Effect of Particle Sizes in Nano -LPG refrigerant on the Performance of Vapour Compression Refrigeration System.

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ABSTRACT: Energy demand for refrigeration systems has been the major consideration for the choice of choosing electrical appliance in homes and industries. This work examines the behaviour of VCRs for various concentrations of nano particle sizes in Liquefied petroleum gas refrigerant (60%propane and 40 % butane). Measurements were made for the pure LPG refrigerant and also for nano LPG refrigerant that contains 0.1, 0.3 and 0.5 g of TiO2 in a vapour compression refrigeration system. The evaporating, condensing and discharge temperatures at the outlet of the evaporator, condenser and compressor of the refrigeration system were measured with thermocouple k. The results shows that evaporating temperature obtained for pure LPG, 0.1,0.3 and 0.5g nano-LPG were -70C,-30C, -80C and -60C respectively. The cooling capacity for pure LPG, 0.1, 0.3 and 0.5 were 9.5, 11.1, 9.99 and 10 while the power consumption were 70, 65, 60 and 70Kw.The coefficient of performance for pure LPG, 0.1, 0.3 and 0.5g nano-LPG were 2.53, 3.55, 2.95 and 2.67. Because of low power consumption, higher cooling capacity better coefficient of performance, 0.3g of nano-LPG (TiO2) among all gives the best performance.

Index terms — Vapour compression refrigeration system, R134a, Domestic refrigerator, Particle sizes, LPG, TiO2, Cop.

1 INTRODUCTION

In recent time, energy conservation and environmental safety has become a global challenge. The Ozone Depleting Potential (ODP) and the effect of Global Warming potential (GWP) have become the most essential criteria in the development of new refrigerants. The current Chlorofluorocarbons and Hydro chlorofluorocarbons used in refrigeration system contained chlorine and have environmental challenge. As a result of the depletion of the earth's ozone layer, the United Nations Environment Program set the phase out of R11 and R12, used in conventional refrigeration and air conditioning equipment at 1996 and HFCFC at 2030 UNEP [17]. Therefore, Scientists investigate more environmentally friendly refrigerants and a way of improving their performance in refrigeration system. Liquefied Petroleum Gas (LPG) has been identified as one of the alternative refrigerants to R134a in domestic refrigeration system. James and Missenden [4] carried out an experiment on the use of propane in household refrigerators putting into consideration energy consumption, compressor lubrication, costs, environmental and safety. The results revealed that propane offered better performance compared to R12. Jung *et al.*[5] conducted an experiment on the performance of a mixture of R600a and R290 in domestic refrigerators, the thermodynamic performance analysis revealed that the coefficient of performance of the system was improved by 2.3% compared to R12 in the system. Lee and Su [6] carried out a research on experimental study on R600a as a substitute in a domestic refrigeration system. The results indicate that R600a has better coefficient of performance when compared with CFC-12 and HCFC-22 in the system. Agarwal *et.,al* [1] conducted an experiment to compare mixtures of propane and iso-butane using the ideal refrigeration cycle with R134a evaporating temperature of -25 ^{O}C and a condensing temperature of 55 ^{O}C, the results revealed that iso-butane has lower discharge temperature and higher COP with lower volumetric capacity compared with R134a. Maclaine-cross *et al.*, [7] conducted an experiment to compare R600a with R134a and R12 in domestic refrigerator, it was found that R600a has about 20 % energy saving compared to R134a and R12 in the refrigerator. Oyelami. S and Bolaji B. O.[11] has Investigated experimentally the performance of liquefied petroleum gas (LPG) Refrigerant in vapour compression refrigeration system and the result showed that the system performed better with LPG than R134a in term of low pressure ratio, higher refrigerating capacity and higher Cop. N. Austin *et.,al* [10] conducted an experimental study on the mixtures of

