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PERFORMANCE ANALYSIS OF BINARY NANOPARTICLES WITH LIQUEFIED PETROLEUM GAS ON DOMESTIC REFRIGERATOR SYSTEM VARYING REFRIGERANT CHARGE

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ABSTRACT

In this paper, performance analysis of Liquefied Petroleum gas with bi-nanoparticles on a domestic refrigerator were carried out experimentally, varying the refrigerant charge (w_r) and the two different nanoparticles TiO_2 and SiO_2 with different gram charge 0.1, 0.3 and 0.5 were dispersed in carpella oil based lubricant, cycling and continuous running tests were performed on a domestic refrigerator under tropical conditions using LPG and Nano-concentration (TiO2 and SiO2) as the working fluid of various charges on a domestic refrigerator system. The performance of the system was investigated using the following test parameters: power consumption, compressor suction and discharge pressures, evaporator air temperature, in order to achieve the specified International Standard Organization (ISO) requirement for standard evaporator air temperature with small refrigerator. The results show that the designed temperature and pull-down time set by ISO for small refrigerator are achieved earlier using refrigerant charge 60g of LPG with nano-particles at 60 minutes, pure-LPG -4^{0}C ,TiO_2-0.3g -3^{0}C and SiO_2 -0.3g were achieved. The highest COP (2.53, 4.76 and 2.96) were obtained using 60g charge of pure LPG, SiO_2 (0.3g) and TiO2 (0.3g)**.** The average COP obtained were 17.8% and 88 % than that of pure LPG respectively. Based on the results of this study, SiO_2 (0.3g) offered lowest power consumption. The compressor consumed 54.2 % less power compared to LPG and 14.3 % less power than TiO2 (0.3g) in the system. In conclusion, the system performed best with LPG-SiO_2 (0.3g) in terms of COP and electric power consumption but in terms of cooling capacity LPG SiO_2 (0.1g) performed best. This shows that LPG with nano concentration (SiO_2, TiO_2) can be used as replacement for R134a in domestic refrigerator.

Keywords: Nanoparticles, cooling capacity, refrigeration system, COP, LPG.

INTRODUCTION

International concern about these global environmental problems has resulted in a series of the international treaties demanding a gradual phase out of chlorofluorocarbon (CFC) and hydrochloroflourocarbon (HCFC) refrigerants. It is therefore becomes necessary to change from using ozone depleting refrigerant to non-ozone depleting refrigerants in refrigeration system. Recent alternative refrigerant R134a hydro-fluorocarbon (HFC) which has zero ozone depleting potential, its global warming potential is relatively high. Consequently, this has caused researcher to investigate the use of more environmentally friendly refrigerants than R134a and they are natural refrigerants, such as hydrocarbons which have been renewed in recent years because of the environmental problems of ODP and GWP associated with synthetic HFC and HCFC refrigerants. LPG (hydrocarbon) is one of the proposed alternative refrigerants to replace R134a in domestic refrigeration. Some researchers have made some findings on alternative refrigerant to R134a. A research was conducted by Bolaji (2010) on experimental study of mixture of hydrocarbon as a replacement for R12 in domestic refrigerators. Results reveals that Power consumption was considerably reduced with mixture of hydrocarbon. Recently, Mohanraj *et al*. (2012) conducted study between a mixture of R290, R600a and R134a. Tests were carried out with cycling running and continuous running. The continuous running test had a better performance with varying ambient temperature (24, 28, 32, 38 and 43^{o}C), the cycling running tests performed only under 32^{o}C ambient temperature, the power consumption reduced with increased in COP. Another study, Fatouh and Kafaty (2012) experimentally performed the analysis of propane and commercial butane as a drop in replacement for R134a in domestic refrigerator, the results indicates that refrigerator using LPG of 60 g and capillary tube length of 5 m were compared with the refrigerator using R134a of 100 g and capillary tube length of 4 m, the actual COP of LPG refrigerator increases by about 7.6% than that of R134a. Lower on-time ratio and energy consumption of LPG

