JJMIE

Volume 6, Number 1, Feb. 2012
ISSN 1995-6665
Pages 63 - 70

Jordan Journal of Mechanical and Industrial Engineering

Experimental Study of Solar Powered Air Conditioning Unit Using Drop – In Hydro Carbon Mixture to Replace R-22

Anas Farraj*[,a], Mohammad Abu Mallouh[b], Abdul-Rahim Kalendar[c], Abed Al-Rzaq Al-Shqirate[d] and Mahmoud Hammad[a]

[a]Department of Mechanical Engineering, University of Jordan, Amman, Jordan
[b]Department of Mechatronics Engineering, Hashemite University, Zarqa, Jordan
[c]Department of Mechanical Engineering, Queens University, Kingston, Canada.
[d]Al-Shoubak University College, Al-Balqa' Applied University, Al-Salt, Jordan.

Abstract

In this study the performance of a one ton split air conditioning unit (A/C) was experimentally investigated. The unit was originally designed to use R-22 as refrigerant. Liquefied Petroleum Gas Mixture (LPGM) of 30 % propane, R-290 and 70 % butane, R-600, (weight ratio) was evaluated as a drop in replacement for the R-22. This work is part of the worldwide efforts to explore replacements for the Chlorofluorocarbons and Hydrochlorofluorocarbons. Ozone depletion and climate changes warranted such efforts. It is a well-known fact that air conditioners (A/C) power consumption has a large share from the total building sector energy consumption. As a result of that, solar electricity was attempted in powering this unit. A photo voltaic array of twelve modules was used as an electrical generator. The performance of the unit was studied for both refrigerants used and then compared with each other. Experiments of day-long runs were carried out. Performance parameters were studied as dependent variables such as: coefficient of performance (COP); capacity; power consumption of the compressor; heat rejection and mass flow rate of refrigerant. In addition, changes of independent variables such as: evaporation temperature (Te); and condensing temperature (Tc) were evaluated. It was found experimentally that the COP of the system using LPGM as refrigerant and the capacity are lower than that using the R-22. Both the COP and the capacity are 25% lower at optimum working conditions. In spite of that LPGM has other advantages such as: higher refrigeration effect; lower mass rate of flow; lower compressor exit temperature and lower power consumption. The power consumption of the compressor when using LPGM was found to be 35% lower than that when using R-22. This gives an advantage of using LPGM as a refrigerant to replace R-22 especially when the A/C system is powered by solar energy.

© 2012 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved

Keywords: Air Conditioning; LPGM; R-22; Solar powered systems; R290/R600

Nomenclature

Abbreviations

A/C	Air conditioning system
AC	Alternating Current
CFC	Chlorofluorocarbon
DC	Direct Current
COP	Coefficient of performance of split air-conditioning unit
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HR	Heat rejection rate (kW)
I	Current (Amp)
LPGM	liquefied petroleum gas mixture of 30% propane and 70% butane

Symbols

I	Electrical current
H	Enthalpy (kW)
P	Electrical compressor power consumption (kW)
RE	Refrigeration effect (kJ/kg)
T_c	Condensation temperature (^{o} C)
T_e	Evaporation temperature (^{o} C)
V	Voltage (Volt)

Greek symbols

$\dot{m}$	The mass rate of flow (kg/s)
$\dot{q}$	Cooling capacity (kW)
$\dot{w}$	Compressor work (kW)
ζ_e	Electrical efficiency
ζ_m	Mechanical efficiency

1. Introduction

Hydroflourocarbons and Hydrochloroflourocarbons, (HFCs and HCFCs) are widely used as refrigerants in air conditioning and refrigeration systems since they provide the characteristics and properties required for optimal performance. According to the Montreal protocol; this initiated world-wide controls on production and phase out

* Corresponding author. e-mail: hammad@ju.edu.jo

time table of CFCs and HCFCs because of their significant role in Ozone depletion and global climate changes. They have high Ozone depletion potentials and make a significant contribution to global warming when emitted to atmosphere. These effects were the incentive for scientists and engineers to explore suitable replacements for these refrigerants. During the last few years, several studies have been conducted to investigate physical and thermodynamic properties, system performance and environmental effect for different alternative refrigerants. Any alternative refrigerant must have suitable physical and thermodynamic properties, chemical and thermal stability, good miscibility with the used lubricant, low toxicity and low flammability. Hydrocarbon (HC) refrigerants are considered as a good alternative to replace R-22 and other refrigerants. Many experimental studies were conducted to investigate the performance of HC refrigerants in refrigerators, A/Cs and heat pump systems. It was found that using a mixture of propane and butane R290/R600 is the best alternative to replace these refrigerants as drop in method. The only problem associated with HC is the flammability; this may be disregarded when the amount of charge of HC in the system is so minimal, safety precautions are considered and installed in large volume places.