HC to replace R134a in a domestic refrigerator with testing and training of ANN. The result reveals that the actual COP of mixed refrigerant in the refrigerator was higher by 8.1% than that of R134a. Results obtained in this experiment show a positive sign that using mixed refrigerant will perform better in household refrigerator. COP started increasing with increase in percentage of R134a while it reach a maximum value at 15% of R134a (Mixture-2) started decreasing with increase in R134a mass fraction. Bi *et al.* [2] conducted an experimental study by using mixture of R600a and nano refrigerants TiO_2. The result revealed that nano refrigerant mixture caused reduction in energy consumption also improved the COP and miscibility of oil with refrigerants. Also TiO_2-R600a nano refrigerants work normally and safely in the refrigeration system. Shahrul et al. [15] 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, increases the specific heat capacities equally with increase in temperature. Whereas study on effect of particle sizes in nano and using LPG as refrigerant on the performance of domestic refrigerator is very scarce. Therefore, in the present study the effect of particle sizes of nano -LPG refrigerant on performance of vapour compression refrigeration system would be considered. The budding of replacing R134a with LPG and particle sizes of nano lubricant was also explored. The prime objectives of the study were

- To know the effect of sizes of nano particle with LPG on a domestic refrigerator.
- To determine the best size of nano particle with LPG for optimal charge.
- To know the best size of nano –LPG in term of COP, cooling capacity and lower power consumption.

1.1 Nomenclature

Tio_2		Titanium oxide
Sio_2		Silicon oxide
h	[kJ/Kg]	Enthalpy of the refrigerant
ṁ	[Kg/s]	Mass flow rate
P	[kPa]	Pressure
Q	[kW]	Cooling capacity
W	[kW]	Power consumption
T	[^oC]	Temperature
E		Evaporator
dis		Discharge
Suc		Suction
R		Ratio

2 ANALYSIS METHOD

Figure 1. Shown the experimental setup of a domestic VCRS of 1 ton of refrigeration (TR) capacity that was designed to work with R134a, an evaporator of 62 litre capacity, wire mesh air cooled condenser and a reciprocating compressor. The refrigerator was incorporated with two pressure gauges at the inlet and outlet of the compressor for measuring the suction and discharge pressure, Thermocouples measure the temperatures at the evaporator compartment (T_1) compressor outlet (T_2), condenser outlet (T_3), outlet of the throttle pipe (T_4) and a power meter (with 0.01 kW h accuracy) for measuring the energy consumption. The test rig was thoroughly checked and trial test was carried out prior to the main experiment. Several tests at various conditions were carried out. Figure 2. showed the schematic diagram of the refrigeration cycle while Figure 3.Showed the schematic diagram of refrigerating system. Table 1 shows the specification of the refrigerator system while Table 2 showed the characteristics of measuring instruments. Different sizes of nano particle (0.1, 0.3 & 0.5 gram me) , was separately mixed with the lubricating oil and vibrated with ultrasonic oscillator (Branson M2800H) which separated nanoparticles to improved their uniform distribution within the lubricant. The mixture was then infused into the system compressor and standard operating parameters were recorded in two segment: (i) For Pure LPG as a baseline and comparison for the period of four hours at 30 minutes interval for 40, 60 and 80g charges respectively. (ii) Experiment were repeated severally on the test rig which has nanoparticle-lubricant based LPG refrigerants (TiO_2,) of different particle sizes were introduce into the system and subjected under the same condition, data's were also recorded concurrently. LPG refrigerant used for the experiment was obtained locally which has a purity of 99.7%. The characteristics of the nanoparticles used for the experiment are as indicated in Table 3, while that of lubricating oil is shown in Table 4. A digital weighing balance (CAMRY ACS-30-ZC41) was used to measured the LPG refrigerant with the range of 5 to 30000g while Digital weighing balance (OHAUS Pioneer TM PA114) with measuring range of 0.0001 to 110g were used to measured the required gram charge . To prepare for another experiment, a vacuum pump was adopted for extracting spent refrigerant after each trial.

