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Performance of A R22 split-air-conditioner when retrofitted with ozone friendly refrigerants (R410A and R417A)

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Abstract
R22 that has been used predominantly in air conditioning and in medium and low-temperature applications contains ozone depleting chlorine atoms and hence will be phased out eventually. This paper presents the experimental performance study of a split-air-conditioner using ozone friendly alternative refrigerants. The existing split-air-conditioner originally designed for R22 as the working fluid was retrofitted with R410A and R417A respectively, and the performance of the system was evaluated and compared with its performance when R22 was used. Experimental results showed that with R417A, the system had 1.9% higher refrigeration capacity and 14.2% lower with R410A when compared to that of R22. The average discharge pressure of the compressor obtained with R417A and R410A were 3.8% lower and 10.3% higher, respectively, than with R22. The lowest compressor power consumption and pressure ratio were obtained with the R417A retrofitted system. The average coefficient of performance (COP) obtained using R417A is 2.9% higher, while that of R410A is 8.4% lower than that of R22. Generally, with R417A the system consistently had the best performance in comparison to both R22 and R410A, indicating that R417A would be a better choice for retrofitting existing split-air-conditioners originally designed to use R22 as working fluid.

Keywords: retrofitting, split-air-conditioners, experimental, performance, R22, R410A, R417A

1. Introduction

The depletion of ozone layer and global warming are still part of the main environment problems that the world is facing today. From the 1930s, chlorofluorocarbon (CFC) substances were widely used as refrigerants, blowing agents, cleaning agents, fire extinguishing agents, spray propellants in refrigeration, air-conditioning, foaming, and the electronics and medicine industries due to their favourable physical and chemical properties. In the 1980s, scientists found that CFC substances not only do great damage to the ozone layer, but also create the greenhouse effect, and badly affect telluric environment and human health (Bolaji, 2005; He *et al.*, 2005).

Hydro-chlorofluorocarbons (HCFCs) cause less harm to the ozone layer. They contain less chlorine atoms in their chemical structure than CFCs. Therefore, they have less ozone depletion potential than CFCs. However, they are considered to be harmful as well. CFCs have been banned in developed countries since 1996, and from January 1st 2010, production and use of CFCs is prohibited completely all over the world. HCFC refrigerants will also be phased out by 2020 and 2030 in developed and developing countries, respectively (Devotta et al., 2005; Bolaji, 2010a; Fatouh et al., 2010).

CFCs and HCFCs are controlled substances by the Montreal Protocol, and greenhouse warming gases are controlled by the Kyoto Protocol. Non-ozone depleting hydrofluorocarbons (HFCs), which have been used as alternative refrigerants for the past two decades, are part of greenhouse warming gases. Consequently, in the long run, refrigerants with low greenhouse warming potential (GWP) and zero ozone depletion potential (ODP) are to be used in refrigeration and air-conditioning applications. At the same time, the performance of refrigeration and air-conditioning equipment has to be improved to reduce the indirect greenhouse warming caused by the use of electricity generated mainly by the combustion of fossil fuels (Bolaji, 2010b; Park and Jung, 2009).

R22 has been used predominantly in residential air-conditioners and heat pumps and has the largest sales volume among all refrigerants. R22, however, is an HCFC containing the ozone depleting chlorine atom and hence has to be phased out eventually. The search for alternatives to R22 is a key issue. Many studies have been reported on alternatives to R22 (Fatouh *et al.,* 2010; Park and Jung, 2009; Jabaraj *et al.,* 2006; Chen, 2008; Park *et al*., 2008). At present, alternative refrigerants available for R22 in residential air conditioners and heat pumps can be categorized into three types. First, hydrofluorocarbons (HFCs) represented by R410A, R407C, R417A and R134a. Second, natural substances represented by CO_2 and R717 (Ammonia). However, when working under a supercritical cycle, CO_2 systems have extremely high working pressure, low operation efficiency, and high manufacturing and operation cost. Third, hydrocarbons (HCs) represented by R290 (Propane) and R600a (Isobutene) are also in the group of natural substances. The hydrocarbon has excellent thermal performance and causes a low greenhouse effect, but its safety performance is unacceptable. It is usually flammable or toxic, which limits its use in residential air conditioners and heat pumps (Nicola *et al*., 2005; Bolaji, 2008; Chen, 2008).