Considering the problem of peak load of electricity consumption in summer due to air conditioning systems, solar powered air-conditioning systems could be an effective solution of energy conversion, reduction of peak electric power and global environmental problems. Moreover, since the electric power demand reaches peak in summer especially in the daytime, the load pattern agrees well with the Photovoltaic power output pattern.

2. Literature Review

Many studies had focused on substitutes for R-22 and R-12 using HCs mixtures as alternative refrigerants. Abuzahra [1] investigated experimentally the performance of a 1.4-ton window type A/C unite when replacing R-22 refrigerant with methane and LPG. He found that methane gas was not a suitable replacement for R-22 in this type of A/C due to compressor overheating problems. But LPG can be used satisfactorily.

Purkayastha and Bansal [11] studied experimentally the use of a mixture of propane (R290) and LPG as a refrigerant that replaced R22 in a heat pump. They found that COP with R290 and LPG mixture is higher than R-22 by about 18% and performed better than R290 alone but with a small loss of condenser capacity. Hammad and Tarawnah [6] studied the performance of 2.5-ton split A/C unit when the R-22 was replaced by a mixture of butane and propane with different ratios without any modifications or adjustments made to the A/C unit. It was shown that the mixture of 90% propane gives equal pressure as R-22 with higher COP while the mixture of about 60% propane gives equal COP, with lower pressure. It was found also that the capacity and compressor work decreased when propane percentage increased. It was concluded that all mixtures of propane and butane can be used as possible alternative refrigerants to R-22 and 100% propane mixture has the highest COP values among all hydrocarbons. They found that 90% propane mixture is the most suitable alternative refrigerant to R22 based on both higher COP and equal saturated pressure.

Nofal [10] studied the performance of a chest freezer when LPG was used as a substitute refrigerant for R134a. The results showed that LPG refrigerant had higher COP than R-134a by 20%. Lower refrigeration capacity and slightly lower power consumption were noticed.

Devotta et al [3] studied the performance of a 5.13 kW window air conditioner designed for R22 when filled with propane. The performance of the air conditioner with R290 was compared with the performance with R-22. It was concluded that the COP for R290 was 7.9% higher at lower operation conditions and 2.8% higher at higher operating conditions.

Jung [9] studied the thermodynamic performance of two pure HC and seven mixtures composed of propylene (R1270), propane (R290), HFC152a and R170 in residential A/C. Heat pump with capacity of 3.5 kW was used in these experiments. Results showed that the COPs of all alternative refrigerants were up to 5.7% higher than that of R-22, except that for the R1270 which was 0.7% lower than that of R22.

Chang and Kim [2] compared experimentally the performance of a heat pump system when the R22 was replaced with propane, isobutene, butane, propylene and a mixture of propane/isobutene and propane/butane. It was concluded that the capacity and the COP of R290 were slightly higher than that of R22 which was an indication of a possible use as alternative in air conditioning and heat pump application.

Jabaraj et al [7] studied the possibility of using HFC407C/R290/R600 as a refrigerant mixture to substitute R22 in a window A/C and to evolve an optimal composition for the mixture. HC blend considered was of 45.2% of R290 and 54.8% of R600a. It was found that the COP was 8.19% to 11.15% higher than that of R22 at various condenser inlet air temperatures and the power consumption was 2.34% to 10.45% higher than that of R-22. It was found that among the mixtures considered, the above mentioned mixture would be the best choice for R-22 window air conditioners without changing the mineral oil.

Hammad and Alsaad [5] studied the possibilities of replacing R12 refrigerant with a mixture of propane, butane and isobutene. Four ratios of mixtures were studied experimentally. It was concluded that the mixture with 50% propane, 38.3% butane and 11.7% % isobutene is the most suitable alternative refrigerant with the best performance among all other HC mixtures investigated in the study.

Jawad [8] studied the performance of a domestic refrigerator when R12 was replaced with a mixture of 50% propane and 50% butane. These results showed that the best performance was for 90 grams charge mass and it gave 15% saving in input power. COP was higher than that of R12 by 10.2%. It was concluded that the hydrocarbon blend is a good substitute for R12.

Solar cooling system using absorption refrigeration cycle has been studied by several researchers such as Bong et al. [13], Duffy et al. [14], and Zhai et al. [12]. Some other works have been concerned on cooling systems using solar power based on photovoltaic principle such as

Kunio et al. [15], Habib et al. [4]. The main problems facing solar cooling systems are its initial cost, low system performance and solar energy usage for part of the day operation. Researchers suggested some improvements on the main components of the solar cooling systems to obtain better performance and reduce the initial cost.

