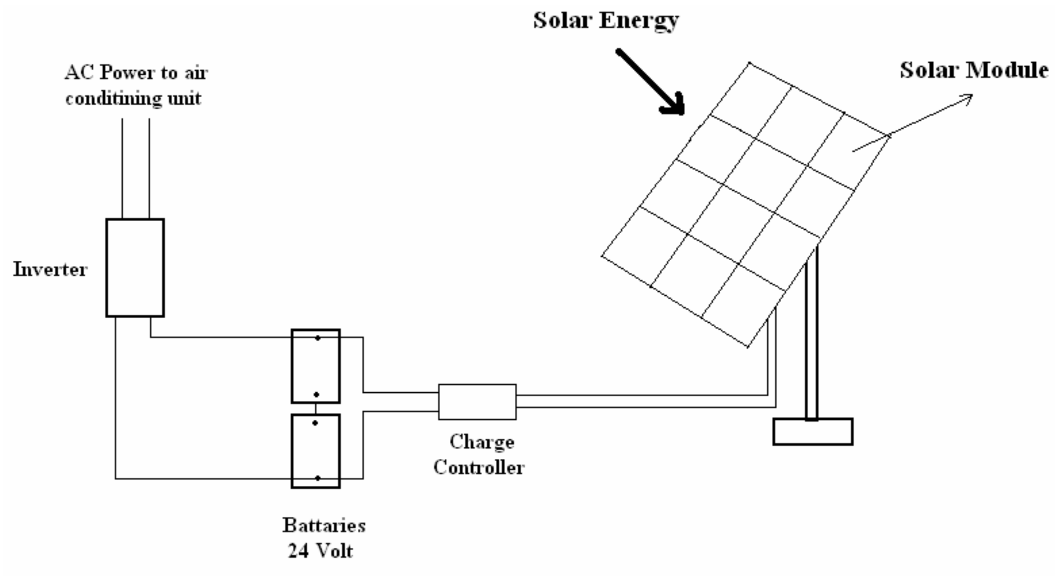


Figure (4.1) Solar system with inverter

4.2.1 Inverter

Inverter mass sine 24/1500-230V/50Hz with nominal battery voltage 24 V, Low battery volt switches off at 19V; ±0,5V and low battery volt switch on at 22 V with efficiency 92% and nominal capacity of 1200 VA and peak power 2900 VA was used in the experiment.

4.2.2 Battery

Two battery type OUTDO model OT120-12 deep cycle lead acid with nominal voltage 12V, rated capacity (1,3,10 hour rate) equal 72Ah, 95Ah, 120Ah and initial charging current less than 36 A. These specifications are denoted by the manufacture.

4.2.3 Charge controller

A 30-amp charge controller model Prostar -30 version PS-30M was used with system voltage 24.

4.3 Third part

In this part tests were performed on LPG mixture with solar energy, the same as the second part, the air conditioning was evacuated from R22. The system was charged with (150,200,250,300,350,400,500,650g) of LPG mixture and all calculations were competed to get the COP and this done to determine which charge quantity gives the best system performance, then the pest one was charged and the same parameters were studied as second part.

4.4 Instrumentation and Procedure

To determine the performance of the unit the following parameters must be measured: Temperature, pressure (low and high), power consumption and refrigerant mass flow rate.

4.4.1 Temperature Measurement

The temperature readings were measured by copper-constant thermocouples, type K which was connected to a microprocessor. Thermocouple wires were fixed to eleven locations at which temperatures have to be measured. Figure (4.2) shows these locations.

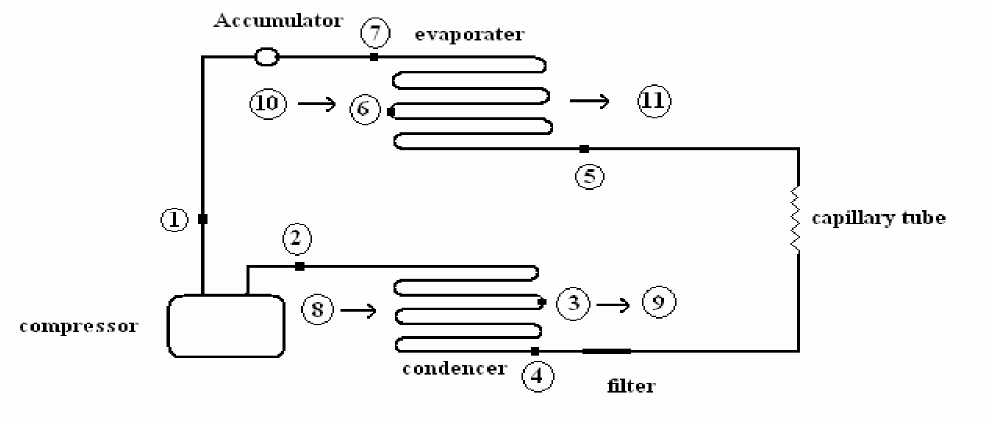


Figure (4.2) Measuring location of the test air conditioning

The thermocouples were fixed in certain points in the system by a tape, then it well insulates to obtain a good results. These points as shown in figure (4.2) are:

1. Suction of the compressor T1
2. Discharge of compressor T2
3. Midpoint of the condenser T3
4. Outlet of the condenser T4
5. Inlet on the evaporator T5
6. Midpoint of the evaporator T6
7. Outlet of evaporator T7
8. Ambient temperature T8
9. Air temperature out of condenser T9
10. Inside air temperature T10
11. Air temperature out of evaporator T11

4.4.2 Pressure measurement

Suction line of the compressor and discharge line are two points were the pressure was measured by using the pressure gage. The measuring pressure device used in this work is the refrigeration gage manifold.

4.4.3 Compressor power consumption measurement

Clamp meter and Voltmeter were used to measure the current and the voltage of the compressor.

4.4.4 Weight

A digital scale was used to weight the charge of the used refrigerant. It has an accuracy of one gram.

4.5 LPG Mixture

As mentioned by Jordanian petroleum refining site in internet, LPG bottle which is filled there contains 30% propane and 70% butane by mass. Many charges were used to determine the optimum charge. The result shows that the best amount of charge of the propane and butane mixture is 420 g. The same A/C unit is used in the tests of the two refrigerants.

4.6 Experimental work

The following tests were carried out:

A- Solar energy variation test

The intensity of solar radiation increase to reach peak then it reduce, this variation affect the total capacity power of the modules solar system. This power store in the batteries then it changes through the inverter to AC power. In this test temperature at eleven locations, pressure and power consumption were recorded with time variation from 10:00 to 19:00. The state at each point in the system can be determined from these data. The test was done for air conditioning once with R22 and the best charge of LPG (420 g) once.

B- Evaporation and condensation temperature variation test

In order to decrease the values of the condenser temperatures, water was sprayed through the fins by using small fan over the condenser. In order to increase the values of condenser temperatures speed regulator was used to change the speed of condenser fan motor , so as the condenser fan motor speed is reduce then the condenser temperature increases. When T_c was constant T_e variation was conducted by reducing the indoor fan speed. During the period of T_e variation, the temperature reading, pressure and power consumption were recorded. The relation between T_e variation and all parameters at many constant condensation temperatures was used to get the relation between T_c with all parameters at T_e was constant. This done because it was difficult to control the evaporation temperature at constant value and changing the condensation temperature.

CHAPTER FIVE

THEORETICAL PRESENTAION AND MATHIMATICAL ANALYSIS

5.1 Refrigeration Cycle

The vapor- compression cycle is the most widely used refrigeration cycle in practice. In this cycle a vapor is compressed, then condensed to a liquid, following which the pressure is dropped so that fluid can evaporate at a low pressure.

5.2 Compression Refrigeration Cycle

Vapor compression cycle consist of four main parts which are evaporator, compressor, condenser, and expansion valve as illustrated in Figure (5.1)

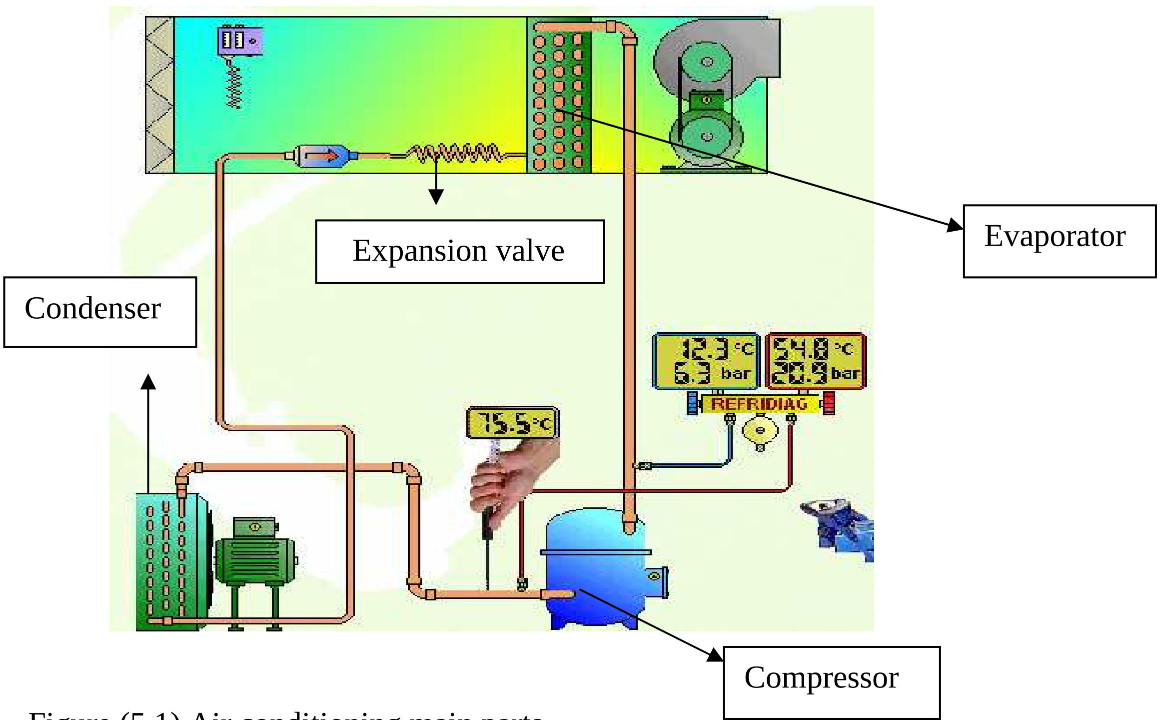


Figure (5.1) Air conditioning main parts.

(Kotza International – Le Chene- 05130 Tallard kotza@kotza .com)

In this study the pressure loss in both the condenser and the evaporator were neglected

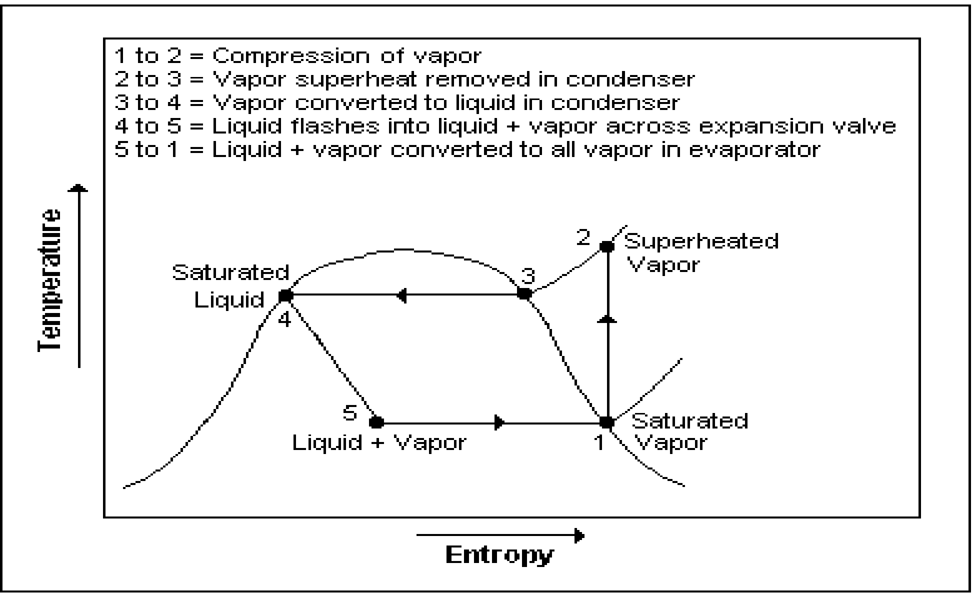


Figure (5.2). Temperature- Entropy diagram for ideal vapor compression cycle.

1-2 Compression from around saturated vapor to the condenser pressure

2-4 Rejection of heat at constant pressure, causing desuperheating and condensation of the refrigerant

4-5 Expansion at constant enthalpy from saturated liquid to the evaporator pressure

5-1 Addition of heat at constant pressure causing evaporation to around saturated vapor

5.3 Energy Balance

An energy balance and certain performance parameters can be derived from the first low of thermodynamics. Applying the steady- flow equation for the first law of thermodynamic at each part of the vapor compression cycle the following equations can be derived:

- **Compression (power consumption of compressor)**

$W = \dot{m}\ (h_2 - h_1)$ (5.1)

- **Condenser (Heat reject)**

$Q_{24} = \dot{m}\ (h_2 - h_4)$ (5.2)

- **Expansion valve**

$h_4 = h_5$

- **Evaporator (capacity)**

$Q_{51} = \dot{m}\ (h_1 - h_5)$ (5.3)

The heat rejected in the condenser must equal the sum of the heat absorbed in the evaporator and the work of compression.

5.4 Coefficient of Performance (COP)

The coefficient of performance (COP) indicates the performance of a refrigeration system. A high coefficient of performance is desirable because it indicates that a given amount of refrigeration required only a small amount of work.

$$COP = \frac{\text{Refrigeration effect}}{\text{Net work input}} \quad (5.4)$$

$$COP = \frac{h_1 - h_5}{h_2 - h_1} \quad (5.5)$$

5.5 Cooling Capacity

The heat removed from the space is the cooling capacity of the unit and it depends on the actual mass of refrigerant circulated per unit of time $\dot{m}$. It can be calculated from the following equation in kW

$$Q = \dot{m} \, (h_1 - h_5) \qquad (5.6)$$

5.6 Mass flow rate of Refrigerant

This represents the amount of flow of refrigerant in kg per second and we can calculate the flow rate if we know the power consumption of the compressor in (kW) and Δ h of compression process as below, and both electrical and mechanical efficiencies of the compressor , (η_e , η_m)

$$\dot{m} = \frac{\text{energy consumption in kW}}{h_2 - h_1} \times (\eta_e \times \eta_m) \qquad (5.7)$$

$\eta_e \times \eta_m = 0.8$, This value was considered because the unit is new

The mass of flow controls the capacity and power requirement more directly than the volume rate of flow. The mass rate of flow, $\dot{m}$ kg/s, through a compressor is proportional to the displacement rate in liters per second and the volumetric efficiency and inversely proportional to the specific volume of gas entering the compressor

$$\dot{m} = \text{displacement rate} \times \frac{\eta_{vc}/100}{v_{suc}} \qquad (5.8)$$

As the suction pressure drops, the specific volume entering the compressor increases and this reduces the mass rate of flow at low evaporating temperatures.

5.7 Refrigeration Effect

Heat absorbed in the evaporator (indoor unit) from inside door air per one kg of refrigerant flow is called the refrigerating effect, (q_e) and equals:

$$q_e = h_1 - h_5 \quad (5.9)$$

5.8 Properties of Refrigerant

In this research we compared the performance of split unit with capacity one ton by using the refrigerant R22 once and LPG mixture of R290 and R600 (30%/70%) as alternative of R22 when the unit powered by solar energy, here Table (5.1) below, the most important properties for these refrigerants are shown:

Table (5.1) Thermodynamic and chemical properties for R22, R290 and R600 (ASHREE 1993)

Refrigerant	R22	R290 (propane)	R600 (butane)
Chemical formula	$CHClF_2$	$CH_3CH_2CH_3$	$CH_3CH_2CH_2CH_3$
Boiling point(^oC)	-40.76	-42.07	-0.5
Freezing point (^oC)	-160	-187.7	-138.5
Critical temperature (^oC)	96	96.8	152
Critical pressure (bar)	4974	42.54	37.94
Latent heat of vapor (kJ/kg) at one atmosphere pressure	233.51	423.3	386
ODP	0.05	0	0
Temperature glide (^oC)	0	0	-----
GWP	1700	~ 20	~ 20

Molecular weight (kg/kmol)	86.47	44.1	58.13
Miscibility with lubricant oil (Mineral oil)	Good	good	good
Toxicity	Non – toxicity		
Reaction with water	Low which is good		
Availability	Available	Available	Available

These thermodynamic and chemical properties for HC refrigerant compared of R22 are considered for HC to be good alternative refrigerant for R22 and this reduces environment effects ozone depletion and global warming. Also energy consumption of the system with HC is lower for all operating condition than with R22 by more than 10%. This made driving the system by solar energy to be more effective (Devotta and Padalkar, 2005) and (Jabaraj and Narendran, 2006).

5.9 Energy consumptions

Rating power consumption for any device is the amount of power consumes from the device by motors and electric equipments such as lights and resistances in running mode and this amount of power is more less than power need to start the device.

$$\text{Rating Power in watt (Energy consumption)} = I\,V\cos Ø \qquad (5.10)$$

and:

$$\text{Power (kW)} = \dot{m}\ W = \dot{m}\ (h_2 - h_1) \qquad (5.11)$$

The power by using power meter can be measured so it becomes easy to calculate the mass flow rate of the refrigerant.

5.10 Calculations

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

5.10.1 Enthalpy calculations

In order to calculate refrigeration parameter cycle, enthalpies at different location in the cycle have to be calculated first.

For R22 temperature and pressure values are enough to calculate the enthalpy at any location in the cycle using R22 saturated and superheated tables

One way to calculate the enthalpy of mixture of LPG (propane and butane) is to calculate first the enthalpies of its main constituents (propane and butane) and then calculate the enthalpy of the mixture using these enthalpies and the mass fraction of each constituent in the mixture.

Table (5.2) Mass fractions of Propane and Butane in LPG mixture

Component	Mole fraction	Molecular weight	Mass (kg/kmole)	Mass fraction
Propane	0.36	44.1	15.87	0.3
Butane	0.64	58.13	37.2	0.7

Hence the enthalpy of the mixture of 30% / 70% by mass at any state may be calculated using the mass fraction of each material which is 0.3 (propane), 0.7 (butane) using the following equation:

$$h_m = 0.3\, h_p + 0.7 h_b \qquad (5.12)$$

Where h_p and h_b are the enthalpies of propane and butane respectively

To calculate h_p and h_b we need to define the partial pressure for each component as follows:

P (propane) = 0.36 × P_t (5.13)

P (butane) = 0.64 × P_t

Where P_t is the total pressure of the mixture

At point 4 where refrigerant leaving the condenser, the enthalpy was considered as saturated liquid enthalpy at that pressure.

Also there was a difference in temperature of refrigerant when it was leaving the evaporator and entering the compressor, this increasing occurred because of losses through some parts of copper pipe. Prime sign was used to represent the point of exit evaporator so enthalpy was represented as h_1' for leaving evaporator and h_1 for entering the compressor.

Because pressure drop across capillary occurred with constant enthalpy, so $h_4=h_5$

5.11 Sample Calculation for the Mixture:

A sample calculation is presented for the 420 g mixture charge at time 11:45 for day history performance of LPG as shown in appendix A

Suction pressure = 0.152 Mpa

Discharge pressure = 0.586 Mpa

Exit température of evaporator = 12 ^oC

Inlet temperature of the compressor = 15 ^oC

Outlet temperature of the compressor = 57 ^oC

Condensing temperature = 39 ^oC

Outlet temperature from the condenser = 34 ^oC

Evaporating temperature = 13 ^oC

Compressor current = 3.4 amp

Voltage across the compressor= 230V

$h_1'_m = 0.3h_p + 0.7\ h_b$

$P_p = P_t \times 0.36$

$P_p = 0.152 \times 0.36 = 0.05472$Mpa

So from the P h chat of propane at T=12 °C and P= 0.05472 Mpa

$h_1'_p = 920$ kJ/ kg

$P_b = P_t \times 0.64 = 0.0973$ Mpa

From the P h chart of butane at T= 12 °C and P=0.0973 Mpa

$h_1'b = 700$ kJ/ kg

$h_1'_m = 0.3 \times 920 + 0.7 \times 700 = 766$ kJ/kg

And the same procedures for all h then:

$h_{1m} = 773.3$ kJ/kg

$h_{2m} = 853.5$ kJ/kg

$h_{4m} = 554$ kJ/kg $= h_{5m}$

$COP = (h_1'_m - h_{5m})/(h_{2m} - h_{1m}) = 2.643391521$

$q_e = (h_1'_m - h_{5m}) = 212$ kJ/kg

Power consumed by compressor = V× I × 0.9=230×3.4×0.9=703.8 W

$W = (h_2 - h_1) = 80.2$ kJ/ kg

Power consumed by compressor $\times\ \eta_e \times \eta_m = \dot{m} \times (h_2 - h_1)$

$\dot{m} = (0.7038 \times 0.8)/80.2 = 0.00702$ kg/s

$Q_e = \dot{m}\ (h_1'_m - h_{5m}) = 0.00702 \times 212 = 1.49$ kW

CHAPTER SIX

RESULTS AND DISCUSSION

The aim of this research is to investigate and compare between R22 and LPG as a refrigerant when the air conditioning powered with solar energy. First a comparison should be made between the performances of different charge quantities of the LPG to find out the best mass to be charged in the air conditioning unit. All performance parameters for the R22 and LPG are plotted versus time of day (Day history), also the performance parameters with variable values of the evaporating and condensing temperatures T_e and T_c respectively were conducted. The performance parameters investigated in the present work are: cooling effect, coefficient of performance, mass flow rate, cooling capacity, heat reject, power consumption and exit temperature of the compressor.

6.1 Charge Quantity

Seven different LPG charge quantities were charged and their coefficient of performance was calculated. This part of the experiment was conducted at time when the ambient temperature was 19 ^{o}C. Figure (6.1) shows the variation of the COP with the seven different selection 200, 250, 300, 350, 400, 500, and 650g. The best charge will found was about 420 g.

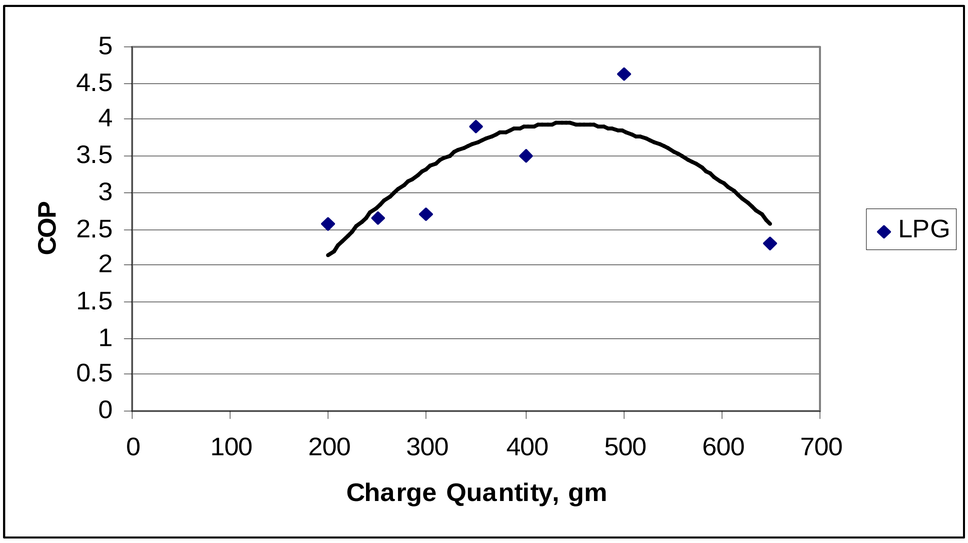


Figure (6.1) Coefficient of Performance vs. Charge Quantity of LPG

The air conditioning was run along the day with solar energy using R22 once and the best charge of LPG another time. Since the source of solar energy is variable along the day and it stored in batteries and then it converted to AC by inverter, shutdown occurred many times along the day for the unit and then returned to restart. Batteries have their full charge when the voltage reaches 26.8 V and when it reaches 18 V the system shutdown. Between the shut down time and restart time of air conditioning , batteries were recharged, their voltage reached 25 V. Batteries seem like storage tank fill with variable energy, the variable energy comes from PV modules , when the output energy was more than the input the system was shutdown, when it was partly filled again the system returned to restart. Fig (6.3) and Fig (6.4) represent shutdown and restart time for the air conditioning for R22 and LPG respectively. Because power consumption using LPG was more less than R22, the air conditioning remained running until sun set, therefore continuous running also investigated in the next day.

6.2 Power Consumption of the Compressor for R22 and LPG

Power consumption of LPG refrigerant was less than using R22 as refrigerant as shown in the Fig (6.2) below, this indicate why using LPG as a refrigerant is more effective in the air conditioning unit , the unit remained in running for about 9 hour then it was shutdown but for R22 the unit was shut downed after 5 hour .

