International Journal of Automotive and Mechanical Engineering (IJAME)
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 11, pp. 2243-2252, January-June 2015

DOI: http://dx.doi.org/10.15282/ijame.11.2015.7.0188

# EXPERIMENTAL STUDY OF A DOMESTIC REFRIGERATOR WITH POE-$Al_2O_3$ NANOLUBRICANT

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## ABSTRACT

This paper presents the performance of a minibar domestic refrigerator operating with and without nanoparticles of alumina oxide, $Al_2O_3$. The $Al_2O_3$ nanoparticles were mixed with polyolester (POE) lubricant to form nano-lubricant at 0.2% concentration by volume and were prepared via a two-step method. The nano-lubricant was introduced into the refrigerator at different refrigerant charges ranging from 36 to 44 psi. The evaluation was carried out by determining the general performance in terms of refrigeration capacity ($Q_L$), compressor work, coefficient of performance (COP), and the power and energy consumption of the system working with both lubricants, POE-$Al_2O_3$ and POE. The refrigerator attained its optimum operating level at 42 psi for both. It also worked normally and safely with POE-$Al_2O_3$ lubricant during the experiment. The performance of the refrigerator operating with POE-$Al_2O_3$ was improved compared with the system working with POE in terms of energy consumption and COP. The energy consumption of the refrigeration system with POE-$Al_2O_3$ at optimum refrigerant charge was the minimum and maximum COP of 321 Wh and 2.67. The highest percentage of energy consumption reduction was 2.1% at the optimum refrigerant charge. Thus, the addition of $Al_2O_3$ nanoparticles to the base fluid (POE) gave better performance and reduction of power consumption.

***Keywords*:** Domestic refrigerator; $Al_2O_3$/POE nano-lubricant; energy consumption.

## INTRODUCTION

In Malaysia, refrigerators are reported to have consumed 20 to 23% of electricity in the residential sector annually since 1997, when the number of refrigerators was around 3.4 million units. However, the number has increased from year to year, reaching with 5.6 million in 2005, and it is predicted that the number will reach 9.2 million by 2015 and 11.3 million by 2020 [1, 2]. In line with the increase in the number of refrigerators, the electricity consumption in the residential sector is also estimated to increase by 2015 to about 5254 GWh per year. The Malaysian government has taken the initiative to overcome the high demand for electricity by the residential sector by implementing energy-efficient products including refrigerators [3-5]. Energy consumption by refrigerators can be improved by using nanoparticles, as shown by [6]. The authors introduced suspended metallic nanoparticles in conventional heat transfer fluids (nanofluids) in order to improve the rate of heat transfer. Applications of nanofluid as part of nanotechnology are reported by many researchers and it can equally well be applied in the refrigeration system [7-11]. The latter author also reported that there is no comprehensive literature on the nanoparticles as additives with conventional refrigerants and oils used in the refrigeration system. Previously, [12] conducted experimental work to test the thermal conductivity characteristics of carbon nanotube (CNT) nanorefrigerants and to build a model for predicting their thermal conductivities. R113 was used as the host refrigerant for the experiments. The experimental results showed that the thermal conductivities of CNT nanorefrigerants are much higher than those of CNT–water nanofluids or spherical-nanoparticle-R113 nanorefrigerants. Bi et al. [13] conducted an experiment on mineral oil with $TiO_2$ nanoparticle mixtures as lubricant in a domestic refrigerator. The refrigerant was R134a and the lubricant was POE. The refrigerator's performance with the nanoparticles was investigated using energy consumption test facilities with 26.1% less energy consumption. The same authors examined the performance of a domestic refrigerator using $TiO_2$–R600a nano-refrigerant as working fluid with concentrations of 0.1 g/L and 0.5 g/L. The performance of the refrigerator showed 9.6% less energy use with 0.5 g/L $TiO_2$-R600a nano-refrigerant [14].