This experimental work is meant to study the performance of solar powered A/C split unit of one ton of refrigeration capacity using an environmental-friendly alternative refrigerant. Experiments were carried out using LPGM as drop-in replacement of R-22 in existing air-conditioning system. The effects of the solar energy power variation during the operating time when using R-22 and LPGM as a refrigerant in air-conditioning system operation were investigated. Furthermore, in this experimental study a comparison between LPGM and R-22 was carried out under the same working conditions and using solar power. Parameters such as: refrigeration effect; cooling capacity; compressor power; compressor exit temperature; COP; mass flow rate of refrigerant and heat rejection were considered. These were dealt with as functions of evaporating temperature and condensing temperature.

3. Experimental Apparatus and Procedures

The schematic diagram of the system and its components are shown in Figures 1 and 2. It consists of 12 solar modules, battery system, inverter, controller and split air conditioning system. The specifications of the individual components of the system are shown in tables 1, 2 and 3.

The electrical energy produced by the PV modules will be stored in the batteries. Batteries DC will be inverted to AC power by the inverter. The photovoltaic solar array used 12 modules. Each six parallel modules were connected as two series parts.

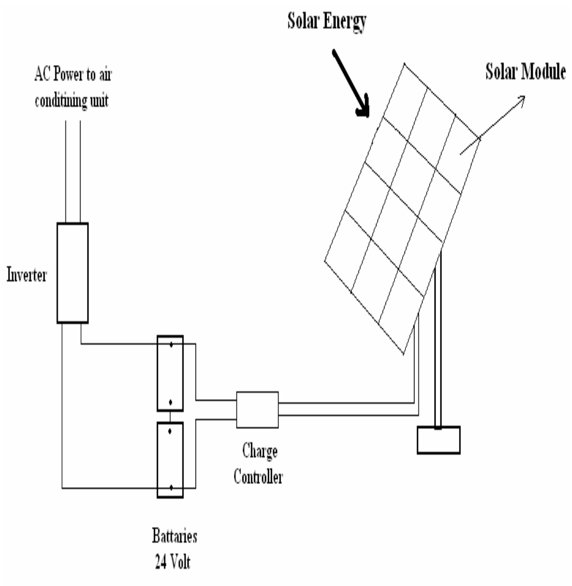

Figure 1: Solar system diagram.

Table 1: Specification of A/C unit.

Type	CHIGO Split Unit
Model	KF-32GW/AC30
Voltage	220-240/50/1
Capacity	12000 BTU (3.5kW)
Power input	1250 W (cooling mode)
Operating current	5.6 Amp
Refrigerant	R22
Air flow	550 m^3/h
Indoor unit	Three speed fan

A set of eleven copper-constantan (K-type) thermocouples with an accuracy of ±1 oC were installed at different points of the A/C refrigerant flow circuit to measure the refrigerant temperatures at different locations.

Table 2: Specification of photovoltaic unit.

Made	China
Model	C75D/80D
V max (V)	17 V
Voc(V)	21.5 V
I max (A)	4.42-4.71 Amp
I sc (A)	4.85-5.17 Amp
Power (W)	80 W
Dimension	670×990×40 mm
Weight	7 kg

Table 3: Specification of battery, inverter and controller.

Inverter	Model	Mass sine 24/1500-230V/50Hz
	Nominal Battery Voltage	24 V
	Nominal Capacity	1200 VA
	Peak Power	2900 VA
	Efficiency	92%
	Switch off volt	19 V
	Switch on volt	22 V
Battery	Model	OUTDO model OT120-12 deep cycle lead acid
	Nominal Battery Voltage	12 V
	Rated Capacity	72Ah, 95Ah, 120Ah
Charge Controller	Model	Prostar-30 version PS-30M
	Voltage	24 V
	Current	30 A

These thermocouples were installed; fixed and well insulated at their locations as shown in Figure 2. Their locations are described in Table 4. Temperature - Entropy (T-S) diagram is shown in Figure 3 for a typical vapor

 © 2012 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 6, Number 1 (ISSN 1995-6665)

compression cycle. The points of measured temperatures are shown.

Table 4: List of measured temperature points.

Suction of the compressor	T1	Outlet of the evaporator	T7
Discharge of compressor	T2	Ambient temperature	T8
Midpoint of the condenser	T3	Air temperature out of condenser	T9
Outlet of the condenser	T4	Inside air temperature	T10
Inlet of the evaporator	T5	Air temperature out of evaporator	T11
Midpoint of the evaporator	T6		

The pressures at the suction and the discharge lines were measured using pressure gauges with an accuracy of ± 1 kPa.

A clamp meter and voltmeter were used to measure the current and voltage of the compressor with an accuracy of ±0.5 A and ±0.5 V respectively.

A digital scale was used to weight the charge of the refrigerants with an accuracy of ±1g.