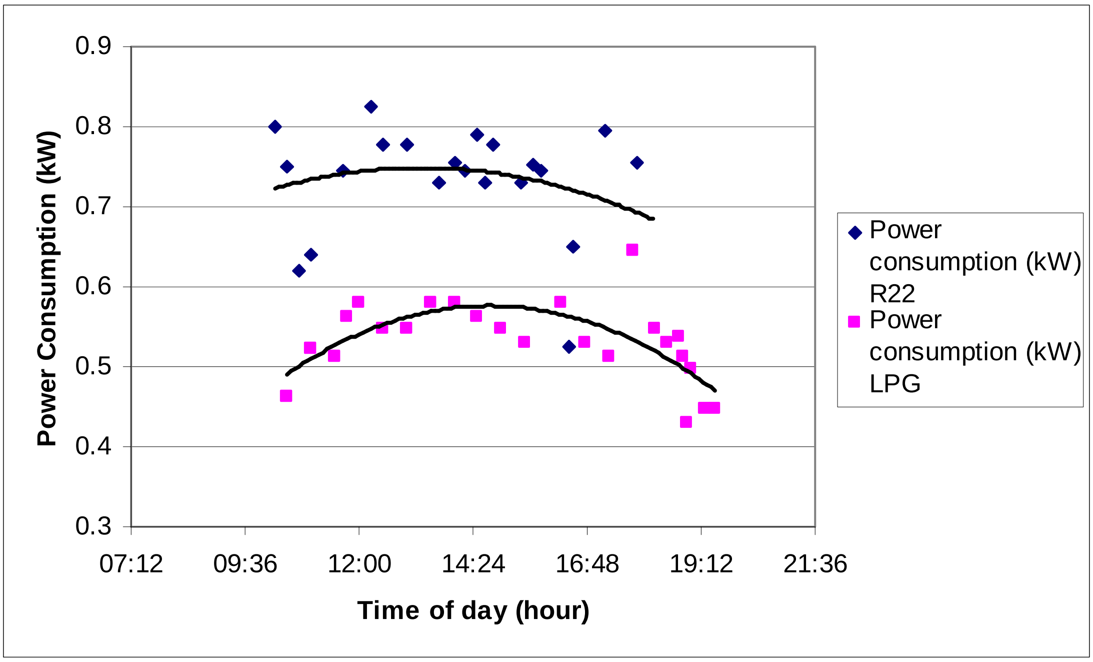


Figure (6.2) Power consumption of the compressor for R22 and LPG vs. time of day

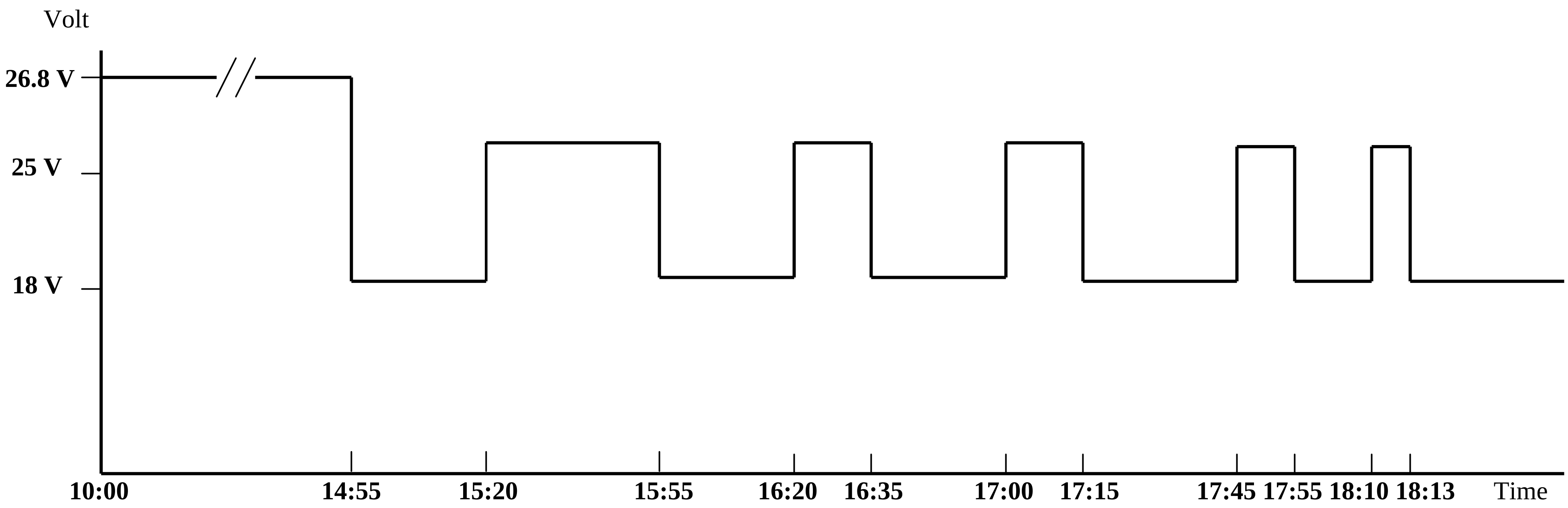


Figure (6.3) Shutdown and Restart with time of day for R22 when powered with solar energy

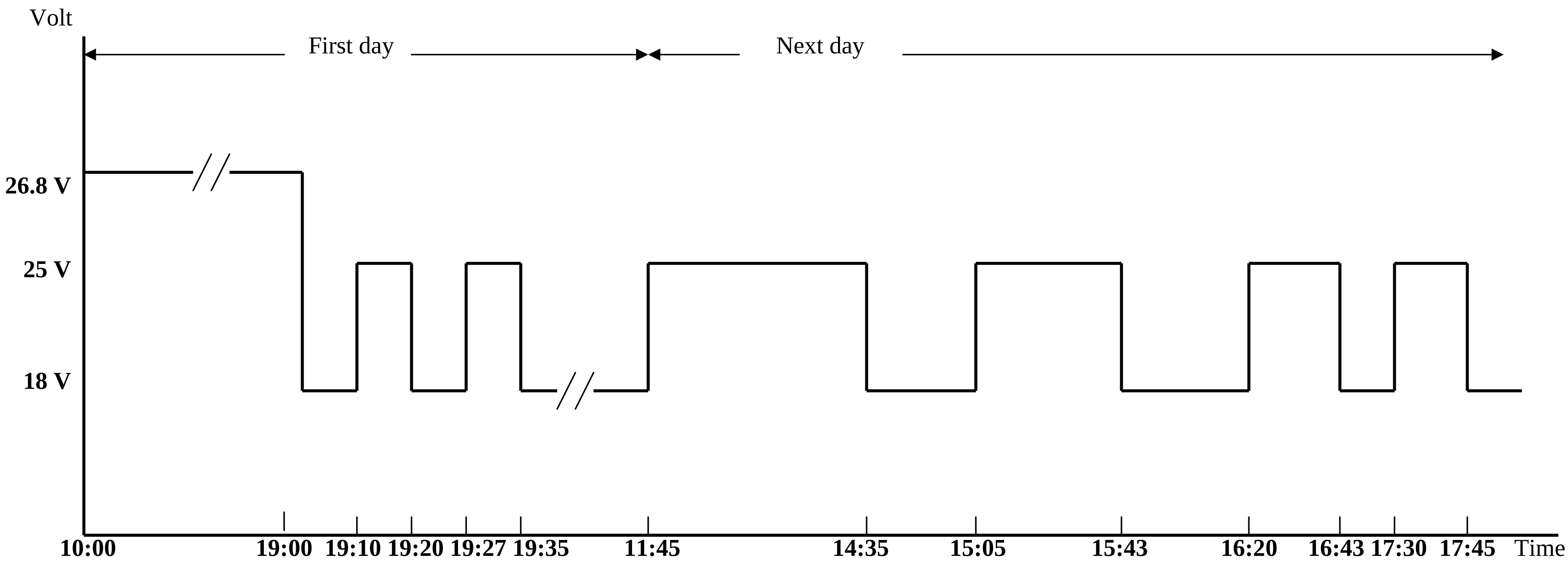


Figure (6.4) Shutdown and Restart with time of day for LPG when powered with solar energy

6.2 Time of Day History Variation Test (R22) Using Solar Power

6.2.1 Refrigerating Effect

Figure (6.5) represent the variation of refrigeration effect with the time of day for R22, It is show that refrigerating effect decreases to reach the minimum value at 13:00, this because T_c increased from the effect of ambient temperature which reached the highest value at the solar intensity peak time. Increasing T_c results in increasing the enthalpy of the refrigerant entering the evaporator. At the time of shutdown and restart of the unit which was represented by dark and white stars, refrigeration effect increased, the time of restart and shutdown was not sufficient to reach the steady state of the system, this influence the performance of the system.

6.2.2 Coefficient of Performance

Figure (6.6) shows the variation of COP with time of day. Since the COP equal refrigeration effect divided by the work of compression and the last one increases when T_c increases, this explains why the COP will be minimum value at the solar intensity peak time. COP increased at 16:25 to reach 6 because the unsteady state of system as mentioned previously.

6.2.3 Mass Flow Rate

Figure (6.7) shows the variation of mass flow rate (kg/s) with time of day, its equal the power consumption of compressor divided by compression work in (kJ/kg), as the compression work decreases, the mass flow rate increases.

6.2.4 Capacity

Variation was occurred to capacity along the day. Since refrigeration capacity equal mass flow rate multiplied by the refrigeration effect, increasing the ambient temperature which increase the T_c will reduce the mass flow rate and refrigeration effect, this explain why the capacity at mooring was higher than the solar intensity peak time ,as shown from Figure (6.8) the capacity between 11:00-14:00 almost between (2.7- 3.5) kW.

6.2.5 Power Consumption

Figure (6.9) shows the variation of power consumption with time of day. As shown it's decreased to minimum value then it returned to increase, power consumption equal mass flow rate multiply by deference enthalpy across the compressor, the curve shows that the effect of mass flow rate is more than effect of enthalpy deference.

6.2.6 Heat Reject

Heat reject is the heat rejected to the environmental by the condenser, this variation of heat reject was occurred because of mass flow rate variation, it is reduced to the minimum value at the solar intensity peak time as shown in Figure (6.10)

6.2.7 Compressor Exit Temperature

Figure (6.11) shows that the discharge temperature increased to maximum value at solar intensity peak time, since the ambient temperature increase, this rises the condensing temperature and the pressure ratio.

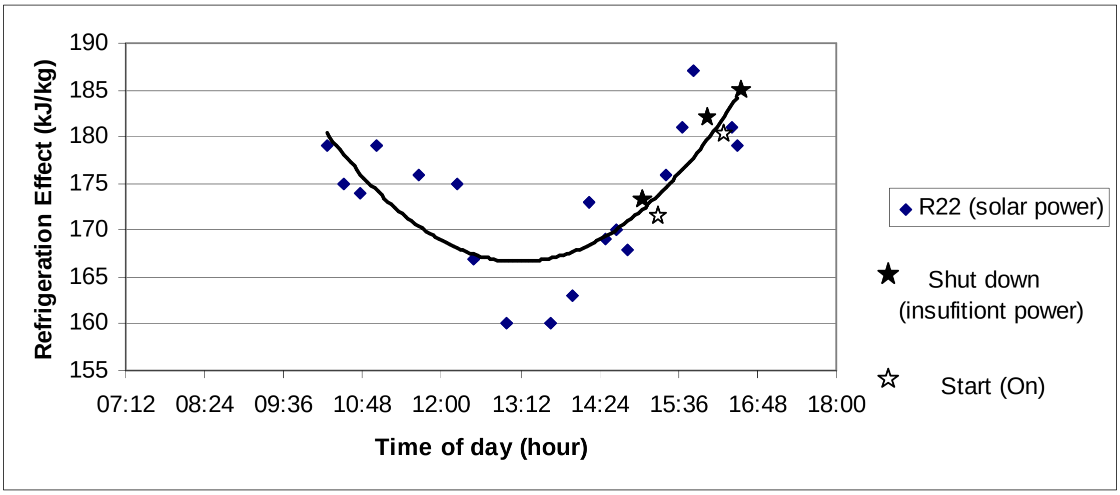


Figure (6.5) Refrigeration Effect vs. Time of the day for R22, solar energy

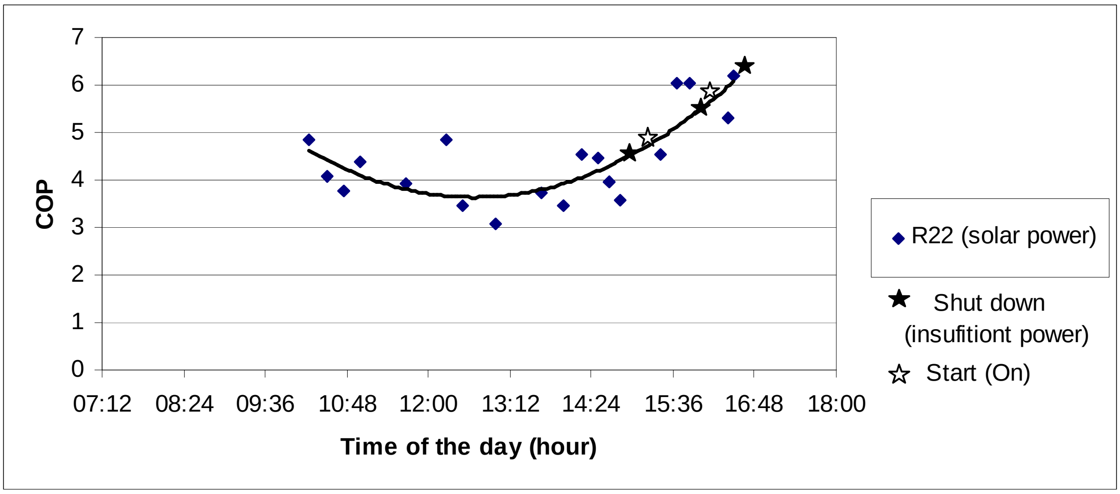
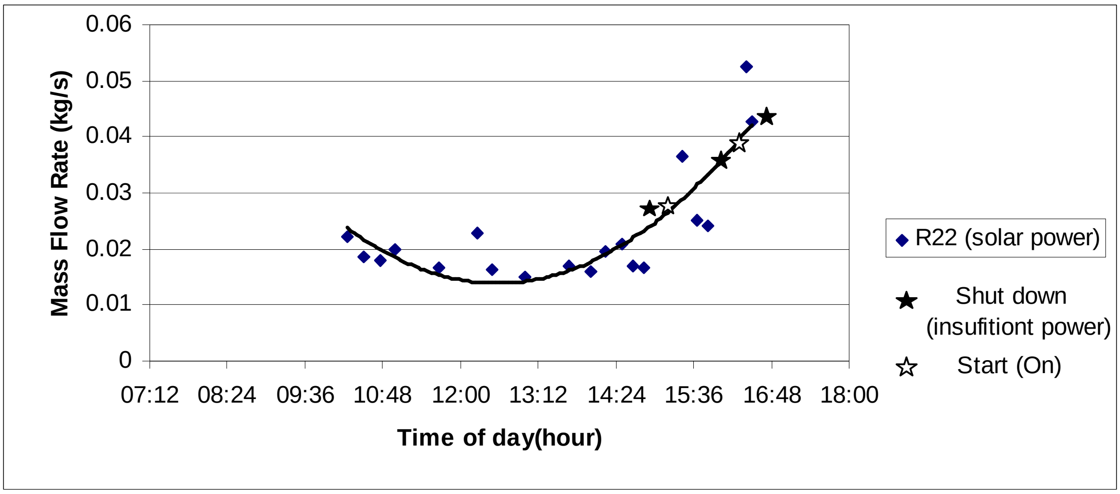


Figure (6.6) Coefficient of Performance vs. Time of the day for R22, solar energy



Figure(6.7) Mass Flow Rate vs. Time of the day for R22, solar energy

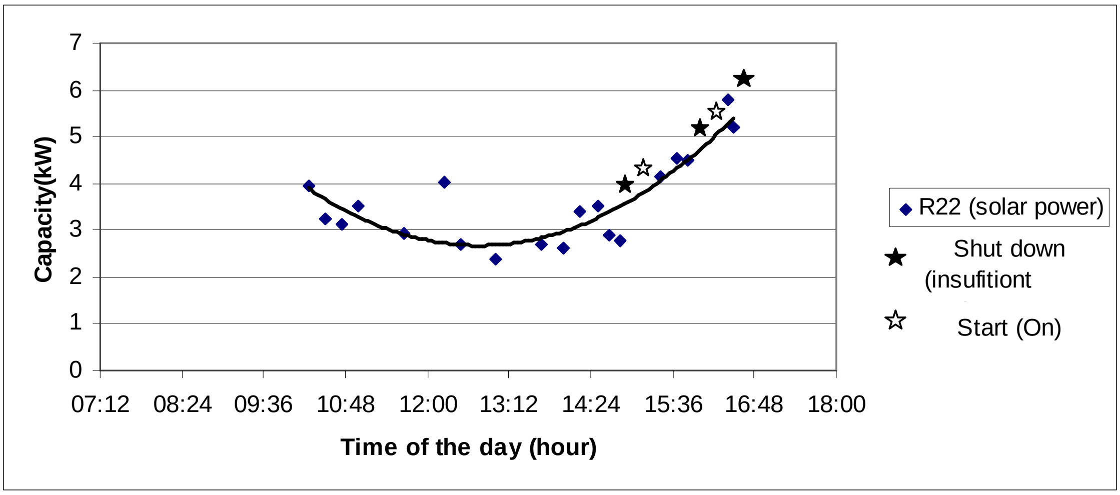


Figure (6.8) Cooling Capacity vs. Time of the day for R22, solar energy

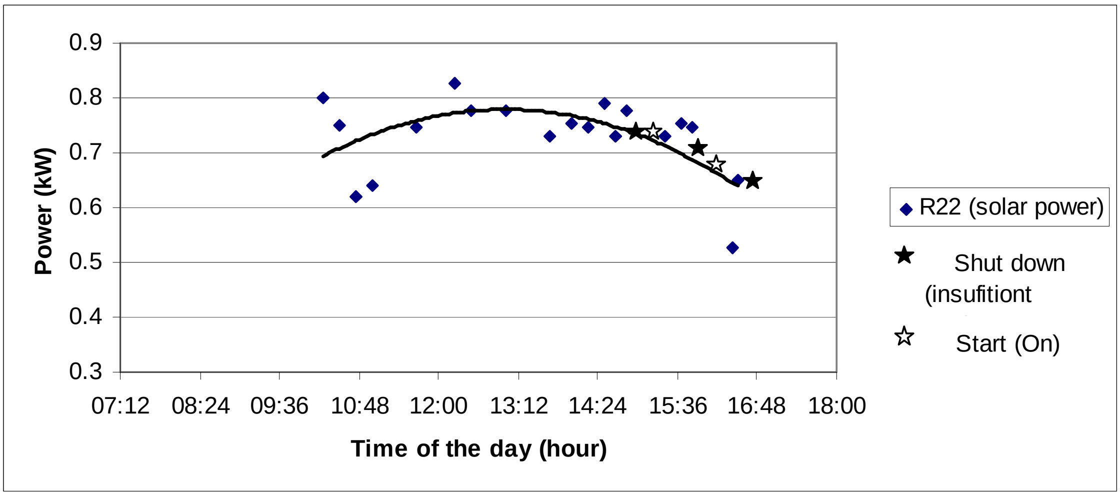


Figure (6.9) Power Consumption vs. Time of the day for R22, solar energy

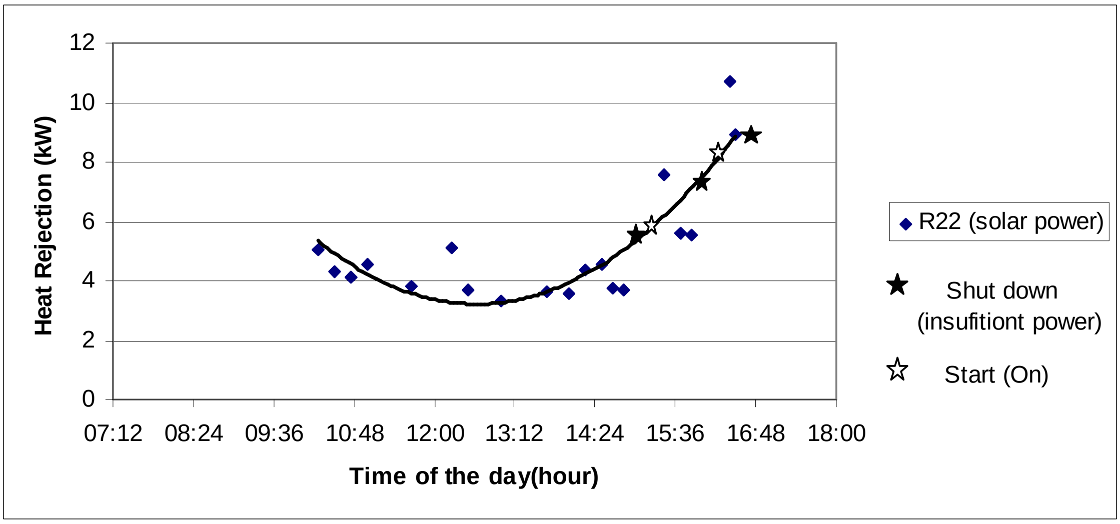


Figure (6.10) Heat Rejection vs. Time of the day for R22, solar energy

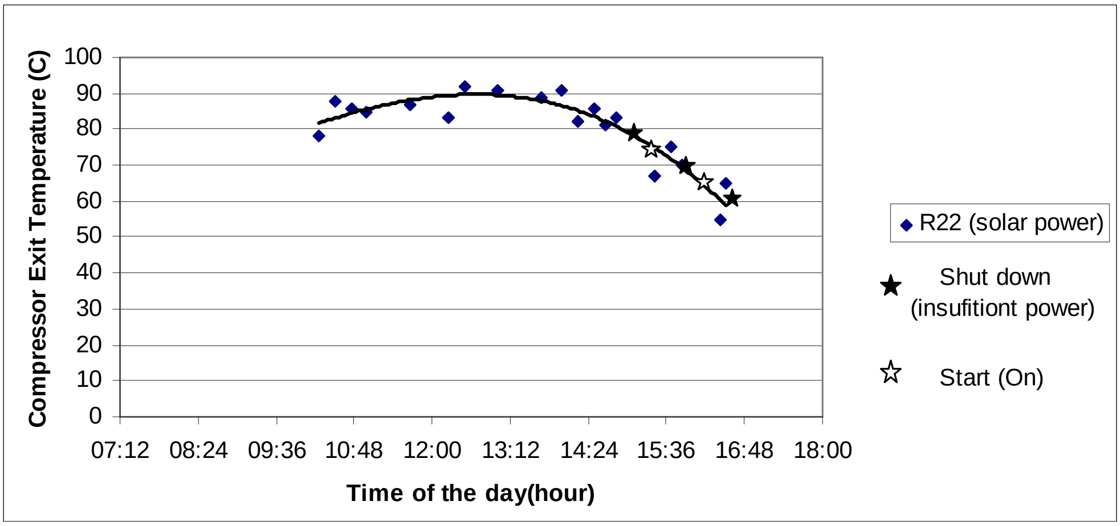


Figure (6.11) Compressor Exit Temperature vs. Time of the day for R22, solar energy

6.3 Time of Day History Variation Test (LPG) Using Solar power

In these tests the performance was conducted for two days because the unit in the first day started at 10:00 and it was continued in running to sun set time, then shutdown occurred. In the next day the unit started running at 11:45 because there was insufficient energy in batteries to start the unit, the performance of the unit also was conducted in the next day and figured.

6.3.1 Refrigerating Effect

Figure (6.12) represent the variation of refrigeration effect with the time of the day using LPG, It is shown that refrigerating effect decreased to reach the minimum value at 15:21, the minimum value shifted to left of solar intensity peak time in the first day and the unit was shutdown at sun set time, the same behavior was occurred in the next day.

6.3.2 Coefficient of Performance

Figure (6.13) shows the variation of COP with time of day. COP reached minimum value at 14:00 with 2.25. The same performance was occurred in the next day.

6.3.3 Mass Flow Rate

Figure (6.14) shows the variation of mass flow rate (kg/s) with time of day, it remained almost constant along first day, slight variation occurs in the next day.

6.3.4Capacity

Slight variation is occurred to capacity along the day as shown from Figure (6.15) the capacity between 11:00-14:00 was almost 1.75 kW. In the next day and because of instability of the system because of shutdown and restart of the unit the capacity is increased.

6.3.5 Power Consumption

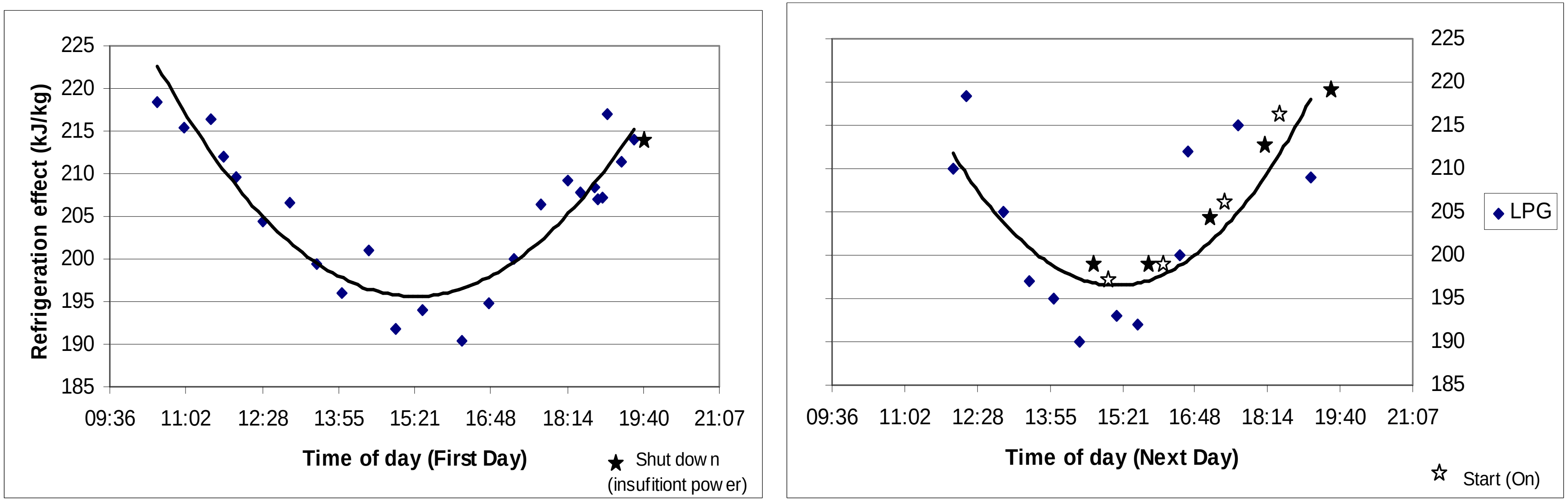
Figure (6.16) shows the variation of power consumption with time of day. As shown the power increased because h_2 increased when the ambient temperature increased then it returned to decrease.

6.3.6 Heat Reject

The variation of heat reject was slight, it increased in the next day when the unit started to shutdown and restart as shown in the Figure (6.17)

6.3.7 Compressor Exit Temperature

Figure (6.18) shows that the discharge temperature decreased after 16:00, since the ambient temperature started to decrease which decrease also the condensing temperature and pressure ratio.



Figure(6.12) Refrigeration Effect vs. Time of the day for LPG, solar energy

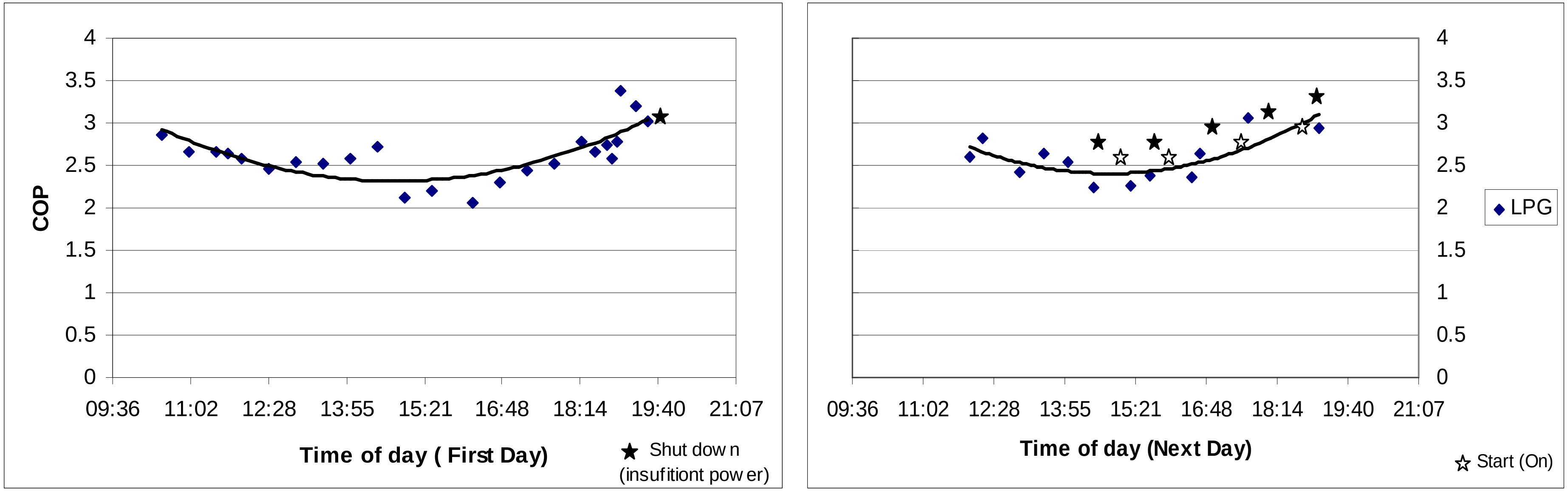


Figure (6.13) Coefficient of Performance vs. Time of the day for LPG, solar energy

