Performance Assessment of an Eco – Friendly Alternate Refrigerant R441a

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ABSTRACT

In this present work, the possibility of using R441a, a hydrocarbon refrigerant which is a blend of R290, R170, R600a, and R600, as alternatives to R134a in domestic refrigerators has been assessed theoretically. The refrigerants are assessed over wider range of condensing and evaporator temperatures. The assessment was done with standard parameters such as Pressure Ratio, Volumetric Cooling Capacity (VCC), Coefficient of Performance (COP) and compressor input power. The results obtained showed that the hydrocarbon refrigerant blend is suitable to be used as alternatives to R134a as there is no mismatch in VCC. R441a has approximately the same VCC with about 5.2% higher COP at lower values of evaporator temperatures. The compressor input power is also considerably reduced while using R441a. The reported results proved that R441a is an energy-efficient and environment friendly alternative to phase out R134a in domestic refrigerators.

Keywords - Domestic Refrigerators, Hydrocarbon Refrigerants, Environment-Friendly Alternative.

1. INTRODUCTION

In various surveys conducted in households across the country, domestic refrigerators have been found to be the major energy consuming domestic appliance. The rapid depletion of ozone layer forced the nations to sign the Montreal Protocol in 1987, which has virtually put a ban on the use of CFCs and its substitute HCFCs as refrigerants. This has played a major role in saving the ozone layer. The potential candidate that automatically came to the spotlight as replacement for CFCs and HCFCs was HFCs. HFCs are ‘ozone-friendly’ refrigerants. R134a was identified and recognized by American Household Appliances Manufacturers (AHAM) to be used in domestic refrigerants as Refrigerant [1]. R134a being non-toxic, was considered as an environmentally safe refrigerant [2] but its GWP (Global Warming Potential) effect is very high. Hence, ‘The Kyoto Protocol’ of the United Nations Framework Convention on Climate Change (UNFCCC) asked for reduction in emission of various greenhouse gases, which also included R134a [3]. Therefore, it is a matter of urgency and of great importance that a better substitute for HFC refrigerant needs to be identified [4].

The use of hydrocarbons and other natural refrigerants in the refrigeration industry has been investigated for the past two decades. It has been cited and reported that hydrocarbon mixtures were found to be an alternate environment friendly refrigerants [5,6]. Hydrocarbons have an advantage of higher latent heat than that of R134a. This would significantly reduce the amount of refrigerant that needs to be charged. The next parameter to be investigated was power consumption. Investigations suggest that by using hydrocarbon refrigerant, around 20% energy consumption could be reduced compared to R12 and R134a. In an investigation conducted by Mohanraj et al. [7] hydrocarbon mixtures consisting of propane and isobutene with a ratio of 45.2:54.8 by weight was used in a domestic refrigerator. The results indicate that the hydrocarbon mixture leads to a reduction in the compressor energy consumption and pull down time by 11.1% and 11.6% respectively. The mixture was the best substitute for R134a. Ghodbane [8] theoretically studied R152a as a possible alternative for R134a in automobile air conditioning systems.

Later Lee and Yoo [9] experimentally studied the performance of R152a as alternative to R134a in the automobile air conditioning. In the light of the theoretical and experimental investigation, it has been concluded that R152a has less GWP and higher coefficient of performance (COP) than R134a. Mao-Gang et al. [10] investigated both theoretically and experimentally the HFC mixture composed of R152a/R125 at different mass percentages of 80/20, 85/15 and 90/10 as alternatives to R12 in domestic refrigerator. It has been reported that the discharge temperature (for 85/15 percentage by mass) is slightly higher than R12 with 2.8–3.2% higher COP. It has also been found out that the energy consumption of the refrigerator with this mixture at 97 g is 1.156 kWh.

Mohanraj et al. [11] reviewed substitutes for halogenated refrigerants and reported that natural refrigerants (hydrocarbon refrigerants) are found to be the best promising alternatives for halogenated refrigerants in domestic refrigerators, deep freezers etc. Aprea and Renno [12] studied experimentally the performance of a commercial vapor compression refrigeration plant using substitute R417A as refrigerant. They reported that the substitute refrigerant (R417A) could serve as a long term replacement for R22; it can be used in new and existing direct expansion R22 systems using traditional R22 lubricants.

The literatures revealed that a lot of research has been done in the field of hydrocarbon refrigerant to be used as a long term replacement for R134a. But no research work has yet been published by using R441a as a possible alternative. Refrigerant R441a is a hydrocarbon blend of Ethane, Propane, Butane and iso-Butane (3.1, 54.8, 36.1, 6 percentage by weight respectively). Since no work has yet be published in this regard, theoretical performance analysis of the refrigerant is done. A computer program has been developed in which the input data are the evaporator temperature, condensing temperature, and compressor specifications and properties of various refrigerants considered for investigation. The program outputs are the performance characteristics of the system such as pressure ratio, COP, refrigerant mass flow rate, volumetric cooling capacity (VCC), amount of heat rejected in condenser, compressor input power, and compressor discharge temperature.

