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Experimental Study of Environment Friendly Mixed Refrigerant to Replace R-134a in a VCR System with Testing and Training of ANN

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ABSTRACT

This work presents an experimental study on environment friendly mixed refrigerant to replace R134a in vapour compression refrigeration (VCR) System. The mixed refrigerants investigated are propane (R290), butane (R600), isobutene (R600a) and R134a. Even though the ozone depletion potentials of R134a relative to CFC-11 are very low; the global warming potentials are extremely high and also expensive. For this reason, the production and use of R134a will be terminated in the near future. Hydrocarbons are free from ozone depletion potential and have negligible global warming potential. The results showed that, mixed refrigerant with charge of 80 g satisfy the required freezer air temperature, when R134a with a charge of 110 g is used as refrigerant. The actual COP of refrigerator using mixed refrigerant was almost nearer that of the system using R134a as refrigerant. The coefficient of performance of the vapour compression refrigeration system using mixed refrigerant MR-3 [R134a/R290/ R600a/ R600 (20/35/40/5)] is having very close value with R134a and the Global warming potential of MR-3 is negligible when compared with R134a. Hence the mixed refrigerant MR-3 is chosen as an environmental friendly alternate refrigerant to R134a. Also the back propagation algorithm is implemented for training artificial neural network (ANN) to find out the optimum mixture having higher COP.

Key words: R134a, Mixed refrigerant, Chlorofluorocarbons, Propane, Butane, Isobutene, REFPROP, COP, ODP, GWP, ANN, Back propagation algorithm, VCR System.

I.INTRODUCTION

Refrigeration is the process of removing heat from the space to be cooled and transferring it to a place where it is unobjectionable. At present in India more than 80% of the refrigerators are working with R134a (Mohanraj et al 2008). R134a possess favorable characteristics such as zero ODP, non-flammability, stability and similar vapor pressure to that of R12. Hydro fluorocarbons, such as R134a, have almost zero ozone depletion potential, as they do not contain chlorine atoms in their chemical structure. Similar to R12, they are safe, non-inflammable and have similar vapor pressures (Tashtoush et al 2002). However, they have lower energy efficiency and are more expensive than R12. They also have a low negative environmental effect of global warming potential (Sattar et al 2007). The concern against the increase of global warming has been the prior issue of study in the present century.

Thus, in 1997 the Kyoto protocol was agreed by many countries there by calling for the reduction in emissions of greenhouse gases including HFCs. The GWP of R134a is 1300 which is considerably high but lower than R12 (Somchai Wongwises et al 2005). Naturally occurring substances such as water, carbon dioxide, ammonia and hydrocarbons are believed to be environmentally safe refrigerants. Now in India CFCs phase out was successfully implemented by replacing R12 with R134a, but it has to be controlled due to relatively high GWP (Akash et al 2003). So, interest towards environmentally safe refrigerants is growing. At the same time the performance of the refrigerants and their flammability are other crucial factors that have to be taken into account while selecting the refrigerants (Adnan Sozen et al 2006).

The algorithm that we developed uses REFPROP subroutines and calculates the coefficient of performance (COP) and the total irreversibility (TI) of the cooling system for the relevant mixture. An artificial neural network (ANN) is used to evaluate and produce results for theoretically obtained values (Kalogirou et al 2000). In other words, since we successfully calculate the COP values of the mixtures given above, using the simulation platform and other mechanisms described earlier. The basic reason for this is that when using the REFPROP depending on the simulation platform and the computer resources, sometimes we have to wait five minutes for a single calculation to be completed while the ANN produces such results almost instantly. Also, sometimes these programs cannot produce results due to the occurrence of infinite loops, while this is not the case when using ANN.

II.EXPERIMENTAL SETUP AND TEST PROCEDURE

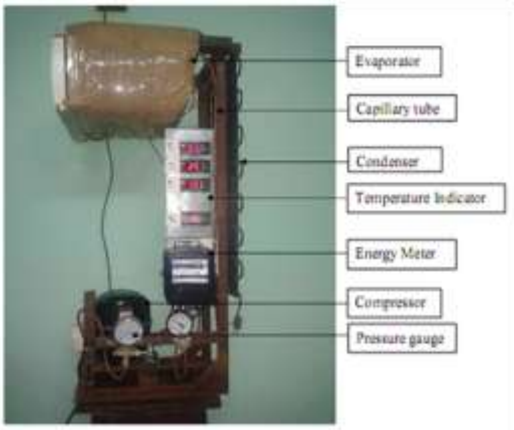

Fig. 1 Schematic of the investigation unit and Apparatus

The schematic of the experimental setup is shown in Figure 1. The vapour compression refrigeration system consists of a hermetically sealed reciprocating compressor, wire mesh air-cooled condenser, expansion device and an evaporator. A 165 l vapour compression refrigeration system of tropical class originally designed to work with R134a is taken for this study. The system was instrumented with four pressure gauges to measure the compressor inlet pressure, compressor delivery pressure, condenser outlet pressure and evaporator inlet pressure. Four temperature sensors are placed to measure the compressor inlet temperature, compressor delivery temperature, condenser outlet temperature and evaporator temperature.

