

Thermal Performance and Energy Consumption Analyses of R290 and R22 Refrigerants in Air-conditioning System

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Abstract. The study investigated the comparative performance of R290 and R22 refrigerants in a domestic air-conditioning system. It used a 2 hp window split air-conditioning system with Capella D oil as lubricant. Performance analysis which include coefficient of performance, cooling capacity, energy consumption and thermal conductivity and viscosity at vapour and liquid phases were determined. The results were employed to carry out the comparative analyses of the efficiency of R290 as a replacement alternative to R22 refrigerant in a domestic air-conditioning unit. The findings show that although R22 performed better in terms of its coefficient of performance and cooling capacity, R290 however showed better results in terms of its energy consumption, thermal conductivity and viscosity at the liquid and vapour phases. Further to this, there is no marked difference in the pull-down time results. The consequence of the results is that R290 can be a suitable alternative air-conditioning refrigerant to R22, the performance notwithstanding. However, the performance can be further improved with a reconfiguration of the thermo-physical properties of the thermodynamic system such as the lubricant. This can be achieved by taking advantage of the ability of metallic and non-metallic nanoparticles to improve the thermal and physical properties of the lubricant and by extension the thermodynamic system. Thus, with improvement in the thermal conductivity and viscosity of the lubricant, there can be further improvement in the performance of R290 as air-conditioning refrigerant. Going by the findings and coupled with the fact that R22 is environmentally malignant, R290 can become a suitable alternative in the long run.

Key words: Energy system, Nano-refrigerant, Nano-lubricants, Power consumption, Heat transfer, Nano-technology, Thermal system

1. Introduction

Globally, the issues of sustainable development and environmental protection have brought about the need to rethink and redesign many of the engineering systems that have shaped the world over. This is done in a bid to reduce energy consumption, thereby encouraging the use of more energy efficient appliances and also reduce the incidents of reliance on fossil fuels for power generation. Based on this, several debates and United Nations Conventions have favoured the adoption of renewable energy and environment friendly sources for power generation (Ajayi *et al.*, 2014; Fagbenle *et al.*, 2011; Ohijeagbon & Ajayi, 2014; 2015). They have also favoured the use of energy efficient appliances, redesign of high energy consumption appliances to make them more energy efficient and the creation of opportunity to promote access to modern energy. These suggestions have placed major focus on energy systems and thermal appliances. Thus, while efforts are geared towards redirecting the resources for power generation to embrace renewable resources, those of thermal appliances/systems have been faced with the need to redesign the systems' energy use pattern and also ensure they operate with environment friendly thermodynamic systems. For instance, refrigeration and air-conditioning systems are two thermal systems that place a very high demand on power. It is reported that air-conditioning and refrigeration appliances consumed the largest amount of electricity domestically (Kubota *et al.*, 2011). Also, in major office spaces, the combined wattage demand of air-



conditioners and refrigerators exceed those of other appliances. Moreover, cooling systems are a necessity, most especially in tropical climatic countries, and during summer periods. Hence, systems design that favours energy efficiency and employs environmentally benign thermodynamic systems will be a welcome improvement. Consequently, some researches have been undertaken to improve the systems' efficiency and also to reconfigure the thermodynamic system for reduced power consumption. Some of such include the improvement in the efficiency of air-conditioners and heat pumps to above 50%. However, other research results were drawn to focus on the outcome of the Kyoto Protocol where refrigerants that have global warming consequences were targeted to be phased out. Such refrigerants include those of hydrofluorocarbons (HFCs). It is reported that HFCs emissions are increasing by 7% per annum and could reach 8.8 gigatons of CO₂ by the year 2050 if it is not controlled (News, 2018). Similar to the HFCs are the hydrochlorofluorocarbons (HCFCs). For instance, the United States of America has set targets for partial to complete phase out of refrigerants with configurations of HFCs and HCFCs between the years 2020 and 2030. Also, the European Union has since ban the use of R134a (fluoromethane), a refrigerant mostly used in mobile air-conditioners (Bhatkar *et al.*, 2013).

