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Hydrocarbon as refrigerant for domestic air conditioner: a comparative study between R22 and R290

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ABSTRACT

Performance of a domestic split type air conditioner was evaluated by using two different refrigerants, i.e., R22 and R290. This paper presents the outcomes of this comparative study. The experimental investigation was conducted by using a 1 hp air conditioning unit. Power consumptions by the complete system including the evaporator as well the by the compressor alone were measured by clamp meter. Temperature was also measured at different locations by digital fluke thermometer whereas digital multimeter was used to measure the current supplied to the system. The air conditioner was run for six hours each time by setting three different set point temperatures, i.e., the cold air temperature coming out from the evaporator. From the measured information, coefficient of performance (COP), and energy efficiency ratio (ERR) were calculated for each refrigerant. The results revealed that R290 refrigerant has better COP and EER compared to R22 refrigerant. The usage of R290 refrigerant can reduce energy consumption up to 11 %. In addition to that, at the same air conditioning unit, the amount of R290 refrigerant required is relatively half of that required by R22 refrigerant.

Introduction

Thermal comfort zone is a primary need of human beings to create a better home or working environment. Cooling process afforded by modern air conditioning is realized to be the best way to create a degree of comfort. Many homes or offices and commercial facilities would not be comfortable without control of temperature, humidity, air motion and radiant source interacting with the occupants [1]. Controlling of the comfort parameters has been developed in wide scale of air conditioning design and energy is a fundamental requirement for all these designs. However, in economic sense, energy is not easily obtained and the issue of its allocation may be one of the most important of our time [2]. This great invention of air conditioning lets a confined space to be controlled but at the same time accelerates energy crisis and environmental pollution, which can be said as a heavy universal problems today and have to be solved urgently. The best ways to solve the problems are development of green energy, applications of green materials, and technology of conserving energy [3].

In split type air conditioning devices, most of the energy is consumed to compress the working fluid called refrigerant. The wide application of air-conditioners plays a significant role to destroy the Earth due to overheating and use of environmentally unfriendly refrigerants. The environmental destruction is extremely serious, especially in the tropical and subtropical countries, which have more applications of air conditioning. According to contrary natural principle, an air conditioner creates cold and heat against climate, which consumes extremely large energy by compressor in compression processes. The contrary natural evacuation of heat by air conditioners rises environment temperature and causes weather instability. The atmospheric ozone layer is well known to protect ultraviolet light from space. However, the use of environmentally unfriendly refrigerants in air conditioning brings environmental pollution. Environmentally unfriendly refrigerants contain chlorine constituent, i.e., Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), and Hydrofluorocarbons (HFCs), which react with ozone and destroy atmospheric ozone layer [4]. Therefore, the development of environmentally friendly, i. e., green refrigerant is an urgent and important task in the twentieth century and hydrocarbon is found to be suitable as green refrigerant which are already numerously investigated recently [5-7].

During the last 15 years several hydrocarbons and hydrocarbon blends have been used commercially as refrigerant. The HFC (hydrofluorocarbon) refrigerants with zero ozone depletion potential have been recommended as alternatives [8]. However, these HFC refrigerants have a considerable effect on global warming. Hydrocarbons have earlier been used as refrigerants, and with increasing awareness of environmental impact, their use has been considered again recently. Some European countries use HC (hydrocarbon) refrigerant in small-size refrigerators [9]. Major hydrocarbons under consideration are propane, isobutane, n-butane, perfluorocyclobutane, cyclo-propane, propylene, etc. [10]. Among these refrigerants, R290 is considered as a replacement for R22 [11]. These natural refrigerants are environmentally friendly, non-toxic, chemically stable, compatible with many materials and miscible with mineral oils [12]. Besides this, the zeotropic refrigerant mixtures of hydrocarbon (HC) refrigerants have potentials to enhance the performance and efficiency of a system due to the temperature gliding effect. It is reported that the heat transfer performance for hydrocarbons is higher than those for R22 [7].

Hydrocarbons have extensively been used in the early years of refrigeration but a number of technical and safety issues caused them to be abandoned when CFC refrigerants became available.