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refrigerator by nearly 14.3% and 10.8%, respectively, which were compared to those of R134a refrigerator that was achieved. Alsaad and Hammad (1998) investigated the compressor power, the refrigeration capacity and Coefficient of Performance (COP) to determine the performance of R-12 in a household refrigerator using with a propane/butane mixture. The results revealed that a mixture of propane and butane was successful as a replacement for R12 in household refrigerators. James and Missenden, 1992 studied the application of propane in household refrigerators. The results showed that propane would be a better attractive substitute to R12. Akash and Said (2003) carried an experiment on the performance of Liquefied Petroleum Gas (LPG) obtained from the local market (15% isobutane by mass, 30% propane and 55% *n*-butane) as a substitute refrigerant for R12 in household refrigerators. The experiments were carried out with LPG at various mass charges of 50, 80 and 100 g. The results indicate that a mass charge of 80g gave the best performance when compared with R12 . Jung and Radermacher (1991) investigated the performance of a mixture of propane and isobutane in domestic refrigerators. The result revealed that a mixture of butane and propane gave a better performance when compared to R134a. Earlier, Bi *et al*. (2008) carried out a research on a domestic refrigerator that was designed to work with R134a and POE oil as the working fluid, TiO2/Al2O_3 nanoparticle addicted mineral oil were compared with R134a and POE oil in the system. Result revealed that energy consumption of 0.1% mass fraction TiO2 nanofluid was 26.1% lower than the POE oil state Also, Al2O_3 addicted nanofluid also showed similar performance.

Wang and Chimraes (2005) compared a system that is using R134a and mineral oil with R134a and POE oil with nanoparticles, the result showed that R134a and mineral oil with nanoparticles gives a better performance in term of power consumption. Another study, Radermacher (2005) analyzed the energy consumption of loads of refrigerants R436A and R600a. Results shows that the lowest annual energy consumer was R600a with a charge of 50g. Saidur *et al*. (2011) has done research on nanopaticles and the result shows, improved performance, and reduction in pressure drops. In a research study, Shahrul *et al.* (2014) have studied the relationship between the nanoparticles concentration in the refrigerants and their specific heat capacity, results showed that thermo physical property affects heat transfer equally, quantitative increases in specific heat capacities and increase in temperature. Bi *et al.* (2008) carried out an experimental study on the performance of a household refrigerator using TiO2-R600a nano refrigerant as working fluid. Result shows that the TiO2-R600a worked efficiently in the refrigerator with energy consumption reduced with 9.6%. The result also reveals that the pull down time of nano refrigerating system was shorter than that with pure R600a system. While study on the effect of new refrigerant LPG on Domestic refrigerator when binanoparticles is used as an enhancement is rare. Accordingly, in the present study the Performance analysis of Liquefied Petroleum Gas with Bi-nanoparticles on domestic refrigerator varying Refrigerant Charge. The potential of replacing R134a with LPG – nano lubricant was also explored. The prime objectives of the study were:

- To obtain the best values for refrigerant charge for optimum performance of VCRS
- To determine the best LPG-Nano refrigerant in replacement of R134a that has ODP and GWP
- To compare the cooling capacities of pure LPG, LPG nano of 0.1,0.3 and 0.5g under identical conditions, COP and power consumption of the refrigerator with Pure LPG and LPG nano (SiO_2 and TiO_2) of 0.1, 0.3 and 0.5g.

Nomenclature

w_r - Refrigerant charge

P_R - Compressor pressure ratio

SiO_2 – Silicon dioxide

W_c - Compressor work (kW)

TiO_2 – Titanium dioxide

T - Temperature ^{0}C

COP – Coefficient of performance

$\dot{m}$ - Refrigerant mass flow rate (kg/s)

LPG – Liquedfied Petroleum Gas

h - Specific enthalpies of refrigerant (Kj/kg)

Dis- discharge

Q_E - Refrigerating capacity (kW)

Suc-Suction

R – Ratio

C- Compressor

MATERIALS AND METHODS

The experimental setup (Fig. 1) consisted of a domestic VCRS with 1/10hp scroll compressor, 2mm diameter array of fins condenser design and 1meter throttle length, it was designed to work with R134a, an evaporator of 48litter capacity, wire mesh air cooled condenser and a reciprocating compressor. Based on ISO (1991) requirement for standard evaporator air temperature with small refrigerator size, test rig was designed to operate at -3°C (8187). The refrigerator was incorporated with valves which are used for charging and discharging of refrigerant within the compressor. Pressure gauges and Digital thermocouples K were integrated on the test rig for measuring the suction and discharge pressure and temperature of the refrigerant, and a power meter with (0.01 kW h accuracy) for measuring the energy consumption. The test rig was thoroughly checked before subjected to series of tests at various conditions. The specifications of the domestic refrigerator used in this study are shown in Table 1. Experiments were conducted with Pure LPG as the base line while 0.1, 0.3 and 0.5g of nano lubricants by varying refrigerant charge from 40g to 80g, with dry bulb temperature of 32°C. The temperature (- 30°C to +90°C), pressure (100 to 1300kPa) and compressor power (0 to 1100W) were measured with an uncertainty of ± 0.1 %.