Going by the aforementioned, some research efforts geared towards seeking alternatives to HFCs and HCFCs are ongoing. Based on this, various alternative refrigerants such as hydrocarbons, carbon dioxide, ammonia, artificially created refrigerants and refrigerant mixtures have been proposed (Bhatkar *et al.*, 2013; Choudhury *et al.*, 2013; Pearson, 2005). The drawbacks of some of these refrigerants are their safety issues and potential flammability. The proponent of hydrocarbons more so, have brought about the suggestions that hydrocarbon refrigerants can be used as alternatives to the environment malignant refrigerants. This is because hydrocarbons are majorly environment friendly substances. However, the shortcomings of employing this class of refrigerants have always been due to their low thermodynamic characteristics and sometimes their flammability when compared to the HCFC and HFC counterpart. Moreover, in selecting alternative refrigerants for a system, there is no general rule of thumb. This is due to the fact that, refrigerants have different thermo-physical properties and therefore exhibits different thermal responses or performance characteristics. One basic and accepted method of alternative refrigerant selection is through comparison, to observe and measure the relative performance of the refrigerants.

This study is focused on this. It aimed at comparing the thermodynamic performance of R290 (propane) as an alternative air-conditioning refrigerant to R22 (dichlorodifluoromethane). R22 is an HCFC compound with ozone layer depletion and minimal global warming potentials. Its ozone depletion and global warming potentials are 0.55 and 1700 respectively, and it is non-flammable. Presently, it is being phased out and new compound cannot be produced, especially in the European Union countries. R290 on the other hand, is purely hydrocarbon, it is natural, has zero ozone depletion and negligible global warming potentials, bearable toxicity but flammable with ignition limits between 1.7 and 10.9% vol. in air. A similar research to this study has been carried out by Choudhari and Sapali (2017). The study however considered employing R290 for refrigeration systems and focused majorly on using already developed models and simulation procedures as basis for comparisons. This study moreover pushes this further by experimentally investigating the thermodynamic performance of R290 as compared to R22 in air-conditioning system.

2. Materials and Method

A domestic split air-conditioning unit was used as the test rig. The compressor suction and discharge pressures were evaluated by means of pressure gauges. The refrigerant temperatures were measured by means of thermocouples fixed at the inlet and outlet of the major components of the air-conditioner. Service ports were used at the inlet of the compressor for charging and recovering the refrigerant. The experiment

was repeated three different times and the average employed as the expected value of results. The base oil employed was Capella D, while the refrigerants were R22 and R290 respectively. Fig. 1 shows the experimental setup while Table 1 displays the split air-conditioning unit specifications and the material component of the working fluids incorporated. Table 2 displays the properties of the lubricant oil (i.e. Capella D).



Figure 1: Experimental setup (Test-rig)

Table 1: Component specification of the refrigerator system and the working fluids

Material	Specification
Unit	2hp Panasonic Air conditioning unit
Conventional Refrigerant/Lubricant	R22 & R290/Capella D
Compressor	Rotary compressor
Evaporator	Finned heat exchanger
Expansion valve	Capillary tube
Charged mass	300 g

Table 2: Physical properties of the Capella D oil

Property	Value
ISO Viscosity Grade	46
Density at 15°C, kg/L	0.9
Flash Point, COC, °C	238
Freon Floc Point, °C	-50
Freon Haze Point, °C	-43
Pour Point, °C	-45
Total Acid Number	0.02
Viscosity at 40°C	42.54
Viscosity at 100°C	6.45
Viscosity Index	100
Breakdown Voltage, kV min	40

Determination of the Coefficient of Performance (COP)

This is a measure of performance of the system. It is the ratio of the heat absorbed from the refrigerated space.

$$COP = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{net.in}}$$

It can also be represented as:

$$COP = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} = \frac{(h_1 - h_4)}{(h_2 - h_1)}$$

where: h_1 and h_2 are enthalpies of compressor inlet and outlet, h_4 = enthalpy of evaporator inlet

Determination of the Refrigeration Effect (RE) or Cooling Capacity

Refrigerating effect is the rate of heat removal from the refrigerated space (space to be cooled). In the case of air conditioners, this may be an entire room, office or auditorium. Mathematically, it is the product of the coefficient of performance and compressor work.

$$RE = COP \times W_c$$

where: W_c = compressor work given by the product of mass flow rate and change in the inlet and outlet enthalpies of compressor ($\dot{m}(h_2 - h_1)$).