Initially, the system was purged with nitrogen gas to check leakage, to remove impurities, moisture and other foreign materials inside the system, which may affect the experimental results. Then the set up was charged with R134a and the base line test was carried out. The pressure and temperature of the refrigerant at the inlet and outlet of the compressor, outlet of the condenser and inlet of the evaporator were monitored and recorded continuously. The refrigeration effect and the coefficient of performance were calculated using the software REFPROP.

The low temperature, low pressure vapour is compressed by a compressor to high temperature and pressure vapour. This vapour is condensed into high pressure vapour in the condenser and then passed through the expansion valve. Here, the vapour is throttled down to a low pressure liquid and passed on to an evaporator, where it absorbs heat from the surroundings from the circulating fluid (being refrigerated) and vaporizes into low pressure vapor. The refrigerator was charged with 110g of R134a and the base line performance is studied. After completing the base line test with R134a, the refrigerant is recovered from the system and charged with the different refrigerant mixtures [MR-1 (R134a/R290/R600a/R600 (10/40/45/5)), MR-2,(R134a/R290/R600a/R600 (15/40/40/5)), MR-3 (R134a/R290/ R600a/ R600 (20/35/40/5)) and MR-4 (R134a/R290/R600a/R600 (25/35/35/5))] one by one and the experiments are conducted and the readings are taken using different mixtures in the same test unit.

III.RESULTS AND DISCUSSIONS

The set up was charged with R134a, and the base line test was carried out. Different parameters like Evaporator temperature, Condensing temperature, Discharge temperature, Evaporator pressure, Pressure ratio, Mass flow rate, Refrigerating effect, Work of the compressor, Power per ton of refrigeration, Volumetric refrigerating capacity, Coefficient of performance are studied and some of the results are discussed.

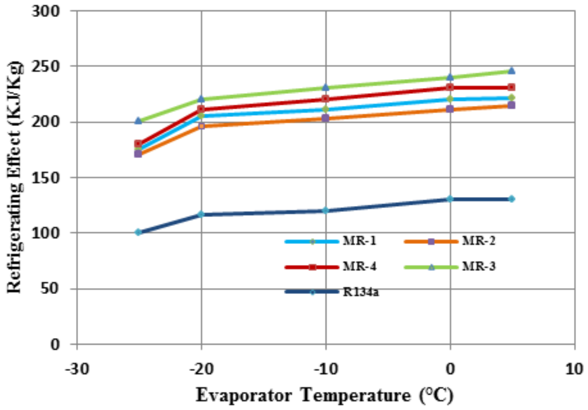

Fig. 2 Refrigerating Effect Vs. Evaporator Temperature

Figure 2 shows the effects of evaporator and condensing temperatures on refrigeration effects of a VCR system. As shown in the Figure for a given condenser temperature as evaporator temperature increases the refrigeration effect increases marginally. The refrigerating effect increases with increasing evaporator temperature for the constant condensing temperature of 52°C and the evaporator temperature ranging from -25°C to 5°C. All the tested refrigerants have much higher refrigerating effect than R134a. The refrigerating effects of MR-3, MR-4, MR-1 and MR-2 are about 78.58% - 90.37%, 71.36% - 72.06%, 65.25% - 67.64% and 61.02% - 63.01% higher than that of R134a, respectively.

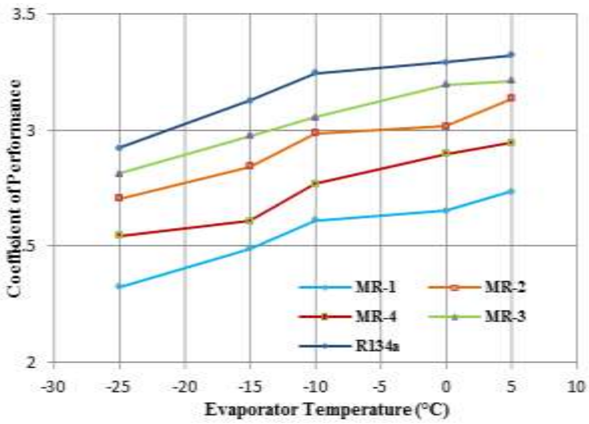

Fig. 3 Coefficient of Performance Vs. Evaporator Temperature

The variation of coefficient of performance with evaporator temperature is shown in Figure 3. The coefficient of performance increases as the evaporator temperature increases for the constant condensing temperature of 52°C and the evaporator temperature ranging from -25°C to 5°C. The decrease in pressure ratio for the compressor also improves the efficiency. The coefficient of performance of R134a and MR-3 is about 4.84% - 5.99% and 0.74% - 2.48% higher than that of MR-2. MR-1 and MR-4 have lower coefficient of performance of about 6.05% - 12.68% and 2.6% -6.05% than that of MR-2. As expected, for a given condenser temperature the coefficient of performance increases rapidly with evaporator temperature, particularly at low condensing temperatures.

