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To cite this article: L. J. Akinlesi *et al* 2019 *J. Phys.: Conf. Ser.* **1378** 042081

Experimental Performance of a Domestic Refrigerator with TiO_2-Nanoparticles Operating Within Selected Ambient Temperature

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Abstract-
This study presents a 40g R600a charge enhanced with various TiO_2 nano-lubricant concentrations (0 g/L and 0.2 g/L nano-lubricants) infused into an R12 domestic refrigerator tested within selected ambient temperature conditions (19, 22 and 25 ºC). The performance test parameters including: energy consumption, discharge pressure, power per tonne of refrigeration (PPTR) and coefficient of performance (COP) were evaluated for the system. The results showed that infusing the nano-lubricant into the system improved the energetic performance of the system. Overall, the use of 40g at 25ºC gave the best performance within the system. In conclusion, application of nanoparticles in refrigeration systems was found to improve the performances of the system even with the effect of ambient temperature. R600a-TiO_2 nano-lubricant mixture works safely and efficiently in the domestic refrigerators but requires adequate optimization.

Key words: R600a refrigerant, nano-lubricant, TiO_2 nanoparticles, ambient temperature

1. Introduction

Refrigeration has vast applications in recent human endeavours [1]. This versatility is justifying recent improved refrigeration systems' designs. Design of refrigeration systems influences their performances [2]. Hence its components, the refrigerant type, the refrigerant charge, and immediate environment conditions have been increasingly studied recently [3]. Energy consumptions of domestic refrigerators are dependent on their immediate environment conditions [4] A study conducted by Björk and Palm [5] on the effect of ambient temperature on the performance of a domestic refrigeration system concluded that the optimum mass charge of the system decreases with increasing ambient temperature. Similar justifications was reported by Geppert and Stamminger [6] and a direct correlation was established between energy consumption and ambient temperature [6].

Nanotechnology has been found to actively improve performance of refrigeration systems. Nanofluid prepared as either Nanorefrigerants (mixture nanoparticles and refrigerant) or nanolubricants (mixture nanoparticles and lubricants) [7] have gained increased adoption within recent refrigeration system applications [8]. Justification for adopting nanofluids within refrigeration systems include improved energy efficiency [9], higher freezing capacity [10], environmental friendliness [1], [11], [12], [13], [14], thermal efficiency [15] and tribological characteristics [16]. Bi *et al.* [2] experimentally investigated the performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant. The results of infusing TiO_2-R600a working fluid into the test rig reduced the energy consumption by 5.9 and 9.60 % respectively [17].

This study experimentally investigates energetic characteristics such as Coefficient of performance, power per tonne of refrigeration, energy consumption and discharge pressure.

2. Methodology

2.1 Experimental Set-up

The test rig setup adopted for this investigation was a domestic refrigerator with a built-in 95W- R12 compressor (See Figure 1 and Table 1 for the schematic diagram and specification of the test rig). The setup had fitted valves to enable charging/discharging of refrigerant and to serve as attachment for appropriate pressure gauges. A 40g mass charge of R600a refrigerant was charge into the refrigeration system after a thorough flushing and evacuation using a vacuum pump (Sigma B42). The temperature variations of the sub-components of the system were obtained using Type K thermocouples, while the energy consumption was monitored using a digital wattmeter. Pressure readings were obtained using digital pressure gauges. The power consumption was also measured using a digital Wattmeter having ±1% measurement accuracy. The experimental room had a 10 tonnes air-conditioner that was used to maintain the room ambient temperature conditions across all experiment trials.

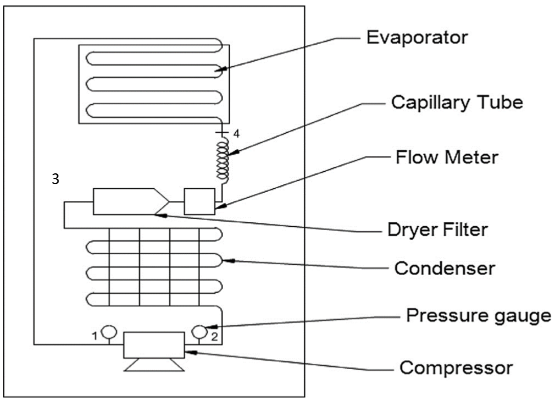

Figure 1: Schematic of experimental test rig

Table 1: Specifications of the experimental test rig

Item	Specification
Gross Capacity (L)	42L
Voltage (V)	220V
Weight	120kg
Refrigerant Type	R600a
Compressor Type	R12
Compressor Rating	0.13 hp
Nanoparticle Type	TiO2