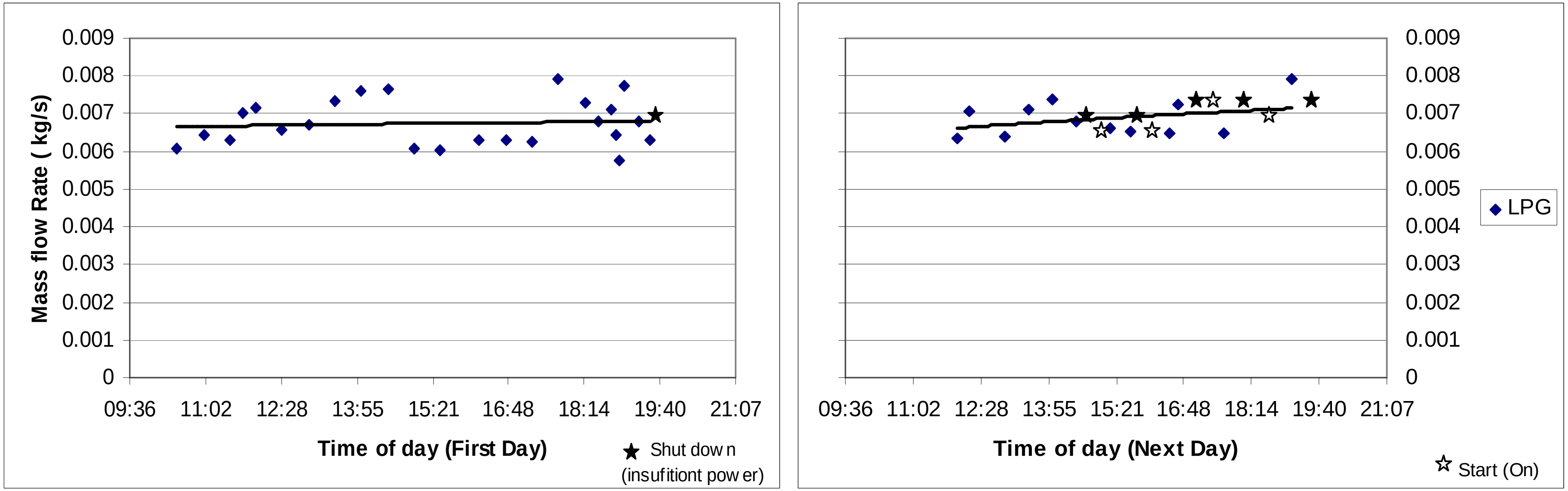


Figure (6.14) Mass Flow Rate vs. Time of the day for LPG, solar energy

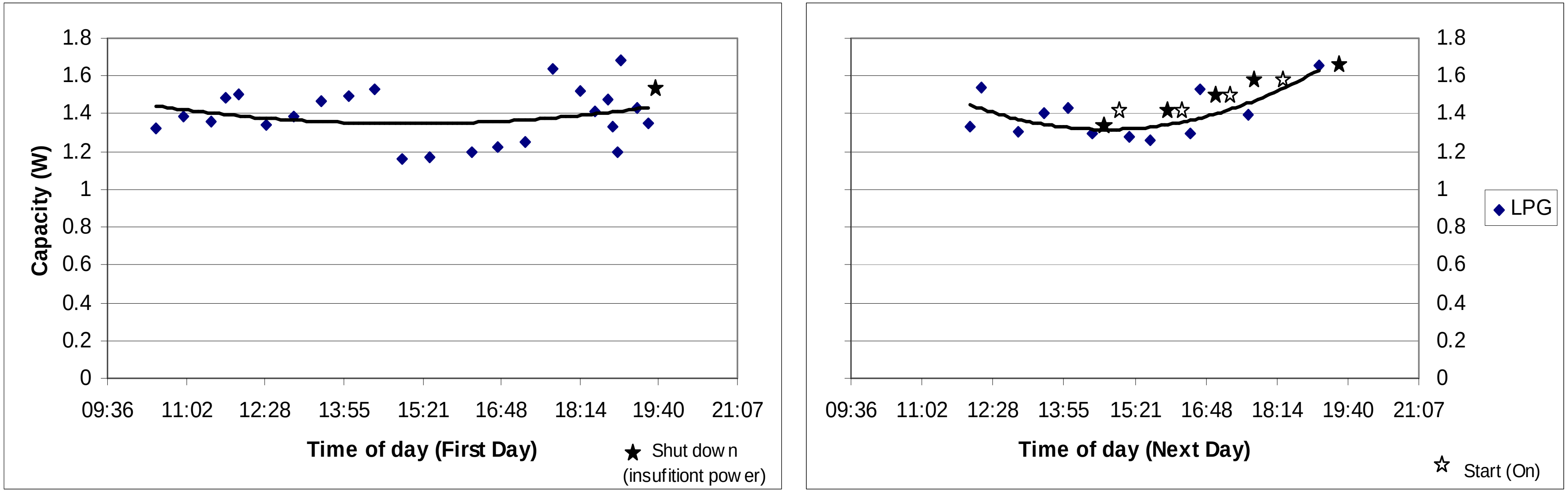


Figure (6.15) Cooling Capacity vs. Time of the day for LPG, solar energy

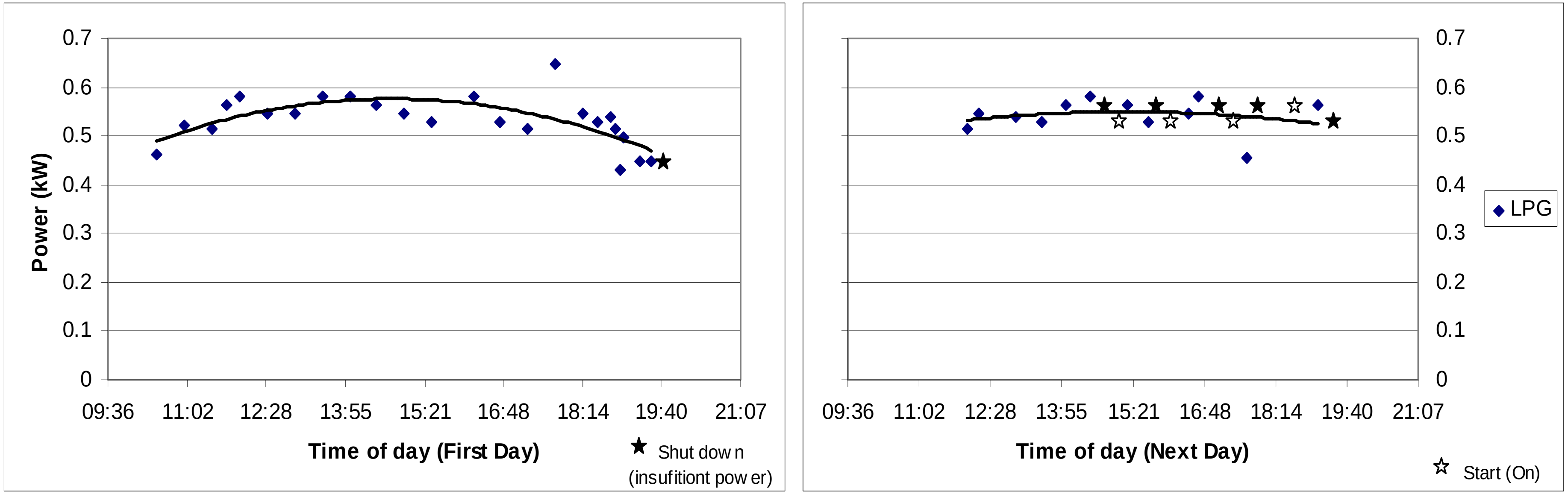


Figure (6.16) Power Consumption of compressor vs. Time of the day for LPG, solar energy

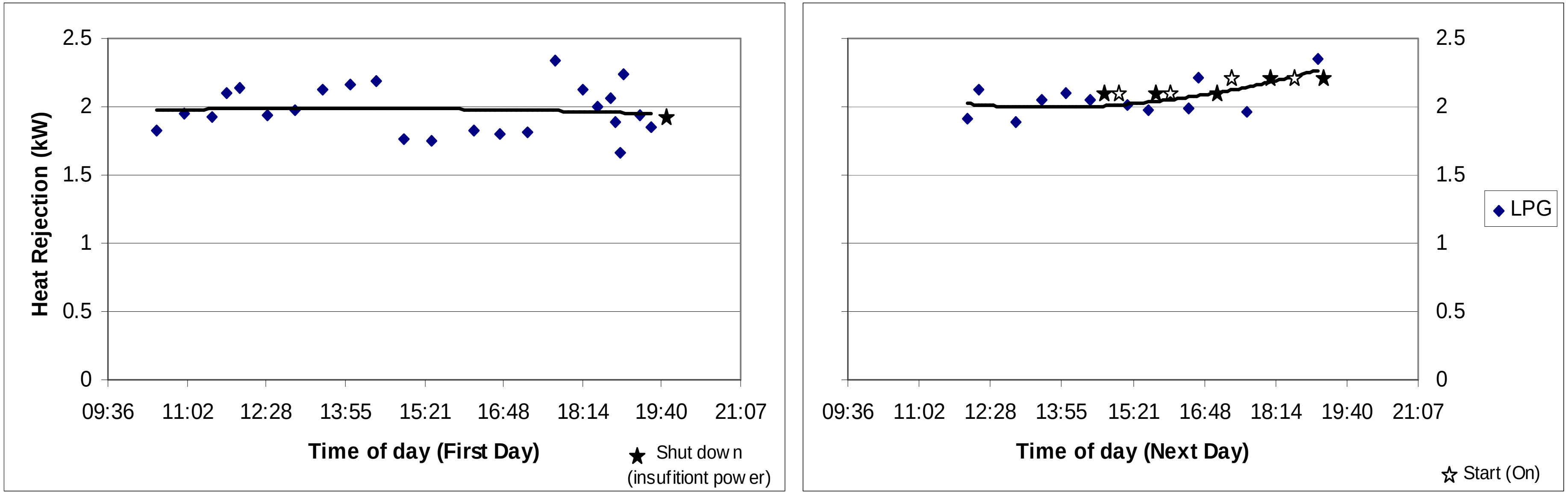


Figure (6.17) Heat Rejection vs. Time of the day for LPG, solar energy

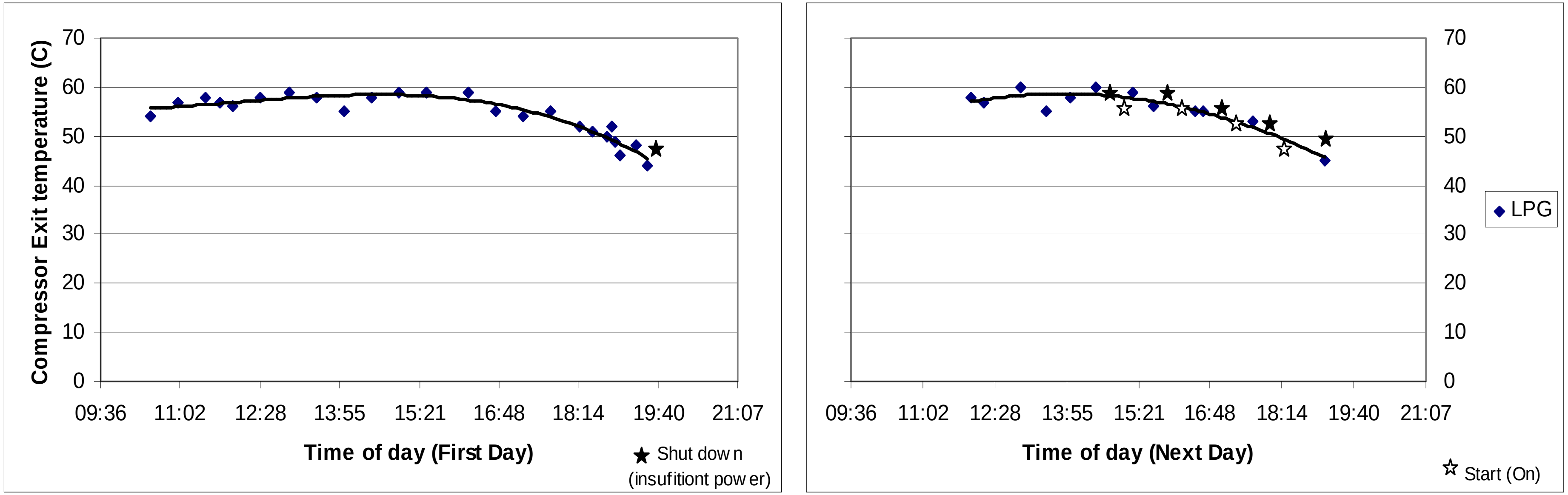


Figure (6.18) Compressor Exit Temperature vs. Time of the day for LPG, solar energy

6.4 Evaporating Temperature Variation Test for R22 and LPG Using Solar Energy.

6.4.1 Refrigerating Effect

Figure (6.19) and Figure (6.20) represent the variation of refrigeration effect with the T_e for R22 and LPG respectively, the tests show that as T_e increases the refrigeration effect increases when T_c remains constant, this because when T_e increases enthalpy at exit evaporator increases slightly while the enthalpy of the refrigerant entering the capillary tube remains constant. Also as shown in the figures the refrigeration effect for LPG is higher than R22.

6.4.2 Coefficient of Performance

Figure (6.21) and Figure (6.22) shows the variation of COP with T_e. COP for R22 refrigerant was higher than LPG and it increases as T_e increases for both because refrigeration effect increased and work of compression reduced.

6.4.3 Mass Flow Rate

As shown in figures (6.23) and (6.24) and referring to equation (3.8) the mass flow rate increases as T_e increases at constant T_c this because the specific volume decreases.

6.4.4 Capacity

The capacity of the unit using both R22 and LPG refrigerant increases as T_e increases as shown in figure (6.25) and figure (6.26) since mass flow rate and refrigeration effect increased. The capacity using R22 is higher than LPG, at T_e = 5 ^{o}C at constant Tc = 40 ^{o}C the capacity using R22 was 4 kW while it was just 0.9 kW for LPG.

6.4.5 Power Consumption

Figure (6.27) and Figure (6.28) represent the variation of power consumption with T_e. As T_e increases the power consumption increases. This indicates that the effect of mass flow rate is higher than work of compression .

6.4.6 Heat Reject

Figure (6.29) and Figure (6.30) represent the variation of heat reject with T_e. As T_e increases the heat reject increases because mass flow rate increased, its effect was more than deference enthalpies across the condenser.

6.4.7 Compressor Exit Temperature

The compressor exit temperature reduces as T_e increases because h_2 reduced when T_e increased as shown in figure (6.31) and figure (6.32).

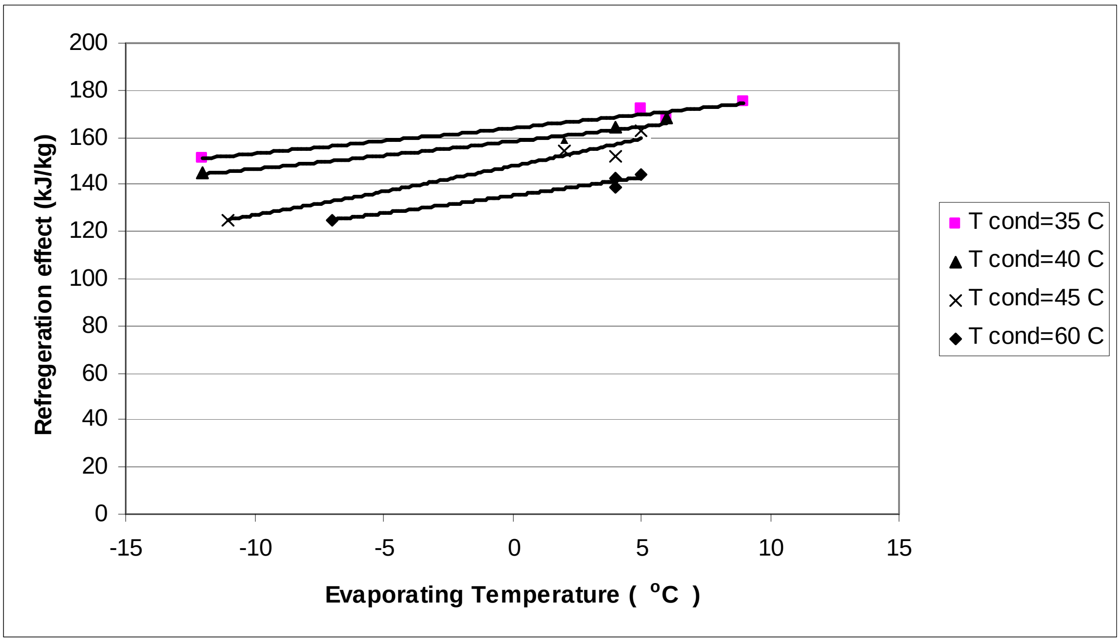


Figure (6.19) Refrigeration Effect vs. Evaporating Temp for R22, solar energy

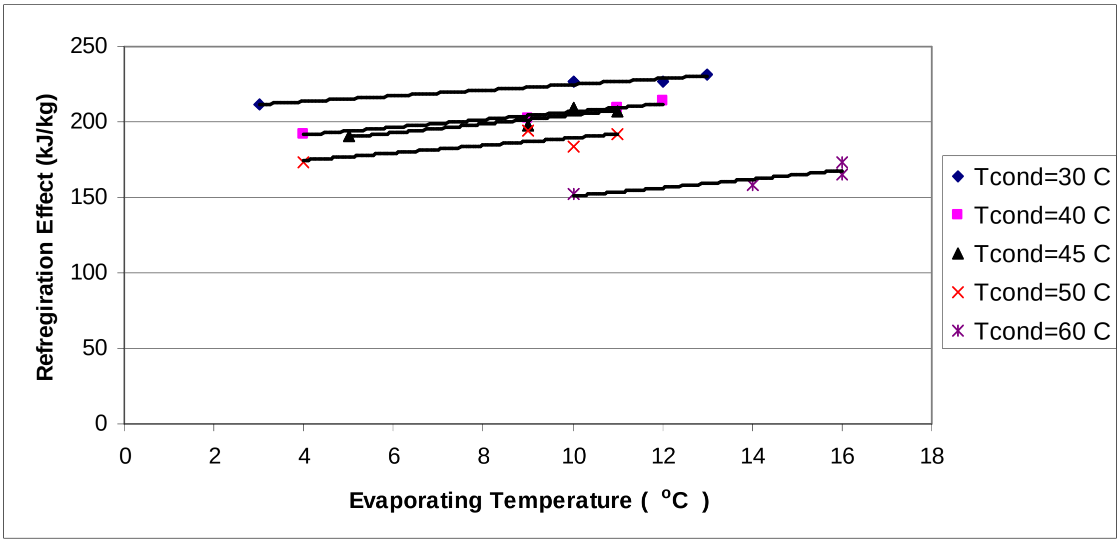
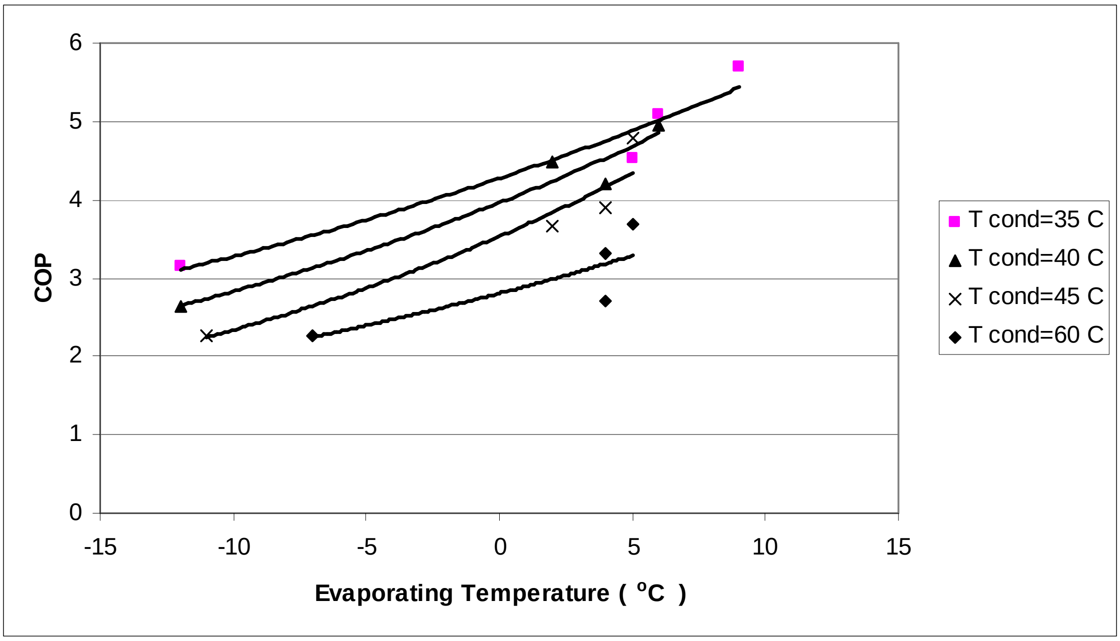


Figure (6.20) Refrigeration Effect vs. Evaporating Temp for LPG, solar energy



Figure(6.21) Coefficient of Performance vs. Evaporating Temp for R22, solar energy

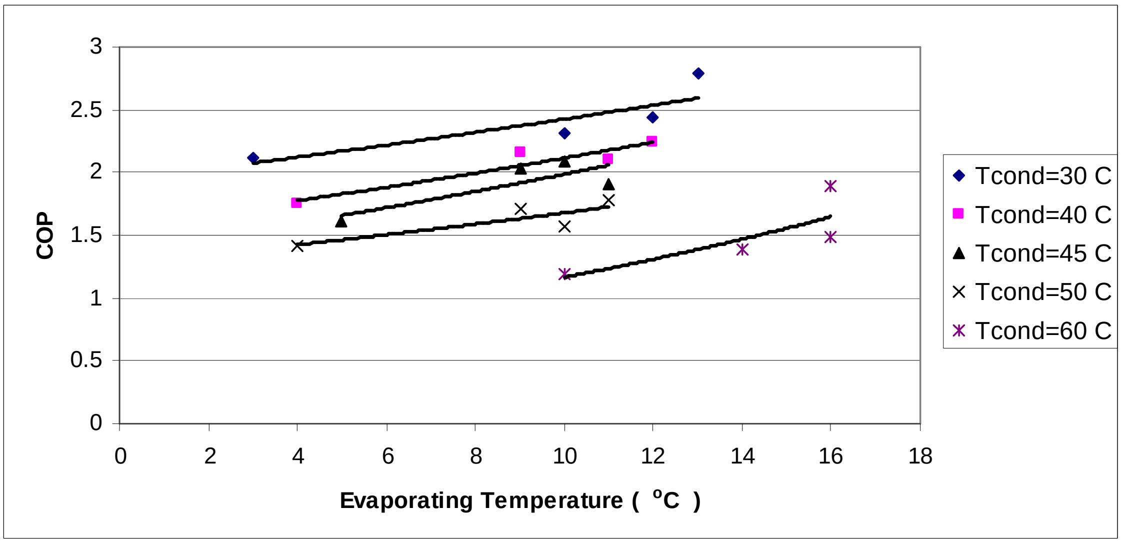


Figure (6.22) Coefficient of Performance vs. Evaporating Temp for LPG, solar energy

