CHAPTER 3

REFRIGERANT MIXTURE SELECTION

3.1 INTRODUCTION

Published literature indicates R-407C as the promising drop-in substitute for R-22. Further, it was understood that the addition of HCs to R-407C mixture makes it compatible with mineral oil and thereby avoiding the usage of hygroscopic POE oil. As there are many possible HC additives available, choosing an eco-friendly and energy efficient additive would be a vital issue. In this chapter the various factors that were considered to select a suitable HC refrigerant that could make R-407C work with mineral oil are discussed. Since R-407C/HC mixture is zeotropic in nature, the preparation and handling procedure followed for the proposed mixture is also discussed.

3.2 REFRIGERANT MIXTURE

Researchers have conducted various studies in refrigeration systems to solve the mineral oil immiscibility issue of the HFCs. It was found that addition of suitable HCs with HFCs would be a feasible solution (Janssen and Engels 1995; Kim et al 1994; Joseph et al 2003). Thus, the selection of refrigerant mixture components was done with an understanding that HC added to R-407C will enhance the miscibility of R-407C with mineral oil that ensures proper mineral oil return. Propane is a common HC refrigerant that could be
considered as a mixture constituent with R-407C due to its higher latent heat, volatility and miscibility with mineral oil. However, the COP of R-134a with R-290 (propane) was lower than that of R-22 and R-290 because of the higher discharge pressure of the mixture (Kim et al 1994). Predictions through REFPROP (NIST 1996) indicates that at 55°C saturation temperature for R-407C/R-290 refrigerant mixture with 20% mass fraction of R-290, the vapour pressure is 28.30 bar, whereas for R-22 it is just 21.75 bar. As a result, decrease in system performance as well as compressor life can happen if R-290 alone were added with R-407C. It was also observed that R-600a (isobutane) could also be considered as an additive with R-134a while the vapor pressure did not shoot up (Janssen and Engels 1995; Alok and Agarwal 1998). A mixture of R-407C/R-600a with 20% mass fraction of R-600a has a lower vapour pressure (20.43 bar) than that of R-22 at 55°C. Further R-407C with HCs normally behaves as a zeotrope. When zeotrope mixture evaporates inside the tubes, the more volatile component evaporates first and the liquid becomes rich in lower volatile component (Stephan 1996). Since R-600a has its boiling point higher than the R-407C, the liquid inside the evaporator becomes rich in R-600a while the vapour will become rich in R-407C and the oil might not return to the compressor as expected (Horst and Florian 1997). Hence to utilize the above advantages of R-290 and R-600a, a HC blend (R-290 + R-600a) (readily available in the market) was considered to be mixed with R-407C. Also the predictions through REFPROP indicate that at 55°C saturation temperature for R-407C/R-600a/R-290 mixture with 20% mass fraction of R-600a/R-290, the vapour pressure is 24.57 bar, which is just 13% higher than that of R-22. The HC blend was also found to be chemically stable and non-reactive with non-metallic components used in hermetic compressor (Colbourne and Ritter 2000). Moreover as the quantity of HC blend used could be restricted to be
within 250g, even if leakage occurs the HC concentration in the room would not exceed the lower flammability level in normal operating circumstances. Hence in this work HC blend has been taken as a viable refrigerant that could be added with R-407C to retrofit the existing R-22 window air conditioner operating with compressor having mineral oil as lubricant. To confirm the properties of the available HC blend, the thermophysical properties of the selected blend as given by the manufacturer have been compared with the property values obtained from the REFPROP (NIST 1996) software for different compositions of R-290 and R-600a. It was found that the property values specified by the manufacturer were matching with the REFPROP values for the HC blend that contains 45.2% propane and 54.8% isobutane.