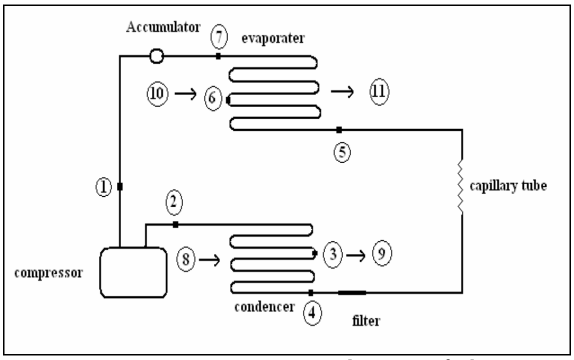

Figure 2: Temperature measuring location of the test air conditioning.

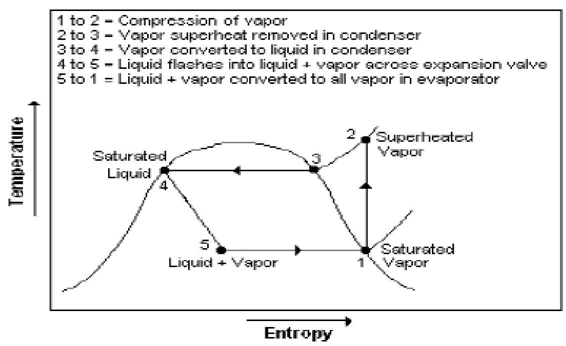

Figure 3: Temperature - Entropy diagram for ideal vapor compression cycle.

LPGM locally filled bottle with weight ratio of 30% propane and 70% butane was used. This LPGM refrigerant is a zeotropic blend charged in liquid phase acts with its composition shift and temperature glide. Drop-in experiments were carried out without any modifications to the experimental apparatus. Air speed regulation and evaporation cooling were used to change both condensing temperature, Tc and evaporating temperature, Te.

4. Mathematical Model

Following are the mathematical relations used in the analysis process:

Mass rate of flow = (Power consumption /work input) * (ζ_m * ζ_e)

$$\dot{m} = [(I*V) / (h_2 - h_1)] *(\zeta_m*\zeta_e) \quad (1)$$

Where (ζ_m*ζ_e) is the product of the mechanical and electrical efficiencies of the compressor, respectively which assumed to be 0.8.

The refrigeration effect:

$$RE = (h_1 - h_5) \quad (2)$$

Cooling capacity:

$$\dot{q} = \dot{m}*(h_1 - h_5) \quad (3)$$

Compressor fluid work:

$$\dot{w} = \dot{m}*(h_2 - h_1) \quad (4)$$

Compressor electrical power consumption:

$$P = I*V \quad (5)$$

Heat rejection in the condenser:

$$HR = \dot{m}*(h_2 - h_4) \quad (6)$$

State points and their numbers are shown on figure 3.

5. Results

5.1. Optimal charging value:

In order to find the optimal charge value for the drop in LPGM refrigerant, seven different LPGM charge quantities were investigated. The variation of the COP with the seven different LPG charges 200, 250, 300, 350, 400, 500, and 650g were tested and presented in Figure 4. The best charge, (that provides maximum COP) was found to be 425 grams. This procedure of finding the best charge was recommended by literature works such as Abuzahra [1]. This amount of charge was used for all experiments of this work. It was found that the weight of LPGM charge used in this air conditioning system was less than that of the R-22 refrigerant by 44%.

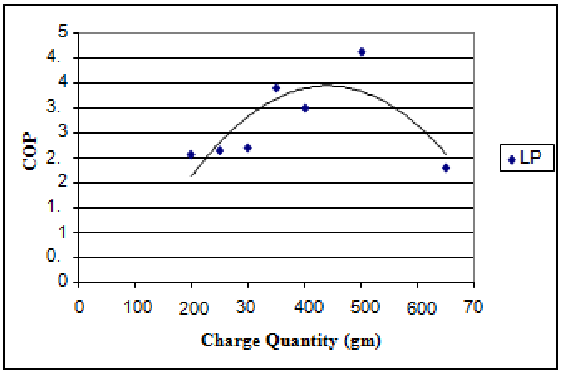

Figure 4: Coefficient of performance vs. charge quantity of LPG.

5.2. Power input:

Since the intensity of solar radiation is not constant along the day, this variation affects the total power generation of the used solar system. The variation of solar energy during the day will affect the power available in the batteries of the solar air-conditioning system. Thus, shutdown is expected to happen when the batteries can not provide enough power. When the batteries are recharged the A/C will restart again. The batteries working voltage ranged from 26.8 V down to 18 V. Between the shut down time and restart time, the batteries were recharged. Both, figures 5 and 6 show shutdown and restart periods for the A/C unit. Because of the fact that power consumption using LPGM was less than that using R-22 as will be discussed later, the A/C unit ran longer times in the case of using LPGM.

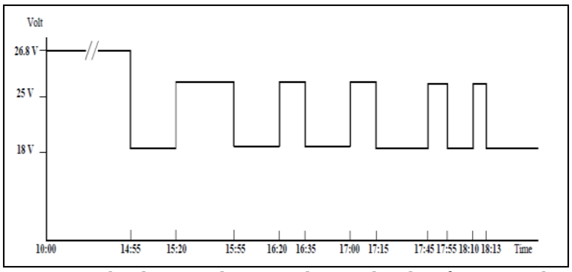

Figure 5: Shutdown and restart during the day for R22 when powered with solar energy.