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They are compatible with the materials and lubricating oils used in conventional refrigeration systems. Hydrocarbons have excellent properties as refrigerant and naturally exist in the atmosphere. R290 is the industrial designation for propane as a refrigerant which has a long history in refrigeration. It has been in use since before CFCs were developed and was re-introduced for use in heat pumps after the CFC phase out. Its thermodynamic data, efficiency, and material compatibility are well known. In some countries, appliance manufacturers and food producers began using R290 as a replacement for R404A or R134a in appliances shortly after 2000, due to environmental concern.

The most important issue regarding hydrocarbons as refrigerants is the flammability issue, some claims have been made regarding the explosion hazard of hydrocarbon refrigerants as horrendous even in systems with small charges such as domestic refrigerators [8]. This has been countered however by the work of James and Missenden [13] who tested several refrigerators charged with R290 for bomb in cabinet accident. In all the refrigerators tested, the measured quantity of refrigerant was less than 40 g and in the worst case accident the explosion and fire was unable to scorch the combustible liner of the fridge. Procedures and standards such as BS4434 of 1995 have now been established with regard to refrigeration safety.

In order to avoid an explosive build up of hydrocarbons in the event of a leak, the maximum mass of refrigerant in a domestic unit is restricted to be 200 g [11]. Summing up the different thermodynamic aspects, R290 could be used as replacement for R22 in many commercial refrigerated medium back pressure and low back pressure applications. R290 is the only candidate, which comes close to R22, in some aspects even outperforming it. The lower pressure ratio and lower discharge temperature even allow for use in certain applications where R22 is problematic. Therefore, the main objectives of this case study are to evaluate the performance of R22 and R290 in split air conditioner and compare the performance of both refrigerants in terms of coefficient of performance, power consumption, energy efficiency ratio and compressor power.

Materials And Method

This section consists of two subsections highlighting the materials used during the test and the experimental procedure to evaluate the performance of hydrocarbon refrigerant, i.e., R290 compared to conventional refrigerant, i.e, R22.

Materials

A complete set of 1hp split air conditioner consists of a condenser and an evaporator was used during experiment. Two types of refrigerant, i.e., conventional refrigerant or R22 and hydrocarbon refrigerant or propane (R290), were used. The following devices were used in recording the testing results during the experiment:

- Digital multimeter (2 units),
- Fluke thermometer (1 unit),
- Fluke thermocouples (6 units),
- Clamp meter (1 unit),
- Copper tube insulation (1 m),
- Fleering set (1 unit), and

Experimental procedure

The experimental setup is in accordance with the standard setup (Figure 1). A picture of experimental setup together with attached data measuring devices can be seen in Figure 2. Experiments were carried out by measuring the power consumptions by the compressor alone and by the whole system as well as measuring temperature of six different points (Figure 1), which are:

- T1 : Compressor inlet
- T2 : Compressor outlet
- T3 : Expansion valve inlet
- T4 : Expansion valve outlet
- T5 : Warm air coming out from condenser
- T6 : Cold air coming out from evaporator

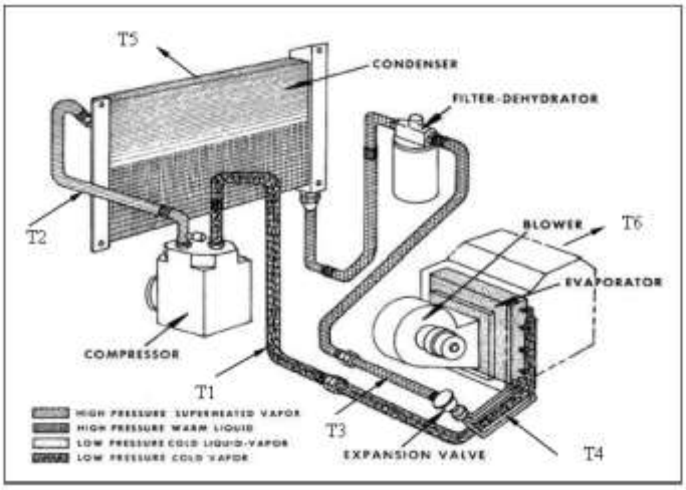

Figure 1. Schematic diagram of real testing [7]