From the literature it was found that addition of 8% to 15% of HCs with HFCs in the refrigeration systems could solve the miscibility problem and also improves the system performance (Janssen and Engels 1995; Camporese et al. 1996; Joseph et al. 2003). Based on the above observation, to check the possibility of improving the performance by increasing the mass percentage of HC blend, in the present work, performance tests (both theoretical and experimental) were conducted for the mixture containing 10%, 15%, 20% and 25% HC blend (by weight) in R-407C. These mixtures are further referred to as M10, M15, M20 and M25 respectively in this thesis. The resultant mixture compositions are as follows.

\[
\begin{align*}
M10 & = R-407C/R-600a/R-290 (90/5.48/4.52\% \text{ by weight}) \\
M15 & = R-407C/R-600a/R-290 (85/8.22/6.78\% \text{ by weight}) \\
M20 & = R-407C/R-600a/R-290 (80/10.96/9.04\% \text{ by weight}) \\
M25 & = R-407C/R-600a/R-290 (75/13.70/11.30\% \text{ by weight})
\end{align*}
\]
3.2.1 **Refrigerant Mixture Properties**

Among the various properties of the refrigerants it has been found from the literature that the vapor pressure, liquid density, vapor density, latent heat and viscosity are the important parameters to predict the performance of alternative refrigerants. Therefore the above properties of the mixtures along with R-22 were obtained from REFPROP (NIST 1996) for the operating temperature ranging from 0°C to 60°C. Figure 3.1 shows the variation of vapor pressure with saturation temperature. From the graph, it could be noted that with the increase in HC blend mass percentage, the suction and discharge pressure shoots up. Among the refrigerant mixtures, the vapor pressure was found to be the highest for M15, which is 12.32% higher than that of R-22 at 55°C. Furthermore, at 7°C evaporating and 55°C condensing temperatures the pressure ratio for R-22 was found to be 3.5, where as for R-407C it was found

![Figure 3.1 Variation of vapour pressure with saturation temperature](image-url)
to be 3.83. With the addition of HC blend beyond 15% to R-407C the pressure ratio got reduced because of higher suction pressure of M20 and lower discharge pressure of M25. Pressure ratios of M20 and M25 were just 2.43% and 2.34% higher than that of R-22. As the pressure ratio reduces with the addition of HC blend in R-407C, less work of compression could be expected and hence better system performance is possible.

The density of the liquid refrigerant is an important parameter that decides the charge quantity. The refrigerant charge used in the hermetically sealed systems is an important parameter that influences the thermodynamic behaviour of the system (Kuijpers et al 1988). It has been found that reducing the charge quantity could reduce the cycling losses. The variation of liquid-density with saturation temperature for the new mixtures and R-22 is

![Figure 3.2 Variation of liquid density with saturation temperature](image-url)
plotted in Figure 3.2. It was found that the mixtures have lesser density than R-22 and with the increase in HC blend in the refrigerant mixture the density decreases. Hence the charge quantity will be lesser for refrigerant mixtures. It was observed that among the considered refrigerant mixtures, the liquid density of M25 was found to be minimum, which was lower than that of R-22 by 30%.

The compression work normally increases with the increase in the fluid density. Since the system considered is vapor compression system, it is necessary to study the vapor density of refrigerants used in this work. Figure 3.3 shows the variation of vapor density of the refrigerants with respect to saturation temperature. As it is seen the increase of HC blend in the refrigerant mixture has caused a drop in the density of the mixture. Hence the

![Figure 3.3 Variation of vapor density with saturation temperature](image-url)
compressor work could be expected to decrease while increasing the HC blend in the refrigerant mixture. Among the refrigerants M25 show 4.48% to 11.25% lesser vapour density than R-22.

The latent heat of vaporization plays an important role in deciding the refrigeration capacity. The variation of latent heat of the mixtures and R-22 is shown in the Figure 3.4. It is observed that the latent heat of the refrigerant mixtures was higher than that of R-22. Further, it could be noted that increase in

![Figure 3.4](image)

**Figure 3.4** Variation of latent heat with saturation temperature

HC blend in the refrigerant mixture increases the latent heat. The figure shows that the latent heat of mixtures is nearly 0.7% to 8.29% higher than that of R-22 for the considered range of composition and saturation temperature ranging
from 0°C to 25°C. Thus there is scope to have the same or better refrigeration capacity of the refrigerant mixtures than R-22.