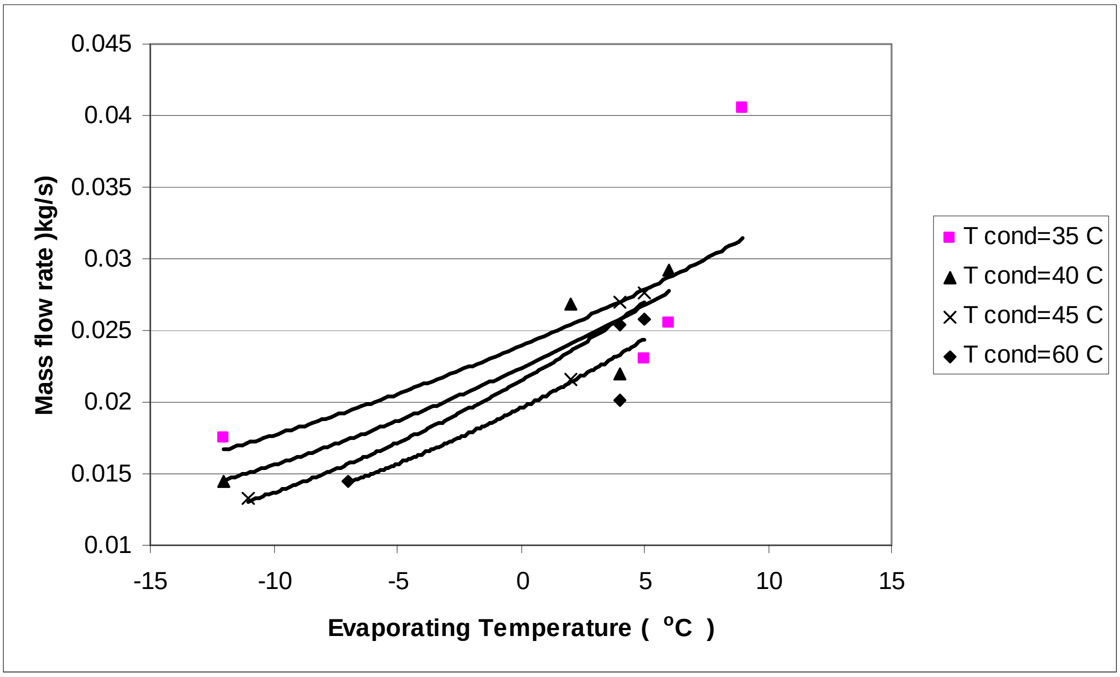


Figure (6.23) Mass Flow Rate vs. Evaporating Temp for R22, solar energy

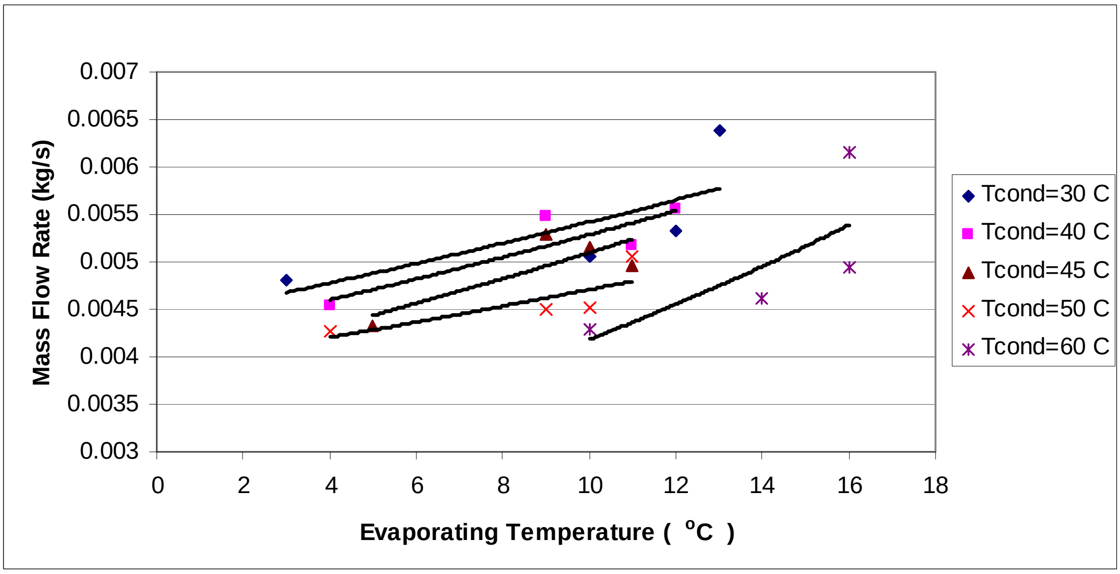


Figure (6.24) Mass Flow Rate vs. Evaporating Temp for LPG, solar energy

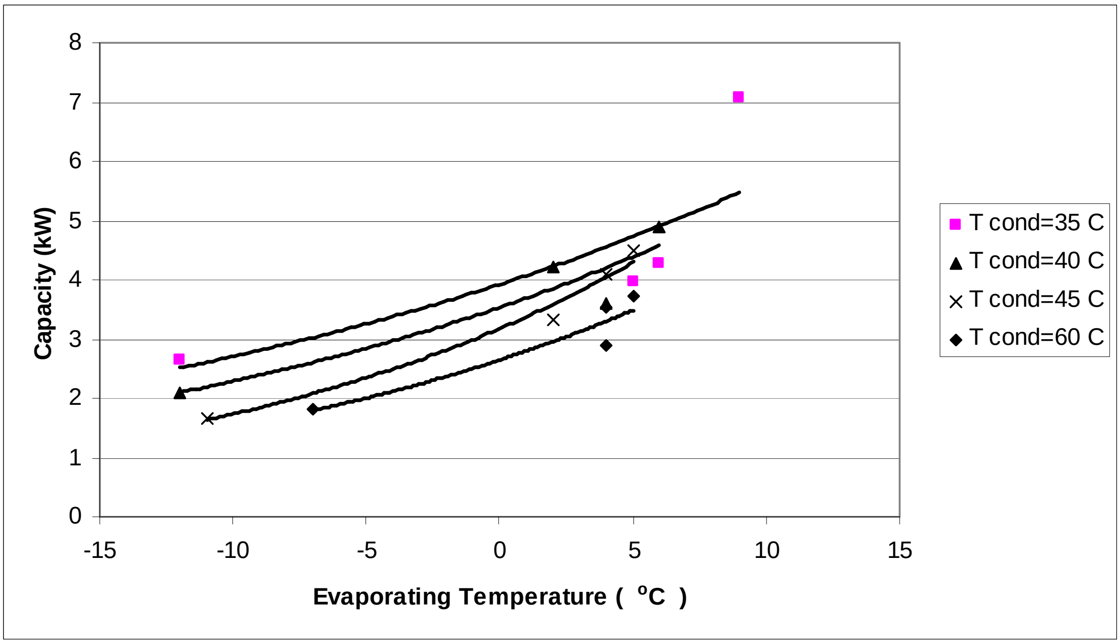


Figure (6.25) Cooling Capacity vs. Evaporating Temp for R22, solar energy

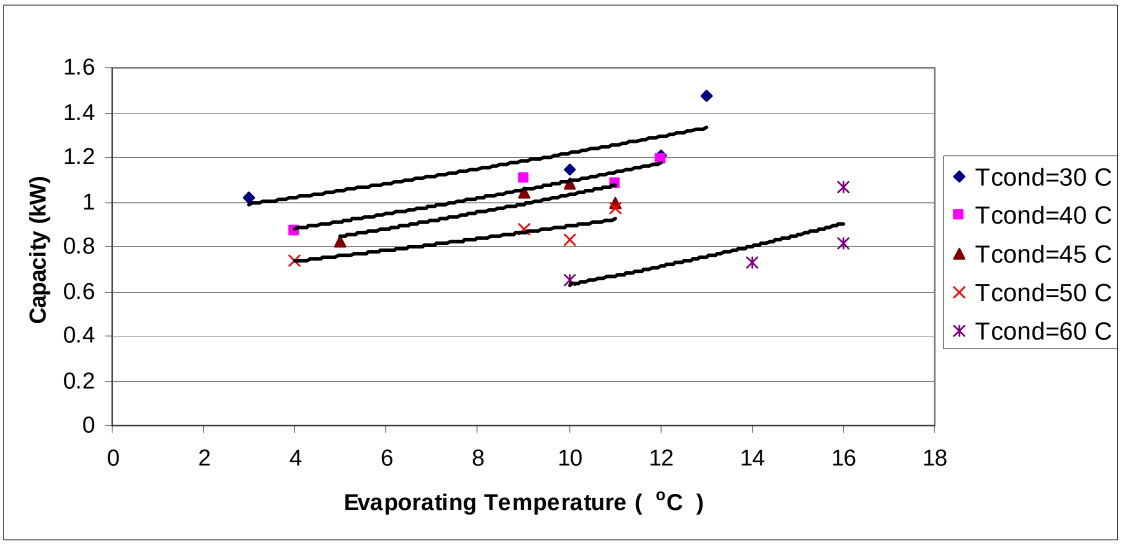


Figure (6.26) Cooling Capacity vs. Evaporating Temp for LPG, solar energy

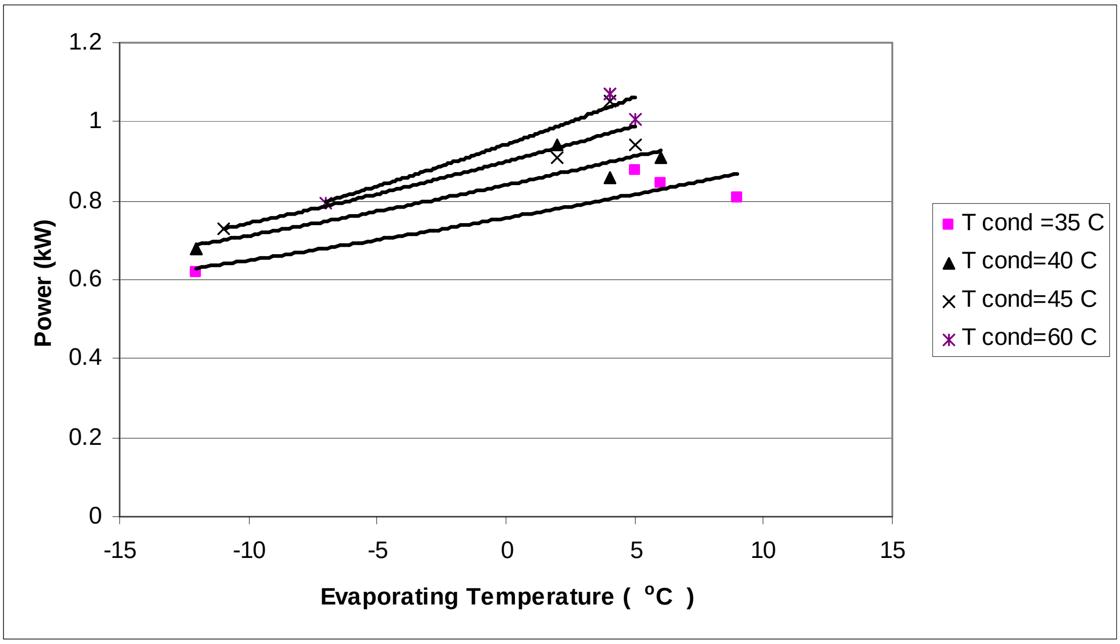


Figure (6.27) Power Consumption vs. Evaporating Temp for R22, solar energy

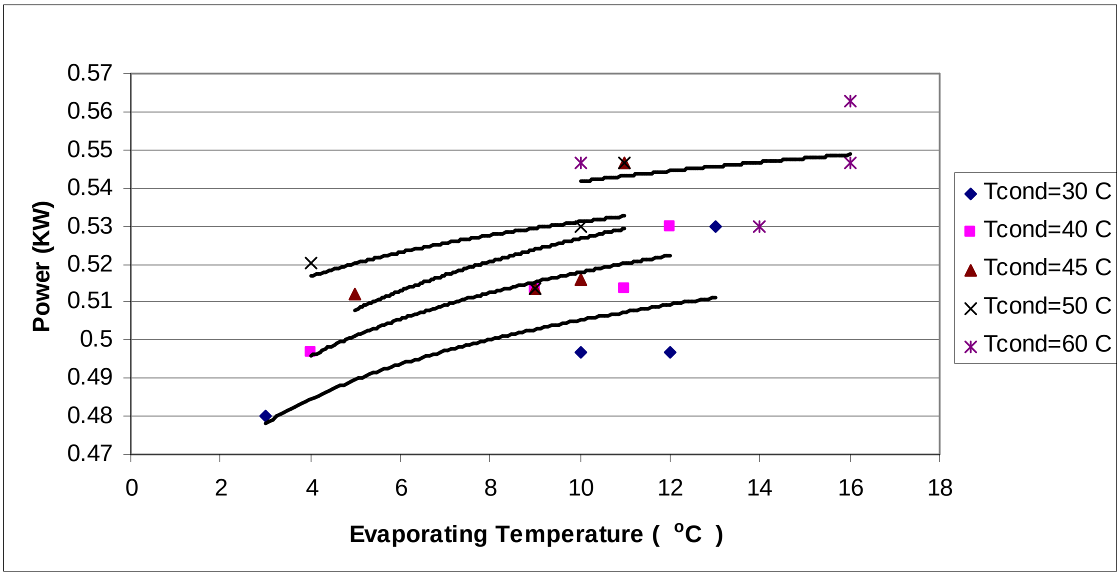


Figure (6.28) Power Consumption vs. Evaporating Temp for LPG, solar energy

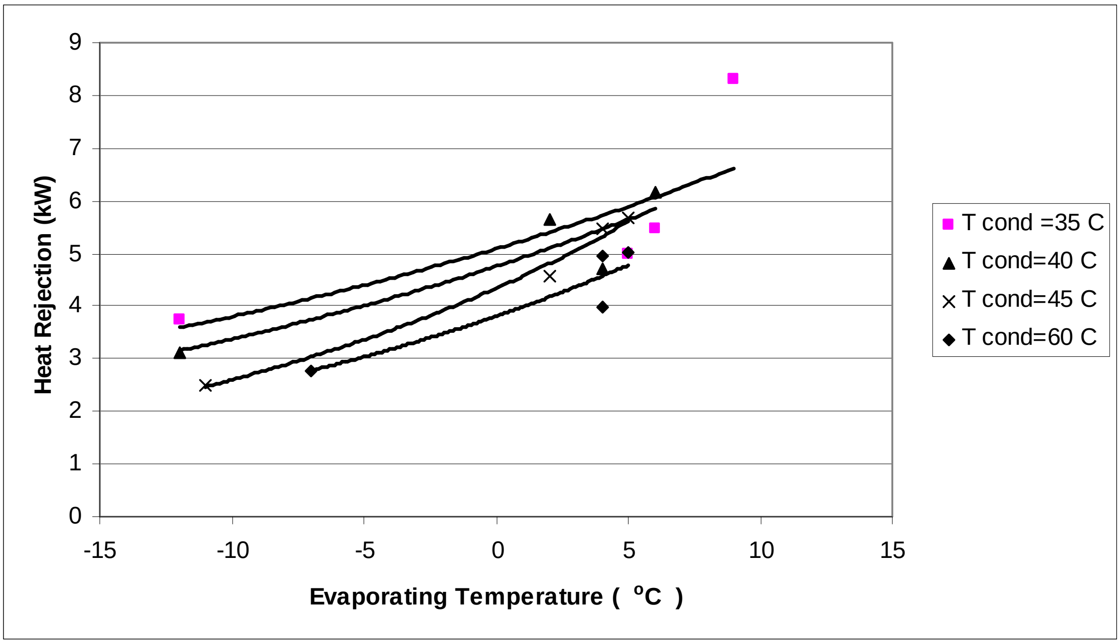


Figure (6.29) Heat Rejection vs. Evaporating Temp for R22, solar energy

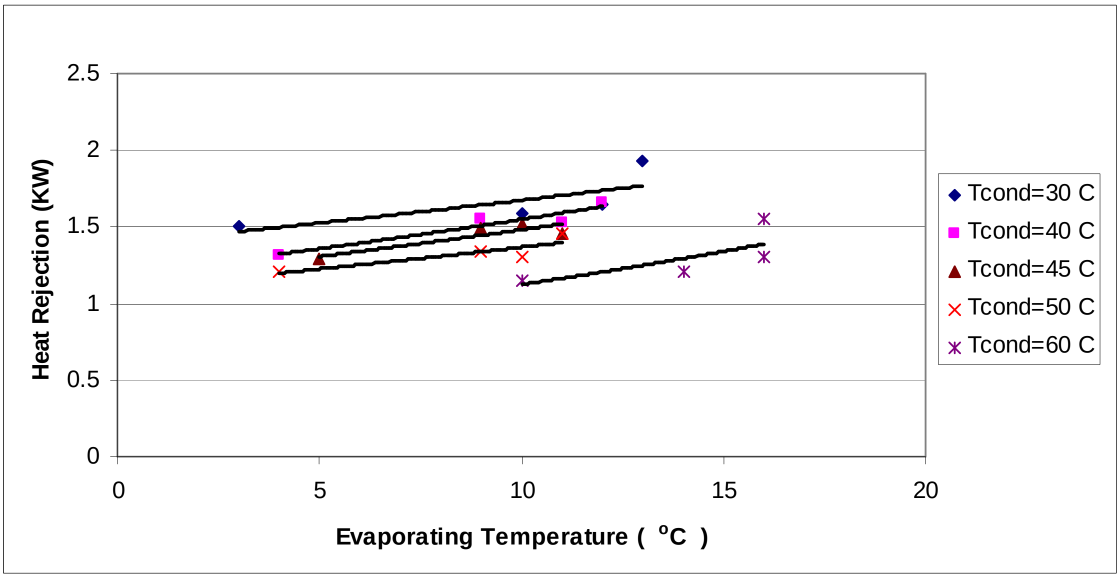


Figure (6.30) Heat Rejection vs. Evaporating Temp for LPG, solar energy

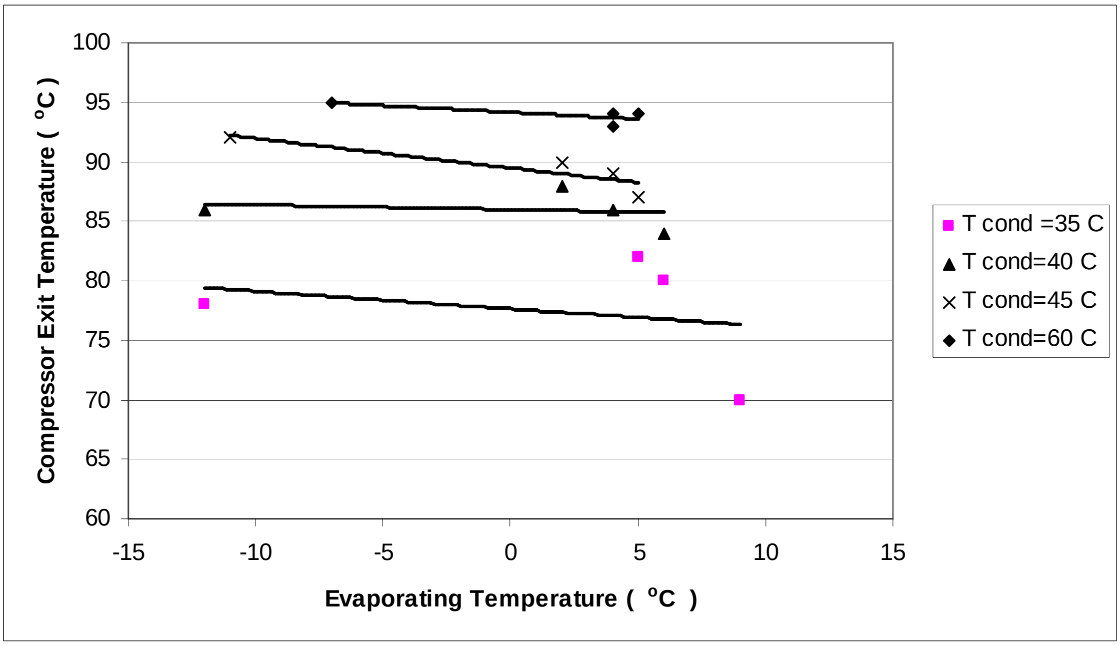


Figure (6.31) Compressor Exit Temperature vs. Evaporating Temp for R22, solar energy

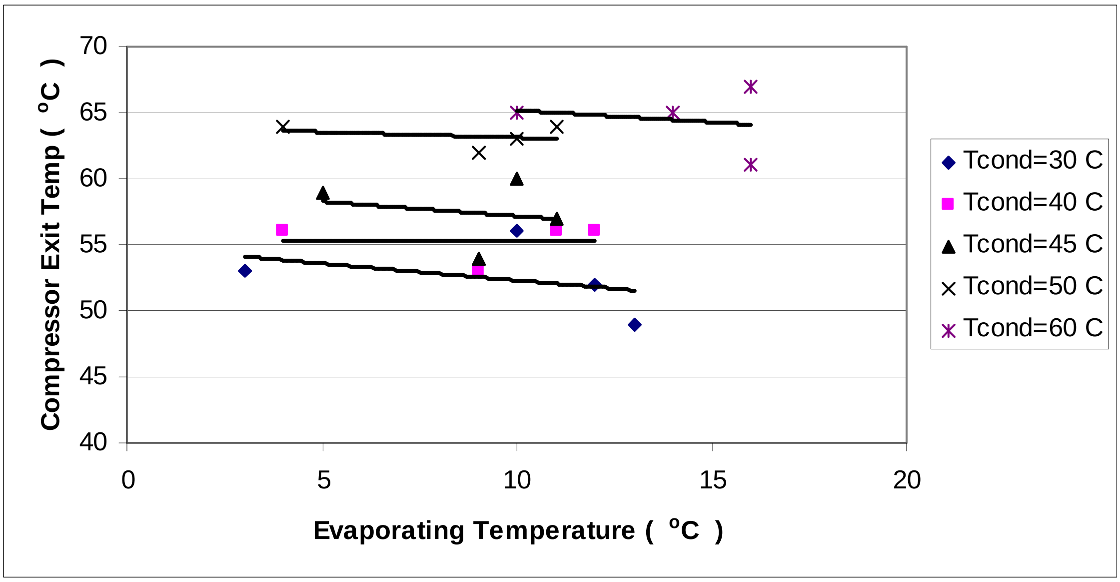


Figure (6.32) Compressor Exit Temperature vs. Evaporating Temp for LPG, solar energy

6.5 Condensing Temperature Variation Test for R22 and LPG Using Solar Energy.

6.5.1 Refrigerating Effect

Figure (6.33) and Figure (6.34) represent the variation of refrigeration effect with the T_c for R22 and LPG respectively, the figures show that as T_c increases the refrigeration effect decreases when T_e remains constant, this because when T_c increases enthalpy entering the capillary tube increases while the enthalpy of the refrigerant exit from evaporator remains constant. Also as shown in the figures the refrigeration effect for LPG is higher than R22 at constant T_e.

6.5.3 Coefficient of Performance

Figure (6.35) and Figure (6.36) show the variation of COP with T_c. COP for R22 refrigerant was higher than LPG and it decreases as T_c increases for both because refrigeration effect increased and work of compression also increased.

6.5.4 Mass Flow Rate

Figure (6.37) and Figure (6.38) represent the variation of mass flow rate with T_c for both refrigerants. It decreases as T_c increases because the difference between the enthalpy across the compressor increased.

6.5.5 Capacity

The capacity for two refrigerant decreases as Tc increases as shown in figure (6.39) and figure (6.40) since mass flow rate decreased and refrigeration effect also decreased.

6.5.5 Power Consumption

Figure (6.41) and Figure (6.42) represent the variation of power of compressor in (kW) with respect of T_c, the power increases as T_c increases; this shows that the effect of work of compression (h_2-h_1) was more of the mass flow rate for that the power increased.

6.5.6 Heat Reject

Heat reject decreases as T_c increases as shown in figure (6.43) and figure (6.44) for both refrigerants since mass flow rate decreased.

6.5.7 Compressor Exit Temperature

Figure (6.45) and Figure (6.46) represent the exit compressor temperature with T_c. the exit temperature for both R22 and LPG increases as T_c increases.

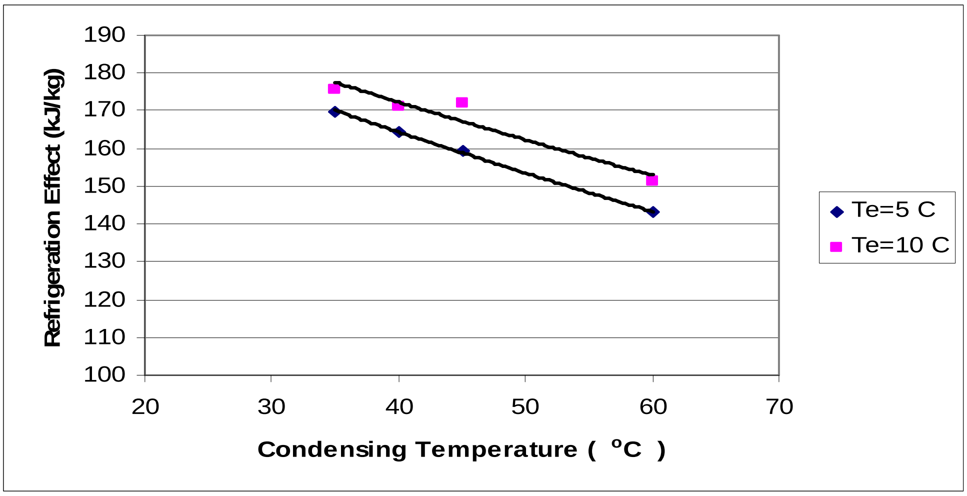


Figure (6.33) Refrigeration Effect vs. Condensing Temp for R22, solar energy

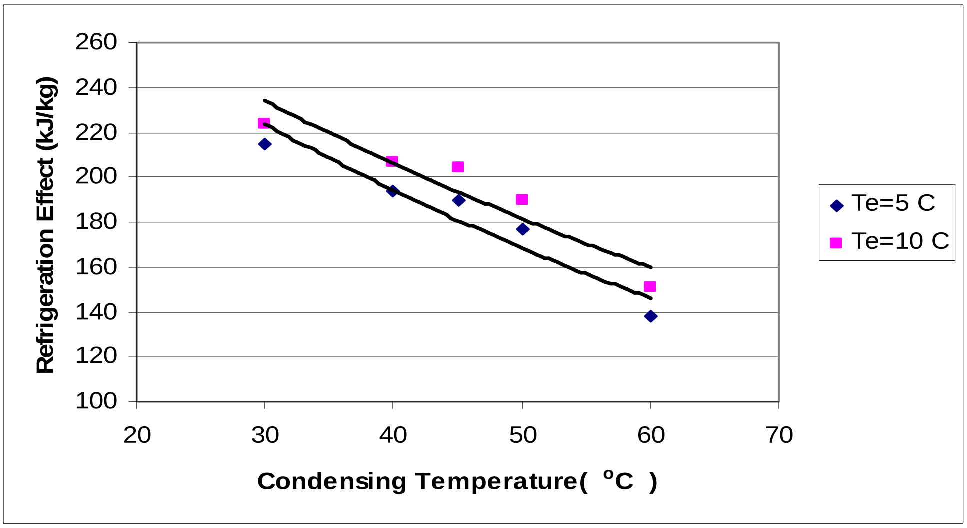


Figure (6.34) Refrigeration Effect vs. Condensing Temp for LPG, solar energy

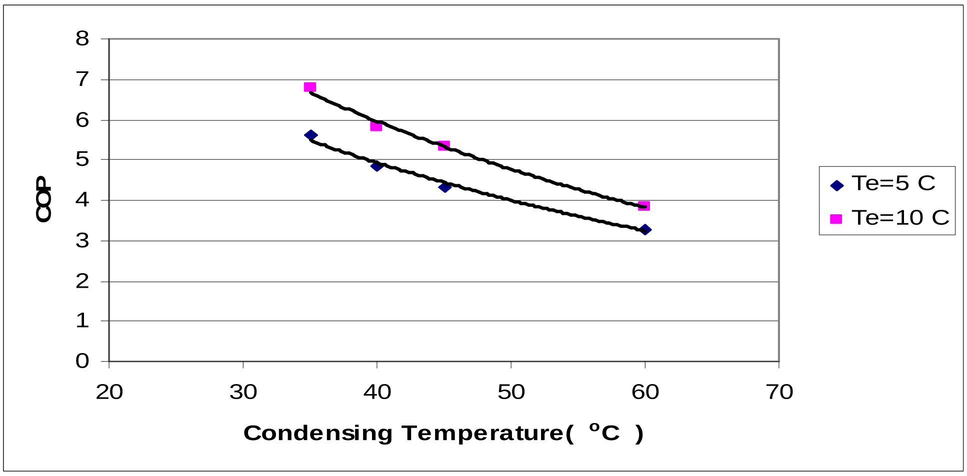


Figure (6.35) Coefficient of Performance vs. Condensing Temp for R22, solar energy

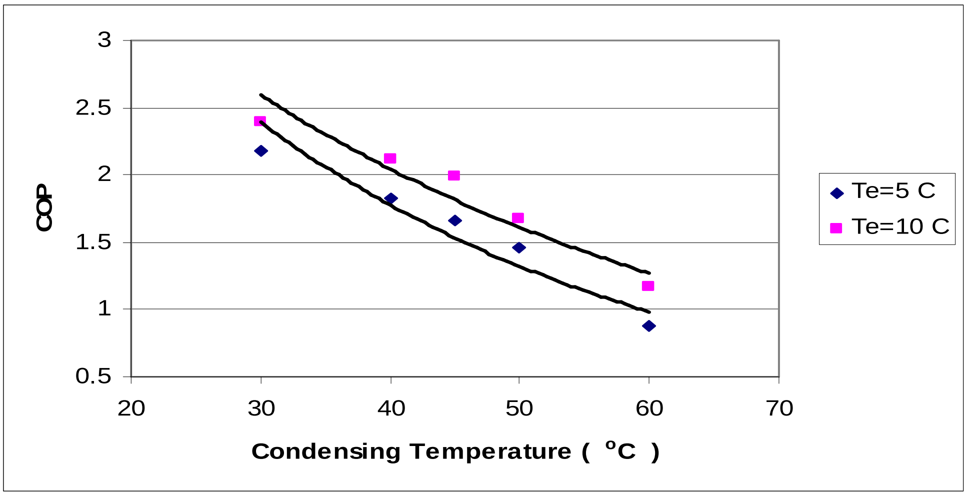


Figure (6.36) Coefficient of Performance vs. Condensing Temp for LPG, solar energy