Determination of the Thermal Conductivity and Viscosity at the Vapour and Liquid Phases

These were evaluated from the combination of experimental values of temperature of refrigerated space, suction and discharge pressures with REFPROP and Genetron Refrigerants Modelling Software

3. Results and Discussion

Fig. 2 displays the comparative variation of the values of the coefficient of performance between R22 and R290 refrigerants in the air-conditioning system. It shows that the system with R22 consistently performed better than that with R290. The degree of performance improvement of R22 over R290 was estimated to be about 44.5%. Further to this, the Figure shows that while the thermal performance of R290 refrigerant was fairly uniform over the period of experiment, that of R22 consistently increased across the period. This invariably suggest that R22 is a better air-conditioning refrigerant than R290.

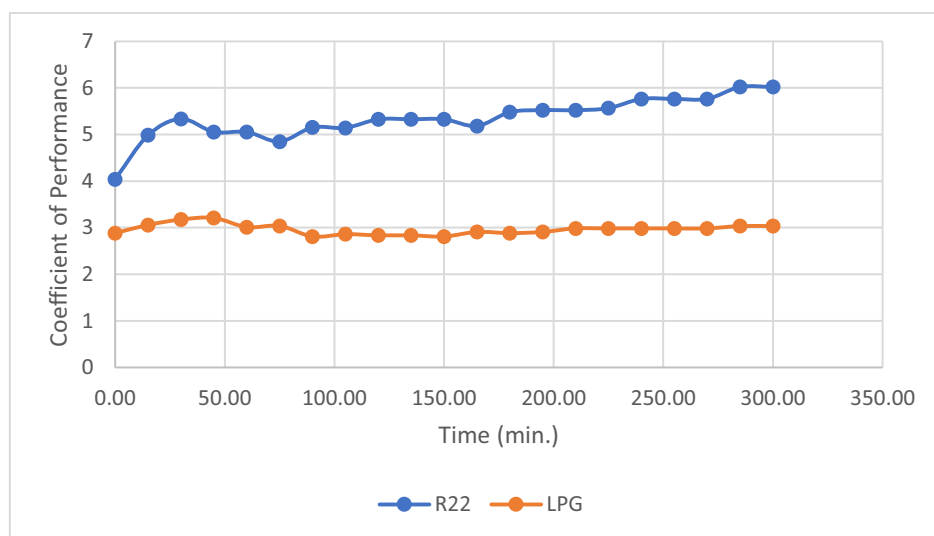


Fig. 2: Variation of the coefficient of performance of the refrigerant variants with time

Similarly, the cooling capacity which depicts the refrigeration effect of the refrigerant on the refrigerated space is displayed in Fig. 3. The result corresponds to the measure of the system's ability to remove heat. It shows that R22 has a higher heat removal capacity than R290. Hence, Fig. 3 reveal that, like the results of COP, R22 demonstrates a better refrigeration effect than R290 across the entire period of experiment. The cooling capacity increased periodically for R22 while it was fairly uniform for R290. The difference in their cooling capacities demonstrates that R290 was 48% lower than R22.