Blends of the HFC refrigerants, in the first category of alternative refrigerants, have been considered as the favourite candidates for R22 alternatives (Bitzer, 2007). In middle 1990s, the application of R407C in residential air conditioners and heat pumps received wide acceptance in the European market. R407C is a ternary mixture refrigerant composed of R32/R125/R134a (23/25/52% in weight). The operation pressure and temperature of R407C are equivalent to those of R22, therefore, just small modifications on existing R22 air-conditioners are needed for changing to R407C.

However, Aprea and Greco (2002) compared the performance between R22 and R407C (azeotropic blend) and suggested that R407C is a promising drop-in substitute for R22. Experimental tests were performed in a vapour compression plant with a reciprocating compressor to evaluate the compressor performance using R407C in comparison to R22. The plant overall exergetic performance was also evaluated and revealed that the performance with R22 is consistently better than that when its candidate substitute (R407C) is used. R407C is a non-azeotropic refrigerant mixture, and its temperature glide can reach 4–6°C. The operation efficiency of a R407C air-conditioner is low and it is difficult to repair and maintain the system for its bigger variation of evaporation temperature when R407C is leaked (Han *et al.,* 2007). Therefore, other refrigerants should be considered and studied as alternatives to R22.

Many refrigerants were assessed through the Alternative Refrigerant Evaluation Program (AREP) as potential replacements for R22. Among the promising alternative refrigerants that emerged were R410A a HFC refrigerant mixture and R32 a HFC refrigerant. R410A is a near azeotropic blend composed of R32/R125 (60/40% in weight). The high heat transfer coefficients in the evaporator and condenser provide potential for increased efficiencies. Because of the negligible temperature glide (<0.2 K), the general usability can be seen similar to a pure refrigerant (Bitzer, 2007).

Among all the R22 alternative refrigerants available in the market, is the R417A, which is the ternary mixture refrigerant, composed of R125/R134a/R600 (46.6/50/3.4% in weight). R417A is the mostly recommended for air conditioning equipment and water chillers (Torrella *et al.,* 2010). This refrigerant adds a small percentage of hydrocarbon in order to ensure the return of the lubricant oil to the compressor and the compatibility with traditional mineral oils or new lubricants such as polyol ester oil.

Window air-conditioners are rapidly being replaced by split type air-conditioners due to the latter better performance and lower noise. This paper reports the performances of R410A and R417A investigated experimentally in a split-air-conditioner originally designed to use R22. The air conditioner was retrofitted with the alternative refrigerants and the performance of the system was evaluated and compared with when R22 was used as the working fluid.

2. Materials and methods

2.1 Experimental setup

The split-air-conditioner is composed of the basic components of a vapour compression refrigeration system: a hermetically sealed compressor, a condenser, a capillary tube and an evaporator, and such attachments as accumulator and fans. The schematic diagram representing the experimental air-conditioner is shown in Figure 1. The unit was retrofitted with R410A and R417A, respectively. An oil level indicator was attached to the compressor to check the oil level periodically. To monitor the mass flow rate of the refrigerant in the system, a mass flow meter with ±0.25% accuracy was installed next to the condenser. In order to have a uniform temperature throughout the room, a ceiling fan of 70 W power installed in the centre of the room was used to circulate the air inside the room. To measure the compressor power, a wattmeter with ±0.5% accuracy was used. Room temperature was measured with help of precision thermometer with an accuracy of ±0.1°C. Refrigerant pressures were measured using precision Bourdon's tube pressure gauges with an accuracy of ±5.0 kPa.