2.1 Experimental Performance Analysis

(i).Cooling Capacity (Qevap)
Cooling Capacity (Qevap) is given as follows

Qevap $= \dot{m}\,(h_1 - h_2)$ (kW) ………………….(1)

Where : $\dot{m}$ = mass flow rate (kg/s)

$h_1 - h_4$ = Cooling effect of refrigerant (kJ/kg)

(ii).Compressor power input
Compressor power input is given as follows

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

(ii).Pressure ratio (PR) is given as follows

$PR = P\frac{dis}{suc}$ ………………………………………(3)

Where Pdis = compressor discharge pressure (bar)
Where Psuc = compressor suction pressure (bar)
(iv).Coefficient of Performance

$COP = \frac{QE}{W}$ …………………………………...(4)

Figure: 1 Experimental set up

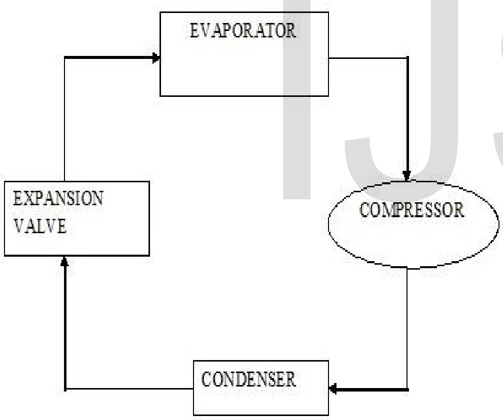

Figure: 2 Schematic diagram of refrigeration cycle

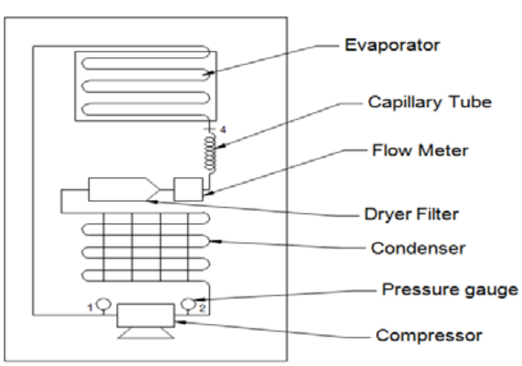

Figure 3. Schematic diagram of refrigerating system

Table 1:
Specification of the Refrigerator System

S/N	Refrigerator	Specification	Units
1	Evaporator size	42	litres
2	Power rating	50-Hz – 110	Watts
3	Voltage rating	220-240	Volts
4	Refrigerant charge size	100	grams

Table 2:
Measuring instruments characteristics

Measured Data	Manufacturers Specification	Range	Uncertainty
Temperature	Digital ThermocoupleK	-50°C-750°C	±1°C
Pressure	Digital pressure gauge	5 - 5000 Pa	±1%
Power Consumption	Digital Watt/ Watt-h-meter	1-3000W(0.0001 1-999.9kWh)	±1%

Table 3:
The Characteristics of nanoparticle

Particle Type	Particle Size(nm)	Purity(%)	Manufacturer	P code
Titanium Dioxide TiO_2	15nm	99.7	Alfa	Aesar

Table 4:
The Characteristics of the lubricating oil

Characteristics of lubricating oil	Units
Oil type Capella	Mineral oil
ISO viscosity grade	68
Flash point	-36°C
Density at 15°C kg/L	0.91
Kinematic viscosity (mm2/s) at 40°C	68
Kinematic viscosity (mm2/s) at 100°C	6.8

Viscosity index 22

3 RESULT ANALYSIS

Results of performance parameters obtained are as follows;
According to ISO. [3], the time required to change evaporator chamber air temperature from ambient condition to the desired final temperature is called pull down time. The refrigerator is designed experimentally to operate at -3^{0}C. Fig. 4. below shows the comparison of pull-down time of pure LPG under varying mass charges of 40, 60, 80g, to determine the optimal charge for pure LPG 0.1, 0.3, 0.5 and nano LPG respectively .The evaporator chamber temperature of -6^{o}C was achieved for pure LPG while -6 ^{0}C,-7^{0}C and -6^{0}C was achieved for nano LPG at 150,120 and 150 minutes for 0.1, 0.3 and 0.5gram.