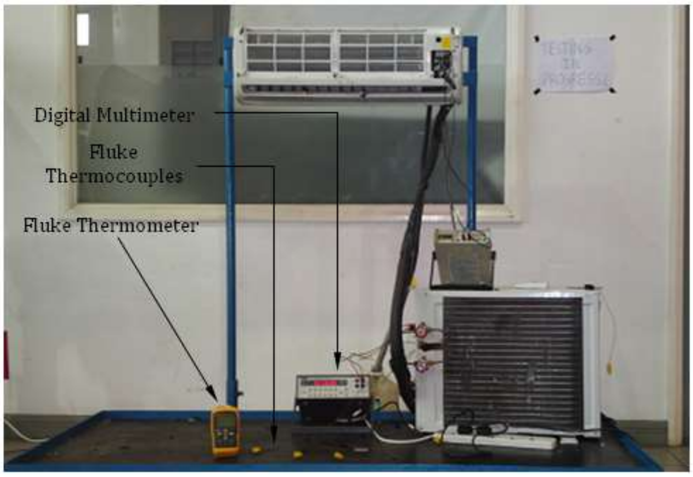

Figure 2. Experimental setup

The following safety precautions were taken into consideration:

- Hydrocarbon refrigerant is highly flammable and extra care is needed to be taken when charging and discharging it.
- All refrigerants are toxic gas therefore proper ventilation is required to prevent serious injury or death on a sudden total release of refrigerant.
- All tubing joints must be connected properly.
- The electrical components like capacitor, thermostat switch, on/off switch, should be sealed using some means.
- Before charging R290 in R22 readily charged air conditioning unit, chemical wash and thorough vacuum need to be done to avoid mixture of refrigerant.
- Charging of R290 need to be done using electronic equipment such as clamp meter to monitor the charging amount of R290. Charging of R290 has to be done by following the normal working current of the compressor.

Data analysis

Parameters which are often used to illustrate the performance of air conditioning are energy consumption (*q*), coefficient of performance (*COP*), and energy efficiency ratio

(*EER*). *COP* is the significant parameter to predict working effect for cooling and heating systems. For cooling system the *COP* value means proportion of heat removal from cold reservoir to imported work. EER here is defined as cooling capacity per unit power consumption. The natural principle shows that the smaller the energy consumption and larger the *COP* and *EER* values are, the better air conditioning for cooling speed, energy conserving, and so on.Raw data measured during the experiment were analyzed for each run to determine the overall power consumption by the system, power consumption by the compressor only, coefficient of performance, energy efficiency ratio, etc. The results are presented in graphical format.

Results and Discussions

This section covers the presentation of key findings on the use of hydrocarbon as refrigerant for domestic split type air conditioner. According to the data obtained, most of the current supplied from power source was used by outdoor unit to run the compressor. Figures 3 and 4 show that for both types of refrigerant, power consumption decreases as the set point temperature increases. This phenomenon is obvious in air conditioning because higher set point temperature means less compressor run time therefore less power consumption. Moreover, the power consumption of R290 is lower compared to R22. This is because the compressor requires less energy to compress R290 than R22. Besides that, molecular size of R290 is bigger and it is easier to compress and expand.