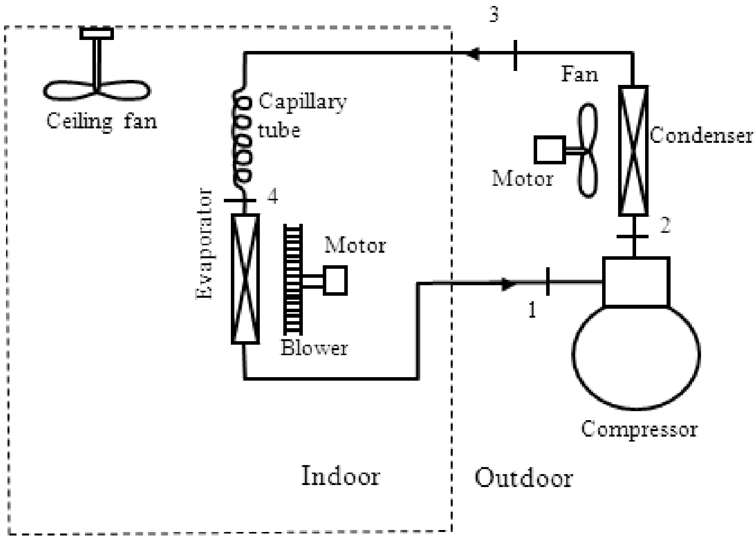

Figure 1: Schematic diagram of the experimental split-air-conditioner

2.2 Retrofitting procedures

The procedure of Devotta *et al.* (2005) was followed. The system was first tested with R22 in order to obtain the baseline data. After the completion of all tests with R22, the air conditioner was retrofitted with R410A and R417A, respectively. Mineral oils and alkyl-benzene lubricants use in R22 systems are immiscible with the alternative refrigerants. R410A and R417A are HFC refrigerants, they have very low solubility and they do not mix well with mineral oil, which could cause poor oil return to the compressor, resulting in possible compressor failure and fouling of expansion device and heat exchanger surfaces, leading to reduced system performance. In order to achieve miscibility of these refrigerants with the lubricant, a polyol ester was used in the retrofitted systems (Bitzer, 2007).

During retrofitting, R22 was first recovered then the compressor was removed from the system and the mineral oil was drained through the suction line of the compressor. The compressor was charged with fresh polyol ester lubricant. The compressor was reinstalled back to the system and the system was recharged with the recovered R22 refrigerant following the standard charging operation. The compressor was operated with the polyol ester lubricant and the R22 refrigerant for 24 hours, after which the polyol ester oil was drained and recharged with fresh polyol ester oil. This was done in order to remove the residual mineral oil from the system. Recharging of the system and running of the compressor were repeated until no significant residual mineral oil was obtained.

R22 was recovered from the system and the capillary tube was replaced with one of greater restriction in order to achieve satisfactory performance. ASHRAE (1998) recommends replacement of the capillary tube with one of the same diameter, but from 70 to 90% longer. Therefore, a 1000 mm long capillary tube used for R22 was changed to 1800 mm long in the retrofitted system. The filter-drier was replaced by a solid core filter-drier compatible with HFC refrigerants. The system was checked for leaks with dry nitrogen. The evacuation of moisture in the system was also carried out through the service ports with the help of a vacuum pump prior to the system being charged with replacement refrigerant. The system was thoroughly checked and commissioned before it was subjected to series of tests at various conditions.

2.3 Performance parameters analysis

The power consumption of the compressor (W_c), the fan in the condensing unit (W_f) and the blower in the evaporating unit (W_b) were measured separately. The total power consumption (W_t) is obtained using Eq. (1):

$$W_t = W_c + W_f + W_b \tag{1}$$

Refrigeration capacity (Q_{evap}) was calculated using the mass flow rate of refrigerant ($\dot{m}$) and enthalpy difference between inlet (h_4) and outlet (h_1) of the evaporator:

$$Q_{evap} = \dot{m}\,(h_1 - h_4) \tag{2}$$

The actual coefficient of performance (COP) for the system is computed at the steady-state when the minimum temperature is achieved in the conditioned room and it is obtained as the ratio between the refrigeration capacity (Q_{evap}) and the total power consumption (W_t). The total power consumption was used in Eq. (3) not just the compressor power in order to obtain the actual overall COP of the system.

