Energy Analysis of R1234yf/R134a as Replacement of R134a in a Domestic Refrigerator

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1 Introduction

India, like other developing countries, has experienced dramatic growth in the use of domestic refrigerator. More than 1 billion domestic refrigerators are currently in operation worldwide. HFC refrigerants have a high global warming potential and have an effect on the environment [1]. In compliance with the Kyoto Protocol, HFC refrigerants release additional greenhouse gases, thereby reducing the use of HFC coolants. Especially, the existing refrigerants R134a have a high GWP (1430), and it is to generate TFA and to bring about the new environmental issue [2]. Based on the environmental safety, it will soon be phased out. By 2012, the European Union took steps to control the emissions of F-gases by two-thirds of its existing 2030 rate and specified that it would be under 150 GWP for the new refrigerant. This gives the research potential to select on alternate refrigerants.

The hydrocarbons as an environmental-friendly refrigerant have a good performance in refrigeration as well as air-conditioning system. Nevertheless, some accidents were observed during manufacture or retrofitting of hydrocarbon equipment [3] because it is denser than air and spreads close to the floor in case of a leakage, thus increasing the risk of inflammation. This reason, the manufacturers fear for, used hydrocarbons in domestic refrigerators. R1234yf is a good environmentally

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friendly refrigerant [4]. It is best suitable alternate for R134a, and its thermo-physical properties are almost nearer than R134a.

Compared to R134a [5], it has GWP-4 and good climate cycle performance and does not increase significantly in the concentration of rainwater in TFA [6]. Regarding safety features, R1234yf has low toxicity, comparable to R134a [7]. The performance assessment has been reported for R1234yf refrigerant for mobile air conditioners, air-conditioning rooms or beverage coolers as a replacement for R134a. There is no proof of breakdown or reaction based on ASHRAE/ANSI standard 97 assessment of R1234yf with copper, steel, aluminium and POE oils [8]. Further testing with polymers and lubricants reveals that R1234yf is close to R134a to material consistency. The beverage cooler optimized experimentally for R1234yf had a very similar energy efficiency to R134a and a decreased environment performance of the overall life cycle [4].

Some research has been performed on R1234yf substitutes for R134a in the domestic refrigeration application. As such, when comparing R134a in domestic refrigeration system, R1234yf has achieved the required requirements in terms of security, reliability and compatibility. R1234yf's thermo-physical properties were compared to R134a in refrigeration cycles. It was shown that the capacity was 2.9% lower and COP was 2–7% less than R134a [8]. The theoretical model was developed and validated by experimental data from R134a. Their model indicated that R1234Yf was 9% less COP and 6% less capacity than R134a [9].

The mild flammability is a major problem for R1234yf. Recently, one of Europe's major auto companies has refused to adopt R1234yf because of its inflammability, with its low flammability limit of 6.2%. For the replacement of R134a in chillers, an azeotropic blend consisting primarily of the R1234yf was recommended [10]. For different applications like MACs and bottle coolers, an azeotropic blend of R1234yf/R134a is proposed for substitution. When the R134a mixture is added to the R1234yf by 10–11%, with GWP under 150 and COP, it is non-flammable and the discharge capacity temperature is similar to that of the R134a [11].

In this work, a mathematical simulation studied to check the performance of an R1234yf/R134a mixture in a household refrigerator. The result shows that R134a can be added up to 10% to keep the GWP of the mixture below 150. The simulation also shows that the variation in COP is not significant, when the mixture is used instead of pure refrigerant. In the simulation process, the software tool 'MATLAB' was used for the simulation, and the 'REFPROP' refrigerant property database was used to integrate difference in thermal physical properties of refrigerants in the simulation [12].

1.1 Refrigerant Selection

The choice of refrigerant is one of the most important functions to choose the appropriate refrigerant based on its thermo-physical properties. The properties of refrigerants obtained from REFPROP are plotted for the operating temperatures −23–47 °C