Sabareesh [15] conducted investigations on the effect of dispersing a low concentration (0.005 to 0.015 by volume) of $TiO_2$ nanoparticles in mineral oil-based lubricant for a vapor compression refrigeration system. The system used R12 as the refrigerant. An enhancement of the COP was obtained of 1.43 compared with 1.22 without $TiO_2$ nanoparticles. Thermal conductivity and viscosity of $Al_2O_3$/R141b nanorefrigerant for 0.5 to 2 vol.% concentrations at temperatures of 5 to 20 °C were investigated by [16]. The average diameter sizes of nanoparticles of 13nm were used in the experiment. The experimental results showed that thermal conductivity of the $Al_2O_3$/R141b nanorefrigerant increased with the increase of particle concentrations and temperatures. The highest thermal conductivity and viscosity were observed to be 1.626 and 179 times greater than those of the base fluid for two volume concentrations (%) of particles, respectively. The rheological properties of $Al_2O_3$/R141b in the refrigeration system were also analyzed. Concentrations of 0.05 to 0.15% by volume with temperatures ranging from 4 to 16ºC were applied in a further study [17]. Thermophysical properties, pressure drop and heat transfer performance of nanorefrigerant $Al_2O_3$/R134a were investigated by [18]. The authors used concentrations of 1 to 5% by volume and average diameter size of 30 nm. The thermal conductivity of $Al_2O_3$/R134a nanorefrigerant increased with increasing particle concentration but temperature, however, decreased with particle size intensification. Much research remains to be done on implementing nanoparticles in refrigeration systems, especially for energy reduction. Therefore, this study was designed to investigate the effect of nanoparticles on the performance of domestic refrigerators with an experimental method. Two main parameters were investigated: the power of the refrigerator and energy consumption. Compressor work, refrigeration effect and COP were also analyzed in general.

## METHODS AND MATERIALS

### Experimental Setup

The refrigeration system used in the present study was an UPSON minibar refrigerator. It had a 47-liter capacity and used R134a as refrigerant. Table 1 provides the technical specification of the refrigerator test rig. Figure 1 shows the minibar refrigerator which was used as the test rig complete with thermocouple, two pressure gauges, thermocouple recorder and power analyzer. The experimental rig development is described in [19]. The authors discussed location of measurement points (pressure, temperature and flowrate) for domestic refrigerators. The calibration method was applied by the authors and the measurement devices were able to work perfectly. Development of an experimental rig for domestic refrigerators, especially a method to measure pressure and temperature, was discussed by [20]. Locations of measurement were also discussed. In [21] development of a refrigerator test rig is considered for the purpose of performance testing with different charging quantities. Two pressure gauges for suction and discharge respectively were applied, together with four temperature measurement points.

Table 1. Technical specification of the minibar refrigerator.

| Properties | Specifications |
|---|---|
| Model | UPSON |
| Model number | URF-M5 |
| Rated voltage | 240V |
| Electricity consumption | 0.5kWh/24h |
| Power | 90W |
| Weight | 19kg |
| Volume | 47L |
| Refrigerant | R-134a |

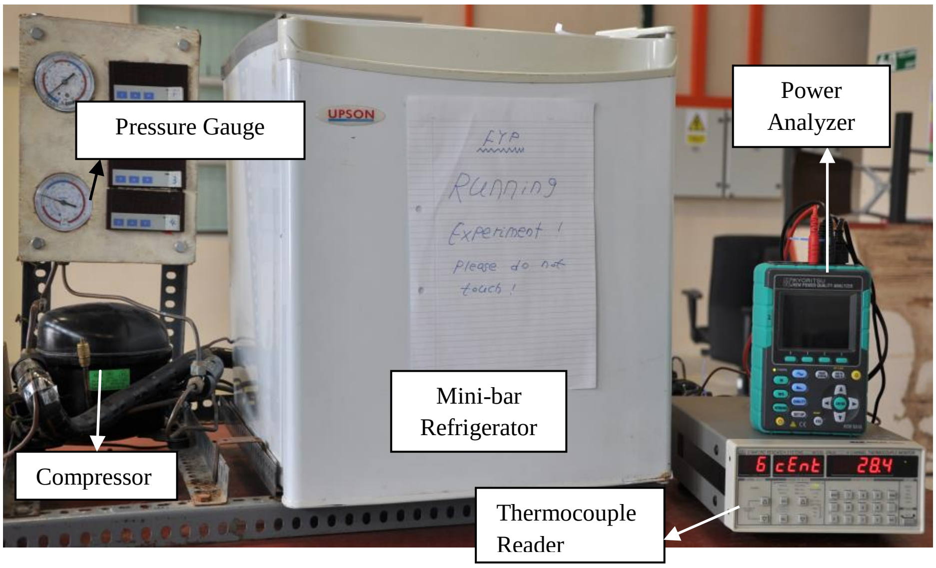


Figure 1. Setup of experimental test rig.