Table 1. Specification of the rig , ranges and condition for continuous and cycling experiment.

Item	**Specification**
Unit Type	Freezer
Internal Volume	44L
Refrigerant/Lubricant	LPG /carpella oil
Compressor	1/10hp scroll Compressor
Refrigerant type	LPG
Power rating	50-Hz – 110Watts
Voltage rating	220-240Volts
Capacity tube length (m)	1.2 to 1.5m

Fig. 1. Experimental set up.

Table 2. Measurement of uncertainty.

Quantity	**Range**	**Uncertainty**
Temperature	0 - 50°C	± 0.1%
Pressure	0 – 2500kPa	± 0.1%
Power	0 - 10000W	± 0.1%

The refrigerants were charged into the system with digital charging system. A temperature gauge was used for measuring the evaporator air temperature in order to obtain the pull-down time (required time to varying ambient temperature to the evaporator chamber air temperature and to the desired final temperature). To reduce qualms in the experiment, it was repeated five times, average values were measured. Table 2 showed the quantities measured with their qualms. The disparity in experimental values from the average value is within ±5%. Temperatures at different locations were recorded every 15 minutes intervals. The experiment was carried out under the average ambient temperature of 32°C at no load and closed door conditions. The enthalpy (*h*) of the refrigerant using temperatures from the readings as input data were determined using the *REFPROP* version 9.0software. The results were used to calculate the Cooling capacity (Q_E), compressor pressure ratio (P_R), the compressor power consumption (W_c), and the COP of the refrigerator, as defined in the following fundamental equations.

(i) Cooling capacity (Q_E)
Cooling capacity (Q_E) is given by

$$Q_E = \dot{m}\,(h_1 - h_4)\ \text{(kW)} \qquad (1)$$

Where: $\dot{m}$ = mass flow rate (kg/s)
$h_1 - h_4$ = refrigerating effect (kJ/kg)
(ii) Power requirement of compressor
The compressor power consumption is given by

$$\dot{W}_c = \dot{m}(h_2 - h_1)\ \text{(kW)} \qquad (2)$$

Compressor pressure ratio (P_R) is given as:

$$P_R = \frac{P_{dis}}{P_{suc}} \qquad (3)$$

Where
P_{dis} = compressor discharge pressure (bar)
P_{suc} = compressor suction pressure (bar)
(iii) Determination of coefficient of performance (COP)

According to the first law of thermodynamics, the measure of performance of the refrigeration cycle is the Coefficient of Performance (COP) also is the refrigeration effect per unit of work or the compressor power consumption (Dossat and Horan, 2002). It is expressed as

$$\text{COP} = \frac{Q_E}{W} \qquad (4)$$

RESULTS AND DISCUSSION

The effects of LPG and bi-nanoparticles, varying refrigerant charge on vapour compression refrigeration system. Parameters were analysed for pure LPG and TiO2 and SiO2 -LPG with objective of obtaining the best values for refrigerant charge for optimum performance of VCRS. The study also investigated the best LPG-Nano