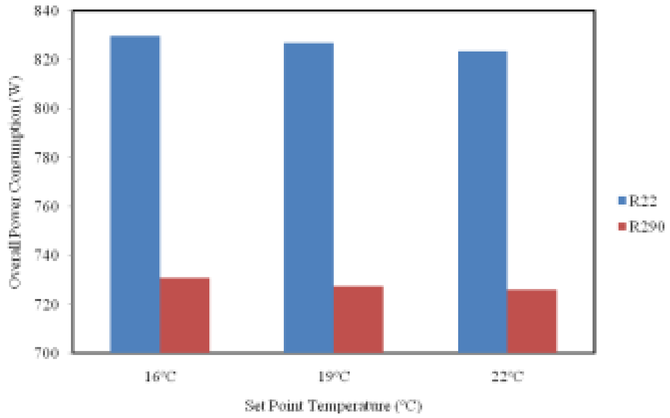

Figure 3. Overall power consumption at different set point temperature

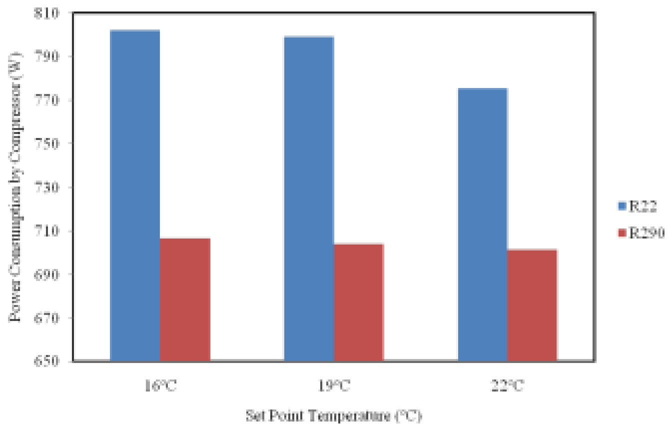

Figure 4. Power consumption by the compressor at different set point temperature

In terms of coefficient of performance (COP), R290 is better than R22 according to Figure 5. By comparing the energy efficiency ratio, R290 still has better efficiency than R22 according to Figure 6. The percentages of energy saving have been calculated where R22 is set as reference and the results are illustrated in Figure 7. From the measured data, the compressor outlet temperature against set point temperature have been plotted for both the refrigerants (Figure 8). The results show that R290 can easily be compressed compared to R22. In addition, R290 also has better characteristic in term of expansion valve outlet temperature. Figure 9 shows that R290 can easily expand compared to R22.