The operating time considered was from 10:00 AM to 5:00 PM. The performance was measured in terms of the refrigeration effect, COP, cooling capacity, mass flow rate, power consumption, and compressor exit temperature.

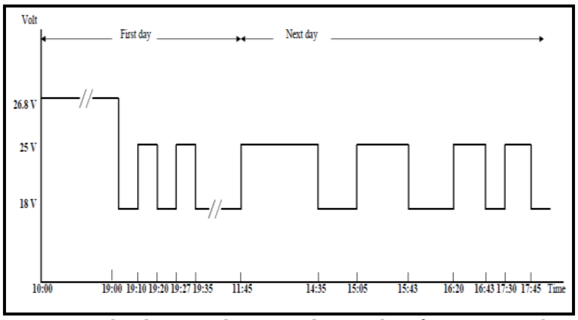

Figure 6: Shutdown and restart during day for LPGM when powered with solar energy.

5.3. Operating periods:

Figure 7 shows a typical day history of power consumption. This figure shows that the R-22 consumed more power than LPGM over the operating time considered in this study. The lower power consumption of LPGM is an encouraging factor to use solar energy as a source in driving the air conditioning system.

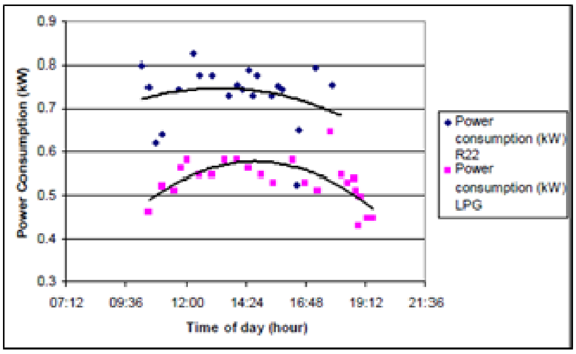

Figure 7: Power consumption using R-22 and LPGM.

Typical day history of refrigeration effect is shown in Figure 8. This figure shows that the refrigeration effect for the LPGM is higher than that of R-22 and thus the capacity required can be reached using lower mass rate of flow, . This effect produced lower power consumption, as discussed earlier.

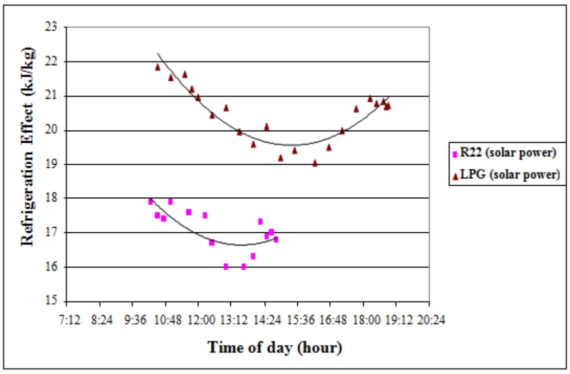

Figure 8: Refrigeration effect using R-22 and LPGM.

The mass flow rate through the compressor is proportional to the displacement rate in liters per second, the volumetric efficiency and inversely proportional to the specific volume of gas entering the compressor. As the suction pressure drops, the specific volume entering the compressor increases and this reduces the mass rate of flow at low evaporating temperatures. As shown in Figure 9 the mass flow rate of R-22 was higher than LPGM and the mass flow rate of R-22 decreased as the time of the day increased where the mass flow rate of LPGM is almost constant during the operating time. This is caused by the fact that the specific volume of LPGM is higher than that of R-22.

 © 2012 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 6, Number 1 (ISSN 1995-6665)

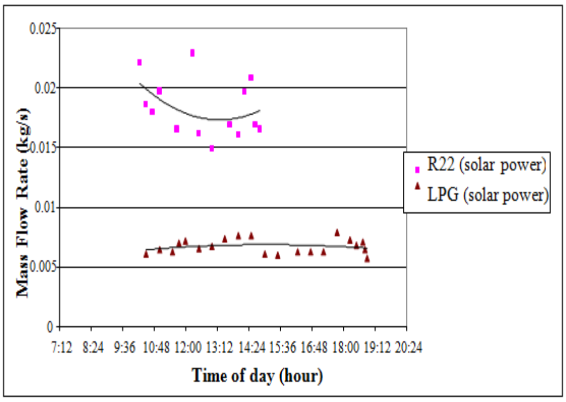

Figure 9: Mass flow rate using R-22 and LPGM.

The cooling capacity of the unit depends on the mass rate of flow of the refrigerant. The variation of cooling capacity versus time of the day is shown in Figure 10. This figure shows that the cooling capacity of the solar A/C unit using R-22 was higher than that when using LPGM by an amount of 25% at optimum conditions.