$$\text{COP} = \frac{Q_{evap}}{W_t} \quad (3)$$

The compressor pressure ratio is the ratio between the compressor discharge pressure (P_{dis}) and suction pressure (P_{suc}):

$$P_R = \frac{P_{dis}}{P_{suc}} \quad (4)$$

3. Results and discussion

R22 and its retrofit refrigerants (R410A and R417A) were used in the split-air-conditioner and the system's performance was evaluated and compared. The result of the refrigeration capacity obtained at different evaporating temperatures is shown in Figure 2. Evaporating temperature was varied between 2°C to 12°C as a result of the variation of the indoor temperatures from 16°C to 27°C using the system temperature control. It was observed that for all the investigated refrigerants, the refrigeration capacity increased with the increase in evaporating temperature. At the same, evaporating temperature, refrigeration capacity obtained with the R417A system is higher than that from the R22 and R410A systems. Average refrigeration capacity of the system containing R417A is higher by 1.9%, while that with R410A is lower by 14.2% than that with R22.

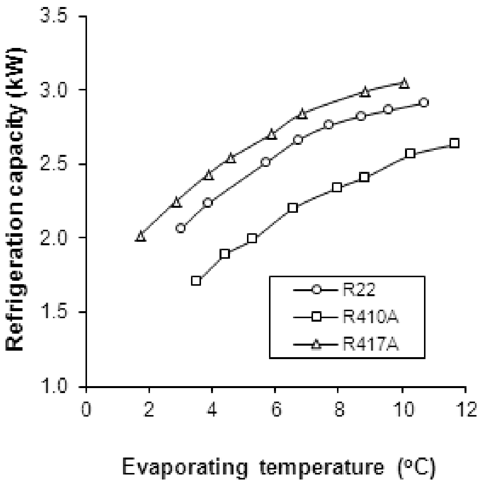

Figure 2: Variation of refrigeration capacity with evaporating temperature

Figure 3 shows the relationship between the compressor power and the evaporating temperature of R22 and the alternative refrigerants. As shown in the figure, the changes of compressor power with evaporating temperature are similar for the three refrigerants; as the evaporating temperature increases, the compressor power also increases. The compressor power with R410A is higher than those with R22 and R417A. Compared with R22, the average compressor power with R410A increased by 11.2%, and that with R417A, reduced by 4.7%.

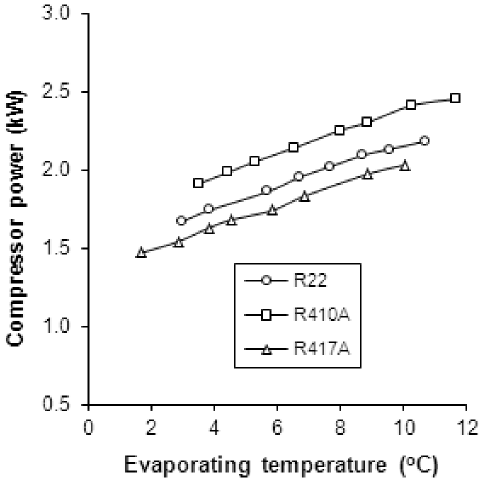

Figure 3: Variation of compressor power capacity with evaporating temperature

The relationship between the coefficient of performance (COP) and evaporating temperature is shown in Figure 4. This figure indicates that when the COP increases the evaporating temperature increases for both R22 and retrofitted refrigerants. The COP with R417A was higher than those with R22 and R410A at all evaporating temperatures. The lowest COP was obtained in the R410A retrofitted system. Compared with R22, the average COP of R417A increased by 2.9%, while that of R410A reduced by 8.4%.