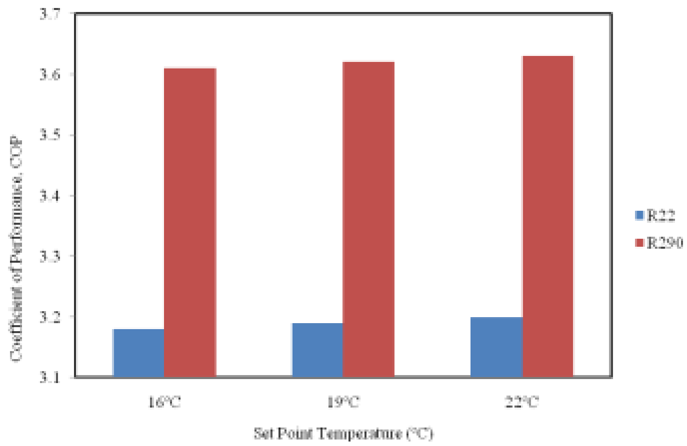

Figure 5. Coefficient of performance (COP) at different set point temperature

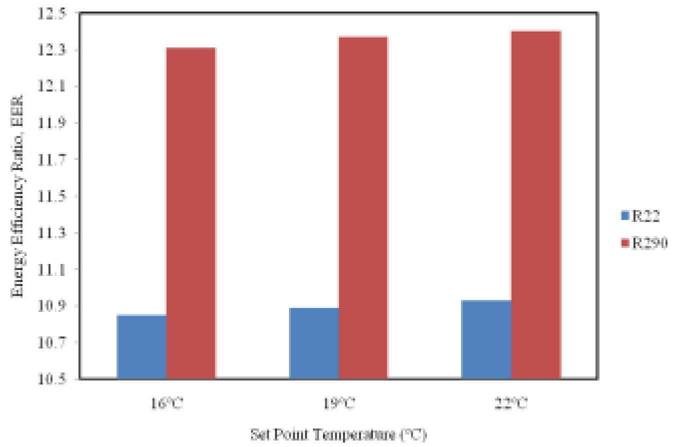

Figure 6. Energy efficiency ratio (ERR) at different set point temperature

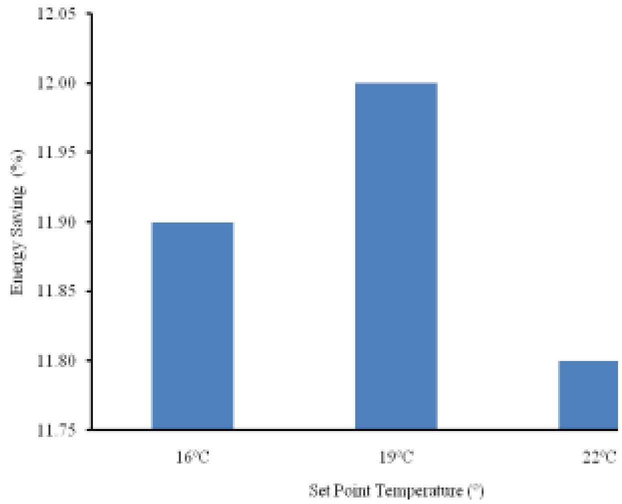

Figure 7. Energy savings by R290 compared to R22

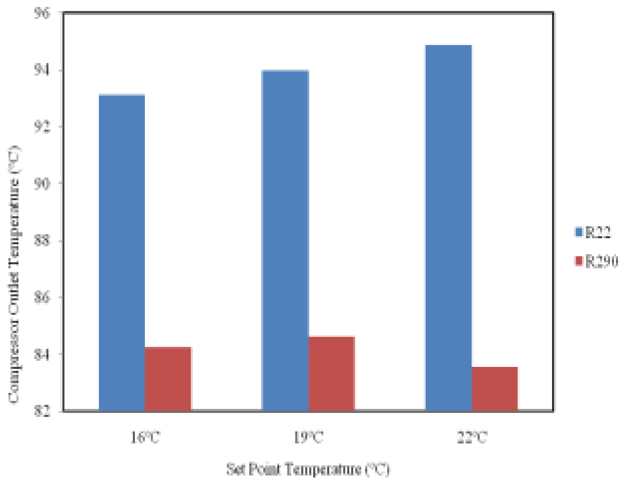

Figure 8. Compressor outlet temperature for both types of refrigerant

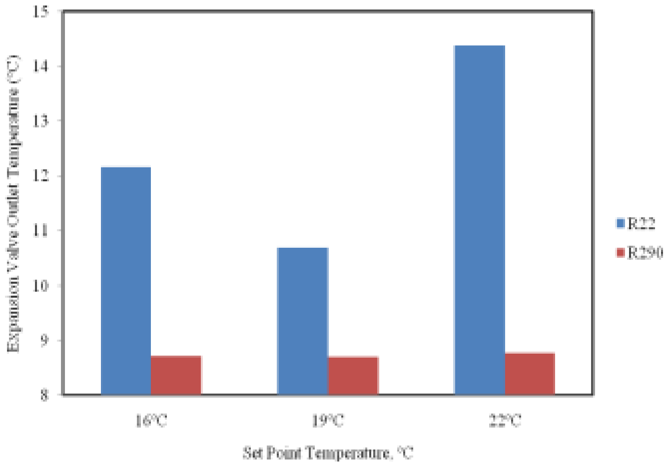

Figure 9. Expansion valve outlet temperature for both types of refrigerant

Conclusions

In term of performance, R290 refrigerant have better COP and EER compare to R22 refrigerant. The usage of R290 refrigerant can reduce energy consumption up to 11 %. In addition to that, the amount of refrigerant required by R290 is relatively half of that required by R22 refrigerant. Due to R290 chemical properties, this refrigerant can easily compress and expand compared to R22 refrigerant. As a result of these properties, the compressor requires less energy to compress the refrigerant which in turn increases the life span of the compressor. The only limitation of R290 is flammability. R290 refrigerant need to be handle with extra care due to its flammability properties.

All refrigerants are toxic gas and ventilation must prevent serious injury or death on a sudden total release of refrigerant. In the case of split air conditioner, the required amount is less than 150 g which is below the explosion limit. The lower explosion limit is 39 g/m^3 and higher explosion limit is 177g/m^3 and the self ignition temperature is 470ºC. In order to replace R290 refrigerant in readily R22 used refrigerant, the unit is required to be washed with chemical and vacuumed thoroughly to avoid mixture of refrigerant. Due to insufficient information available about R290 refrigerant, the maximum and minimum charging limit is unknown. In order to charge the unit with R290, the charging should conduct by following the working current of compressor. Excessive amount of R290 refrigerant can damage or spoilt the compressor.

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