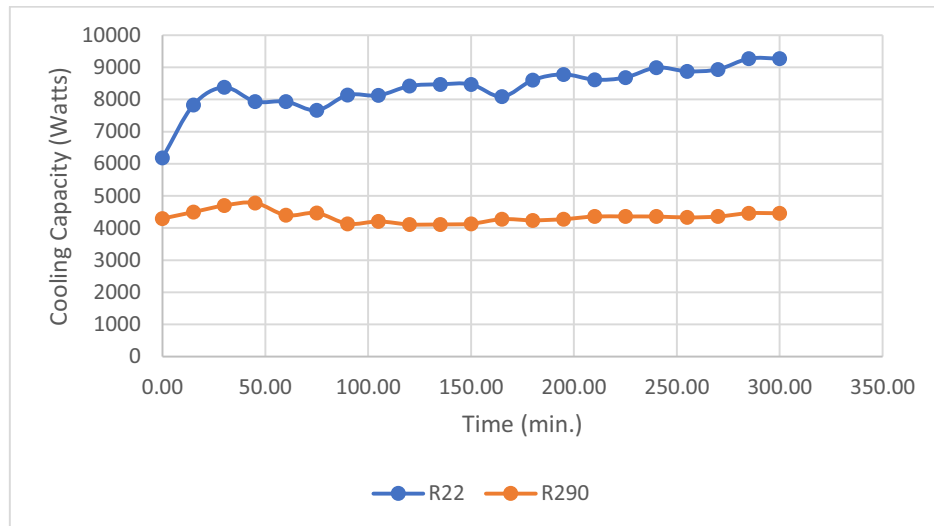


Fig. 3: Variation in the cooling capacities of the refrigerants

Moreover, analysis of the power consumption shows that, despite the performance of R22, it consumed higher amount of energy for every unit drop in the temperature of the refrigerated space. Fig. 4 displays the comparative analysis of the energy consumption of the refrigerants. It reveals that R22 consumed between 1.53 and 1.59 kW power throughout the period compared to that of R290 which was found to lie between 1.45 and 1.49 kW. The energy saving capacity of R290 is about 6.3% better.

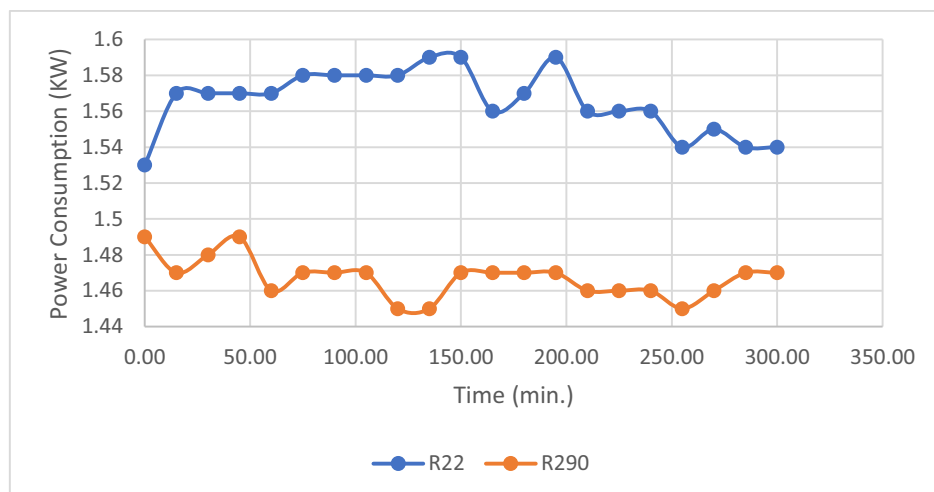


Fig. 4: Comparison of energy consumption between the refrigerants

The implication of the results of energy consumption is indicative of the fact that if there is a means of improving the thermal performance of R290, such that its refrigerating efficiency is enhanced, the

refrigerant may be a better option on the long run. Such enhancement may be achieved with the use of metallic/non-metallic nanoparticles (Ajayi *et al.*, 2017) in a way that reconfigures the working fluid and makes it thermally more efficient with higher coefficient of performance. If this can be achieved, it may bring about a further reduction in the value of energy requirement per degree change in temperature of the system. Furthermore, the time required to achieve the temperature of the refrigerated space for a given period is referred to as the pull-down time. Fig. 5 display the results and show that there is no marked difference in the pull-down time of the two refrigerants. The difference in the temperature of the refrigerated space is not more than 2°C per period of the experiment. Hence, suggesting that, although R22 is thermally more efficient than R290, it however consumes more energy and produces minimal effect of not lower than 2°C per period.