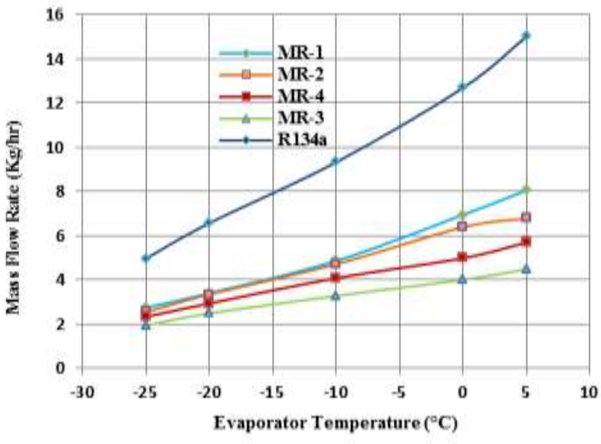

Fig. 4 Mass Flow Rate Vs. Evaporator Temperature

Figure 4 shows the effect of mass flow rate with reference to evaporator temperature. The mass flow rate increases as the evaporator temperature increases. Apart from R134a, all the other tested refrigerants have less mass flow rate. MR-1, MR-2, MR-3 and MR-4 are less by 46.36% - 44.73%, 54.72% - 48.67%, 62.02% - 52.95% and 70.03% - 0.83% than R134a. As evaporator temperature increases the specific volume of the refrigerant at compressor inlet reduces rapidly and the refrigerant effect increases marginally. Due to the combined effect of these two, the volume flow rate of refrigerant per unit capacity reduces sharply with evaporator temperature. This implies that for a given refrigeration capacity, the required volumetric flow rate reduces and hence the size of the compressor becomes very large at very low evaporator temperatures.

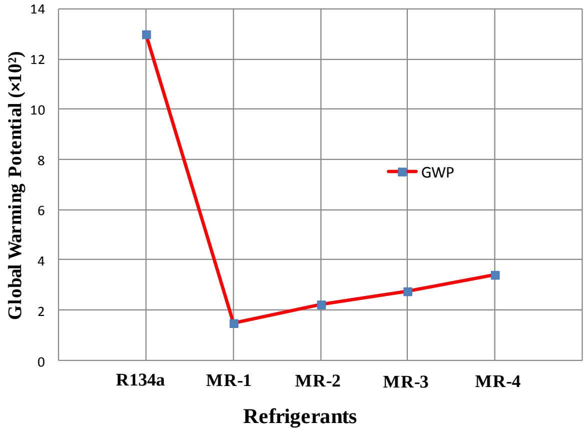

Fig. 5 Variation of Global Warming Potential for Different Refrigerant Mixtures and R134a.

Figure 5 shows the variation of global warming potential for different refrigerant mixtures. Global warming potential is a measure of the mass of greenhouse gas is that estimated to contribute to global warming. From the graph, it is observed that Refrigerant R134a has maximum GWP of value 1300. MR -1 has GWP of about 148 which is less than 200. MR -2 has GWP about 222 which is less than 250. MR -3 has GWP about 276 which is less than 300 and MR -4 has GWP about 340 which is less than 400. While increasing the composition of R134a in the refrigerant mixtures, the global warming potential also increases proportionally.

IV SIMULATION BY ANN

Neural networks have been made up of simple elements that operate in parallel, inspired by biological nervous systems. ANNs differ from the traditional modeling approaches in that they are trained to learn solutions rather than being programmed to model a specific problem in the normal way.

The refrigerant mixtures of R134a, R290, R600a, and R600 in different ratios were used as inputs while the COP calculated is considered as outputs. Henceforth, the input and target values are presented in matrix form as follows. The matrixes X and Y are composed of the input and target values respectively.

X= [Mixture 1, Mixture 2, Mixture 3, Mixture 4,….]

Y= [COP]

A. *Simulation Platform*

We used the MATLAB platform to train and test the ANN. In the training, in order to define the output accurately, an increased number of neurons in a hidden layer have been used. After successfully training the network, it has been tested against the known data. The algorithm that we developed uses REFPROP subroutines and calculates the COP of the relevant mixture. The basic reason for this is that when using the REFPROP depending on the simulation platform and the computer resources, sometimes we have to wait 5 minutes for a single calculation to be completed while the ANN produces such results almost instantly. Also, sometimes these programs cannot produce results due to the occurrence of infinite loops, while this is not the case when using ANNs.