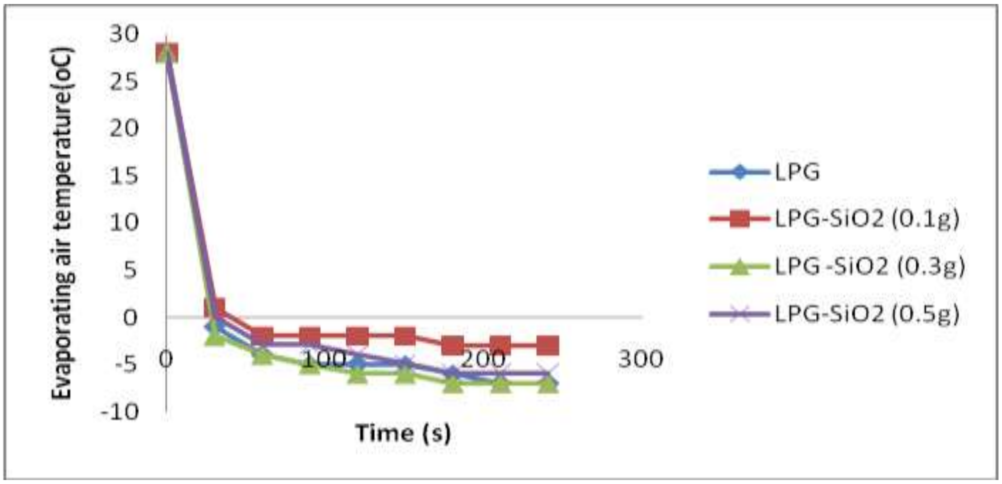


Fig. 2. Effect of refrigerant charge on evaporating temperature with time.

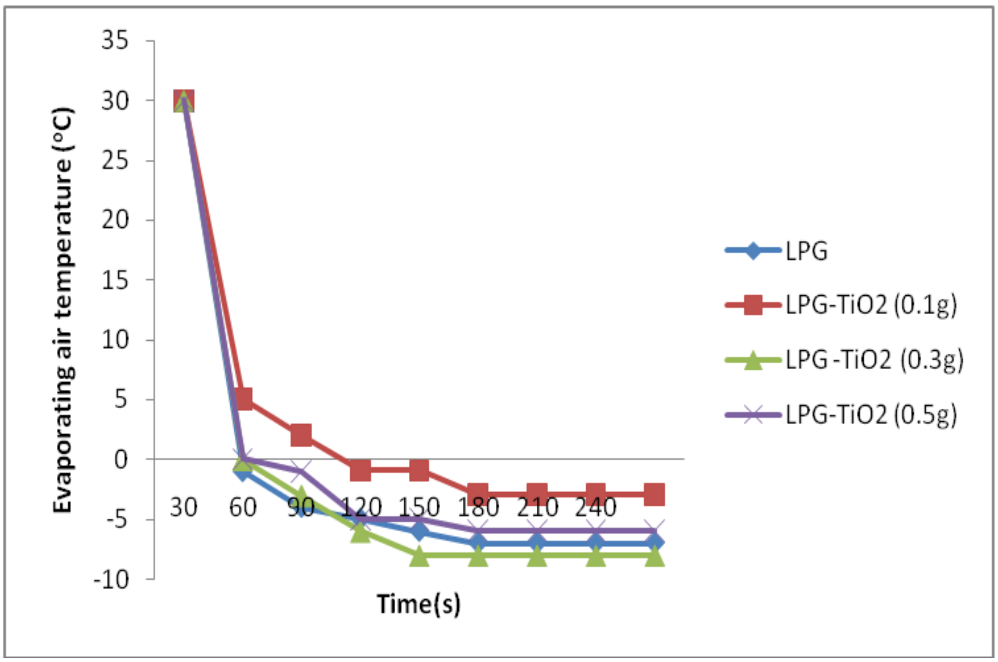


Fig. 3. Effect of refrigerant charge on evaporating temperature with time.

refrigerant in replacement of R134a that has ODP and GWP.

The pull-down time is the time required for the evaporator chamber air temperature to change from ambient condition (32^{o}C) to the desired final temperature (-3^{o}C) to attain the specified International Standard Organization (ISO) requirement for standard evaporator air temperature with small refrigerator size. Figure 2 showed the pull-down time of pure LPG and nano-LPG (SiO_2) of 0.1, 0.3 and 0.5g under varying mass charges of 40, 60, 80g, on the test rig in a bid to determine the optimum charge (Fig. 2). At 60g charge, pure LPG was able to achieve temperature of -5°C at 120 minutes, nano-LPG (SiO_2) of 0.1g achieves -2^{o}C at 90 minutes, 0.3 and 0.5g achieved evaporator air temperatures of -4 and -2^{0}C respectively at 150 minutes and 90minutes.While nano-LPG (TiO_2) of 0.1, 0.3 and 0.5g under same condition achieved evaporating air temperature of -3, -6 and-5^{0}C at 120,150 and 120minutes respectively. Nano-LPG (TiO_2) 0.3g shows the best pull down time when compare with pure LPG according to (Sattar *et al.*, 2013).