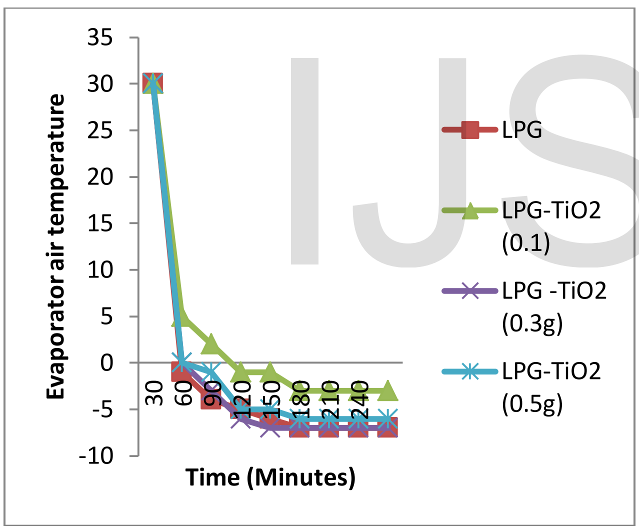

Figure: 4 Pull down time

Figure 5. below shows the effect of the refrigerant charge on the energy consumption of pure LPG and LPG nano-refrigerants at 60g charge. Power consumption reduces as the refrigerant charge increases until it reached the optimal refrigerant charge, which is equivalent to the minimum power consumption. The average power consumption for pure LPG increase by 1.68%. Energy consumption reduces with nano LPG but at higher refrigerant charge of 0.5g, energy consumption increases. LPG / TiO_2 of 0.1, 0.3 reduces with 1.56%, 1.44% and increase with 1.68% according to M.A Sattar [8].

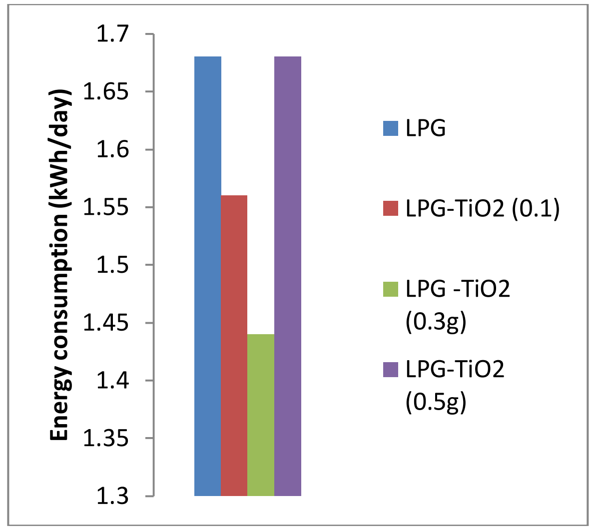

Figure: 5 Energy consumption

Fig.ure 6. below shows cooling capacity of the experiment with ambient temperature for pure LPG and LPG / TiO_2. 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 are 11.1%, 9.99% and 10% respectively according to R. Reji Kumar *et .,al* [13].

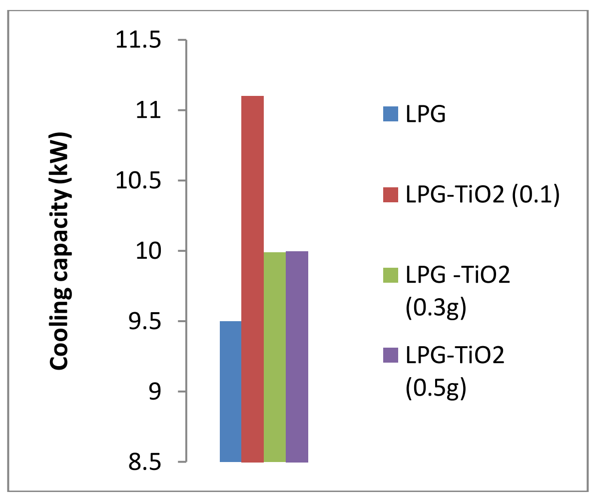

Figure 6. Cooling capacity

Figure 7. below shows the coefficient of performance of the system, the cop increases with nano concentration, COP of 2.53 % was achieved for pure LPG and 3.55, 2.95 and 2.67 % for 0.1, 0.3 and 0.5g of LPG / TiO_2

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respectively. The average cop of LPG / TiO_2 of 0.1, 0.3 and 0.5 are 43.3, 17.8 and 5.3% higher than that of pure LPG. COP increases with refrigerant charge and quantity of refrigerant in the system, which also increase the cooling capacity of the system.