Therefore, in the experimental rig of the present work, the authors decided to assemble a two-unit pressure gauge for suction and discharge pressure respectively ($p_s$ and $p_d$). The thermocouple was installed at three different locations of the refrigerator pipeline for temperature measurement, as shown in Figure 2. The thermocouples were connected to a thermocouple reader from Stanford Research. The technical specification of the thermocouple reader is shown in Table 2. All temperature and pressure data were recorded manually in steady-state operation. The voltage (V), watt (W) and watt hour (Wh) data were recorded automatically with a power analyzer. A KEW 6310 power analyzer was used in this experiment to measure power consumption. The experiment was conducted for 10 hours, from 08:00 to 18:00. A schematic diagram of the experimental rig is provided in Figure 2.

Table 2. Technical specification of the thermocouple.

| Properties | Specifications |
|---|---|
| Model | Standard Research System |
| Model number | SR 630 |
| Channels | 16 |
| Thermocouple Types | B, E, J, K, R, S,T |
| Display Units | Degree C |

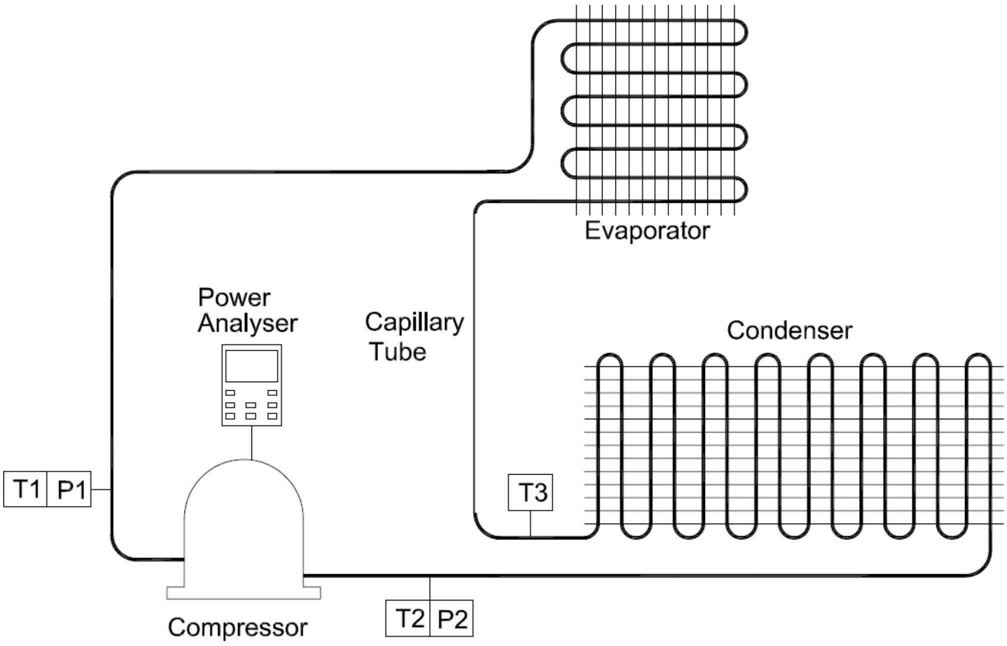


Figure 2. Schematic diagram of the refrigerator test rig.