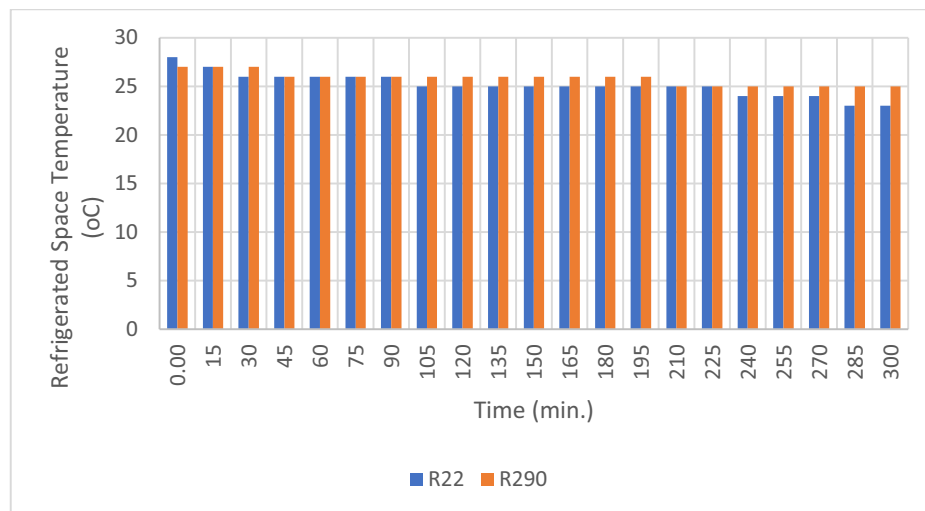


Fig. 5: Variation of pull-down time across the period of experiment

Considering the aforementioned, in order to ascertain the reason behind the difference in performance of the refrigerants, it was worthwhile to determine the variation in the thermal conductivities and viscosities of the refrigerants at the vapour and liquid phases. Figs. 6 and 7 display the results of thermal conductivity analyses for both refrigerants at the liquid and vapour phases.

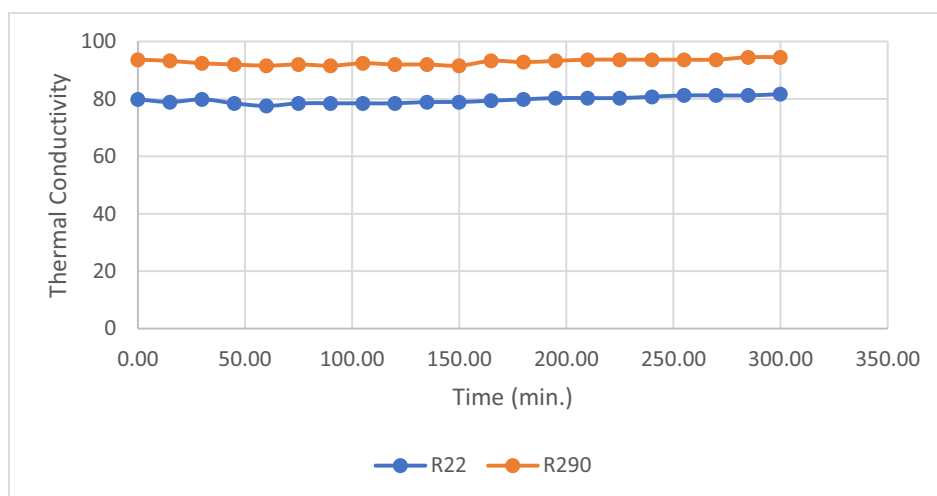


Fig. 6: Variation of the thermal conductivities of the refrigerant at the liquid phase