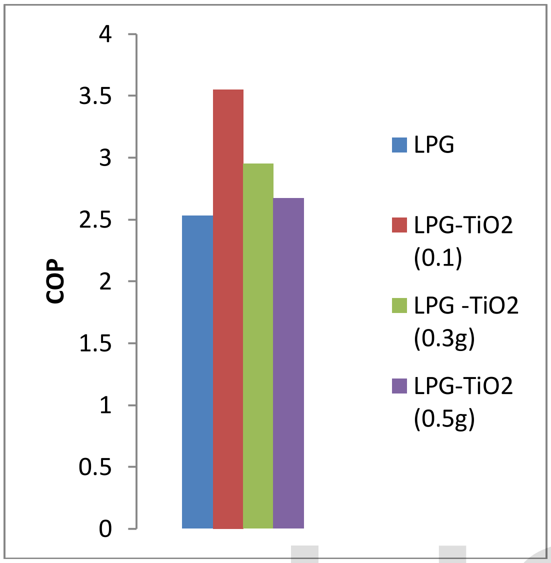

Figure 7. Coefficient of performance

Table 5:

Comparison between LPG and LPG – Tio_2

Test	LPG	LPG-TiO_2
Evaporator air temperature (°c)	-6	-7
Pull down time (minutes)	150	120
Compressor discharge temperature (°c)	65	58
Mass flow rate	0.033	0.033
Compressor power input (W)	3767	3348
Electric power consumption (W)	70	60
Nano gram charge	-	0.3g
Discharge Pressure (kPa)	618	584
COP	2.53	2.95
Energy consumption (kWh/day)	1.68	1.44

4 DISCUSSION

Experimental Investigation of behaviour of diverse particle sizes concentration in refrigeration system were carried out on a domestic refrigerator system using mineral oil based lubricant mixed with TiO2, nanoparticles as well as LPG as the working fluid. The results indicated that TiO2-lubricant can work normally and efficiently in refrigerator according to R.Saidur [14].

5 CONCLUSIONS

The following conclusion were drawn: At refrigerant charge 60g of pure LPG, 0.1g, 0.3g and 0.5g of Titanium / LPG, steady state was achieved at 120 minutes, evaporator chamber temperature was at -8^{0}C for pull down time of 0.3g Titanium/LPG. Therefore 0.3g Titanium / LPG offers the best pull down time. According to P.Shanmugasundaram *et,.al* [12].

The effect of refrigerant charge on the energy consumption in fig. 5 shows that power consumption reduces as the Nano/LPG increases. The average optimal refrigerant charge, which corresponds to the minimum power consumption, for the three different sizes of Nano/LPG concentration 0.1,0.3 and 0.5g and pure LPG are 1.56, 1.44 1.68 and 1.68 kWh/day were obtained during the test. Energy consumption in kilowatts per day of 70, 65, 60 and 70 was achieved. This implies that pure LPG and 0.5g refrigerant charge of Titanium /LPG has same energy consumption. While 0.3g charge has the lowest energy consumption and it's the best of all. While the effect of cooling capacity of the system in kilowatts at pure LPG the cooling capacity was high, addition of 0.1g of Nano / LPG increases the cooling effect compare to pure LPG then it later decreases with 0.3g Nano /LPG and increases with 0.5g Nano/LPG concentration. Therefore 0.1g offers the best cooling capacity according to R. Reji Kumar *et.,al*.[13].

According to Mohd . *et.,al*. [9] the coefficient of performance of the system, for pure LPG, 0.1, 0.3 and 0.5g Nano/LPG are 2.53, 3.55, 2.95 and 2.67. Titanium /Nano concentration of 0.1 has highest cop, but 0.3g has the lowest power consumption, therefore 0.3g is the best.

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