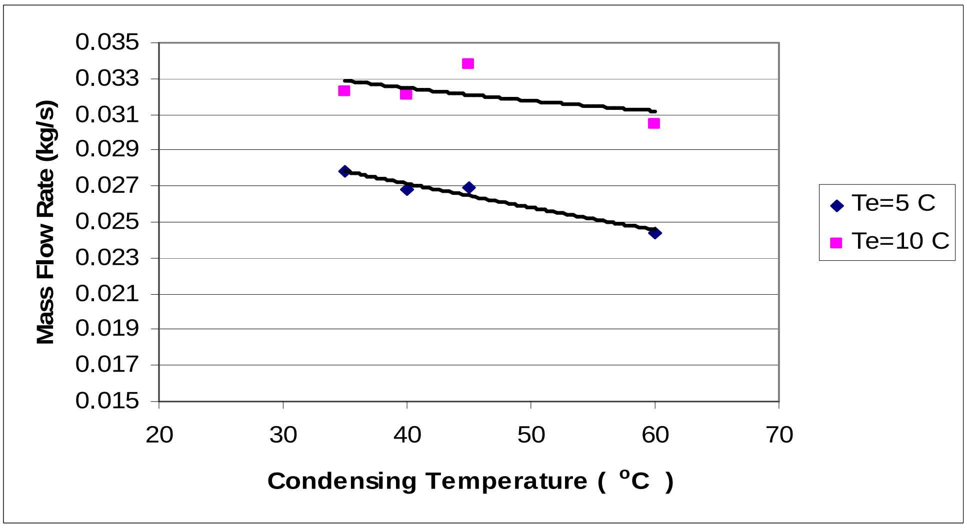


Figure (6.37) Mass Flow Rate vs. Condensing Temp for R22, solar energy

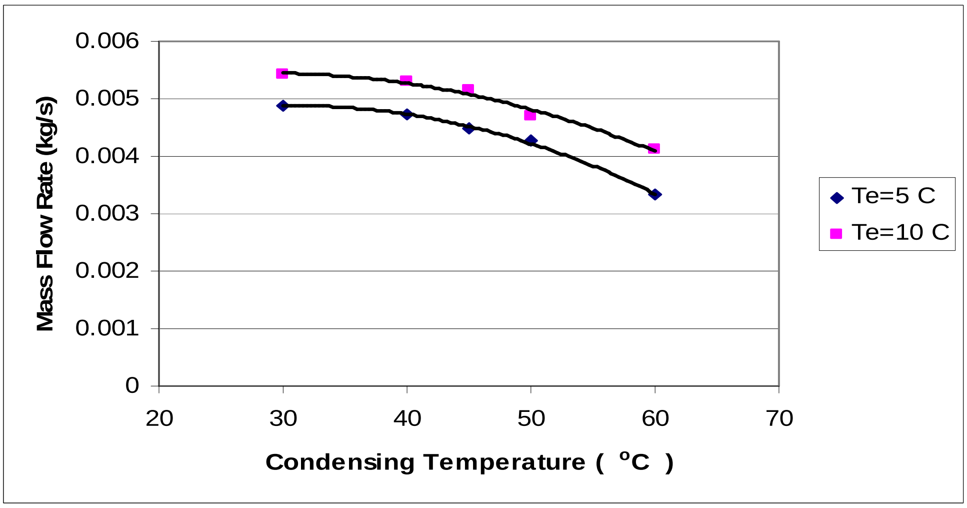


Figure (6.38) Mass Flow Rate vs. Condensing Temp for LPG, solar energy

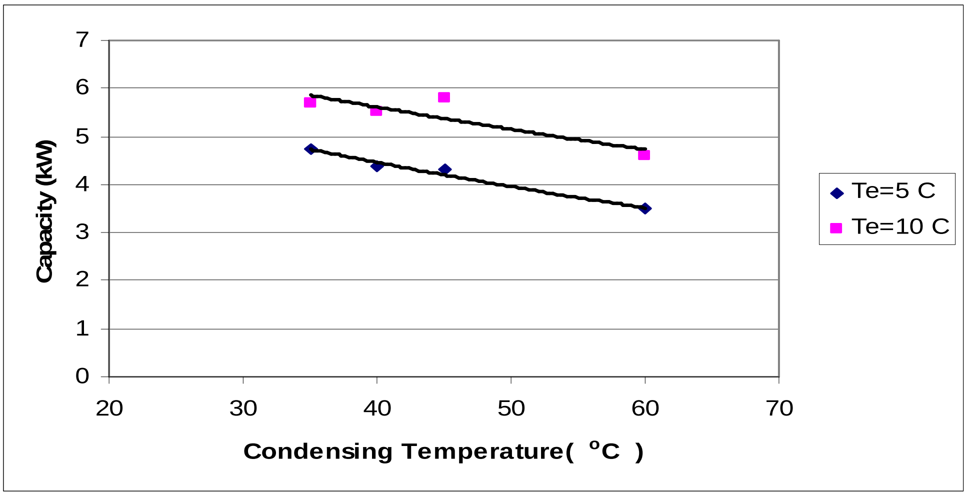


Figure (6.39) Cooling Capacity vs. Condensing Temp for R22, solar energy

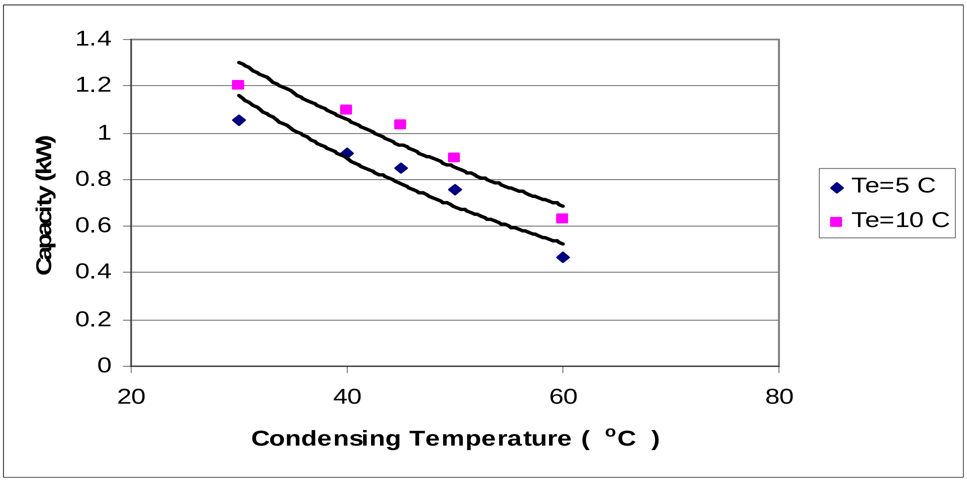


Figure (6.40) Cooling Capacity vs. Condensing Temp for LPG, solar energy

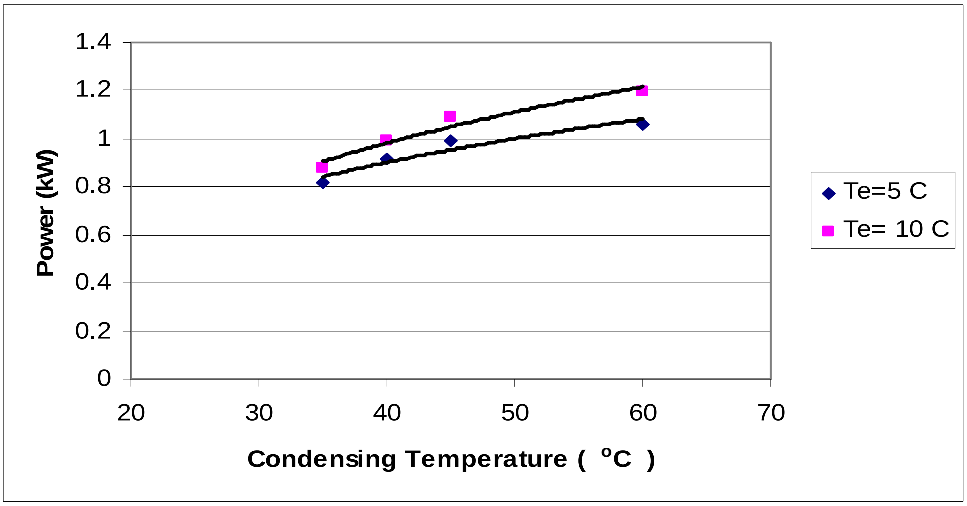


Figure (6.41) Power Consumption vs. Condensing Temp for R22, solar energy

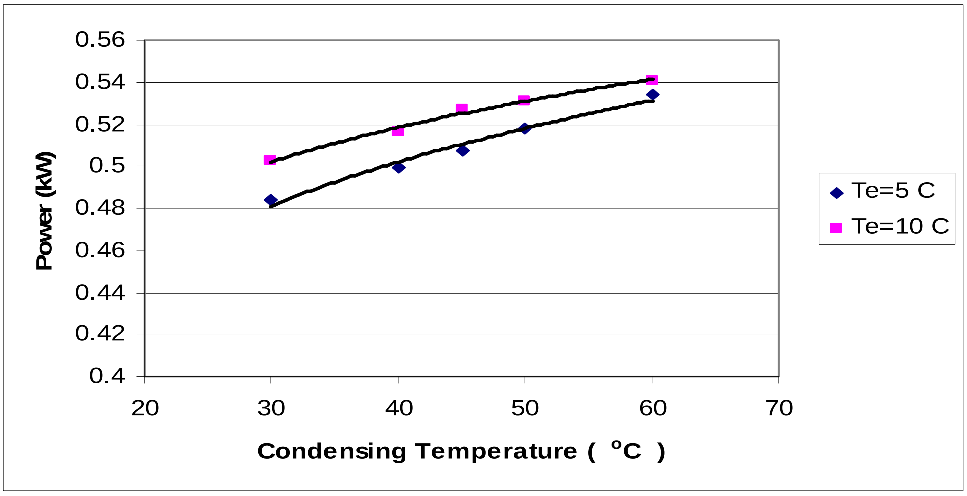


Figure (6.42) Power Consumption vs. Condensing Temp for LPG, solar energy

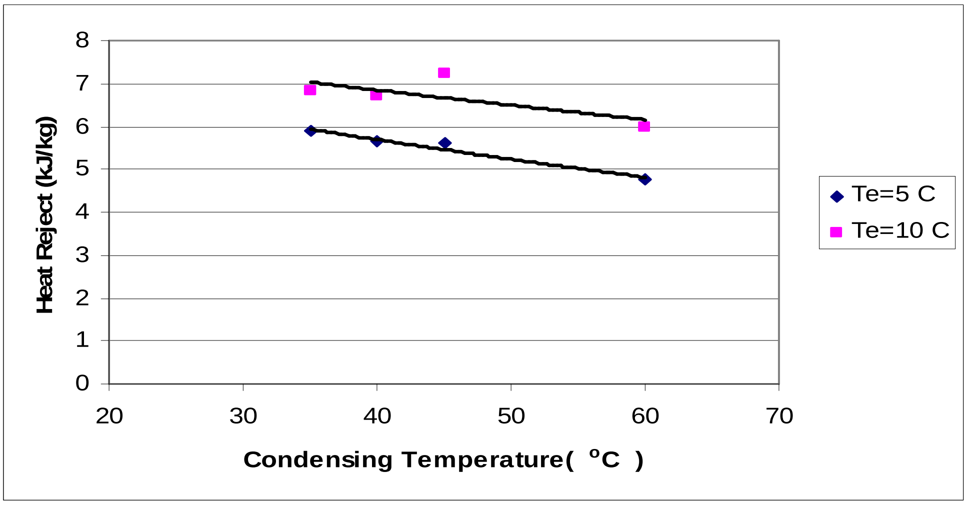


Figure (6.43) Heat Rejection vs. Condensing Temp for R22, solar energy

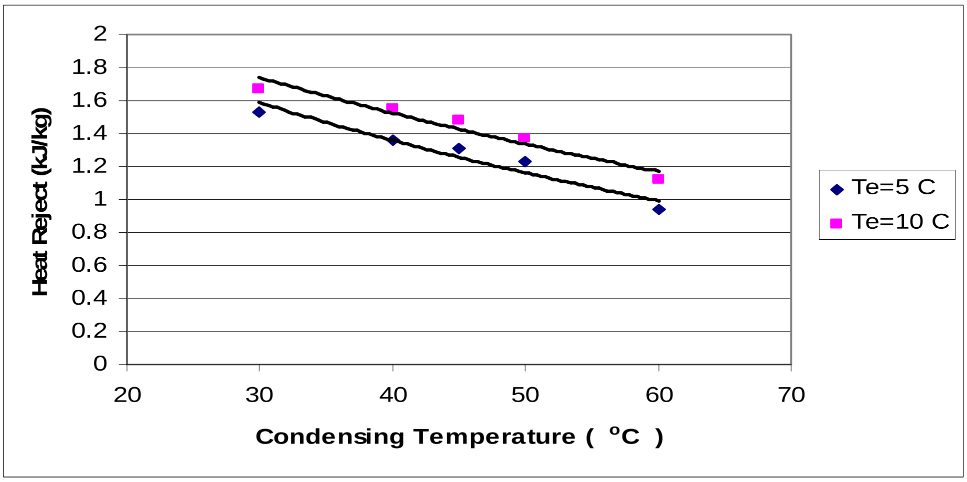


Figure (6.44) Heat Rejection vs. Condensing Temp for LPG, solar energy

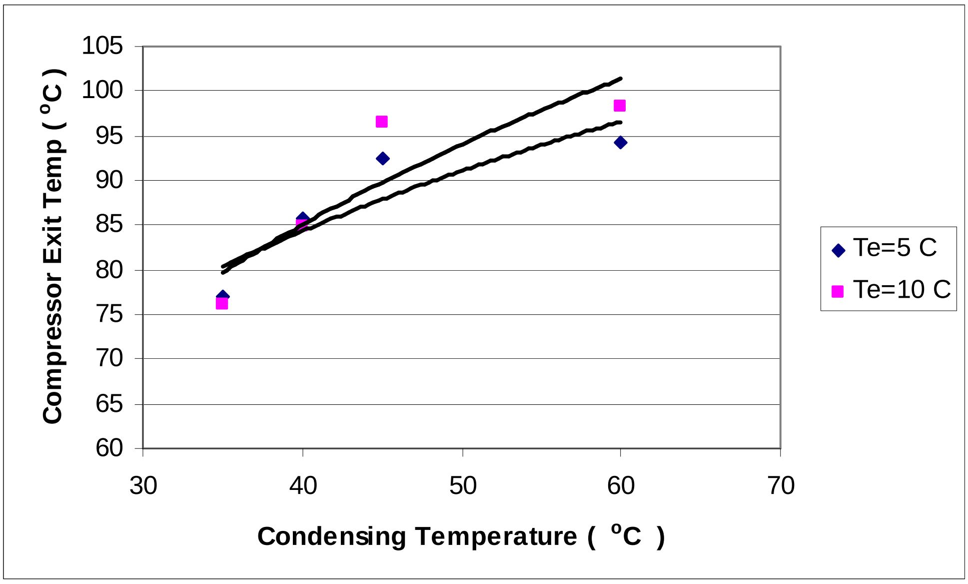


Figure (6.45) Compressor Exit Temperature vs. Condensing Temp for R22, solar energy

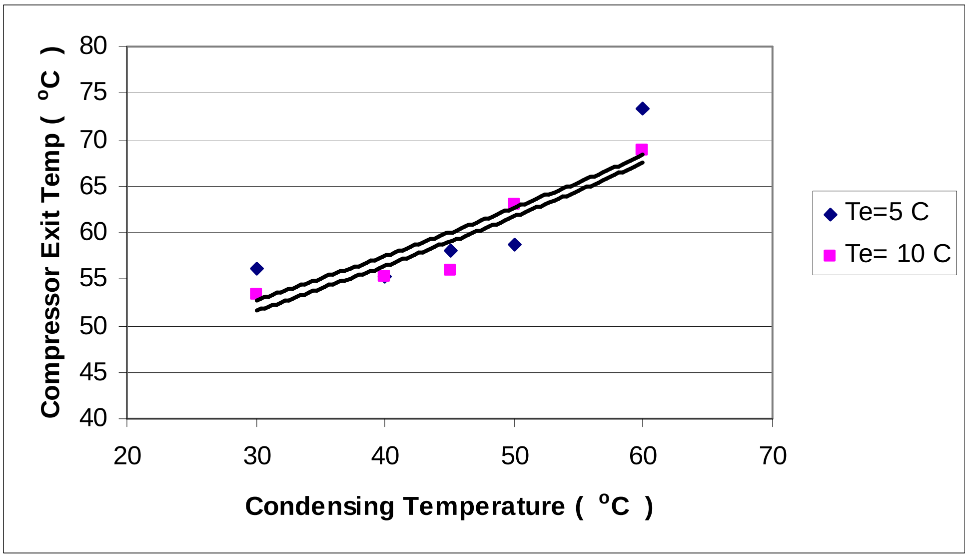


Figure (6.46) Compressor Exit Temperature vs. Condensing Temp for LPG, solar energy

R = Thermal ratio = (Heat Reject / Capacity)

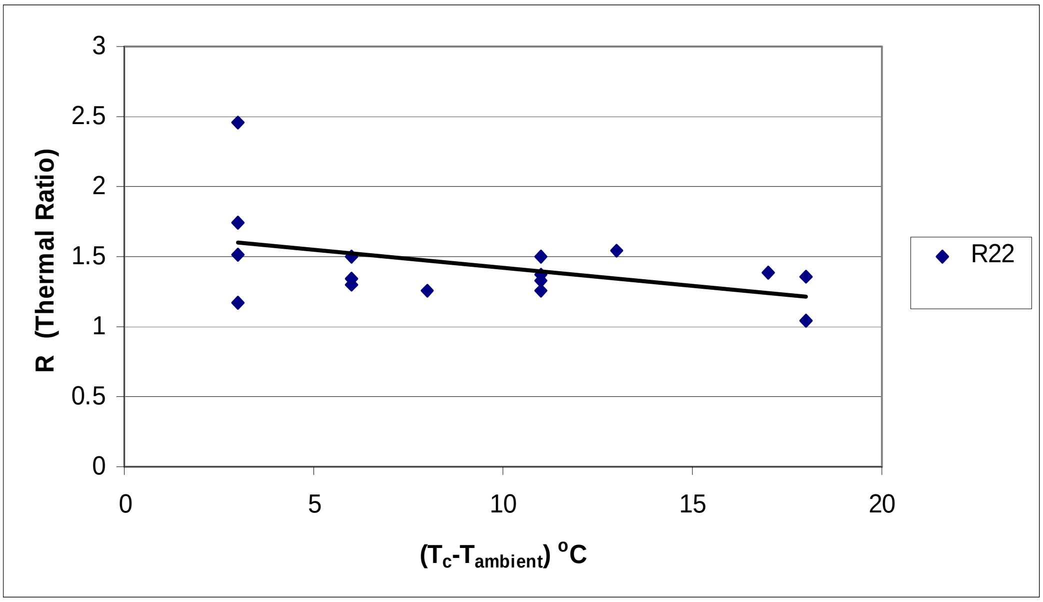


Figure (6.47) ($T_c - T_{ambient}$) vs. Thermal Ratio for R22, solar energy

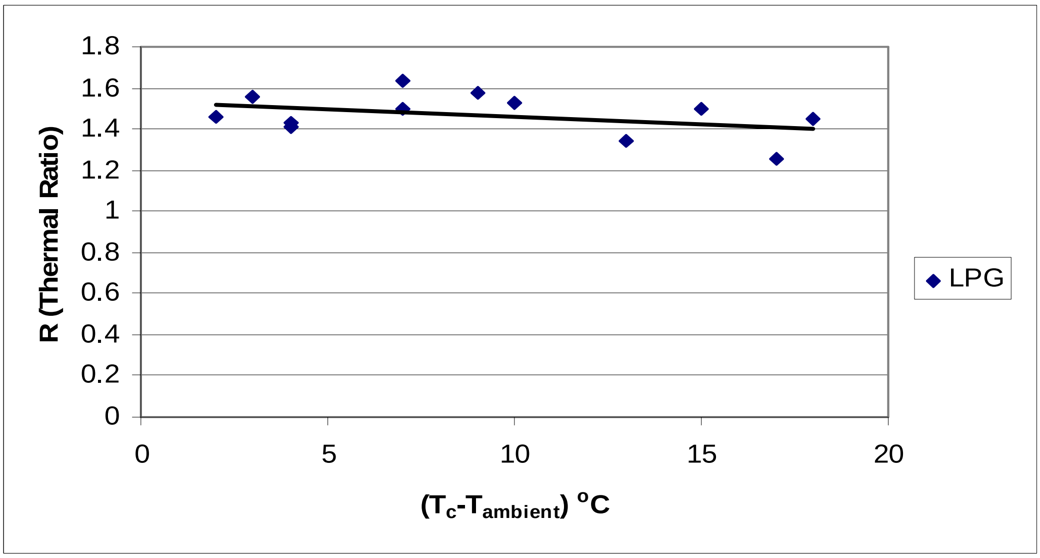


Figure (6.48) ($T_c - T_{ambient}$) vs. Thermal Ratio for LPG, solar energy

6.6 LPG Time of Day, T_e and T_c Variation Tests Compared to that of R22

A- Time of Day Variation Test

In this test the variable parameters that were conducted on the time between restart and shutdown of the unit when it started shutdown and restart because of insufficient power from solar system were represented as a points in the curves for both R22 and LPG. They were considered as a shutdown region in the curves.

6.6.1 Refrigerating Effect

Figure (6.49) represent the variation of refrigeration effect with time of day for R22 and LPG, it shows that the refrigeration effect in (kJ/kg) for R22 using mains power and solar power approach to each other, the refrigeration effect using LPG was the highest.

6.6.3 Coefficient of Performance

Figure (6.50) shows the variation of COP with time of day for LPG and R22. COP for R22 refrigerant was higher than LPG. COP for R22 using solar energy was almost the same as using mains power but the deference happened when the system start shutdown and restart.

6.6.4 Mass Flow Rate

As shown in figures (6.51) the mass flow rate for R22 was higher than LPG, variation of LPG was almost constant, for R22 using solar energy and mains power the mass flow rate approach to each other. Sharp increasing is happened for R22 when solar power was used and the unit restarted and shutdown because of instability of the system.

6.6.5 Capacity

The capacity of the unit using R22 was higher than LPG; it is reached 2.9 kW for R22 and 1.5 kW for LPG at 14:00 as shown in figure (6.52)

6.6.6 Power Consumption

Figure (6.53) represents the variation of power consumption. The power consumption for using R22 as refrigerant was higher than LPG, for that the unit run from 10:00 and the first shutdown was occurred at 19:00 when LPG was used but for R22 it run from 10:00 to14:55

6.6.7 Heat Reject

As shown in figure (6.54) the heat reject for R22 is higher than LPG, it is seen that the variation of heat reject for R22 using solar power was almost the same as using mains power.

6.6.8 Compressor Exit Temperature

The compressor exit temperature for R22 is higher than LPG as shown in figure (6.55). For R22 using mains power the exit temperature is slight higher than using solar energy.

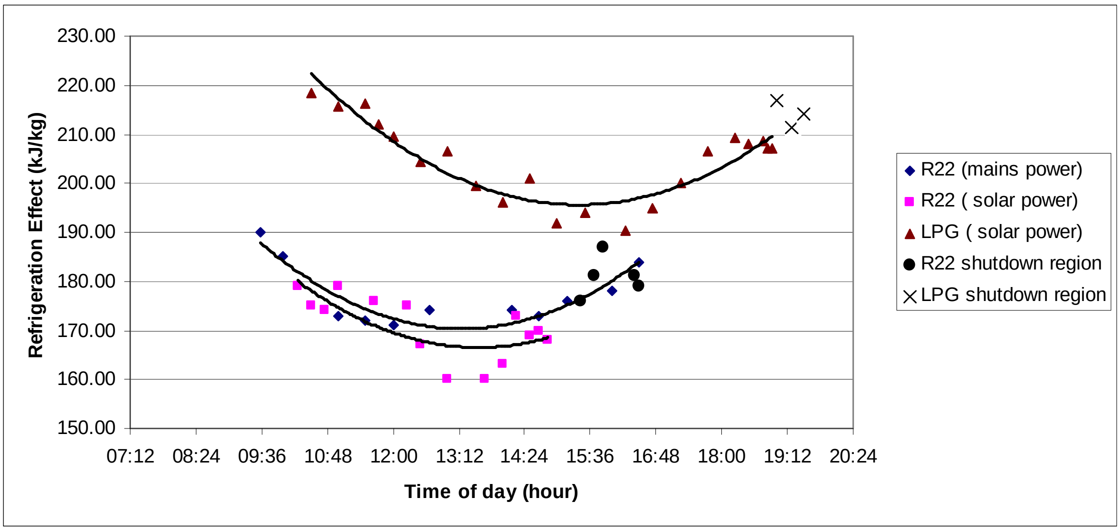


Figure (6.49) Refrigeration Effect vs. Time of the day for R22 & LPG

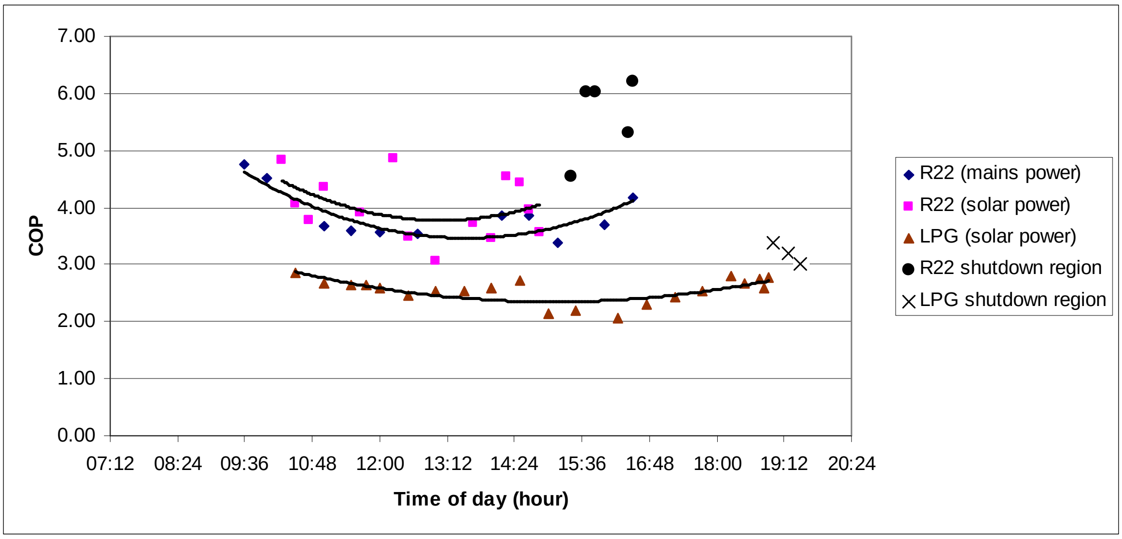


Figure (6.50) Coefficient of Performance vs. Time of the day for R22 & LPG

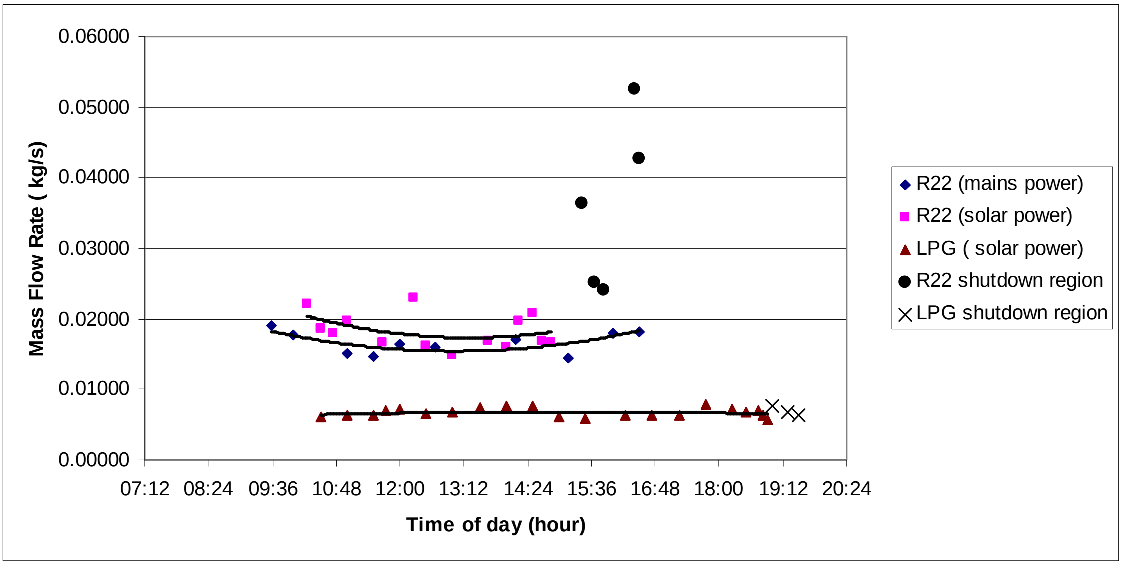


Figure (6.51) Mass Flow Rate vs. Time of the day for R22 & LPG

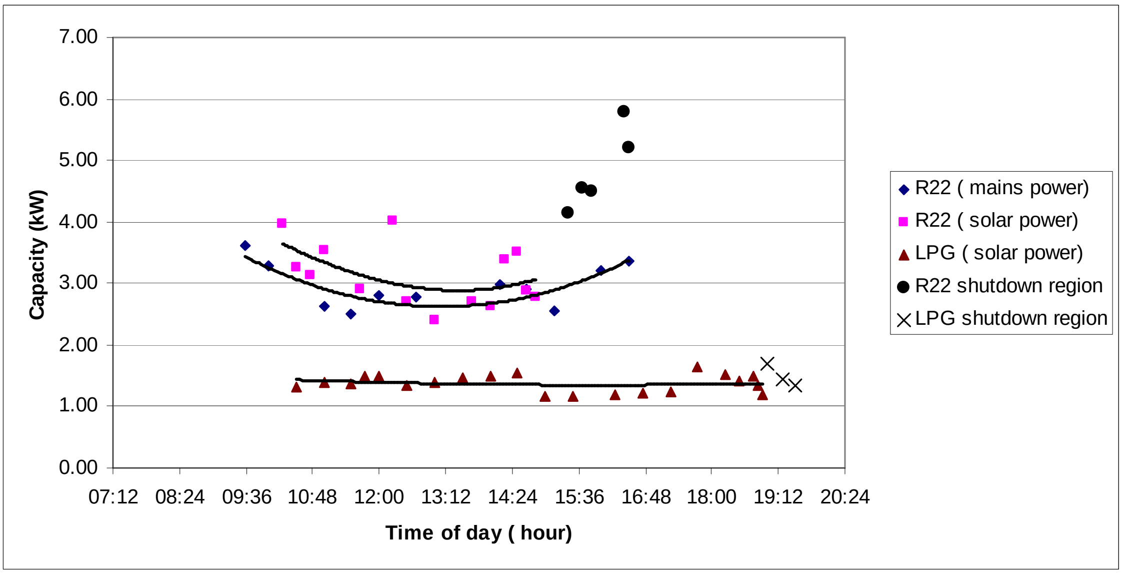


Figure (6.52) Cooling Capacity vs. Time of the day for R22 & LPG

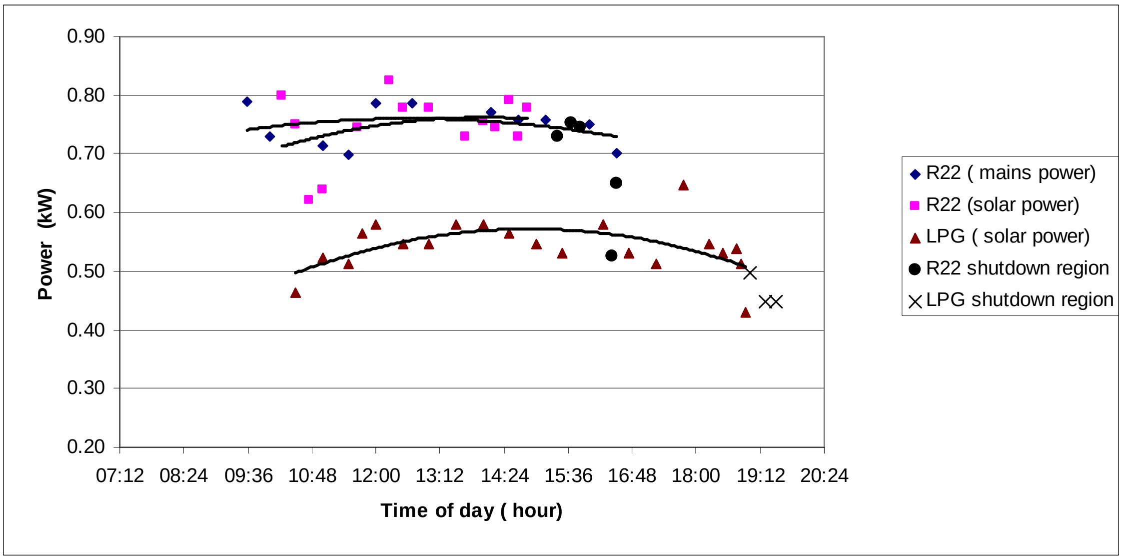


Figure (6.53) Power Consumption vs. Time of the day for R22 & LPG

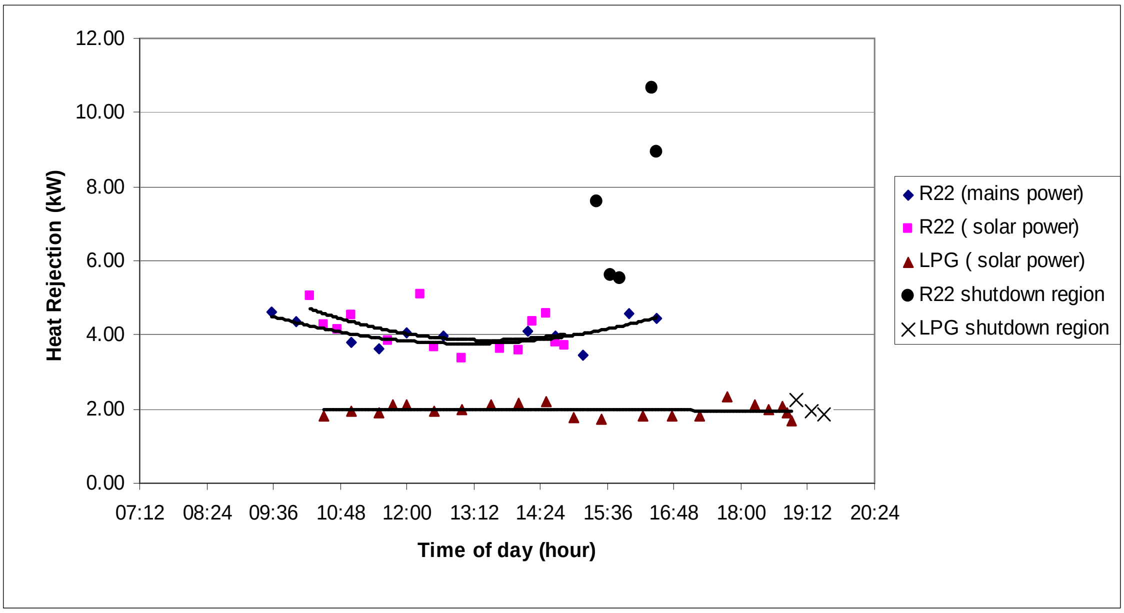


Figure (6.54) Heat Rejection vs. Time of the day for R22 & LPG

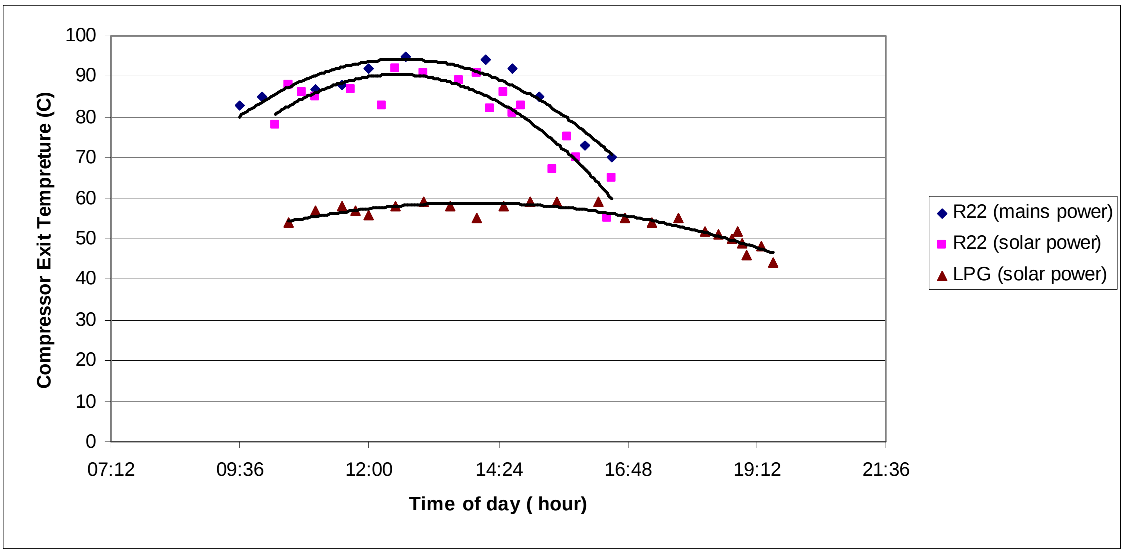


Figure (6.55) Compressor Exit Temp vs. Time of day for R22 & LPG

B- Evaporating Temperature Variation Test

6.7.1 Refrigerating Effect

Figure (6.56) represent the variation of refrigeration effect with respect to T_e for R22 and LPG, it shows that the refrigeration effect for LPG is higher than R22 because the enthalpies of LPG is higher than R22, also it can be seen that refrigeration effect for R22 using solar and mains power look the same.