Nano Concentration	0 and 0.2 g/L
Ambient Temperature	19, 22 and 25 ºC

2.2 Experimental analysis

The collated data [that is suction and discharge temperatures (T_1 and T_2) and pressures (P_1 and P_2), condensing temperature (T_3), cabinet temperature (T_{AIR}) and energy consumption (W)] from the 40 g R600a refrigeration system infused with 0 and 0.2 g/L TiO_2 nanolubricant concentration tested within the selected ambient conditions (19, 22 and 25 ºC) were used to estimate the energetic characteristics of the system. The data was collated at steady state (180 minutes) operation of the system. Required thermodynamic properties of the system were obtained from NIST Ref-Prop version 9.1 software. The obtained thermodynamic properties were saturated vapour enthalpy (h_1), superheated vapour enthalpy (h_2) and saturated liquid enthalpy (h_3). Every trial was conducted under a closed door, no load, continuous cyclic (i.e. running without ON/OFF) operation of the compressor.
Estimated energetic properties of the system were obtained using equations 1-2.

The power per ton of refrigerant (PPTR) is obtained by

$$PPTR = 3.5\frac{Wc}{Qev} = \frac{\dot{m}(h2-h1)}{\dot{m}(h1-h3)} \quad (1)$$

The Coefficient of performance is given by

$$COP = \frac{\mathrm{Qev}}{W} = \frac{\dot{m}(h1-h3)}{\dot{m}(h2-h1)} \quad (2)$$

$\dot{m}$ is the refrigerant mass flow rate (kg/s), h_1 is the saturated vapour enthalpy, h_2 is the superheated vapour enthalpy, h_3 is the saturated liquid enthalpy (kJ/kg), P_{suc} and P_{dis} are the compressor suction and discharge pressures (kPa), respectively and Q_{ev} is the cooling capacity (kW)[18] .

3. Results and discussion

This section presents the results of varying nanolubricant concentration under selected ambient temperatures within a domestic refrigerator using 40g R600a refrigerant.

3.1 Energy Consumption

Figure 2 shows the variation of energy consumption within the system. It was observed that energy consumption reduced with increasing ambient temperature. The test rig with 0 g/L TiO_2 nanolubricant across all selected ambient temperature consumed the most energy. Overall, the range of energy consumption was 71.8W at 25ºC to 77.4W at 19ºC. The use of 0.2 g/L reduced the system energy consumption in the test rig by 3.42 to 4.52% in comparison to the pure.

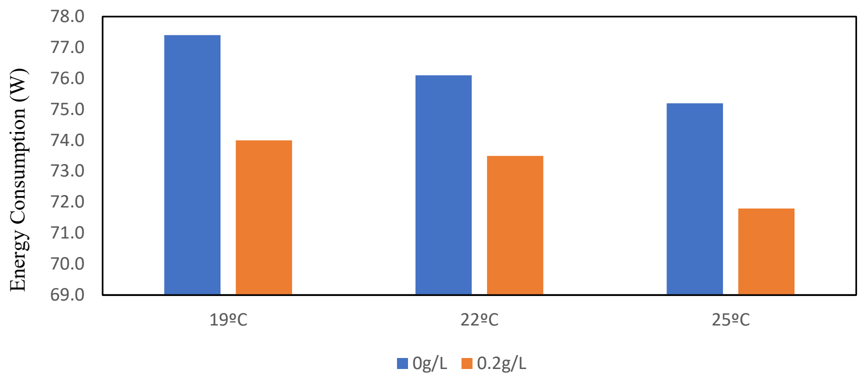

Figure 2: Effect of ambient temperature and nano-concentration on energy consumption of the system at a refrigerant charge of 40g

3.2 Coefficient of Performance

The coefficient of performance of the system is as shown in Figure 3. The coefficient of performance of the test rig improved for 19 and 25 ºC and decreased for 22 ºC ambient temperatures in comparison to the baseline (that is 0 g/L) experimental trials. The range of estimated coefficient of performance within the system was 6.18 at 22ºC with 0.2g/L nano-lubricant concentration and 7.65 at 25ºC with 0.2g/L TiO_2. With addition of 0.2g/L of TiO_2 nanoparticles, the COP was improved by 2.6 - 4.87% when compared with the pure.