**POE-$Al_2O_3$ Nano-Lubricant Preparation**

A two-step method of nanoparticle preparation was used in this study. Alumina $Al_2O_3$ with an average diameter size of 13nm and 0.02% concentration by volume was used. The nanoparticles were directly mixed in the base fluid POE and thoroughly stirred with a hot plate stirrer to become POE-$Al_2O_3$ nano-lubricant,followed by ultrasonic homogenization for about two hours. Sedimentation was conducted after the homogenization process in order to check the stability of the POE-$Al_2O_3$ nano-lubricant. Figure 3 shows the sequence of the sedimentation observation of the POE-$Al_2O_3$ nano-lubricant within 24 hours after the preparation.

0 hour 4 hours 10 hours 24 hours

Figure 3. Sedimentation observation within 24 hours.

## RESULTS AND DISCUSSION

Two important parameters are discussed in this section: 1) power, and 2) energy consumption. Other general parameters which indicate the performance of the refrigeration system such as compressor work, refrigeration effect and COP are addressed with reference to [21]. Temperatures and pressures recorded at the particular locations (as shown in Figure 2) are very significant with regard to compressor work, refrigeration effect and COP. The combination of temperature and pressure has been used to determine enthalpy value with NIST REFPROP software. The following parameters were identified. In this experiment, five sets of data temperatures and pressures were collected for five different refrigerant initial charges. Each set of data was repeated 20 times on different days to ensure its reliability. The temperature and pressure were taken in steady-state condition during the experiment. Combinations of temperature and pressure were used to determine enthalpy at each point of interest by using NIST REFPROP software from ASHRAE. Then the final average enthalpy value was obtained from the 20 repeated experiments. Table 3 shows enthalpy values and experimental errors at the four different points of interest with different refrigerant charges. Enthalpy values at points 3 and 4 are the same because of through metering device process. Table 4 shows the main parameters in the analysis and that they showed little improvement in terms of compressor work, refrigeration effect ($Q_L$), *COP* and energy consumption. Compressor work with POE-$Al_2O_3$ was slightly lower than that of a refrigerator with POE. This is a positive result because less compressor work leads to low energy consumption. The refrigeration effect ($Q_L$) of a system working with POE-$Al_2O_3$ is better than one with POE. High QL means good absorption of heat in the refrigerator compartment by the evaporator so the system is able to achieve the desired temperature in a short running period.

### Power

Figure 4 to Figure 8 show patterns of power of the refrigeration system working with POE-$Al_2O_3$ nano-lubricant. High pitch represents power consumed by the refrigerator during running mode, and low pitch representing the OFF mode of the compressor.

Frequencies of the power cycle for refrigerant charges of 36 to 40 psi are quite close. This means that the system was in very short time of running period either in ON or OFF mode. Fewer cycles of operation within 10 hours as shown by Figure 7 are better because they use less energy. In addition, the duration of OFF mode in Figure 7 was average for a long period compared with the other power–time graphs. A long time in the OFF mode led to less energy consumption.

Table 3. Enthalpy values.

| Charging Pressure (psi) | Point 1 | | | Point 2 | | | Point 3 & 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $h_1$ (kJ/kg) | | Error (%) | $h_2$ (kJ/kg) | | Error (%) | $h_3$=$h_4$ (kJ/kg) | | Error (%) |
| | POE$^+$ | POE | | POE$^+$ | POE | | POE$^+$ | POE | |
| 36 | 277 | 277 | 4.1 | 335 | 336 | 4.3 | 152.5 | 157.5 | 4.2 |
| 38 | 279 | 276.5 | 3.8 | 333 | 332 | 3.9 | 154 | 152.5 | 3.8 |
| 40 | 282 | 276 | 3.9 | 333 | 328 | 3.9 | 153 | 150 | 3.8 |
| 42 | 284 | 283 | 4.4 | 333 | 332 | 4.5 | 153 | 156 | 4.3 |
| 44 | 281 | 277 | 3.2 | 331 | 328 | 3.2 | 153 | 150 | 3.2 |

Table 4. Main parameters of analysis.