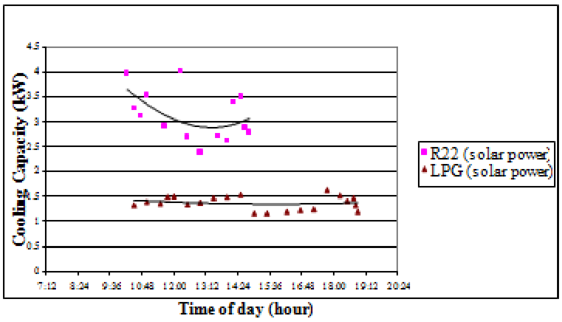

Figure 10: Cooling capacity using R-22 andLPGM.

The cooling capacity using R-22 changes during the time of the day while cooling capacity for LPGM is almost constant during the working period.

Figure 11 shows a daily history of the COP for R-22 and LPGM. The power consumption using LPGM is lower than that using R-22 and the cooling capacity using R-22 is higher than that using LPGM. The COP for R-22 is higher than that of LPGM during the operating period by amount of about 25% at best conditions.

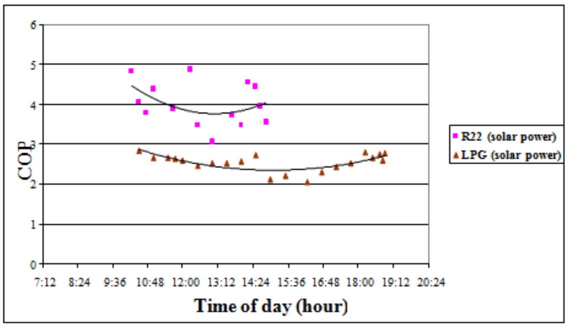

Figure 11: Coefficient of performance using R22 and LPGM.

Comparison of the compressor exit temperature between both refrigerants is shown in Figure 12. This figure shows that the compressor exit temperature for the A/C unit using R-22 is higher than that for the compressor exit temperature using LPGM. This is due to the fact that the LPGM has larger specific volume than R-22 which causes a lower compression ratio. This leads to a safer operation conditions.

Figures 5, 6, 7, 8, 9 and 10 show that the operating periods during the day using LPGM as a refrigerant were longer than that using R-22. As a result of these day time histories of performance, a good comparison between the use of LPGM and the use of R-22 was considerably discussed.

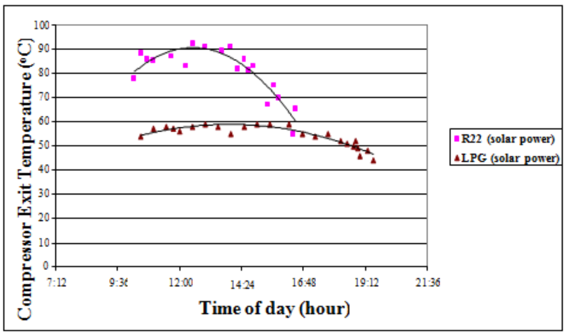

Figure 12: Compressor exit temperature with R22 and LPGM.

5.4. Evaporating temperature effect:

Figure 13 shows the variation of COP with evaporating temperature (Te) for LPG and R-22 using solar power. It is clear that COP for R-22 refrigerant was higher than LPGM and it increased as Te increased for both refrigerants.

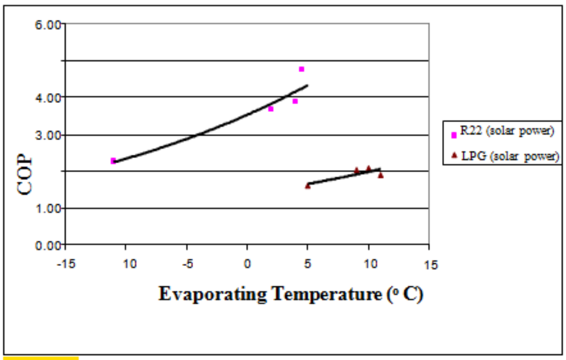

Figure 13: COP vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

The cooling capacity of the unit using R-22 was higher than that when using LPG refrigerant, while it increased for both with increasing of Te as shown in Figure 14.

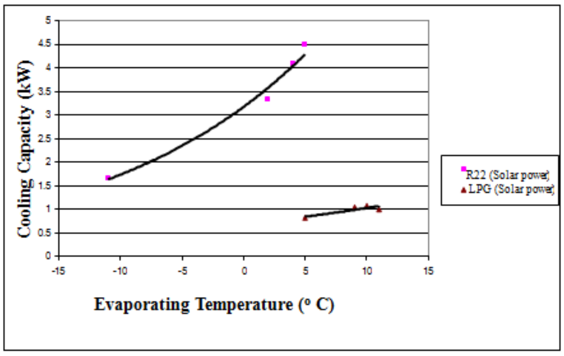

Figure 14: Cooling Capacity vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

The variation of power consumption with respect to Te was represented in Figure 15. It was shown that as Te increased the power consumption increased for both refrigerants, while that of R-22 was higher than that of LPGM.