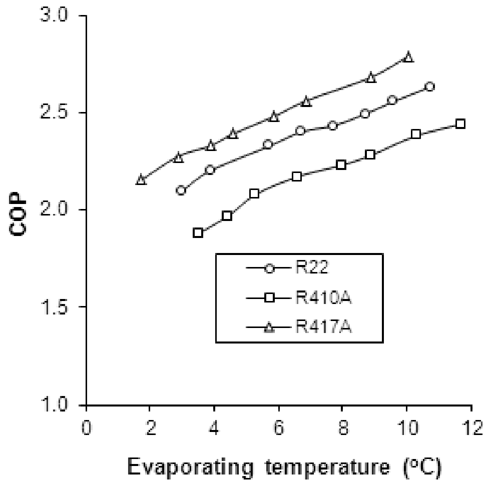

Figure 4: Variation of coefficient of performance with evaporating temperature

The discharge temperature of the compressor is used as a criterion in considering suitability of use. The discharge temperature of the compressor must not be too high since it may impair lubrication and adversely affecting the mechanical parts of the compressor. The relationship between the discharge temperature of the compressor and evaporating temperature for the investigated refrigerants is shown in Figure 5. It was observed in the figure that when the evaporating temperature changes, the discharge temperature remains almost constant with only a very small change. Increase in the evaporating temperature slightly increases the discharge temperature. The system produced a lowest discharge temperature with R417A than with R22 and R410A refrigerants. The average discharge temperatures of the system with R417A and R410A are 3.8% lower and 10.3% higher, respectively, than with R22 system.

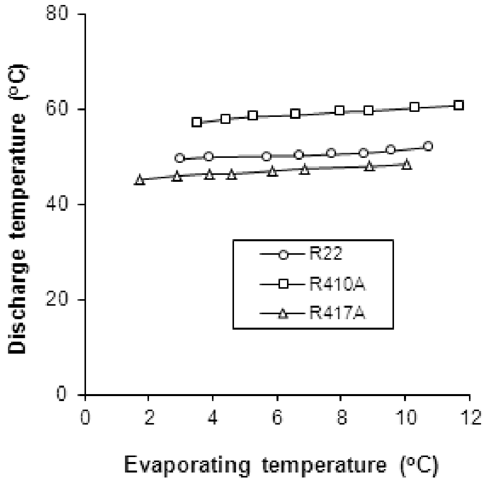

Figure 5: Variation of compressor discharge temperature with evaporating temperature

The performances of investigated refrigerants in the split-air-conditioner were obtained for different ambient air temperatures. The ambient air temperature varied from 26°C in the early hours of the day to 37.5°C in the late afternoon; it increases as the intensity of the solar insolation increases. The refrigeration capacity and COP obtained with R22, R410A and R417A at various ambient temperatures are plotted in Figures 6 and 7, respectively. As shown in these figures, the refrigeration capacity and COP reduce as ambient air temperatures increases. Also, it can be seen from these figures that the performances with R417A system are much better than with R22 and R410A systems.

Figures 8 and 9 compare the variation of compressor power and pressure ratio for the three refrigerants in terms of ambient air temperature. As shown in these figures, compressor power and pressure ratio increase as the ambient temperature increases, but there is considerable difference in the performances with R417A, R22 and R410A. The compressor power and pressure ratio with R410A were found to be the highest among the refrigerants at all ambient air temperatures. Close behaviour was observed when the system was charged with R417A and R22, but with R417A, the system had slightly lower compressor power and pressure ratio, which shows that the split-air-conditioner had better performance with R417A than with R22.