| Charging Pressure (psi) | $W_c$ (kJ/kg) = $h_2$-$h_1$ | | $Q_L$(kJ/kg) = $h_2$-$h_3$ | | COP= $Q_L/W_c$ | | Energy Consumption (Wh) | |
|---|---|---|---|---|---|---|---|---|
| | POE$^+$ | POE | POE$^+$ | POE | POE$^+$ | POE | POE$^+$ | POE |
| 36 | 58 | 59 | 124.5 | 119.5 | 2.15 | 2.03 | 388.2 | 394 |
| 38 | 54 | 55.5 | 125 | 124 | 2.31 | 2.23 | 378.9 | 385.1 |
| 40 | 51 | 52 | 129 | 126 | 2.53 | 2.42 | 356.6 | 363.1 |
| 42 | 49 | 49.5 | 131 | 127 | 2.67 | 2.57 | 321 | 327.8 |
| 44 | 50 | 51 | 128 | 127 | 2.56 | 2.49 | 339 | 345.1 |

POE$^+$ = Polyethylene-$Al_2O_3$ mixture
POE = Polyethylene

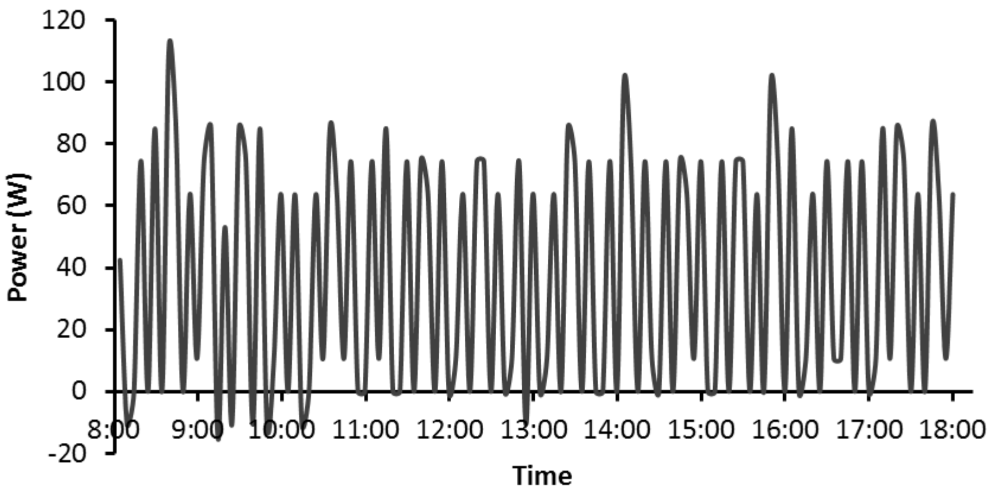


Figure 4. Power of 36 psi charge.

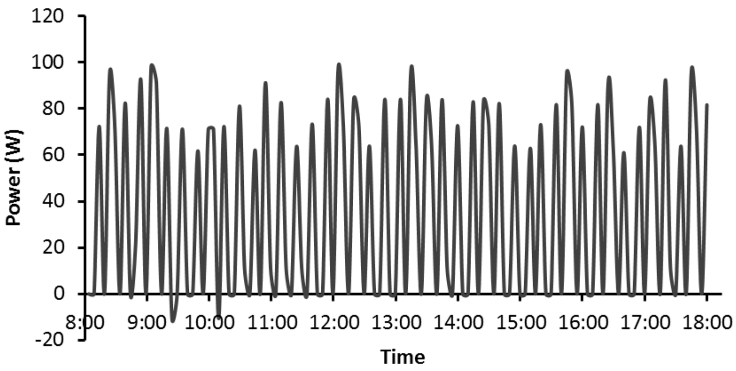


Figure 5. Power of 38 psi charge.

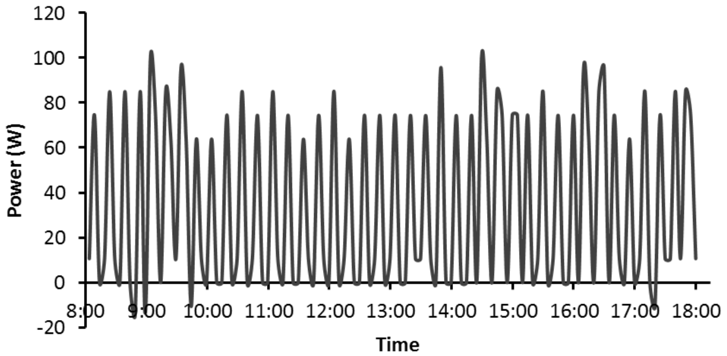


Figure 6. Power of 40 psi charge.