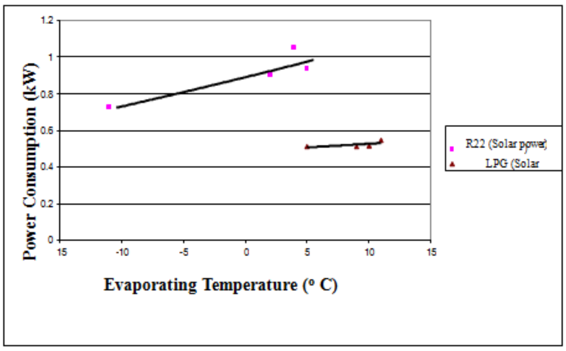

Figure 15: Power Consumption vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

For the heat rejected from both refrigerants, Figure 16 shows that it increased as Te increased and it was higher for R-22 than LPGM.

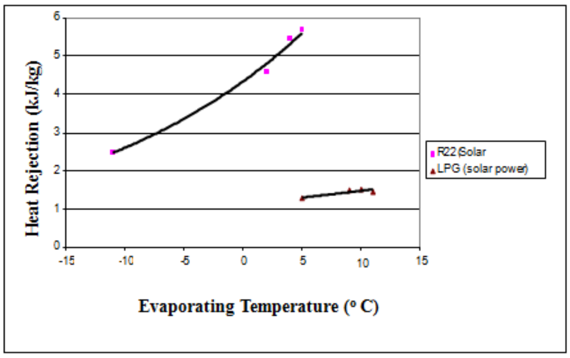

Figure 16: Heat Rejection vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

5.5. Condensing temperature effect:

Figure 17 shows the variation of COP with Tc for LPG and R-22. From this figure it was noticed that COP for R-22 refrigerant was higher than LPGM and it decreased as Tc increased for both refrigerants.

The cooling capacity of the unit using both R-22 and LPGM refrigerants decreased as Tc increased as shown in Figure 18. The cooling capacity using R-22 was higher than that of LPGM.

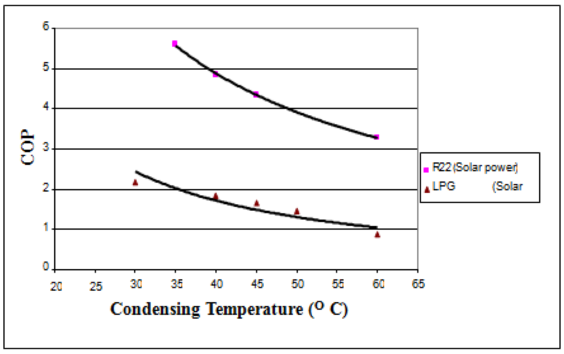

Figure 17: COP vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

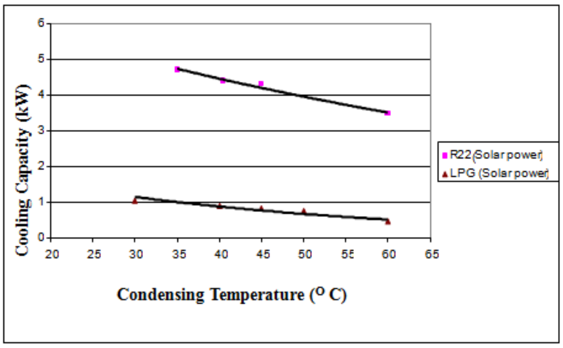

Figure 18: Cooling Capacity vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

The power consumption variation represented in Figure 19 with respect to Tc. It was found that as Tc increased the power consumption increased for both refrigerants.

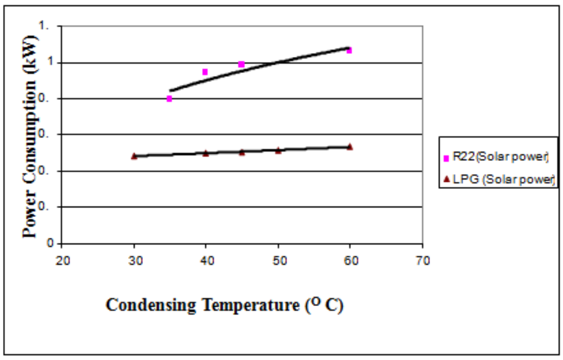

Figure 19: Power Consumption vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

The heat rejection for both R-22 and LPGM was illustrated in Figure 20. It can be seen from the figure that it decreased when Tc increased for both refrigerants.