2. CYCLE ANALYSIS

A performance analysis of the vapour compression refrigeration cycle used in the domestic refrigerators is depicted. The system consists of a hermetically sealed compressor, wire mesh natural convection air-cooled condenser, capillary tube expansion device and an evaporator. In the Vapour Compression Refrigeration system considered, the refrigerant is assumed to undergo sub-cooling and superheating. The following assumptions were made to study the performance of the refrigerant R441a used as alternative: (1) steady-state processes; (2) no pressure losses along the pipe and in the valves (changes only in compressor and capillary tube); (3) isentropic efficiency of the compressor,75%; (4) speed of the compressor, 2,800 and (5) 2°C sub-cooling and 3°C superheating. The parameters that are considered important for selecting an alternative are operating pressure, VCC, COP and power consumption. Standard equations were used calculating the performance of the system.

3. RESULTS AND DISCUSSION

The operating conditions considered in the present study for R134a and R441a, it are :

The condensation temperatures are varied between 35°C to 60°C in steps of 5°C keeping evaporator temperature constant at −15°C.

2.1 Effect of Condensing Temperature

The COP of the investigated refrigerant R441a compared against R134a at various condensing temperatures is shown in Fig. 1. The COP of R441a is higher than that of R134a. COP being the basic parameter to evaluate the performance of the refrigerator and hence the refrigerant used, indicates that R441a, has better performance than R134a. COP of R441a was found to be 6% more than that of R134a.

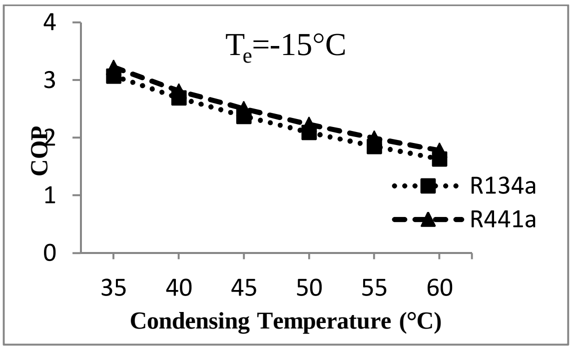

Fig. 1 COP vs Condensing Temperature

Fig. 2 shows the VCC of the investigated refrigerants with reference to condensing temperature. The VCC of R441a is close to that of R134a for condensing temperature between 45°C and 50°C. The VCC of the refrigerant investigated matches with VCC of R134a. Hence, the refrigerant can be used as drop in substitute to R134a.

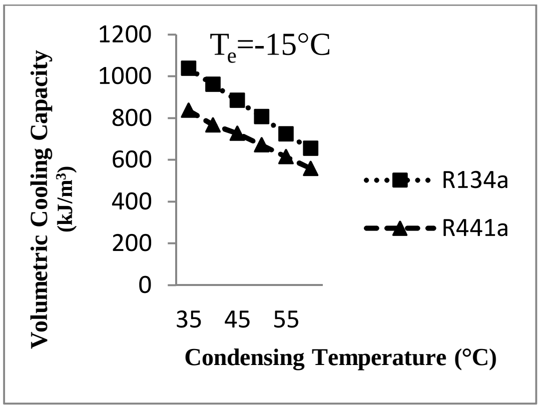

Fig. 2 VCC vs Condensing Temperature

Fig. 3 shows the variation of Compressor input power with various condensing temperatures. It is observed that as condensing temperature increases, the power input also increases. Also, comparing to R134a, the power input to the compressor is less in case of the newly investigated refrigerant R441a.

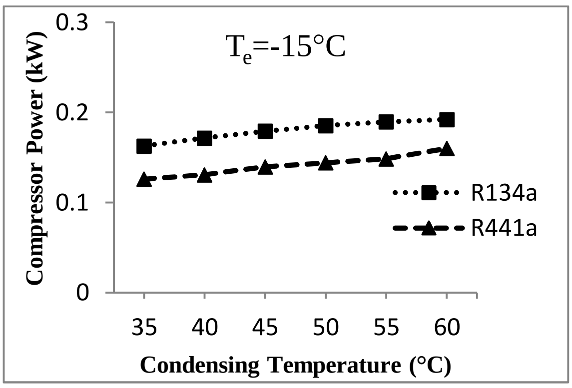

Fig. 3 Compressor Power Input vs Condensing Temperature

4. CONCLUSION

A comparative performance analysis was performed theoretically with R134a and its alternative, R441a, in a domestic refrigerator and the following conclusions are drawn.

- R441a has approximately the same VCC.
- R441a will reduce energy consumption due to lower heat rejection and lower compressor power input.
- The COP obtained by R441a is greater than that of R134a.

The result proved that R441a is the best environment-friendly, energy efficient and promising 'drop-in' substitute (without modification in the existing refrigeration system) for R134a in domestic refrigerators.

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