6.7.2 Coefficient of Performance

Figure (6.57) shows the variation of COP with T_e for LPG and R22. COP for R22 refrigerant was higher than LPG and it increases as T_e increases for both, also COP using solar power and mains power was approach to each other.

6.7.3 Mass Flow Rate

As shown in figure (6.58) the mass flow rate increases as T_e increases at constant T_c. The mass flow rate for R22 was higher than LPG.

6.7.4 Capacity

The capacity of the unit using both R22 and LPG refrigerant increases as T_e increases as shown in figure (6.59). The capacity using R22 is higher than LPG, at T_e = 5 ^oC and T_c = 45 ^oC the capacity using R22 with solar energy was 4 kW, while it was 3.8 kW for R22 using mains power they approach to each other but for LPG it was just 0.8 kW.

6.7.5 Power Consumption

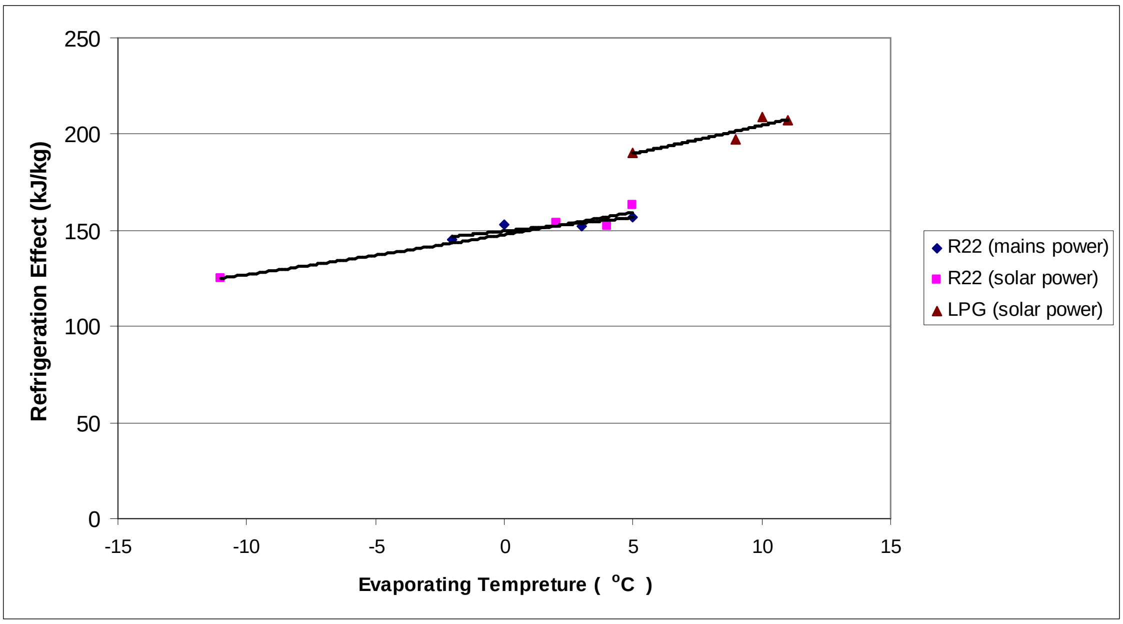
Figure (6.60) represents the variation of power consumption with respect to T_e. As T_e increases the power consumption increases. The power consumption of the compressor for either using solar power or the mains power looks the same.

6.7.6 Heat Reject

It can be seen from figure (6.61) that heat rejects increases when T_e increases for R22 and LPG.

6.7.7Compressor Exit Temperature

The exit temperature of the compressor decreases as T_e increases for both refrigerants as shown in figure (6.62).



Figure(6.56) Refrigeration Effect vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

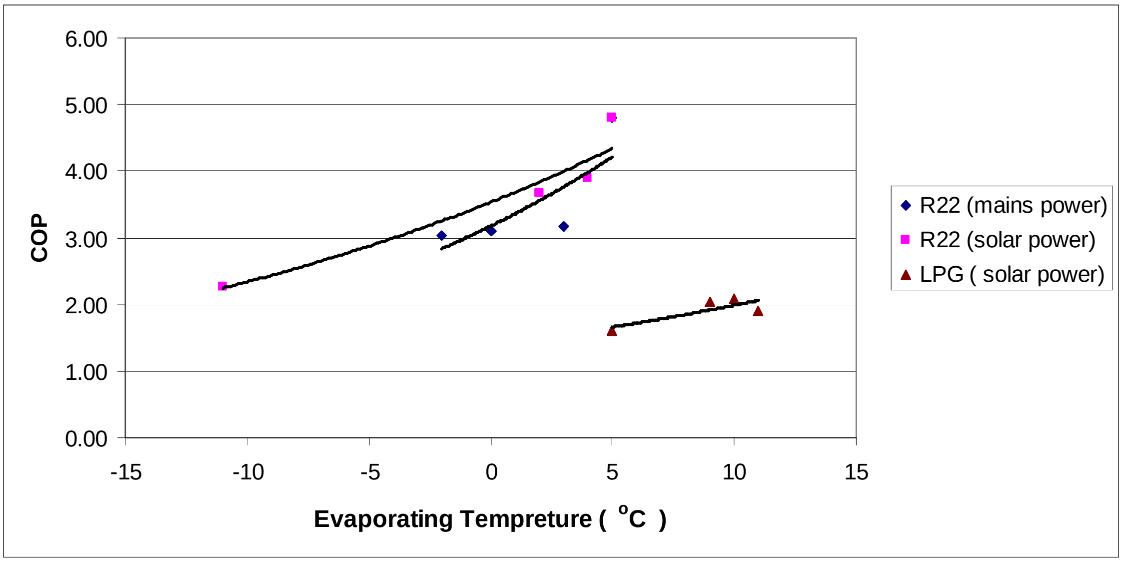


Figure (6.57) Coefficient of Performance vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

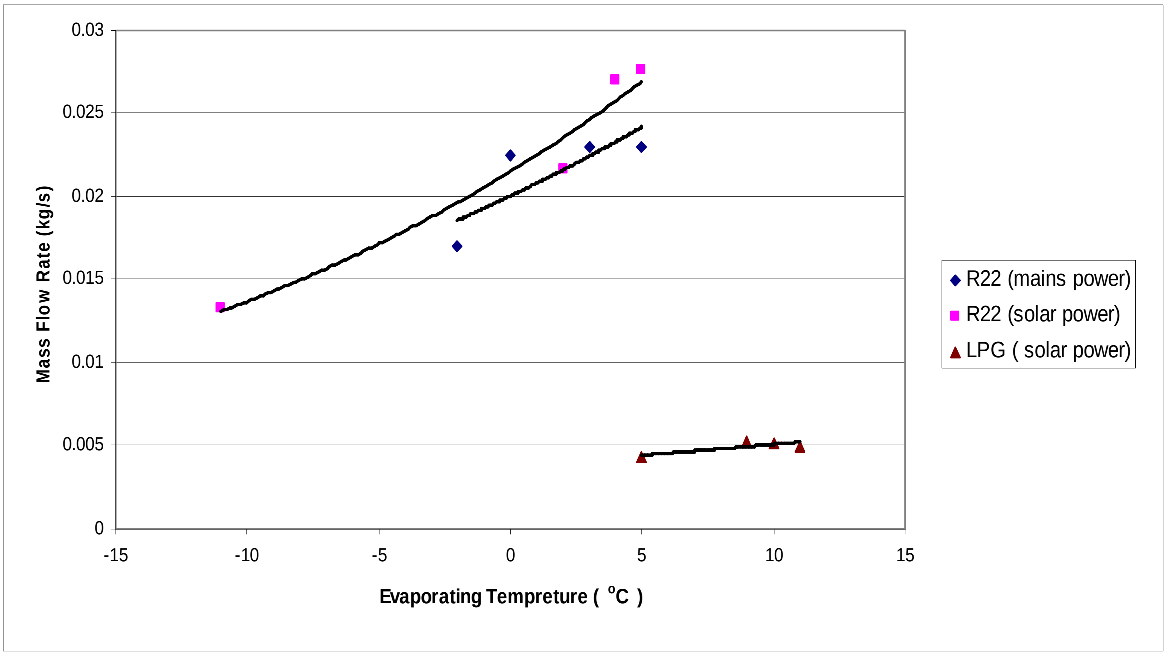


Figure (6.58) Mass Flow Rate vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

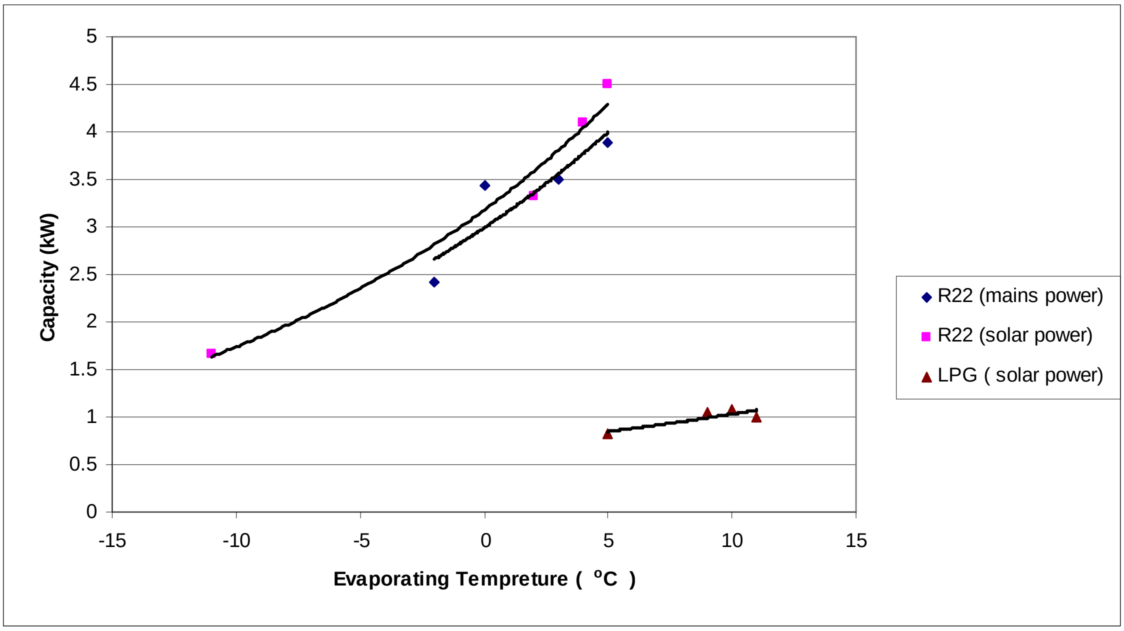


Figure (6.59) Cooling Capacity vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

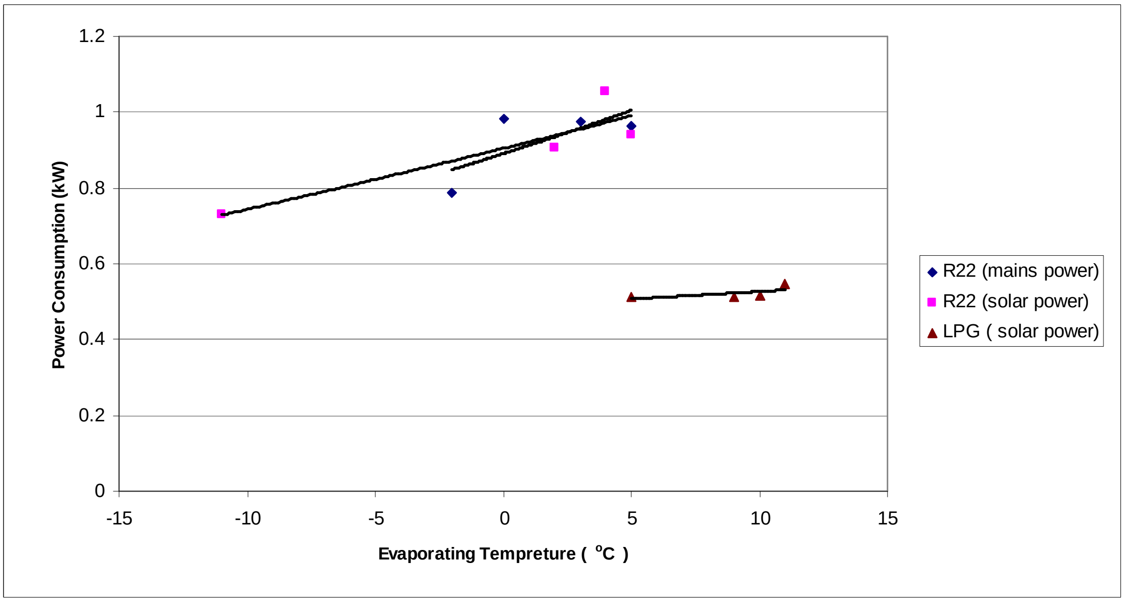


Figure (6.60) Power Consumption vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

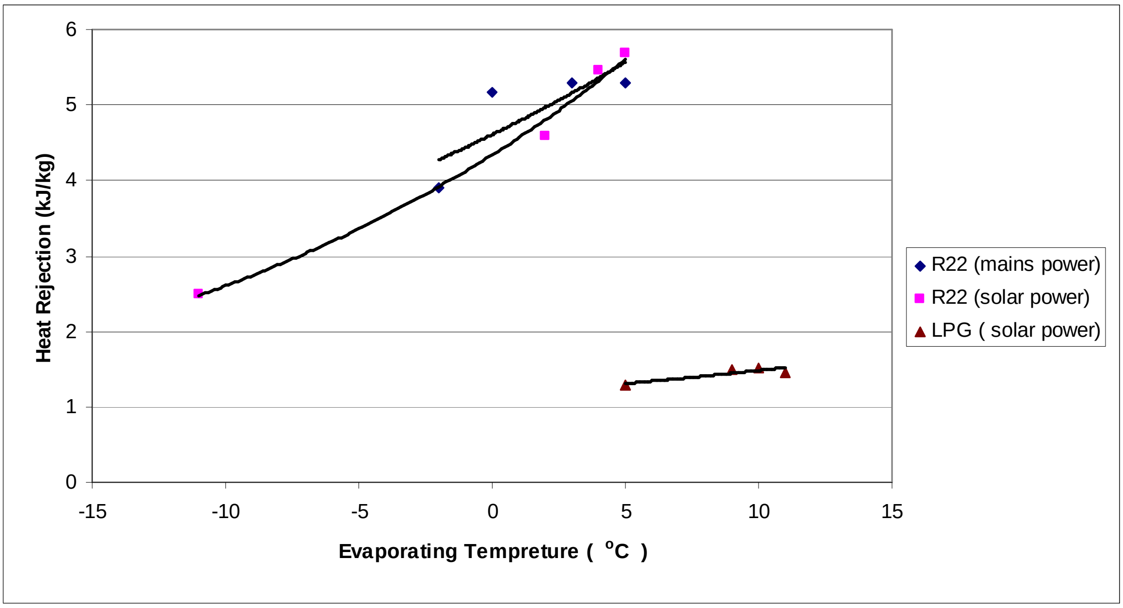


Figure (6.61) Heat Rejection vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

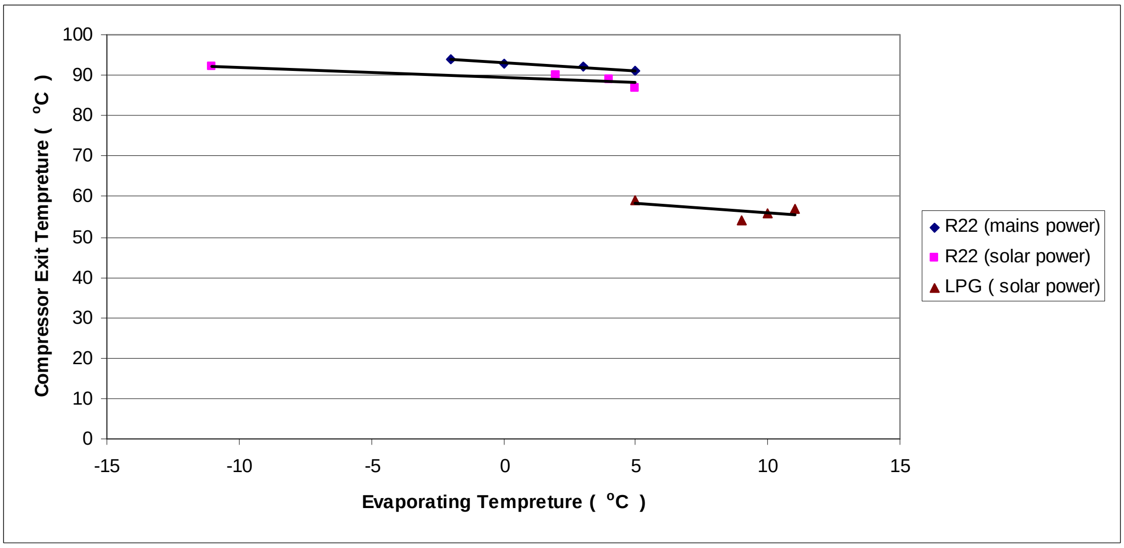


Figure (6.62) Compressor Exit Temperature vs. Evaporating Temp for R22 & LPG at T_c= 45 °C

C- Condensing Temperature Variations Test

6.8.1 Refrigerating Effect

Figure (6.63) represent the variation of refrigeration effect with respect to T_c for R22 and LPG, it shows that the refrigeration effect decreases as T_c increases, also it was for LPG higher than R22. It look the same for R22 either using solar or mains power.

6.8.3 Coefficient of Performance

Figure (6.64) shows the variation of COP with T_c for LPG and R22. COP for R22 refrigerant was higher than LPG and it decreases as T_c increases for both, also COP approach to each other for R22 either using solar power or mains power.

6.8.4 Mass Flow Rate

As shown in figures (6.65) the mass flow rate decreases as T_c increases at constant T_e. The mass flow rate was higher for R22 than LPG.

6.8.5 Capacity

The capacity of the unit using both R22 and LPG refrigerant decreases as T_c increases as shown in figure (6.66). The capacity using R22 is higher than LPG.

6.8.6 Power Consumption

Figure (6.67) represents the variation of power consumption with respect to T_c. As T_c increases the power consumption increases. It looks the same for R22 either using solar or mains power

6.8.7 Heat Reject

It can be seen from figure (6.68) that heat rejects decreases when T_c increases for R22 and LPG.

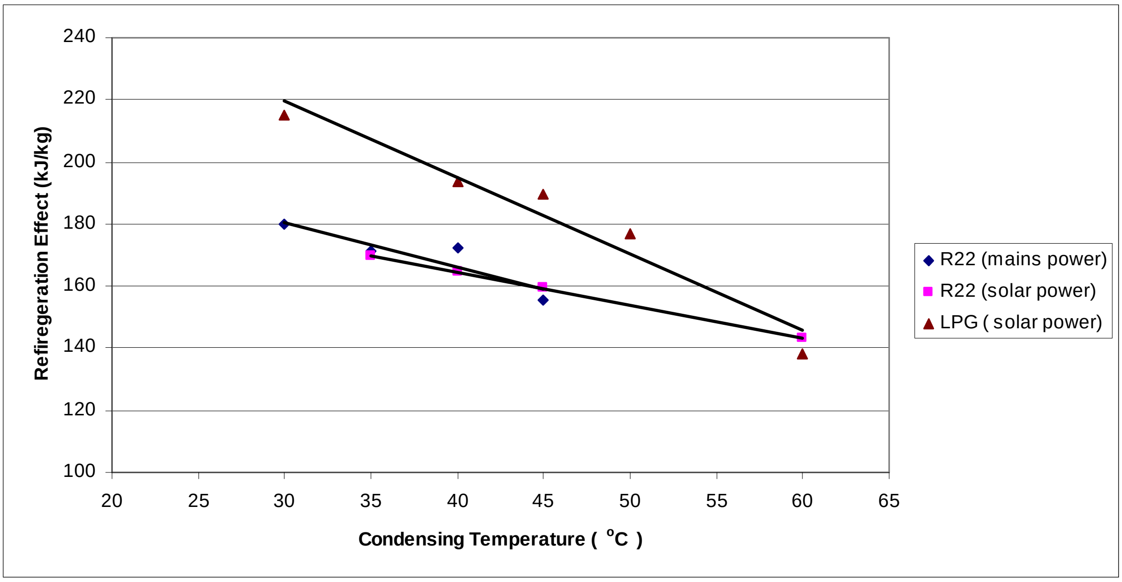


Figure (6.63) Refrigeration Effect vs. Condensing Temp for R22 & LPG at Te= 5 °C

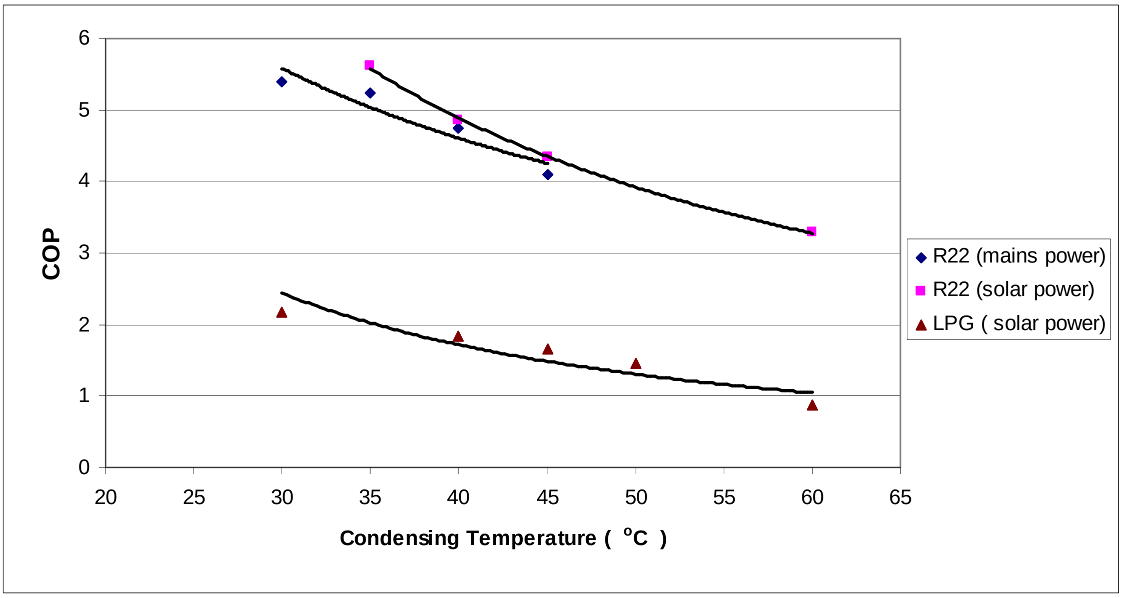


Figure (6.64) Coefficient of Performance vs. Condensing Temp for R22 & LPG at Te= 5 °C