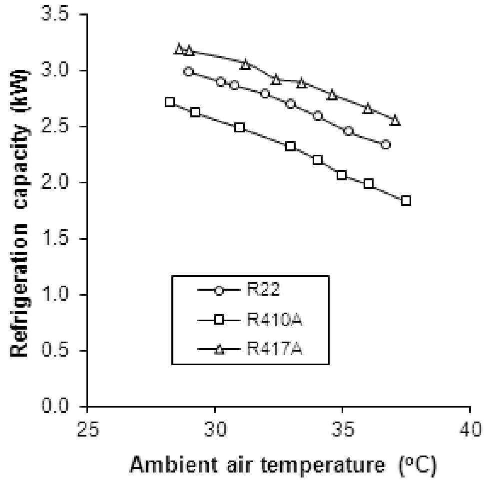

Figure 6: Effect of ambient air temperature on the refrigeration capacity

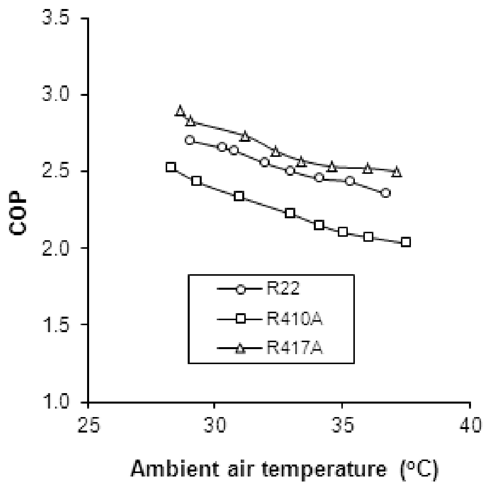

Figure 7: Effect of ambient air temperature on the coefficient of performance (COP)

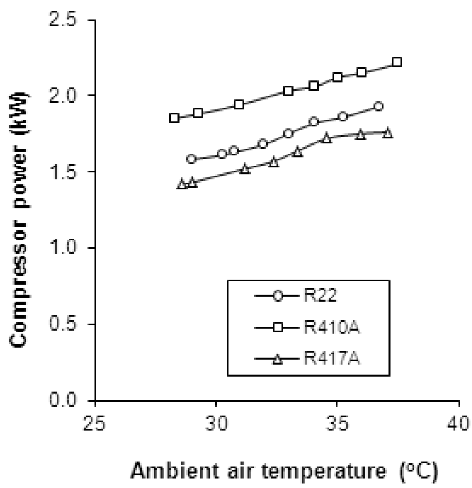

Figure 8: Effect of ambient air temperature on the compressor power

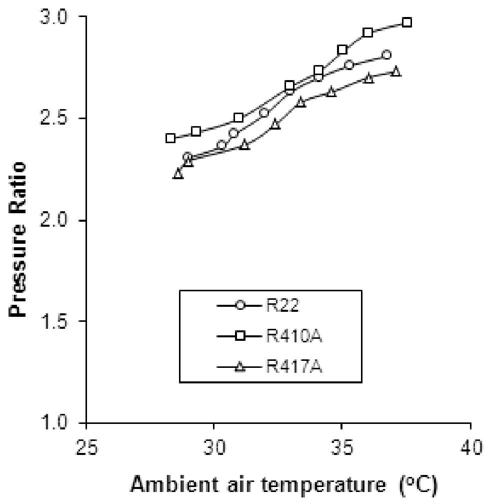

Figure 9: Effect of ambient air temperature on the pressure ratio

4. Conclusion

In this study, experiments were carried out to investigate R22 and its retrofit substitutes (R410A and R417A) in a split-air-conditioner. Based upon the experimental results, the following conclusions were drawn:

(i) For all the investigated refrigerants, the performance parameters increased with the increase in evaporating temperature. Except for compressor discharge, temperature remains almost constant irrespective of evaporating temperature.

(ii) For all the investigated refrigerants, as the ambient air temperature increases, the refrigeration capacity and COP reduce, while the compressor power and pressure ratio increase.

(iii) At the same evaporating temperature, refrigeration capacity obtained with R417A is higher than those obtained with R22 and R410A. The average refrigeration capacity with R417A is higher by 1.9%, while that with R410A is lower by 14.2% than that with R22.

(iv) The lowest power consumption was obtained with R417A retrofitted system. The average compressor power with R417A and R410A was found to be 4.7% lower and 11.2% higher, respectively, than that obtained when using R22.

(v) The average COP with R417A and R410A were found to be 2.9% higher and 8.4% lower, respectively, than that with R22.

(vi) The average discharge pressure of the compressor obtained with R417A and R410A was 3.8% lower and 10.3% higher, respectively, than that with R22.

Finally, the system when charge with R417A consistently had the best performance when compared with when it containing R22 and R410A, therefore, R417A would be a better choice for retrofitting existing split-air-conditioners originally designed to use R22 as the working fluid.

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