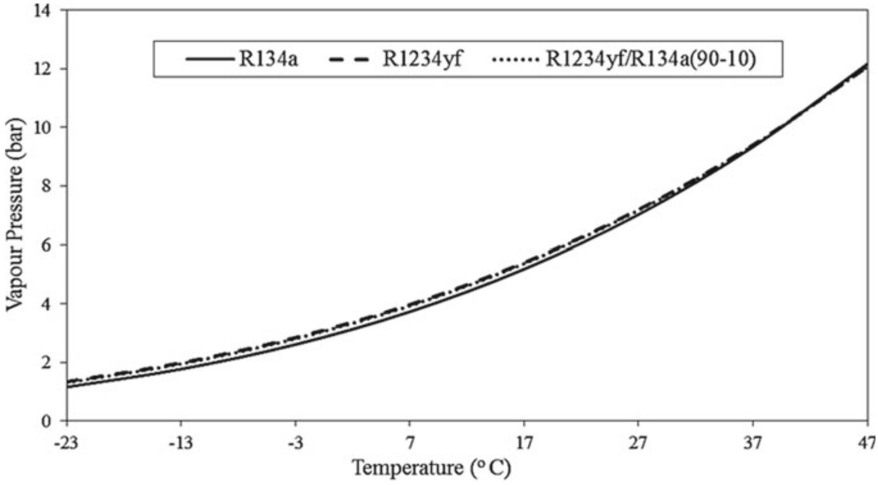

Fig. 1 Variation of vapour pressure with respect to temperature

(Fig. 1). It indicates the vapour pressure of refrigerants. When the vapour pressure is low, the compressor needs less amount of work and gives better performance to the system. However, the vapour pressure of R1234yf and R1234yf mixture is slightly higher than the R134a by about of 7% (Fig. 2) indicating latent heat of refrigerants. The latent heat of refrigerant plays an important role to deciding the refrigeration capacity. The R1234yf and R1234yf blends have an 18% lower latent heat than

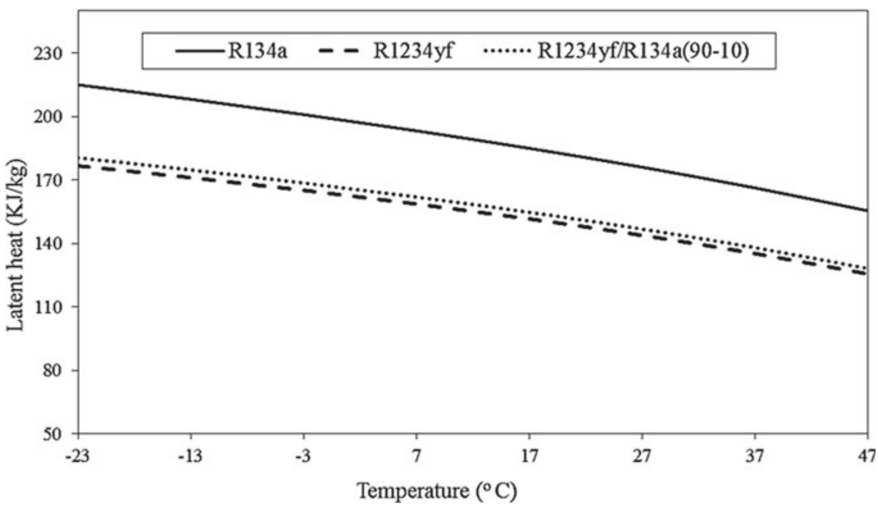

Fig. 2 Variation of latent heat with respect to temperature

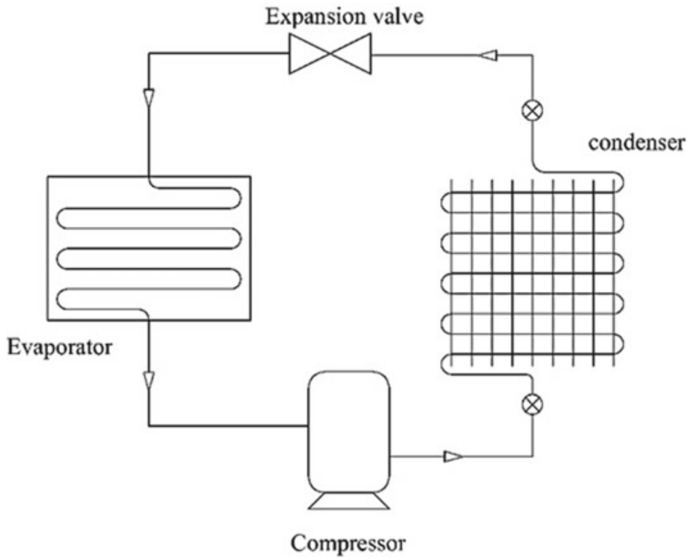

Fig. 3 Schematic diagram of domestic refrigerator

R134a. Based on the observation, the suggested refrigerants properties are almost near than the conventional refrigerant.