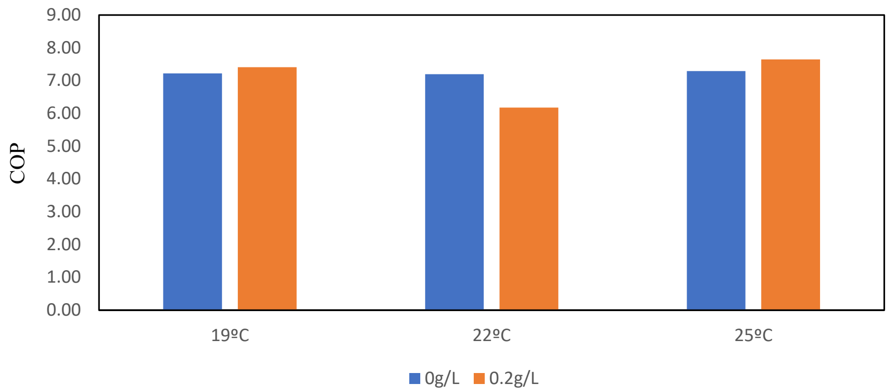

Figure 3: Effect of ambient temperature and nano-concentration on COP of the system at a refrigerant charge of 40g.

3.3 Power Per Tonne of Refrigeration

The effect of varying ambient temperature and TiO_2 nano-lubricant concentration within the 40g charge of R600a refrigerant and the power per tonne of refrigeration of the system is shown in Figure 4. Equation (1) was used to estimate the power per tonne of refrigeration of the system. It was recorded that power per tonne of refrigeration increased and decreased with increasing ambient temperature. It was recorded that the range of PPTR was 0.46kW at 25ºC with 0.2g/L to 0.57kW at 22ºC with 0.2g/L. The use of 0.2 g/L then reduced the power per tonne of refrigeration system by about 2.54 - 4.64% when compared with the pure.

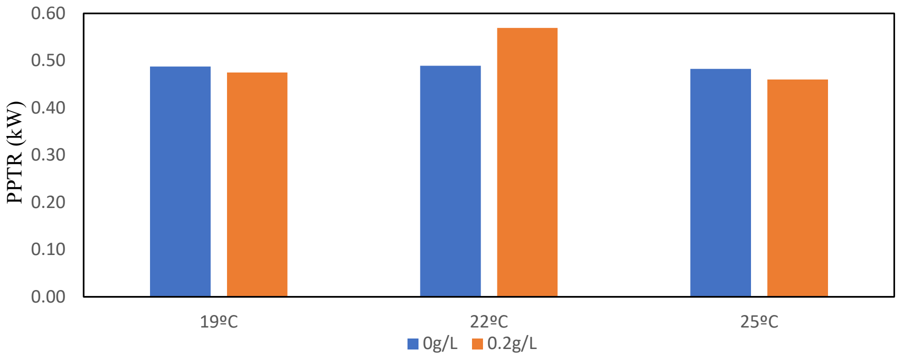

Figure 4: Effect of ambient temperature and nano-concentration on PPTR of the system at a refrigerant charge of 40g

3.4 Discharge Pressure

Figure 5 illustrates the variations in discharge pressure of the system. The application of nano-lubricant was found to reduce the discharge pressure of the test rig. The range of reduction in the discharge pressure of the system was 5.5 – 8.27 % when compared to the baseline. The highest discharge pressure was 1016 kPa at 25ºC with 0g/L concentration, while the infusion of 0.2g/L at 22ºC gave the least discharge pressure value of 928 kPa.

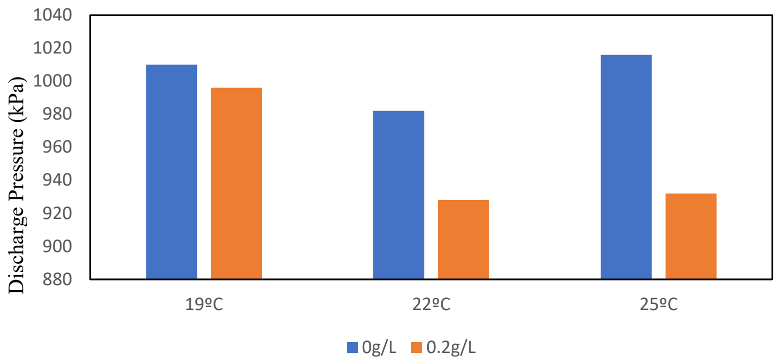

Figure 5: Effect of ambient temperature and nano-concentration on Discharge Pressure of the system at a refrigerant charge of 40g

4. Conclusion

The following deductions were concluded:

- The system worked safely with the infused nanolubricant.
- The least power per tonne of refrigeration observed in the system was 0.45kW with 0.2g/L TiO_2 nanolubricant concentration at 25ºC ambient temperature.
- The best value of coefficient of performance (COP) was obtained at 25ºC with 0.2g/L TiO_2 nanolubricant concentration.
- The least discharge pressure was found with 0.2g/L TiO_2 nano-lubricant concentration at 22ºC.

It can be concluded that infusion of nano-lubricant into the system improved the energetic characteristics of the refrigeration system irrespective of the ambient temperature variation.

Acknowledgements
The authors wish to acknowledge the financial support offered by Covenant University in actualization of this research work for publication.

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