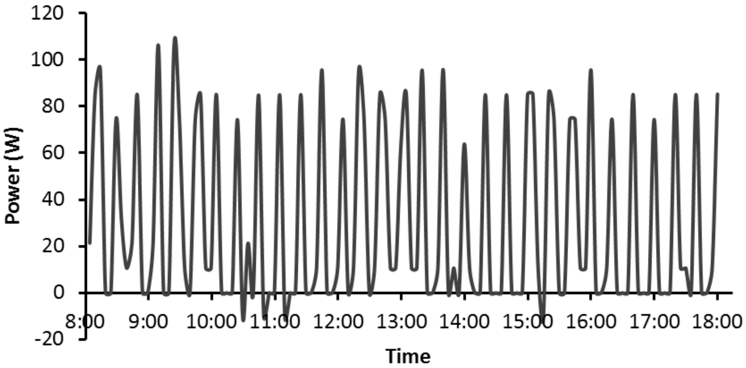


Figure 7. Power of 42 psi charge.

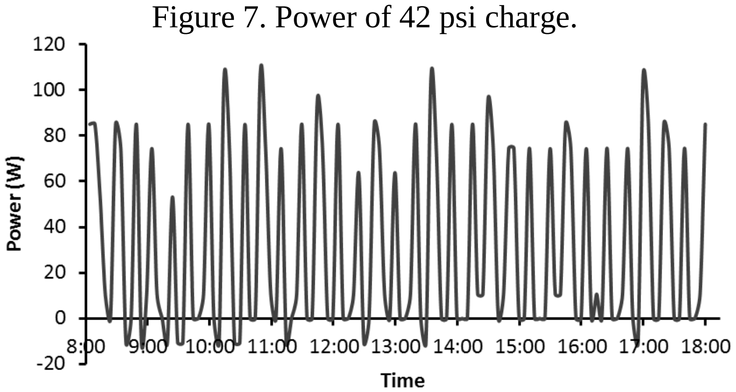


Figure 8. Power of 44 psi charge.

## Energy Consumption

Figure 9 shows pattern of energy consumption by refrigeration systems working with different charge pressure. The system with 42 psi charge pressure shows the lowest energy consumption. The system consumed about 321 Wh for 10 hours of operation. The system with 36 psi charge pressure consumed more power compared with the system working with other charge pressures. In these patterns of energy consumption, the optimum charging condition for the system occurred at 42 psi. The optimum refrigerant charge consumes less energy, as reported by [21]. Figure 10 shows a comparison of energy consumption of the refrigeration system working with POE-$Al_2O_3$ and POE for different charge pressure. The energy consumption reduced as the refrigerant charge increased from 36 psi to 42 psi. However, a charge at 44 psi shows little increase in energy consumption.

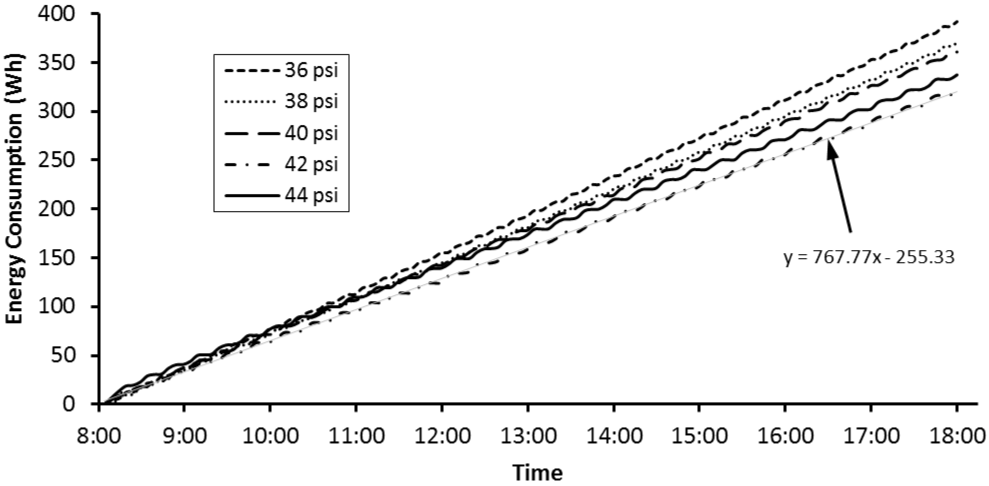


Figure 9. Energy consumption for 10 hours.