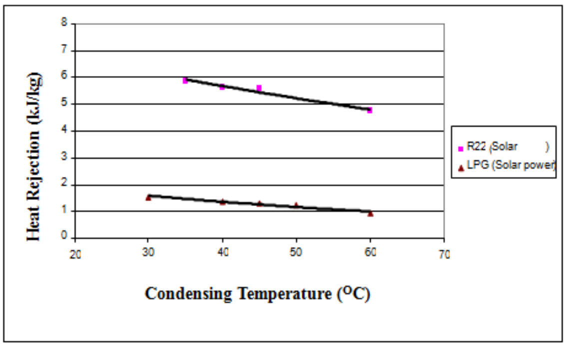

Figure 20: Heat Rejection vs. Condensing Temperature for R22 and LPGM at Te = 5 oC.

6. Conclusion

The refrigerant mixture LPGM used in this study was found to be a possible drop-in replacement for R-22 in the air conditioning system without considering any changes to the system.

The A/C system using LPGM refrigerant consumed less power than that with R-22. Energy conserved found to be more than 35%. This gave an advantage for using

© 2012 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 6, Number 1 (ISSN 1995-6665)

LPGM as refrigerant, especially when the A/C system was powered by solar energy.

The solar powered air conditioning systems using LPGM as a refrigerant had more continuous operation periods than that using R-22. This increased the reliability of the system.

Although systems using LPGM had lower COP and lower capacity than those using R-22, the first systems had the advantages of higher refrigeration effect, lower mass flow rate, lower energy consumption and lower compressor exit temperature.

Acknowledgment

The authors would like to thank the University of Jordan for the support during this work.

References

[1] Abuzahra, Hilal. "Performance of methane gas as a refrigerant for small air conditioning units", MSc, Thesis, Department of Mechanical Engineer, University of Jordan. 1994.
[2] Chang, Y.S. and Kim, M.S., "Performance and heat transfer characteristics of hydrocarbon refrigerants in a heat pump system", International Journal of Refrigeration, 23(2000)232-242. 1999.
[3] Devotta, S. "Alternatives to HCFC-22 for air conditioners", Journal of Applied Thermal Engineering, vol. 21, pp. 703-715. 2000.
[4] Habib, Choauki and Baccar, "Dynamic modeling and simulation of a new air conditioning prototype by solar energy" Journal Renewable energy, Vol. 32 pp. 200-215. 2006.
[5] Hammad, M. and Alsaad, M. "The use of hydrocarbon mixtures as refrigerants in domestic refrigerators", Journal of Applied Thermal Engineering, vol. 19, pp. 1181-1189. 1999.
[6] Hammad, M. and Tarawnah, R. "Hydrocarbon refrigerants performance in air conditioning units", Proceedings of the 4th IIR-Gustav Lorentzen conference on natural working fluids, Purdue University, West Lafayette, IN, USA, pp.167 – 176. 90. 2000.
[7] Jabaraj, D.B. and Narendran, A., "Evolving an optimal composition of HFC407C/HC290/HC600a mixture as an alternative to HCFC22 in window air conditioners" International Journal of Thermal Sciences 46 (2007) 276-283. 2006
[8] Jawad, Ali. "Performance study of a locally manufactured domestic refrigerator using a mixture of propane and butane (505/50%) as replacement to R-12)", MSc. thesis, Department of Mechanical Engineering, University of Jordan. 2000.
[9] Jung, Ki. "Thermodynamic performance of HCF22 alternative refrigerants for residential air conditioning applications", Journal of Energy and Buildings, 39 (2002) pp-675-680. 2006.
[10] Nofal, Abdalla. "Performance of Chest Freezer Using Propane/Butane Mixture as Substitute Refrigerant to R-134a", MSc. thesis, Department of Mechanical Engineering, University of Jordan. 2004.
[11] Purkayastha, B. and Bansal, P.K. "An experimental study of HC290 and a commercial liquefied petroleum gas (LPG) mix as suitable replacements for HCFC22", International Journal of Refrigeration, .Vol.21, NO.1, pp, 3-17, 1998. 1998.
[12] Zhai, X.Q., Wang, R.Z., Wu, J.Y., Dai, Y.J. and Ma, Q., "Design and performance of a solar-powered air-conditioning system in a green building", Journal of Applied Energy, Vol.85, pp. 297-313. 2008.
[13] Bong, T.Y., NG, K.C. and Tay A.O, "Performance study of a solar-powered air-conditioning system ", Solar Energy, 39, pp. 173-182. 1987.
[14] Duffie J.A. and Beckman, W. "Solar engineering for thermal process", John Wiley, New York. 1991.
[15] Kunio Tanaka, Yasuhiro Makino, Etsuo Sakoguchi, Akio Takeoka and Yukinori Kuwano, "Residential Solar-Powered Air Conditioners", Periodicals of Electrical Engineering In Japan, Vol. 114, No. 3, pp. 123-133.