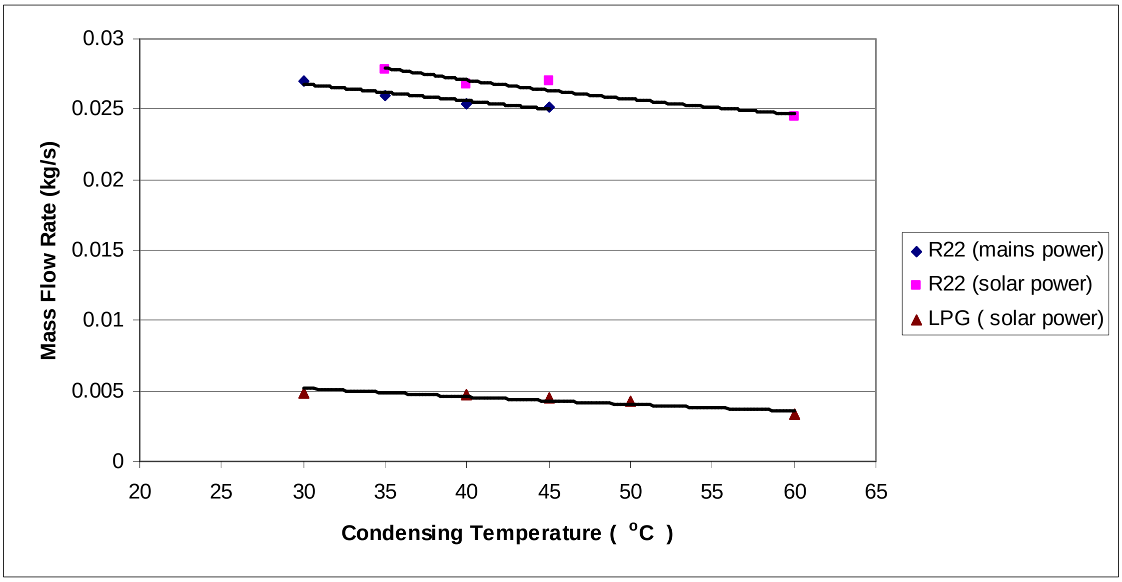


Figure (6.65) Mass Flow Rate vs. Condensing Temp for R22 & LPG at Te= 5 °C

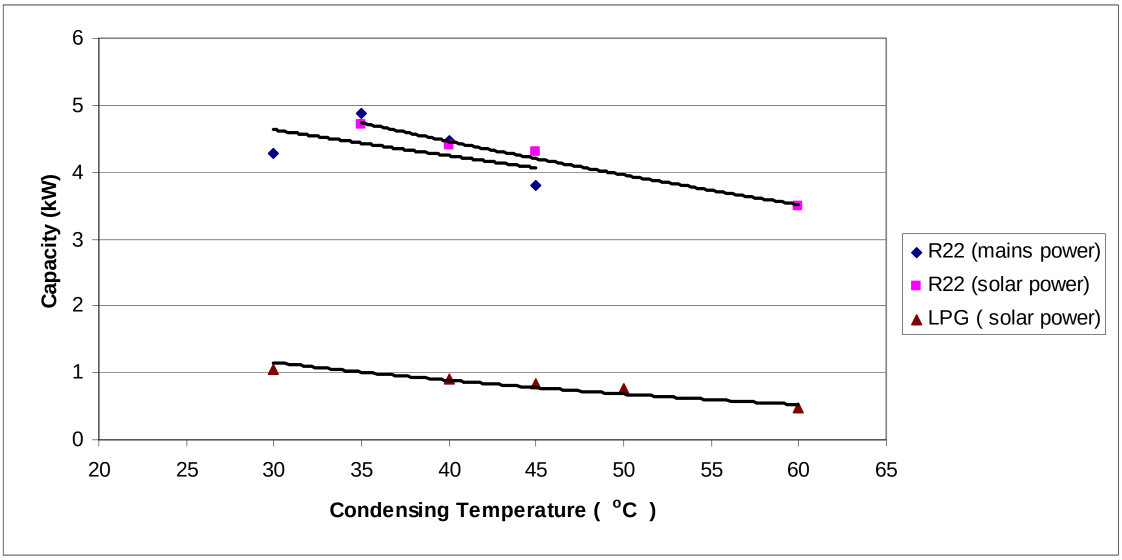


Figure (6.66) Cooling Capacity vs. Condensing Temp for R22 & LPG at Te= 5 °C

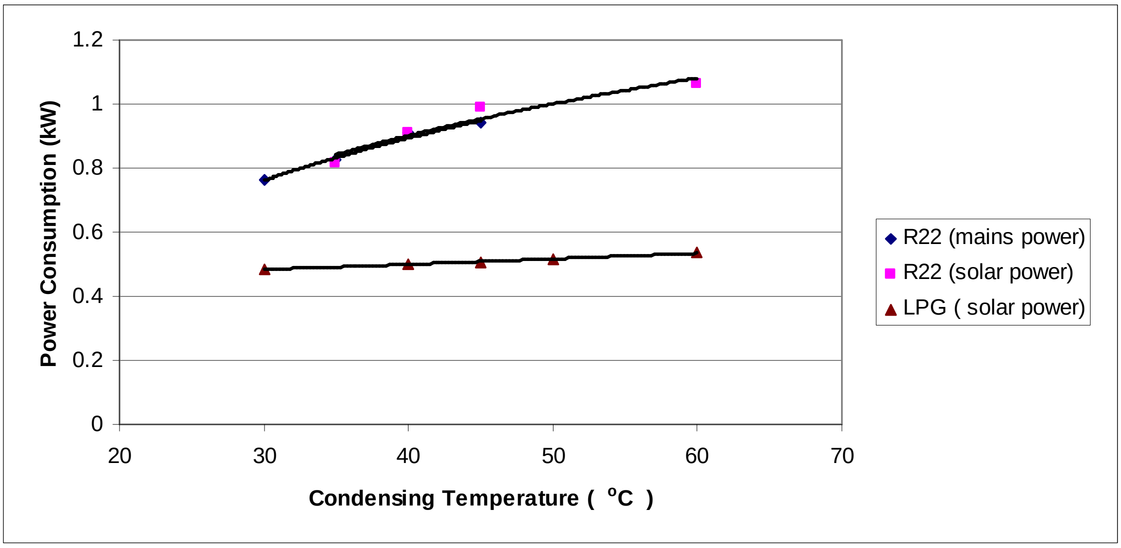


Figure (6.67) Power Consumption vs. Condensing Temp for R22 & LPG at

Te= 5 °C

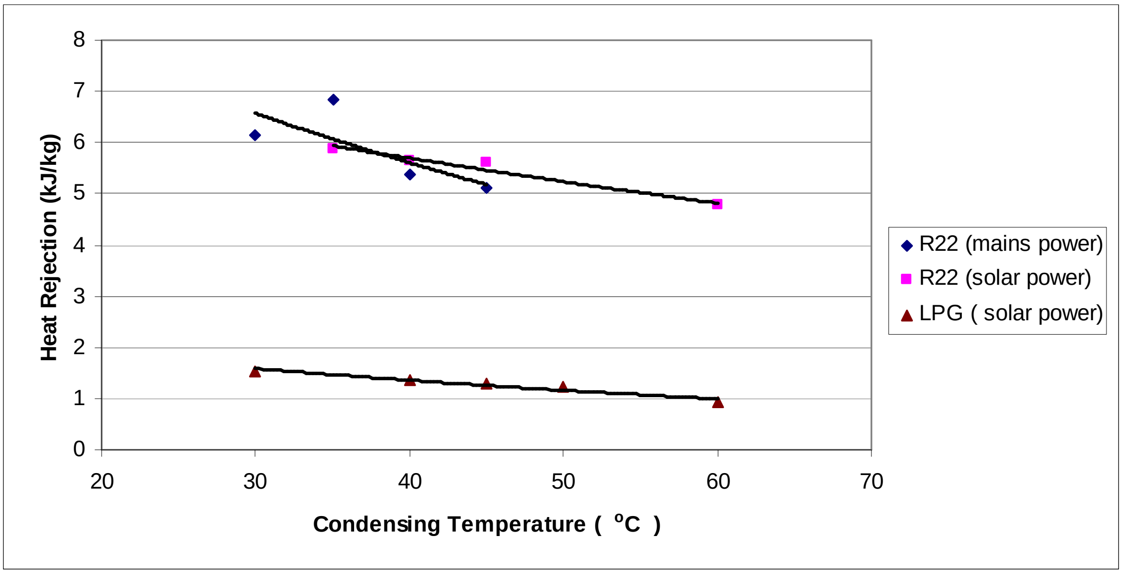


Figure (6.68) Heat Rejection vs. Condensing Temp for R22 & LPG at Te= 5 °C

CHAPTER SEVEN
CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions:

From the experimental results which were performed and calculated and due to discussion several conclusions can be reached:

1- The best method to use solar energy is by storing it in the batteries and then inverts it to AC using inverter.

2- LPG refrigerant has consumes less power than R22 by about 35% and this gives advantage for using LPG as refrigerant because of using solar energy

3- Good performance was produced when solar energy was used instead of usual mains power for air conditioning , it was effected just when the air conditioning start to shutdown and this happened because of instability

4- The performance of the unit looks the same for using either mains power or solar power; this was investigated when comparison was conducted for R22 for mains power and solar power.

5- Wight of quantity charge of LPG refrigerant was more less of R22 by 44%

6- To increase the running time of air conditioning unit, the quantity power store must be increased; this can be done by increasing the number of batteries of system, also this increase the battery life because the depth of discharge will reduce.

7- The initial cost for solar system is very high because modules, inverter and batteries are expensive, but its life cycle cost is reasonable, for expected life is more than 20 years

7.2 Recommendations:

Following recommendations are sight by this work:

1- It is easy to use the P.V. generator to power air conditioning units, so it is recommended that such generators to be installed as packages to power other appliances.

2- More study is to be carried out to use DC compressors or open type compressors driven with DC motors to produce good performance for refrigeration cycles. This may assist to take direct energy from the modules without need for batteries and inverters

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APPENDIX A

DATA TABLES

Table (A.1) Measured Data for R22 Using Usual Power with Variation of Day Time (Day History)

Starting Time	T1 Comp inlet	T2 Comp exit	T3 Mid Cond	T4 Out Cond	T5 In Evap	T6 Mid Evap	T7 Out Evap	T8 Air in Cond	T9 Air out Cond	T10 Air in Evap	T11 Air Out Evap	P1 suc	P2 dis	V Comp	I Comp
9:35	23	91	30	23	9	12	16	25	31	22	11	44	235	210	4.8
10:00	25	98	31	22	8	14	15	27	36	23	10	51	235	210	4.8
11:00	24	103	32	22	8	12	14	30	38	24	12	51	245	210	5
11:30	24	104	32	24	8	11	14	29	39	25	13	51	245	210	4.9
12:00	27	109	34	24	11	15	15	32	38	26	14	58	285	210	5.5
12:40	27	112	35	25	11	15	15	33	39	28	13	59	280	210	5.5
14:10	28	109	35	30	11	15	15	33	39	29	14	58	280	210	5.4
14:40	26	108	35	32	10	14	14	33	40	27	9	57	280	210	5.3
15:10	22	104	33	31	8	12	8	33	39	27	10	52	275	210	5.3
16:00	22	100	32	22	11	13	15	22	30	24	10	45	235	210	4
16:30	18	92	30	20	9	11	12	20	30	24	14	45	235	210	4

Table (A.2) Measured Data for R22 Using Usual Power at Constant T_c = 30 ^oC

T1 Comp inlet	T2 Comp exit	T3 Mid Cond	T4 Out Cond	T5 In Evap	T6 Mid Evap	T7 Out Evap	T8 Air in Cond	T9 Air out Cond	T10 Air in Evap	T11 Air Out Evap	P1 suc	P2 dis	V Comp	I Comp
20	95	30	27	2	6	14	22	27	24	13	35	175	210	4.1
15	95	30	25	-1	2	10	22	26	23	9	33	175	210	4
13	96	31	25	-5	-2	7	24	26	21	6	33	175	210	4.07
9	94	31	25	-7	-3	5	20	27	20	0	31	170	210	3.9

Table (A.3) Measured Data for R22 Using Usual Power at Constant T_c = 35 ^oC

11	95	35	35	-1	-1	-1	31	33	20	5	45	180	210	4.3
10	96	35	34	-5	-3	-3	30	33	20	2	40	175	210	4.25
6	96	35	35	-5	-5	-5	28	36	22	0	40	170	210	4.2
-1	94	35	35	-7	-7	-10	28	37	20	-3	35	170	210	4

Table (A.4) Measured Data for R22 Using Usual Power at Constant T_c = 40 ^oC

T1 Comp inlet	T2 Comp exit	T3 Mid Cond	T4 Out Cond	T5 In Evap	T6 Mid Evap	T7 Out Evap	T8 Air in Cond	T9 Air out Cond	T10 Air in Evap	T11 Air Out Evap	P1 suc	P2 dis	V Comp	I Comp
8	98	40	37	4	4	3	26	39	20	7	50	235	210	5.1
7	98	40	36	3	3	2	26	39	19	5	48	225	210	5
6	97	40	35	2	2	1	26	39	20	4	46	220	210	4.95
-2	98	40	36	-3	-2	-4	26	40	20	-2	45	220	210	4.85

Table (A.5) Measured Data for R22 Using Usual Power at Constant T_c = 45 ^oC

18	105	45	43	4	5	5	31	47	23	6	53	240	210	5.3
18	107	45	44	5	3	3	32	44	20	6	48	230	210	5.1
11	106	45	44	-1	0	0	32	47	21	4	45	225	210	5.05
8	106	45	43	-3	-2	-2	32	47	19	1	36	220	210	4.9

Table (A.6) Measured Data for R22 Using Solar Energy with Variation of Day Time (Day History)

Date 12-8-2008 **R22** **Day history (Full battery discharge)** **Solar Energy**

			Condenser				Evaporator					Psi		Compressor		Battery		Solar
Time	T_1	T_2	T_3	T_4	T_8	T_9	T_7	T_5	T_6	T_{10}	T_{11}	P_L	P_H	I	V	I	V	Rad
10:00	Starting																	
10:15	19	75	35	29	26	32	6	2	3	25	3	53	200	5.05		19.0	25.2	842
10:30	21	85	37	31	28	34	10	3	5	25	6	57	210	4.95		19.4	25.1	871
10:45	21	83	35	31	27	32	8	3	2	25	5	55	215	5.1		20.0	25.0	895
11:00	21	81	35	29	28	33	1	0	0	24	1	50	200	5.0		20.4	24.9	930
11:40	19	84	34	30	27	33	8	3	4	25	5	55	210	4.6		21.5	24.8	1017
12:15	22	80	34	33	29	34	6	3	3	25	5	55	210	5.1		21.6	24.4	1027
12:30	25	89	39	35	32	37	1	0	1	25	4	54	210	4.8		21.7	24.1	1032
13:00	9	89	40	36	33	39	1	1	1	25	5	48	200	4.8		21.8	23.9	1004
13:40	21	86	42	40	36	40	8	3	4	25	6	56	210	4.5		21.1	23.6	958
14:00	19	87	36	34	31	36	0	0	0	25	5	51	210	4.66		20.8	23.3	931
14:15	14	80	32	31	30	34	-1	-2	-2	24	2	49	200	4.6		20.0	22.9	880
14:30	19	84	36	33	29	34	1	0	0	24	4	52	210	4.88	225	19.6	22.6	867
14:40	16	79	34	30	28	33	0	-1	-1	24	6	50	200	4.5		18.7	22.1	837
14:50	10	81	33	31	30	34	0	-1	0	24	6	50	210	4.8		18.5	21.3	831
14:55	Shut down |(Off)															18.1	18.1	800
15:20	Start (On)															16.4	23.4	734
15:25	18	65	31	29	30	32	7	3	2	25	8	47	200	4.5		15.1	23.0	676
15:40	22	73	34	30	28	32	9	2	3	25	7	53	210	4.65		14.8	22.7	643
15:50	23	76	32	28	28	32	7	2	3	23	4	52	210	4.6		14.6	21.6	629
15:55	Shut down (Off)															13.0	18.1	610
16:20	Start (On)															11.8	22.7	510
16:25	24	55	30	29	29	32	8	2	4	23	6	49	210	5.1		10.6	22.2	466
16:30	23	65	31	29	29	32	6	2	3	22	5	50	210	5.0		9.2	21.7	352

16:35	Shut down (Off)															8.3	18.1	309
17:00	Start (On)															6.8	22.5	282
17:10	27	55	30	32	27	32	10	1	3	25	5	45	200	4.9		6.3	22.1	251
17:15	Shut down (Off)															4.7	18.1	245
17:45	Start (On)														225	3.6	21.4	215
17:50	23	45	30	30	27	31	7	3	4	23	6	42	200	4.66		3.3	20.9	209
17:55	Shut down (Off)															2.9	18.1	186
18:10	Start (On)															2.6	21.4	123
18:12	22	42	30	30	28	31	6	2	3	22	5	42	200	4.7		2.1	20.8	119
18:13	Shut Down (OFF)															1.5	18.1	113

Table (A.7) Measured Data for R22 Using Solar Energy at Constant T_c = 30,35,40,45 and 60 ^oC

Date: 30-7-2008 R22 Solar energy Constant condensing temperature

		Condenser				Evaporator					Psi		Compressor		Battery		Solar
T_1	T_2	T_3	T_4	T_8	T_9	T_7	T_5	T_6	T_{10}	T_{11}	P_L	P_H	I	V	I	V	Rad
29	86	30	31	30	34	14	0	0	23	10	45	145	4.0		20.1	25.3	1000
30	83	29	30	30	32	11	-1	-1	23	9	40	140	3.9	225	19.9	25.0	970
26	81	31	31	31	33	7	-2	-2	24	8	37	160	3.8		18.1	24.4	915
27	79	30	31	31	33	-7	-5	-6	24	1	35	165	4.1		18.9	24.3	840
27	70	35	34	32	36	14	4	9	26	12	52	215	5.0		17.7	25.4	935
26	80	35	34	32	38	11	3	6	25	9	60	225	5.2		17.6	25.3	915
25	82	36	35	32	38	15	3	5	25	6	55	220	5.4	225	17.4	25.3	905
1	78	35	35	32	36	-13	-10	-12	24	4	30	200	5.2		17.1	25.3	900

28	84	41	38	32	42	10	5	6	23	8	60	250	5.6		16.8	25.0	880
26	86	40	38	34	42	8	3	4	23	5	59	245	5.3		16.4	25.0	860
24	88	40	39	34	42	4	2	2	24	3	55	255	5.8	225	16.0	24.9	840
1	88	40	40	34	43	-12	-10	-12	24	1	35	225	4.9		16.0	24.8	825
25	91	45	41	34	45	9	4	5	23	6	60	250	5.8		14.7	24.6	795
24	93	45	45	34	49	3	4	4	24	6	61	305	6.5		14.3	24.3	772
13	90	44	44	34	49	3	2	2	24	4	55	275	5.6	225	13.5	24.2	740
-3	80	45	44	34	47	-11	-9	-11	24	2	40	275	4.5		13.1	24.0	747
26	94	60	53	34	54	9	5	5	23	7	65	325	6.2		12.5	23.9	720
21	93	61	52	34	52	3	4	4	23	5	61	320	6.6	225	12.7	23.8	718
12	94	60	52	34	53	3	4	4	24	5	61	325	6.6		12.2	23.7	703
-3	85	59	49	34	51	-8	-6	-7	23	1	40	325	4.9		12.0	23.7	689

Table (A.8) Measured Data for Optimum Charge quantity of Refrigerant LPG

Date 13-8-2008 Propane + Butane (LPG) Charging Quantity

	Condenser				Evaporator						Psi	Compressor			
Mass (gram)	T_1	T_2	T_3	T_4	T_8	T_9	T_5	T_7	T_6	T_{10}	T_{11}	P_L	P_H	I	V
200	30	70	35	31	29	34	18	0	13	25	17	16	80	3.4	
250	27	80	37	32	30	35	10	3	9	24	12	23	100	3.1	
300	13	65	29	33	30	36	10	4	10	24	12	26	100	3.4	
350	14	55	36	29	29	37	9	4	10	23	11	28	110	3.2	225
400	18	55	36	29	32	36	10	4	9	23	12	31	110	3.0	
500	18	52	37	31	32	37	12	6	10	23	13	32	110	2.9	
650	21	49	36	30	30	34	13	8	13	23	14	33	110	2.8	

Table (A.9) Measured Data for LPG Using Solar Energy with Variation of Day Time (Day History)

Date 17-8-2008 (first day) **Propane-Butane (LPG)** **Day history (Full Battery discharge)** **solar energy**

			Condenser				Evaporator					Psi		Compressor		Battery		Solar
Time	T_1	T_2	T_3	T_4	T_8	T_9	T_5	T_7	T_6	T_{10}	T_{11}	P_L	P_H	I	V	I	V	Rad
10:00	Starting																	
10:30	14	54	37	30	27	33	7	12	14	26	15	22	80	2.8		18.1	26.5	881
11:00	14	57	36	32	28	34	8	12	13	25	14	23	85	3.15		18.9	25.5	892
11:30	13	58	36	32	28	34	8	12	14	25	14	22	86	3.1		19.2	25.5	930
11:45	15	57	39	34	30	36	8	12	13	26	15	22	85	3.4		19.2	25.5	965
12:00	12	56	37	31	29	35	8	12	13	26	15	25	90	3.5		19.4	25.5	990
12:30	15	58	37	34	30	36	9	12	14	27	16	25	90	3.3		19.3	25.4	1010
13:00	18	59	40	37	35	39	9	13	13	27	15	25	90	3.3		18.5	25.3	979
13:30	28	58	45	40	37	43	8	12	12	27	15	24	90	3.5		18.5	25.2	970
14:00	25	55	44	39	37	42	9	12	12	28	16	25	90	3.5		17.9	25.1	925
14:30	22	58	43	39	37	41	9	13	13	27	16	24	90	3.4		16.6	25.1	905
15:00	16	59	42	39	35	41	7	11	11	25	14	23	95	3.3	230	14.8	24.9	874
15:30	19	59	41	39	37	41	7	11	10	24	14	21	90	3.2		12.0	24.6	843
16:15	15	59	45	39	34	39	6	10	10	24	14	23	90	3.5		8.6	24.3	680
16:45	14	55	41	36	34	38	6	10	10	24	14	21	100	3.2		6.9	24.0	540
17:15	15	54	38	34	30	35	6	10	10	23	13	20	99	3.1		7.5	23.7	402
17:45	12	55	39	33	29	35	7	11	10	24	14	21	99	3.9		2.8	23.3	282
18:15	14	52	33	31	28	33	6	11	10	24	14	23	80	3.3		1.8	22.9	144
18:30	13	51	35	31	29	34	6	10	10	24	14	20	80	3.2		1.4	22.5	100
18:45	12	50	35	31	29	34	6	10	10	24	14	20	80	3.25		1.1	22.1	56
18:50	14	52	38	33	31	34	6	10	9	24	13	20	85	3.1		0.9	21.4	45
18:55	14	49	34	30	29	33	6	10	9	24	13	20	80	2.6		0.8	20.4	23

19:00	Shut down (Off)															0.1	18.0	7
19:05	Sun set															0.0	21.8	2
19:10	Start (On)															0.0	21.3	0.0
19:15	16	46	34	32	28	31	4	14	10	25	15	20	75	3.0	230	0.0	20.7	0.0
19:17	15	48	33	32	26	30	3	11	9	24	14	20	75	2.7		0.0	18.5	0.0
19:20	Shut down (Off)															0.0	18.1	0.0
19:27	Start (On)															0.0	21.8	0.0
19:30	-4	44	30	26	26	29	-2	3	1	25	15	10	75	2.7	230	0.0	21.6	0.0
19:35	Shut down (Off)															0.0	18.1	0.0

Date 18-8-2008 (next day) **Propane-Butane (LPG)** **Day history (Full Battery discharge)** **solar energy**

			Condenser				Evaporator					Psi		Compressor		Battery		Solar
Time	T_1	T_2	T_3	T_4	T_8	T_9	T_5	T_7	T_6	T_{10}	T_{11}	P_L	P_H	I	V	I	V	Rad
11:45	Starting															20.0	24.2	970
12:00	18	58	40	35	32	38	9	13	14	28	16	23	90	3.1		20.0	24.1	982
12:15	17	57	39	35	32	39	9	13	14	27	16	22	90	3.3		20.2	24.0	1000
13:00	19	60	43	39	34	39	9	13	14	27	16	24	100	3.25	225	20.3	23.4	1056
13:30	20	55	44	39	36	41	9	13	14	27	16	25	100	3.2		20.3	23.2	1043
14:00	18	58	42	40	36	44	9	13	14	26	16	25	100	3.4		19.8	22.7	1000
14:30	19	60	43	42	36	46	8	12	13	26	15	25	100	3.5		20.0	19.5	894
14:35	Shut down (Off)															0.0	18.1	887
15:05	Start (On)															18.1	23.4	852
15:15	16	59	41	36	33	39	8	12	13	26	15	25	100	3.4	225	17.8	23.1	843
15:40	17	56	38	35	33	37	8	12	13	25	15	24	100	3.2		16.5	21.9	840
15:43	Shut down (Off)															0.0	18.1	793
16:20	Start (On)															11.8	24.2	658
16:30	13	55	38	33	32	36	8	12	13	26	15	23	99	3.3	225	11.0	22.9	635
16:40	14	55	36	34	32	36	7	12	13	26	15	25	99	3.5		7.9	21.7	601

16:43	Shut down (Off)															7.0	18.1	550
17:30	Start (On)															4.6	23.9	325
17:40	15	53	35	32	32	35	13	14	14	26	14	23	80	3.6	225	4.2	22.0	298
17:45	Shut down (Off)															0.0	18.1	282
19:00	Start (On)															0.5	23.2	12
19:05	13	45	33	29	28	31	10	10	9	23	13	15	75	3.4	225	0.3	21	04

Table (A.10) Measured Data for LPG Using Solar Energy at Constant T_c = 30,35,40,45 and 60 ^oC

Date: 19-8-2008 **Propane-Butane (LPG)** **Solar energy** **Constant condensing temperature**

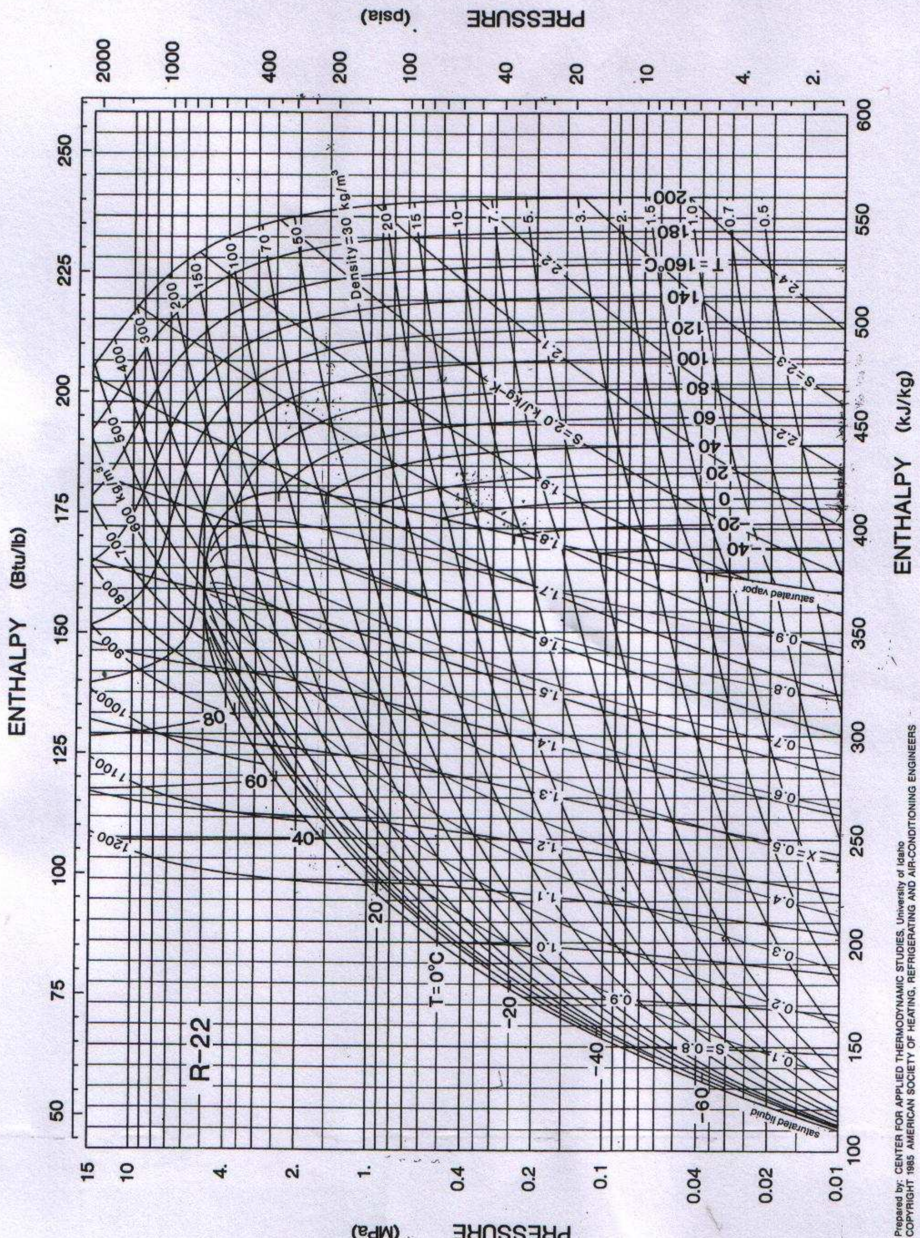
		Condenser				Evaporator					Psi		Compressor		Battery		Solar
T_1	T_2	T_3	T_4	T_8	T_9	T_5	T_7	T_6	T_{10}	T_{11}	P_L	P_H	I	V	I	V	Rad
17	49	30	29	30	36	9	13	13	27	15	25	75	3.2		19.0	25.4	1010
16	52	29	29	33	36	7	11	12	27	13	20	75	3.0	230	18.5	25.4	1010
15	56	31	29	31	36	7	11	12	28	13	21	80	3.0		18.1	25.3	1005
14	57	30	29	36	39	1	04	03	27	07	18	75	2.9		17.9	25.3	1000
24	56	41	36	38	42	8	12	12	27	15	25	88	3.2		18.4	25.2	953
20	56	40	37	36	40	7	10	11	27	13	23	87	3.1	230	18.2	25.2	945
16	53	40	37	36	40	6	9	9	28	13	21	90	3.1		18.0	25.2	935
13	56	40	39	36	39	2	5	4	28	07	17	86	3.0		17.9	25.2	929
18	57	45	39	38	40	8	11	11	24	15	24	95	3.3		14.4	24.8	881
18	56	45	38	36	40	6	10	10	25	13	22	100	3.2		15.3	24.9	879
17	54	44	40	36	40	6	9	9	26	13	21	100	3.1	230	15.7	24.9	878
16	59	45	40	37	42	3	6	5	27	8	18	90	3.0		16.6	25.1	877