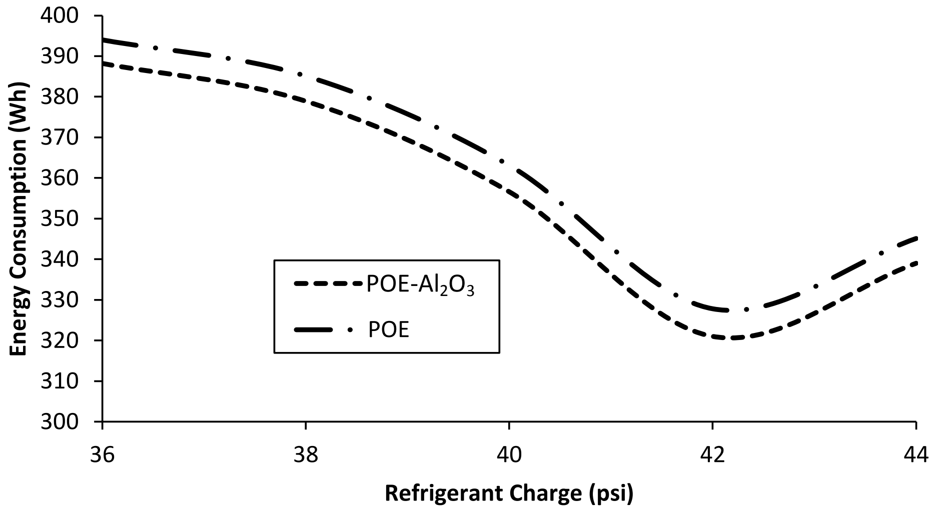


Figure 10. Comparison of energy consumption.

The same pattern of energy consumption was demonstrated by the refrigeration system working with POE-$Al_2O_3$ and POE. However, the POE-$Al_2O_3$ line is lower than the POE line which means less energy consumption. A reduction in energy of 2.1% was obtained at charging pressure of 42 psi. However, [14] found that 9.6% of energy has been reduced for concentration 0.5g/L TiO2-R600a nano-refrigerant. In [13] has reduce 26.1% of energy for refrigerator working with TiO2 and POE oil. The concentration was 0.1% by weight. The authors also conducted a test of the system working with mineral oil-$Al_2O_3$. Energy saving of up to 23.24% was recorded for 0.06% fraction by weight. A different approach has been used in the present study from that in [9,10]. The present study used POE- $Al_2O_3$ and [9,10] used refrigerant nanoparticles. These two approaches yield different results.

## CONCLUSIONS

The performance of a domestic refrigerator working with POE-$Al_2O_3$ was investigated experimentally. The working fluid, refrigerant R134a, was compatible with POE-$Al_2O_3$. POE-$Al_2O_3$ with 0.2% concentration by volume is very stable according to the sedimentation study and it is able to reduce the energy consumption of the domestic minibar refrigerator. The highest reduction in energy consumption obtained was 2.1% at charging pressure of 42 psi. At this level, the energy consumption was at the minimum level, which is 321 Wh. COP of 2.67 and refrigerating effect of 131 kJ/kg were obtained. Wide-ranging concentrations of POE-$Al_2O_3$ can be implemented in future work in order to obtain a good combination of POE-$Al_2O_3$ concentration and amount of refrigerant charge.

## ACKNOWLEDGEMENTS

The authors would like to thank the Faculty of Mechanical Engineering in Universiti Malaysia Pahang (UMP) and Universiti Malaysia Pahang for financial support under RDU121408.

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