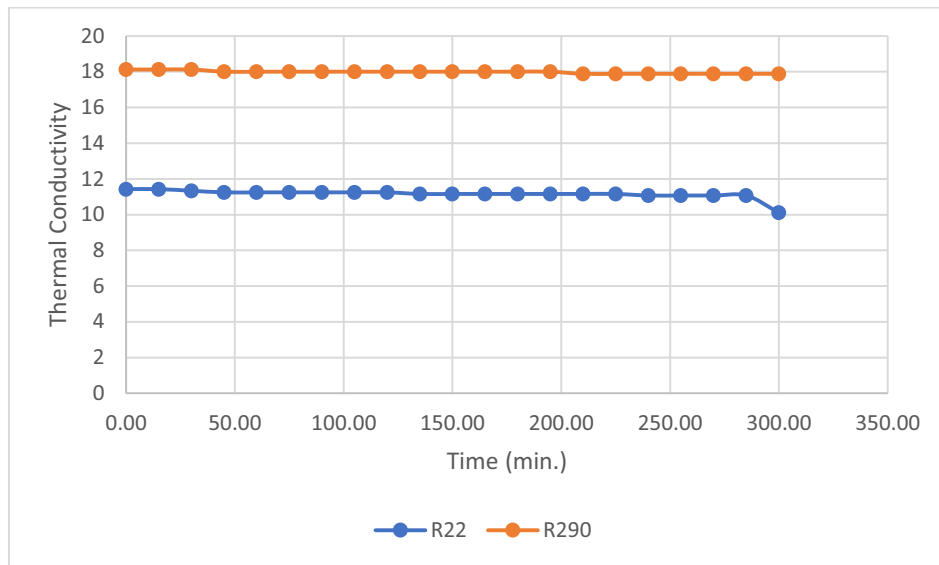


Fig. 7: Variation of the thermal conductivities of the refrigerant at the vapour phase

The Figures demonstrate that the thermal conductivity of R290 at both liquid and vapour phases is higher than that of R22. The results depict that, despite the thermal performance of R22, R290 has a better capacity to convey a higher magnitude of heat per unit time. Hence, with little improvement in the thermal efficiency of R290, its coefficient of performance may exceed that of R22. This improvement as suggested earlier, may be achieved by reconfiguring the thermodynamic system. In addition to this, the values of viscosity analyses (Figs. 8 and 9) for both refrigerants at the liquid and vapour phases depicts that R290 has a better visco-energetic performance than R22.