2 Analytical Study

The schematic diagram considered in the analysis is illustrated in Fig. 3. It consists of hermetically sealed reciprocating compressor, air-cooled condenser, capillary tube and evaporator. For the simulation of the above components, MATLAB software was used.

In previous studies [13–18], the compressor, condenser, capillary and evaporator are modelled. The different steps used for the simulation are shown in the flow chart (Fig. 4).

3 Result and Discussion

The variation of refrigeration effect with ambient temperature using with both refrigerants such as R1234yf and R1234yf mixture has been calculated and plotted in Fig. 5. Here, the cooling effect decreases as the ambient temperature increases. It is observed that the R1234yf mixture is about 8% and 2% lower than R134a and 2% higher than R1234yf.

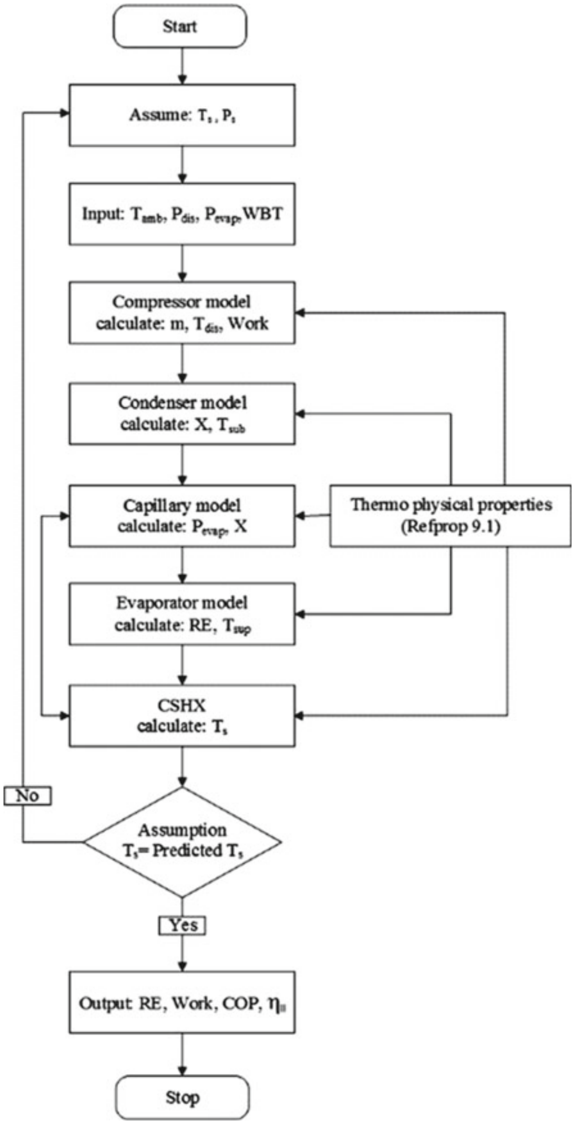

Fig. 4 Flow chart for simulation model of the domestic refrigerator

The compressor work variations with ambient temperature using both the R1234yf and R1234yf blend have been calculated and recorded in Fig. 6. Here the compressor work increases as the ambient temperature increases. It is observed that R1234yf blend is higher than the R134a and lower than R1234yf by about of 6% and 1%, respectively.

The variation of COP with ambient temperature using both refrigerants such as R1234yf and R1234yf mixture has been calculated and plotted in Fig. 7. Here the COP decreases with increase in ambient temperature. It is observed that R1234yf