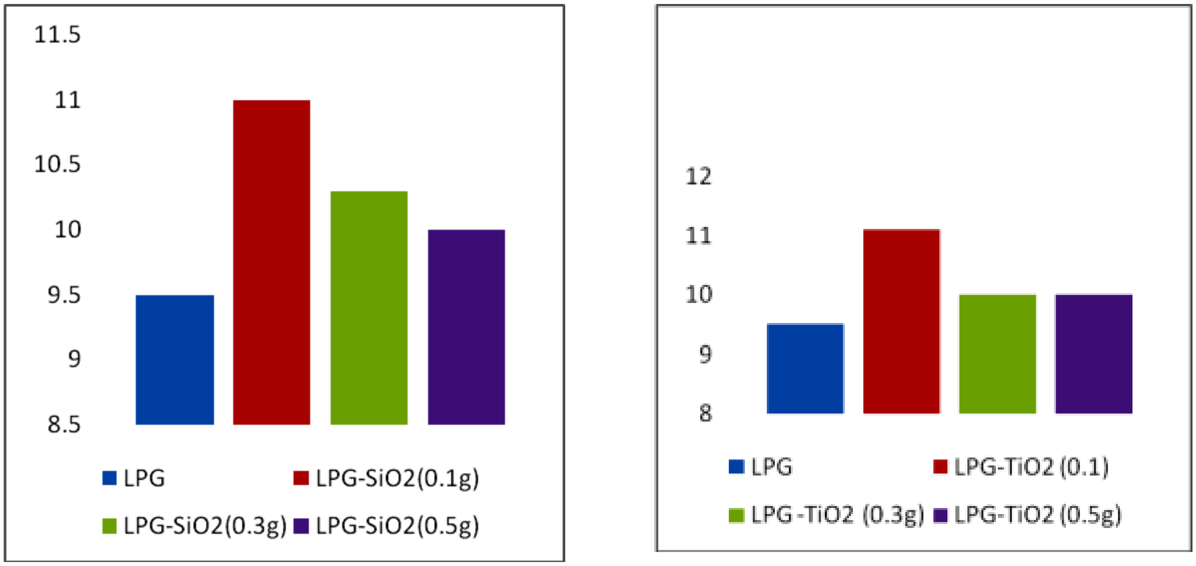


Fig. 4 and 5. Effect of refrigerant charge on cooling capacity with time.