The heat transfer properties of refrigerants improve with the reduction in viscosity (Colbourne and Suen 2000). Viscosity also influences the flow characteristics of refrigerants inside the capillary tubes and expansion valves. Hence the liquid and vapor viscosity of the refrigerants used in this study were calculated and plotted in Figures 3.5 and 3.6 respectively. The figures show that the viscosity of the mixtures is less than that of R-22. Further the viscosity reduces with the increase of HC blend in the refrigerant mixture. Among the refrigerant mixtures M25 shows maximum of 30.34% to 36.08% and 4.14% to 10.78% less viscosity than R-22 in liquid and vapour phase.

![Figure 3.5 Variation of liquid viscosity with saturation temperature](image)

**Figure 3.5 Variation of liquid viscosity with saturation temperature**
respectively. Hence better thermodynamic transport properties could be expected with the refrigerant mixtures. The properties of refrigerants at atmospheric pressure are given in Appendix 1.

![Figure 3.6 Variation of vapour viscosity with saturation temperature](image)

**Figure 3.6** Variation of vapour viscosity with saturation temperature

### 3.3 PREPARATION OF REFRIGERANT MIXTURE

The R-407C/HC blend refrigerant mixture that was considered in this work is zeotropic in nature and hence only liquid refrigerant was charged into the system. Preparation, handling and charging of the zeotropic mixture is also critical. Many guidelines have been reported in the literature regarding the characteristics of zeotropes (Franco and Curtis1996; David et al 1997; Yanho et al 1997 and Per 1998). The four mixtures M10, M15, M20 and M25 were prepared in separate cylinders before they were charged into the system. To
keep concentration shifts within 2% the guideline is that the liquid charge in the refrigerant mixture cylinder should not fall below 10% volume at any time while charging the system. Hence the prepared mixture quantity was sufficiently high to satisfy the above condition always. To have an accurate charging by weight the mixtures were prepared in small cylinders with 2 kg capacity. However, for capillary flow characteristics study, the mixture was prepared in a 15 kg cylinder additionally.

Initially the cylinders were cleaned and flushed with R-407C twice. Then they were evacuated to 0.1 mbar. While filling to avoid pressure build-up inside the cylinders they were kept in a low temperature bath. Since HC blend has a vapour pressure lower than R-407C initially the cylinders were filled with the required quantity of HC blend. A weighing balance with 0.1-g accuracy was used for this purpose. To maintain the required mass percentage in the total filled quantity the required mass of R-407C was calculated and filled. Each cylinder was properly labelled to indicate the name and quantity of filled refrigerant mixture.

3.4 EQUIVALENT CHARGE QUANTITY OF MIXTURES

The equivalent is the mass charge of the mixture having the same volume flow at suction conditions. Suction conditions will have maximum specific volume of the refrigerant and hence that is always taken as the reference location for all design purposes. 7°C was considered as the reference temperature. The charge quantity of mixture required for R-22 system is not equal to that of R-22 as the specific volume of the mixture is different. Boot (1990) and Agarwal (1998) have calculated the equivalent charge quantity
based on the specific volume of the mixtures at the suction of the compressor for domestic refrigerators. The same procedure was followed in the present study. Considering the specific volume of the refrigerants, the equivalent quantity of R-22 for 1 g of R-407C and HC blend is 1.037 g and 2.29 g respectively.

Let 

- HFC be the mass of R-407C present in the mixture
- HC be the mass of HC blend in the mixture
- HCFC be the R-22 charge quantity in a system

Then

\[ 1.037 \text{ HFC} + 2.29 \text{ HC} = \text{HCFC} \]  

(3.1)

where,

- 1.037 and 2.29 are the liquid density ratios of R-22 with R-407C and R-22 with HC blend mixture at 7°C.

Using the above equation (3.1) the mass of R-407C and HC blend present in the equivalent charge were calculated. In case of M10, \( \frac{\text{HFC}}{\text{HC}} = \frac{90}{10} \Rightarrow \text{HFC} = 9\text{HC} \). Hence the equivalent quantity for 950 g R-22 was arrived as 816g (734g R-407C and 82g HC blend). Similarly the quantities of other mixtures were also calculated.