B. *Back propagation Algorithm (BPA)*

The BPA uses the steepest-descent method to reach a global minimum. The number of layers and number of nodes in the hidden layers are decided. The connections between nodes are initialized with random weights. A pattern from the training set is presented in the input layer of the network and the error at the output layer is calculated. The error is propagated backwards towards the input layer and the weights are updated. This procedure is repeated for all the training patterns. At the end of each iteration, test patterns are presented to ANN and the classification performance of ANN is evaluated. Further training of ANN is continued till the desired classification performance is reached.

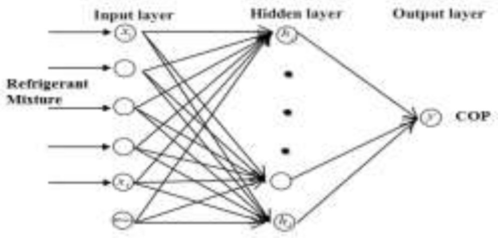

Fig. 6 Architecture of Neural Network

The root absolute fraction of variance (R) and mean square error (MSE) formula is shown as below

$$R = \sqrt{1 - \frac{\sum_i (t_i - o_i)^2}{\sum_i (o_i)^2}},$$

$$MSE = \frac{1}{N} \sum_i | t_i - o_i |^2 ,$$

$$\%\text{Error} = \frac{t_j - o_j}{t_j} 100$$

Where o is the output value, t is the target value, and N is the number of patterns.

The output of network is compared with the desired output at each presentation and errors are computed. These errors are back propagated to the neural network for adjusting the weight such that the errors decrease with each iteration and ANN model approximates the desired output. The neurons in the hidden layer have no transfer functions. The inputs and outputs are normalized in the range 0-1. Logistic sigmoid (log-sig) transfer function is being used in ANN.

The transfer function used is given by

$$f(Z) = \frac{1}{1 + e^{-Z}}$$

Where Z is the weighted sum of inputs.

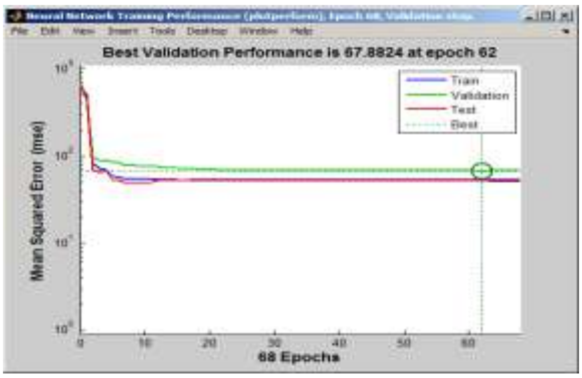

Fig. 7 Performance of LM Algorithm with 2 Hidden Neurons

Figure 7 shows the ANN model output being trained with Levenberg Marquardt back Propagation algorithm which was obtained from a network with 2 hidden neurons. During training, R value is 0.99999. The validation of the training function is also based on the value of coefficient of multiple determinations R-square. Function TRAINLM has achieved the value of R-square almost closest to unity.

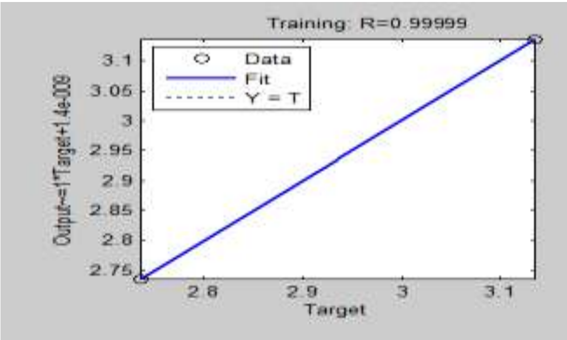

Fig.8 Regression Chart of LM Algorithm with 2 Hidden Neurons

Figure 8 shows Validation Performance of Levenberg-Marquardt Algorithm with 2 Hidden Neurons. It shows the decrease of the MSE at each epoch during the training process. Corresponding to this diagram, the best validation performance is 82.14 at epoch 28.

V. CONCLUSION

The following conclusions are derived from this research work.The system obtains the maximum coefficient of performance with R134a followed by MR-3.The system obtains the maximum refrigerating effect of 245.23 kJ/kg with the mixed refrigerant MR-3.The GWP of MR-1 is very low, compared to R134a and increasing when the percentage of the R134a increases. The experimental results shows MR-3 obtained the COP closer to R134a and the GWP is very minimum compared to R134a. Hence MR-3 can be a suitable replacement for R134a.imulation shows the possibility of using neural networks for the calculation of the performance of a VCR system using refrigerant mixtures.

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