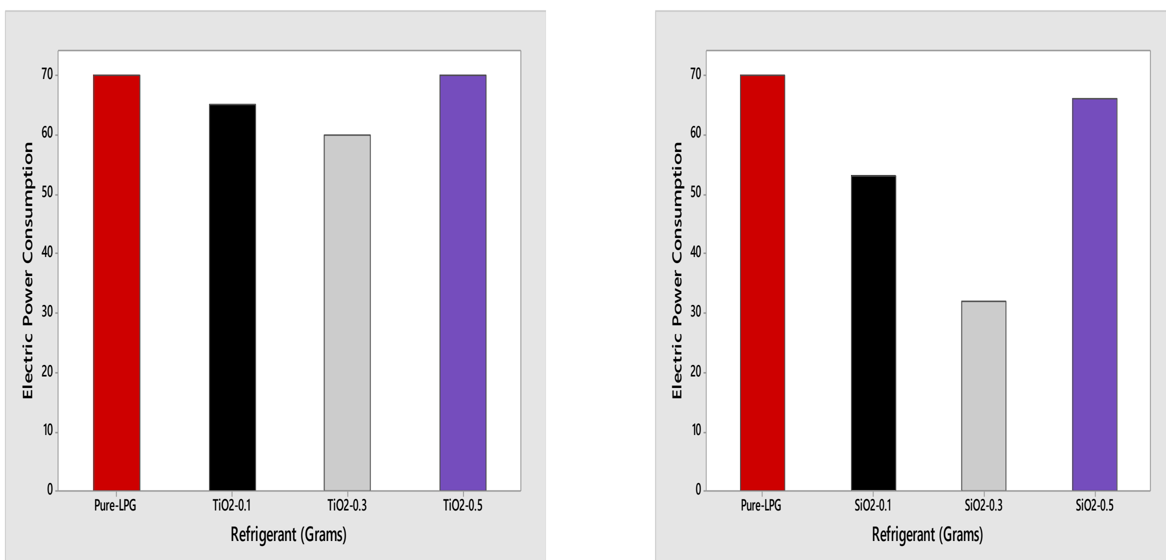


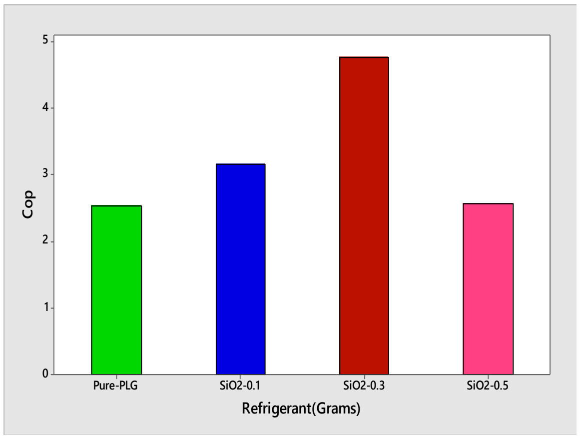
Fig. 6 and 7. Effect of refrigerant charge on power input.

Cooling Capacity of the refrigerator

Figures 4 and 5 shows that cooling capacity decreases with increase in mass charge in nano-LPG. It was observed that the compressor power contribution increases with increase in ambient temperature for nano -LPG and decrease in pure LPG refrigerant, the cooling capacity of pure LPG is 9.5% which is lower than that obtained for nano – LPG. The cooling capacity for 0.1, 0.3 and 0.5g of SiO_2&TiO_2 were 11, 10.3, 10 and 11.1, 9.99 and 10%, respectively according to (Reji Kumar and Sridhar, 2013).

Power Consumption of the refrigerator

Figures 6 and 7 shows the effect of the refrigerant charge on the power consumption. The figures show that power consumption of pure LPG is higher but when nano were added the power reduces as the refrigerant charge increases with bi-nano LPG unlike SiO_2 and TiO_2 at 0.5g that increases with increase in refrigerant charge. The power inputs of 40, 60 and 80g charge of SiO_2 nano particle were 53, 32 and 66kW respectively while the power input of 40, 60 and 80g charges of TiO_2 were 65, 60 and 70kW respectively, the average power input of LPG-bi-nanoparticle reduced with 30% and increased with 18.3% when compared with pure-LPG.SiO_2 and TiO_2 at 0.3g is the best because of the low power consumption.



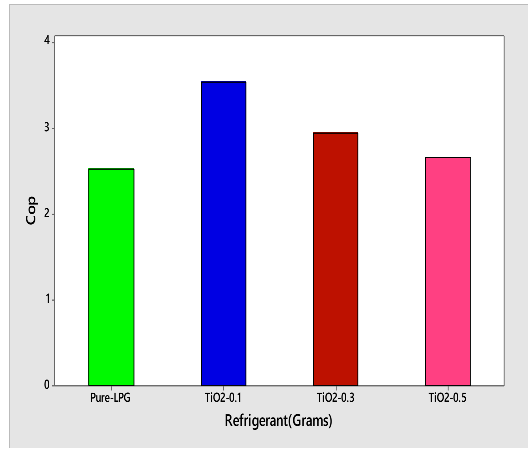


Fig. 8 and 9. Effect of refrigerant charge on COP with time.

Coefficient of Performance (COP) of the refrigerator

Figures 8 and 9 shows the variation of COP with time. The COP increases with time for all refrigerant charges SiO_2 and later decreases, also decreases with increase in refrigerant charge of TiO_2. The average COP of 40, 60g and 80g charge of LPG bi-nanoparticle (SiO_2 and TiO_2), for SiO_2 0f 0.1, 0.3 and 0.5g were 19, 88 and 1.17% respectively. While for TiO_2 of 0.1, 0.3 and 0.5g were 40, 17 and 5.5% respectively. LPG-bi nanoparticle for SiO_2 0.3g is 68.46 % higher than that of 0.1g and 87% higher than that of 0.5g while TiO_2 0.1g is 40%,0.3 reduced by 26% and 0.5g reduced by 11%. LPG-SiO_2 (0.3g) has the highest cop of 4.76 better than pure LPG.