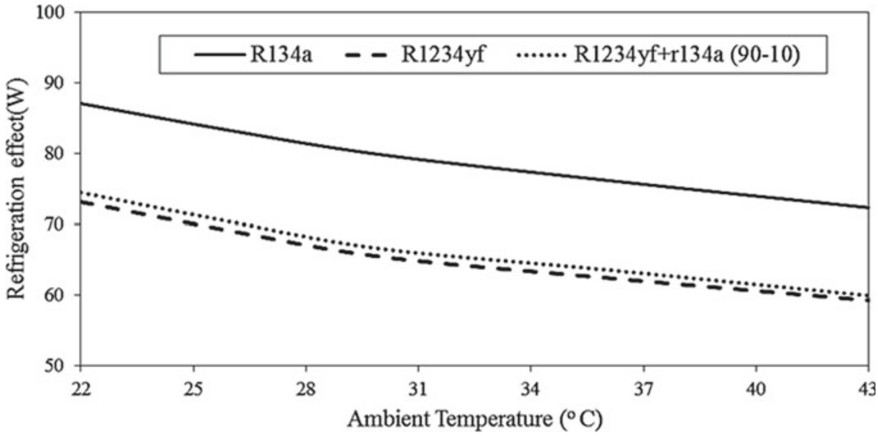

Fig. 5 Variation of refrigeration effect with various ambient temperature

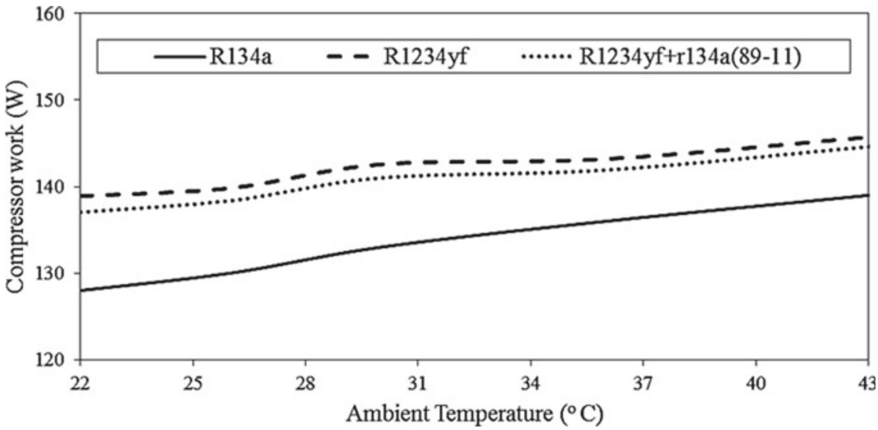

Fig. 6 Variation of compressor work with various ambient temperatures

blend is lower than the R134a and higher than R1234yf by about of 8% and 3%, respectively.

4 Conclusion

The performance analysis of domestic refrigeration systems with environmentally friendly refrigerants, such as R1234yf and R1234yf blends rather than conventional refrigerants, was studied in order to assess the potential for energy conservation, and the following conclusions are drawn from the theoretical study using MATLAB:

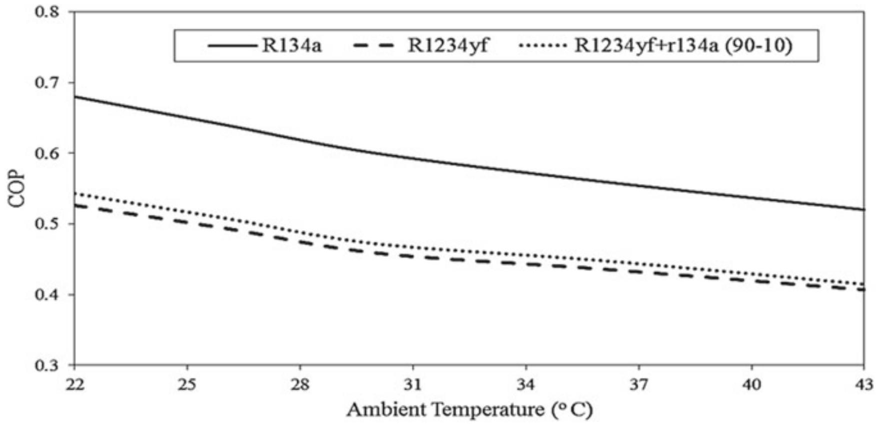

Fig. 7 Variation of COP with various ambient temperatures

1. The refrigeration effect R1234yf blend is lower than the R134a and higher than R1234yf by about of 8% and 2%, respectively.
2. The compressor work R1234yf blend is higher than the R134a and lower than R1234yf by about of 6% and 1%, respectively.
3. The COP of R1234yf blend is lower than the R134a and higher than R1234yf by about of 8% and 3%, respectively.
4. The performance of R1234yf blend is slightly lower than the R134a. Based on the environment, it is a suitable alternate for R134a.
5. The R1234yf/R134a has considerable environmental advantages and requires limited technical developments, and the gas is mild flammable. As a result, additional protections in handling, storage, implementation and servicing are needed by the manufacturing industry.

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