22	64	50	47	38	49	8	12	11	24	16	26	130	3.3	230	11.0	24.4	844
17	63	50	46	36	46	7	10	10	24	13	24	110	3.2		10.8	24.5	842
15	62	51	43	35	47	6	10	09	25	12	21	110	3.1		9.6	24.9	838
14	58	50	46	38	49	3	05	04	27	10	15	115	3.9		16.1	25.0	831
28	61	60	55	37	48	13	17	16	26	19	25	140	3.4	230	12.5	23.9	1000
27	67	61	54	37	47	13	14	16	26	17	26	150	3.3		12.7	23.8	1023
18	65	61	53	37	49	13	11	14	26	16	25	150	3.2		12.2	23.7	1067
16	69	60	54	37	53	08	08	10	27	11	21	155	3.3		12.0	23.7	1097

APPENDIX B

REFRIGERNT PROPERTIES

TABLE AND CHARTS



Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Fig. 6 Pressure-Enthalpy Diagram for Refrigerant 22

Refrigerant 22 (chlorodifluoromethane) Properties of Saturated Liquid and Saturated Vapor

Temp,* °C	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
−150.00	—	1701.5	—	26.01	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.	—	—	123.1	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.	254.7	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	2.725	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 = boiling point c = critical point

17.54 1993 Fundamentals Handbook (SI)

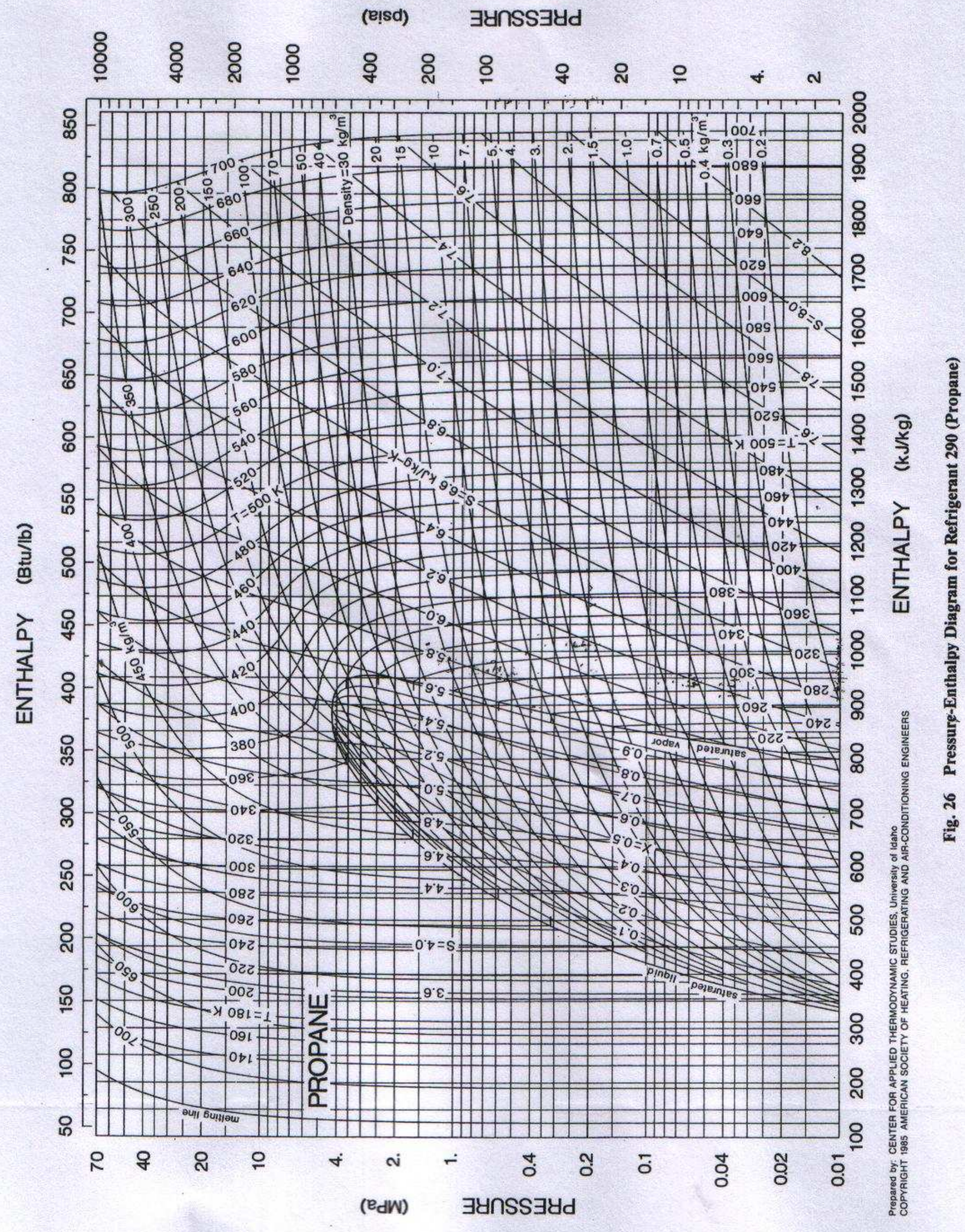


Fig. 26 Pressure-Enthalpy Diagram for Refrigerant 290 (Propane)

Refrigerant 290 (Propane) Properties of Saturated Liquid and Saturated Vapor

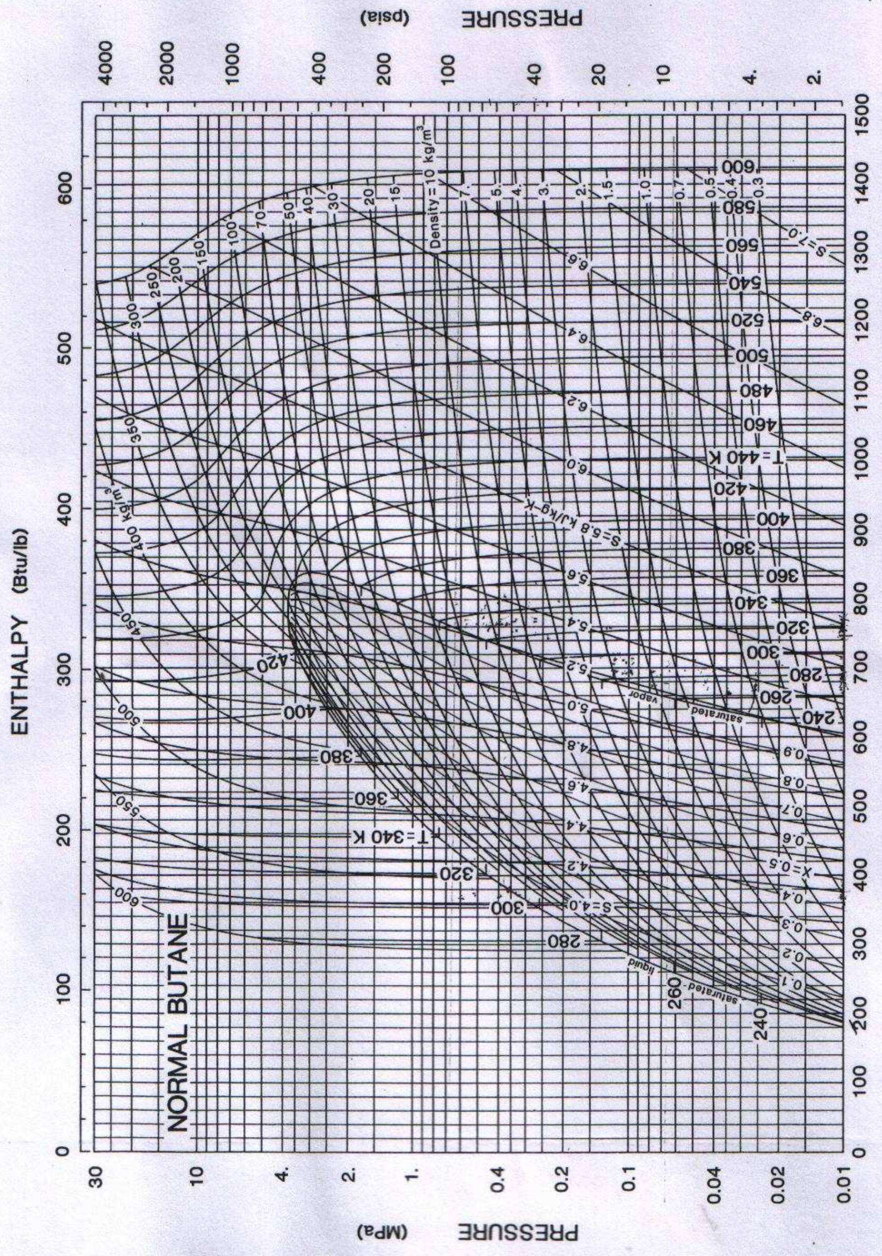
Temp, K	Pressure, MPa	Vapor Volume, m^3/kg	Liquid Density, kg/m^3	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)	
				Liquid	Vapor	Liquid	Vapor
**85.47	0.30E-09	53716674.	732.90	124.92	690.02	1.8738	8.3548
90	0.15E-08	11180892.	728.37	133.56	693.58	1.9723	8.0953
95	0.75E-08	2362188.	723.37	143.13	697.78	2.0758	7.8413
100	0.32E-07	585463.	718.36	152.74	702.23	2.1743	7.6163
105	0.12E-06	166434.	713.34	162.37	706.88	2.2682	7.4163
110	0.39E-06	53276.	708.32	172.03	711.71	2.3581	7.2377
115	0.11E-05	18913.	703.29	181.73	716.68	2.4443	7.0778
120	0.31E-05	7351.7	698.25	191.46	721.78	2.5271	6.9343
125	0.76E-05	3095.9	693.20	201.23	726.98	2.6069	6.8051
130	0.000018	1399.6	688.14	211.03	732.27	2.6838	6.6885
135	0.000038	674.08	683.07	220.88	737.64	2.7581	6.5833
140	0.000077	343.54	677.99	230.77	743.07	2.8300	6.4881
145	0.000149	184.22	672.90	240.70	748.57	2.8997	6.4018
150	0.000274	103.41	667.79	250.67	754.12	2.9674	6.3237
155	0.000484	60.504	662.66	260.70	759.72	3.0331	6.2529
160	0.000822	36.755	657.51	270.78	765.37	3.0971	6.1886
165	0.001347	23.102	652.34	280.91	771.06	3.1594	6.1304
170	0.002139	14.979	647.15	291.10	776.80	3.2202	6.0775
175	0.003297	9.9919	641.93	301.34	782.58	3.2796	6.0296
180	0.004945	6.8399	636.68	311.66	788.40	3.3377	5.9862
185	0.007238	4.7946	631.41	322.03	794.26	3.3946	5.9469
190	0.010354	3.4347	626.09	332.48	800.15	3.4503	5.9114
195	0.014506	2.5100	620.74	343.01	806.08	3.5049	5.8793
200	0.019934	1.8681	615.35	353.61	812.03	3.5586	5.8502
205	0.026912	1.4138	609.91	364.29	818.01	3.6113	5.8241
210	0.035741	1.0867	604.43	375.07	824.01	3.6631	5.8005
215	0.046753	0.84713	598.89	385.94	830.02	3.7142	5.7793
220	0.060307	0.66902	593.29	396.90	836.04	3.7645	5.7603
225	0.076789	0.53470	587.62	407.97	842.06	3.8141	5.7433
230	0.096607	0.43206	581.89	419.16	848.08	3.8631	5.7280
231.07	0.101325	0.41333	580.65	421.57	849.37	3.8735	5.7249
232	0.10556	0.39788	579.58	423.68	850.49	3.8827	5.7224
234	0.11515	0.36698	577.25	428.24	852.89	3.9022	5.7170
236	0.12540	0.33899	574.91	432.83	855.28	3.9217	5.7118
238	0.13634	0.31358	572.55	437.44	857.68	3.9412	5.7069
240	0.14800	0.29049	570.19	442.07	860.07	3.9605	5.7022
242	0.16041	0.26946	567.80	446.72	862.45	3.9798	5.6977
244	0.17361	0.25028	565.41	451.40	864.83	3.9990	5.6934
246	0.18761	0.23275	562.99	456.10	867.21	4.0182	5.6894
248	0.20246	0.21672	560.57	460.84	869.58	4.0373	5.6855
250	0.21819	0.20202	558.12	465.58	871.94	4.0563	5.6817
252	0.23483	0.18854	555.66	470.36	874.30	4.0753	5.6782
254	0.25242	0.17614	553.18	475.16	876.64	4.0942	5.6748
256	0.27098	0.16474	550.68	479.98	878.98	4.1130	5.6716
258	0.29056	0.15423	548.16	484.82	881.30	4.1318	5.6685
260	0.31118	0.14453	545.62	489.70	883.62	4.1505	5.6656
262	0.33288	0.13557	543.06	494.60	885.93	4.1692	5.6628
264	0.35569	0.12727	540.48	499.52	888.22	4.1878	5.6601
266	0.37966	0.11959	537.88	504.47	890.50	4.2063	5.6576
268	0.40482	0.11247	535.25	509.45	892.77	4.2248	5.6551
270	0.43120	0.10586	532.61	514.45	895.02	4.2433	5.6528
275	0.50276	0.091279	525.87	527.07	900.58	4.2893	5.6475
280	0.58278	0.079054	518.97	539.88	906.03	4.3349	5.6426
285	0.67186	0.068737	511.88	552.87	911.36	4.3804	5.6383
290	0.77063	0.059978	504.58	566.06	916.54	4.4257	5.6343
295	0.87971	0.052499	497.05	579.47	921.57	4.4709	5.6305
300	0.99973	0.046079	489.26	593.11	926.41	4.5160	5.6270
305	1.1314	0.040539	481.17	607.01	931.05	4.5611	5.6235
310	1.2753	0.035735	472.76	621.18	935.45	4.6062	5.6200
315	1.4321	0.031549	463.97	635.66	939.57	4.6516	5.6164
320	1.6027	0.027881	454.74	650.49	943.38	4.6971	5.6124
325	1.7876	0.024653	445.00	665.70	946.81	4.7431	5.6080
330	1.9876	0.021794	434.65	681.37	949.79	4.7896	5.6030
335	2.2036	0.019247	423.56	697.56	952.21	4.8368	5.5969
340	2.4362	0.016960	411.55	714.38	953.92	4.8850	5.5896
345	2.6866	0.014888	398.35	731.96	954.71	4.9346	5.5803
350	2.9556	0.012985	383.54	750.52	954.23	4.9861	5.5681
355	3.2445	0.011206	366.37	770.44	951.90	5.0405	5.5516
360	3.5551	0.0094896	345.34	792.50	946.56	5.0997	5.5277
365	3.8902	0.0077145	316.22	818.95	935.15	5.1699	5.4883
*369.80	4.2420	0.00457	219.	879.2	879.2	5.330	5.330

**Triple point

*Critical point

Temp., K	Viscosity, μPa·s: Sat. Liquid	Sat. Vapor	Gas at 101.325 kPa	Thermal Conductivity, mW/(m·K): Sat. Liquid	Sat. Vapor	Gas at 101.325 kPa	Specific Heat, kJ/(kg·K): Sat. Liquid c_p	Sat. Liquid c_v	Sat. Vapor c_p	Sat. Vapor c_v	Gas at 0 Pa c_p	Gas at 0 Pa c_v	Velocity of Sound, m/s: Sat. Liquid	Sat. Vapor	Gas at 101.325 kPa
150	661	4.25	—	190.9	6.00	—	2.00	1.35	1.10	0.91	1.10	0.91	1649	185	—
160	554	4.50	—	182.9	6.45	—	2.02	1.36	1.14	0.94	1.14	0.94	1575	190	
170	467	4.74	—	174.6	6.99	—	2.04	1.37	1.17	0.98	1.17	0.98	1505	195	—
180	397	4.99	—	166.3	7.60	—	2.07	1.39	1.21	1.01	1.21	1.01	1436	199	—
190	327	5.25	—	158.2	8.29	—	2.10	1.40	1.24	1.05	1.24	1.05	1370	203	—
200	298	5.52	—	150.3	9.05	—	2.13	1.42	1.28	1.09	1.27	1.08	1306	207	—
210	265	5.80	—	142.8	9.86	—	2.16	1.44	1.32	1.13	1.31	1.12	1243	210	—
220	236	6.09	—	135.7	10.72	—	2.20	1.46	1.37	1.16	1.35	1.15	1182	213	—
230	207	6.39	—	128.9	11.62	—	2.25	1.49	1.42	1.21	1.39	1.19	1122	216	—
231.08[a]	205	6.42	6.42	128.2	11.73	11.73	2.25	1.49	1.43	1.22	1.39	1.20	1115	218	218
240	186	6.70	6.66	122.5	12.72	12.52	2.29	1.51	1.48	1.26	1.43	1.24	1062	219	222
250	169	7.02	6.93	116.5	13.84	13.40	2.34	1.53	1.55	1.31	1.47	1.28	1003	220	227
260	153	7.38	7.19	110.8	14.93	14.34	2.41	1.56	1.63	1.36	1.51	1.32	944	220	231
270	140	7.78	7.46	105.5	16.10	15.31	2.48	1.59	1.70	1.41	1.55	1.36	885	219	236
280	129	8.22	7.72	100.4	17.35	16.33	2.56	1.62	1.81	1.47	1.59	1.41	826	218	240
290	119	8.70	7.99	95.5	18.70	17.37	2.65	1.66	1.93	1.53	1.64	1.45	766	216	244
300	110	9.22	8.26	90.8	20.23	18.44	2.76	1.69	2.06	1.60	1.68	1.49	705	214	248
310	93.4	9.78	8.52	86.3	21.89	19.54	2.89	1.73	2.22	1.67	1.73	1.54	642	211	252
320	82.3	10.4	8.79	81.9	23.70	20.66	3.06	1.77	2.43	1.74	1.77	1.58	577	206	256
330	71.9	11.0	9.05	77.5	25.64	21.79	3.28	1.81	2.72	1.82	1.82	1.63	509	198	260
340	61.6	11.7	9.32	73.3	27.71	22.96	3.62	1.85	3.12	1.90	1.86	1.67	437	188	264
350	51.7	12.5	9.58	69.4	29.92	24.13	4.23	1.89	4.30	2.00	1.91	1.72	359	174	268
360	40.1	14.7	9.85	66.4	40.3	25.34	5.98	1.96	7.66	2.18	1.95	1.76	269	155	271
369.96[b]	28.8	28.8	10.11	∞	∞	26.54	∞	∞	∞	∞	2.00	1.81	0	0	275
370	—	—	10.11	—	—	26.55	—	—	—	—	2.00	1.81	—	—	275
380	—	—	10.38	—	—	27.79	—	—	—	—	2.04	1.85	—	—	278
390	—	—	10.64	—	—	28.03	—	—	—	—	2.08	1.90	—	—	282
400	—	—	10.90	—	—	30.30	—	—	—	—	2.13	1.94	—	—	285
420	—	—	11.41	—	—	32.87	—	—	—	—	2.22	2.03	—	—	292
440	—	—	11.92	—	—	35.50	—	—	—	—	2.30	2.12	—	—	299
460	—	—	12.42	—	—	38.18	—	—	—	—	2.39	2.20	—	—	305
480	—	—	12.92	—	—	40.93	—	—	—	—	2.47	2.28	—	—	311
500	—	—	13.41	—	—	43.73	—	—	—	—	2.55	2.36	—	—	317

[a]Normal boiling point. [b]Critical point. [c]Very large. [d]Large. [e]Small.



Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Fig. 27 Pressure-Enthalpy Diagram for Refrigerant 600 (n-Butane)

Refrigerant 600 (n-Butane) Properties of Saturated Liquid and Saturated Vapor

Temp, K	Pressure, MPa	Vapor Volume, m^3/kg	Liquid Density, kg/m^3	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)	
				Liquid	Vapor	Liquid	Vapor
**134.86	0.67E-06	28631.	735.27	−0.001	494.21	2.3056	5.9702
135	0.69E-06	27909.	735.14	0.270	494.37	2.3076	5.9676
140	0.17E-05	11635.	730.48	9.953	499.96	2.3778	5.8779
145	0.40E-05	5196.0	725.82	19.678	505.64	2.4460	5.7974
150	0.87E-05	2468.0	721.15	29.444	511.39	2.5121	5.7251
155	0.000018	1238.9	716.48	39.252	517.23	2.5764	5.6601
160	0.000035	653.74	711.80	49.102	523.13	2.6389	5.6016
165	0.000065	360.83	707.11	58.997	529.11	2.6998	5.5490
170	0.000117	207.45	702.41	68.938	535.16	2.7592	5.5017
175	0.000202	123.77	697.70	78.928	541.29	2.8172	5.4592
180	0.000337	76.368	692.98	88.969	547.48	2.8738	5.4211
185	0.000544	48.591	688.25	99.065	553.74	2.9292	5.3870
190	0.000853	31.797	683.50	109.22	560.07	2.9835	5.3564
195	0.001304	21.349	678.74	119.43	566.47	3.0366	5.3291
200	0.001944	14.675	673.96	129.71	572.93	3.0887	5.3048
205	0.002835	10.308	669.16	140.05	579.46	3.1398	5.2833
210	0.004048	7.3860	664.34	150.45	586.06	3.1900	5.2643
215	0.005672	5.3900	659.50	160.93	592.71	3.2394	5.2476
220	0.007808	4.0004	654.63	171.49	599.42	3.2879	5.2331
225	0.010575	3.0158	649.74	182.12	606.20	3.3357	5.2205
230	0.014106	2.3065	644.81	192.83	613.02	3.3828	5.2097
235	0.018553	1.7877	639.85	203.62	619.90	3.4292	5.2006
240	0.024083	1.4029	634.85	214.50	626.83	3.4749	5.1929
245	0.030882	1.1135	629.81	225.47	633.80	3.5201	5.1867
250	0.039153	0.89335	624.73	236.52	640.82	3.5647	5.1818
255	0.049112	0.72380	619.61	247.67	647.88	3.6087	5.1781
260	0.060996	0.59183	614.43	258.92	654.97	3.6523	5.1755
262	0.066343	0.54736	612.34	263.45	657.81	3.6696	5.1748
264	0.072055	0.50691	610.25	267.99	660.66	3.6868	5.1742
266	0.078148	0.47005	608.15	272.55	663.52	3.7039	5.1737
268	0.084640	0.43641	606.03	277.13	666.38	3.7210	5.1734
270	0.091547	0.40566	603.91	281.72	669.24	3.7380	5.1732
272.64	0.101325	0.36906	601.09	287.80	673.02	3.7603	5.1732
274	0.10668	0.35175	599.63	290.96	674.98	3.7718	5.1733
276	0.11495	0.32808	597.47	295.60	677.85	3.7886	5.1736
278	0.12371	0.30634	595.31	300.26	680.72	3.8054	5.1739
280	0.13297	0.28634	593.13	304.94	683.60	3.8220	5.1744
282	0.14277	0.26791	590.94	309.64	686.47	3.8387	5.1750
284	0.15311	0.25092	588.74	314.36	689.35	3.8552	5.1756
286	0.16403	0.23522	586.52	319.09	692.23	3.8718	5.1764
288	0.17553	0.22071	584.29	323.85	695.11	3.8882	5.1773
290	0.18765	0.20728	582.05	328.62	697.99	3.9046	5.1783
292	0.20039	0.19484	579.79	333.41	700.87	3.9210	5.1794
294	0.21379	0.18330	577.52	338.22	703.75	3.9373	5.1806
296	0.22786	0.17258	575.24	343.05	706.62	3.9536	5.1819
298	0.24263	0.16261	572.93	347.90	709.49	3.9698	5.1832
300	0.25811	0.15334	570.62	352.77	712.36	3.9860	5.1846
305	0.30010	0.13284	564.75	365.05	719.53	4.0263	5.1885
310	0.34706	0.11556	558.77	377.46	726.67	4.0663	5.1928
315	0.39934	0.10094	552.67	390.01	733.77	4.1062	5.1975
320	0.45731	0.088483	546.44	402.71	740.84	4.1458	5.2025
325	0.52133	0.077825	540.06	415.58	747.85	4.1854	5.2077
330	0.59179	0.068662	533.53	428.61	754.80	4.2248	5.2132
335	0.66906	0.060747	526.82	441.84	761.69	4.2642	5.2189
340	0.75354	0.053881	519.92	455.25	768.49	4.3035	5.2248
345	0.84563	0.047899	512.81	468.88	775.20	4.3428	5.2307
350	0.94573	0.042667	505.46	482.74	781.79	4.3822	5.2367
355	1.0543	0.038071	497.86	496.85	788.27	4.4217	5.2426
360	1.1717	0.034017	489.96	511.22	794.60	4.4613	5.2485
365	1.2984	0.030429	481.73	525.89	800.76	4.5012	5.2542
370	1.4350	0.027238	473.11	540.88	806.72	4.5412	5.2597
375	1.5819	0.024388	464.07	556.21	812.43	4.5817	5.2649
380	1.7396	0.021832	454.51	571.94	817.86	4.6225	5.2696
385	1.9088	0.019528	444.34	588.10	822.93	4.6638	5.2738
390	2.0901	0.017438	433.43	604.76	827.56	4.7058	5.2771
395	2.2844	0.015530	421.61	621.97	831.63	4.7485	5.2793
400	2.4923	0.013773	408.60	639.85	834.95	4.7922	5.2800
405	2.7151	0.012137	394.00	658.55	837.27	4.8373	5.2786
410	2.9538	0.010587	377.09	678.30	838.10	4.8842	5.2740
415	3.2101	0.0090753	356.41	699.62	836.57	4.9342	5.2641
420	3.4863	0.0075018	328.05	723.89	830.34	4.9903	5.2437
*425.16	3.7961	0.00441	227.	783.5	783.5	5.129	5.129

**Triple point

*Critical point

دراسة تجريبية لأداء وحدة تكييف تعمل على الطاقة الشمسية عند استخدام الغاز المسال كوسيط تبريد

اعداد
أنس مصطفى فراج

المشرف
الاستاذ الدكتور محمود حماد

ملخص

يهدف هذا البحث التجريبي لدراسة وفحص اداء وحدة مكيف هواء نوع المنفصل قدرة 1 طن تبريد عندما يستبدل الغاز الاصيل بالغاز المسال، وتكون مصدرالطاقة الكهربائية من الطاقه الشمسية ، إن استهلاك الطاقه الكهربائية من اجهزة التكييف تأخذ نصيبا عاليا من الاستهلاك العام وبسبب شح مصادر الطاقة الاساسية فإن العالم الان يبحث عن بدائل للطاقة وبالذات الطاقة المتجددة مثل طاقة الشمس ،كما انه وبسبب تأثير غاز R22 على البيئة من خلال تأثيره على طبقة الاوزون تم بحث استبدال هذا الغاز بغاز هيدروكربوني صديق للبيئة.

في هذه التجربه تم دراسة اداء وحدة تكييف نوع منفصل قدرة 1 طن عندما غذيت بالطاقة الشمسية وباستخدام غاز الفريون R22 مرة والغاز المسال (LPG) مرة اخرى بعد استبدال غاز R22.
تم استخدام انفرتر لتغذية جهاز التكييف الاعتيادي في التجربه.و تم التحقق من بعض المتغيرات مثل معامل الاداء، القدرة ، كتلة تدفق غاز التبريد ومقدار شغل الضاغطة ومقدار تغيرها عند تغير الوقت خلال اليوم ودرجة حرارة المبخر ودرجة حرارة التكثيف .

من التجربة تبين بان استخدام نظام الطاقة الشمسي باستخدام بطارية (Deep cycle) , وانفيرتر هو انسب طريقة لاستخدام الطاقة الشمسية كبديل عن الطاقة الاعتيادية ولتشغيل الادوات الكهربائية عالية الطاقة.

العلاقات بين المتغيرات والتي تم رسمها توضح اداء جيد لوحدة التكييف ولكن هذا الاداء تأثر عندما استنزفت الطاقة المستمدة من نظام PV ولم تعد الطاقة قادرة على ابقاء وحدة التكييف في حالة التشغيل، حيث حدث فصل في التشغيل.ويلاحظ ايضا ان اداء وحدة التكييف متقاربة جدا عند استخدام غاز تبريد مثل R22 وتغيير مصدر الطاقة الاعتادية بالطاقة الشمسية.

ان استخدام غاز LPG كمبرد يستهلك طاقة اقل ويحقق معامل اداء اقل مقارنة ب R22 بحوالي 35% و 40% على التوالي .يلاحظ أن استخدام LPG كمبرد في وحدات التكييف انسب عندما يكون مغذى بالطاقة الشمسية.