The performance analysis of Liquefied Petroleum Gas with Bi-nanoparticles on domestic refrigerator varying refrigerant Charge of LPG and nano-LPG which are environmentally friendly refrigerants with zero ozone depletion potential (ODP) and low global warming potential (GWP) were studied experimentally in a domestic refrigerator, the following conclusions can be drawn out based on the results obtained:

- The pull-down time set by ISO for small refrigerator was achieved earlier using refrigerant nano-LPG than pure LPG.
- The average COP obtained using nano- LPG-SiO_2 (0.3g) has the highest COP of 4.76 which has better performance than pure LPG.
- LPG-SiO_2 (0.3g) offers lower power consumption. The compressor consumed about 24%, 54% and 6% less power than pure LPG and LPG- TiO_2.
- The cooling capacity of LPG is about 14%, 8% and 5% higher than pure LPG and LPG- TiO_2 respectively.

CONCLUSION

In conclusion Nano-LPG is an appropriate long-term candidate to replace R134a in the existing domestic refrigerator in terms of power consumption, cooling capacity and COP. The system performed better with nano-LPG than pure LPG , which shows that nano-LPG could be used as replacement for R134a in domestic.

REFERENCE

Alsaad, MA. and Hammad, MA. 1998. The application of propane/butane mixture for domestic refrigerators. Applied Thermal Engineering. 911-918.

Akash, BA and Said, SA. 2003. Assessment of LPG as a possible alternative to R-12 in domestic refrigerator. Energy Conversion Management. 44:381-388.

Bi, SS., Shi, L. and Zhang, LL. 2008. Application of nanoparticles in domestic refrigerators. Applied Thermal Engineering. 28:1834-1843.

Bolaji, BO 2012. Experimental study of R152a and R32 to replace R134a in a domestic refrigerator. Energy. 35:3793-3798.

Bolaji, BO. 2010. Experimental analysis of reciprocating compressor performance with eco-friendly refrigerants. Journal of power and energy. 224(6):781-786.

Dossat, RJ and Horan, TJ. 2002. Principle of Refrigeration. Prentice-Hall International Inc., New Jersey, USA.

Fatouh, M. and El Kafafy, M. 2006. Experimental evaluation of a domestic refrigerator working with LPG. Applied Thermal Engineering. 26:1593-1603.

ISO-International Standard Organization. 1991. International Standard-8187, household refrigerating applications (refrigerators/freezers) characteristics and test methods.

James, RW. and Missendon, JF. 1992. The use of propane in domestic refrigerator. International Journal of Refrigeration. 15:95-100.

Jung, DS. and Radermacher, R.1991. Performance simulation of a two evaporator refrigerator-freezer charged with pure and mixed refrigerants. International Journal of Refrigeration. 254-263.

Mohanraj, M., Jayaraj, S. and Muraleedharan, C. 2012. Applications of artificial neural networks for refrigeration, air – conditioning and heat pump systems-A review.

Radermacher, R. and Hwang, Y. 2005. Vapor compression heat pumps: with refrigerant mixture. Taylor & Francis.

Reji Kumar, R. and Sridhar. K. 2013. Heat transfer enhancement in domestic refrigerator using nano refrigerant as working fluid, International Journal of Computational Engineering Research. 3(4):42-50.

Sattar, MA., Saidur, R. and Masjuki, HH. 2007. Performance Investigation of Domestic Refrigerator Using Pure Hydrocarbons and Blends of Hydrocarbons as Refrigerants World Academy of Science. Engineering and Technology. 29.

Saidur, R., Kazi, SN., Hossain, MS., Rahman, MM. and Mohammed, HA. 2011. A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems. Renew Sustain Energy Rev. 15:310-23.

Shahrul, IM., Mahbubul, IM., Khaleduzzaman, SS., Saidur, R. and SabriM, FM. 2014. A comparative review on the specific heat of nanofluids for energy perspective. Renew Sustain Energy Rev. 38:88–98.7

Wong Wises, S. and Chimraes, N. 2005. Experimental Study of Hydrocarbon Mixtures to Replace HFC 134a in a Domestic Refrigerator. En. Conv. And Man. 46:85-100.

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