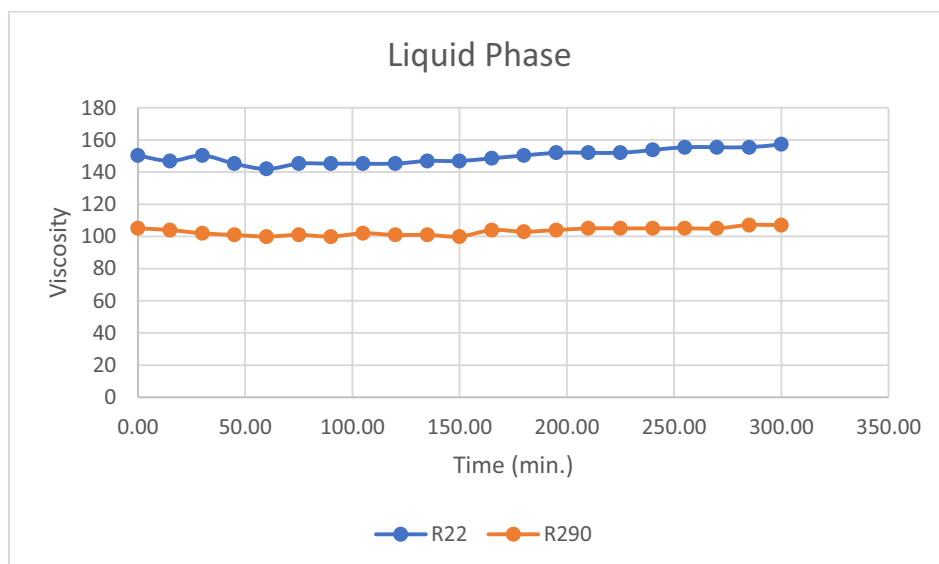


Fig. 8: Variation of the viscosity index of the refrigerant at the liquid phase

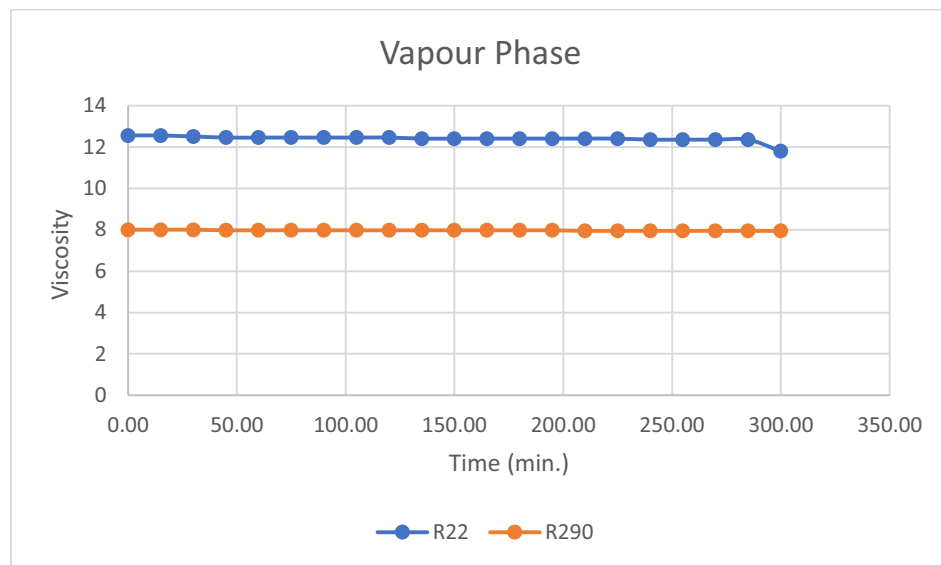


Fig. 9: Variation of the viscosity index of the refrigerant at the vapour phase

The results show that the viscosity of R290 at both liquid and vapour phases is lower than that of R22. Worth noting is the fact that, the value of viscosity is proportional to the power requirement of the compressor for fluid transport. Hence, the higher the viscosity, the higher the power required to transport the fluid through the compressor passage. More so, the ease with which the fluid passes through the compressor depicts the ease of heat expulsion from the compressor. Thus, the lower values of the viscosity of R290 at both the liquid and vapour phases show the stronger ability of the refrigerant to expel heat from the system and also reduce the compressor work. The results corroborate those of Fig. 4. However, comparing the results of the Figs. 6 to 9 with those of Figs. 3 to 4 clearly demonstrate that, although R290 has a better thermal conductivity and viscosity than R22, the COP and Cooling Capacity is lower. The reason can be adduced to the effect of the thermodynamic system on the performance of R290. The Capella D lubricant variant of mineral oil may not be very compatible with the R290 as refrigeration fluid system. Hence, an improvement in the thermo-physical properties of the lubricant may enhance the performance of R290.

4. Conclusion

The study investigated the performance of R290 as a replacement alternative to the environment malignant R22 refrigerant. It used a 2 hp window split air-conditioning system with Capella D oil as lubricant. Comparative analyses of the thermodynamic performance of the refrigerants were carried out and the effects of the lubricant on the refrigerant performance was highlighted. The findings show that despite that R22 outperformed R290 in terms of its coefficient of performance and cooling capacity by 44.8% and 48%, R290 showed better results in terms of its energy consumption, thermal conductivity and viscosity at the liquid and vapour phases. Further to this, there is no marked difference in the pull-down time results. Going by the findings, when consideration is given to the fact R22 adds to the burden of the environment and also the fact that the manufacture of new products of it have been banned around the globe, employing R290 with improved lubricant property can be a good decision in the long run.

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