



Experimental Study of HC Mixtures to Replace R-134a in a Domestic Refrigerator with Testing and Training of ANN

KEYWORDS

R134a, Mixed refrigerant, chlorofluorocarbons, propane, Butane, Isobutene, REFPROP, COP, Energy consumption, ANN

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ABSTRACT

This work presents an experimental study on the application of hydrocarbon mixtures to replace R134a in a domestic refrigerator. The hydrocarbons investigated are propane (R290), butane (R600) and isobutene (R600a). A refrigerator designed to work with R134a was used as an investigation unit to assess the prospect of using mixed refrigerants. Even 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 permanent running and cycling results showed that, mixed refrigerant with charge of 80 g satisfy the required freezer air temperature of -21°C when R134a with a charge of 110 g is used as refrigerant. The actual COP of mixed refrigerant refrigerator was higher than that of R134a by about 8.1%. The COP and other result obtain in this experiment shows a positive indication of using mixed refrigerant as refrigerants in household refrigerator. The COP started increasing with the increasing percentage R134a and reach a maximum value at 15% of R134a (Mixture-2) and then started decreasing with a further increase in R134a mass fraction. Also the Back propagation algorithm was implemented for training ANN to find out the optimum mixture of obtaining higher COP. The RMS error values are smaller than 0.002 and R^2 values are about 0.99999, which can be considered to be excellent. The field of neural networks is vast and interdisciplinary. Speed of calculation, capability of learning from examples and simplicity are the advantages of the ANNs. These features enable the ANNs to be used in thermal systems. Reducing the time and effort spent for the numerical studies using our approach for other mixture ratios, the COP values can be achieved.

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 (SomchaiWongwises and Nares Chimres 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. 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.

II. EXPERIMENTAL SETUP AND TEST PROCEDURE

This section provides a description of the facilities developed for conducting experimental work on a domestic refrigerator. The technique of charging and evacuation of the system is also discussed here. Experimental data collection was carried out in the research laboratory of our institution. The experimental setup of the test unit and apparatus is shown in the Figure 1.

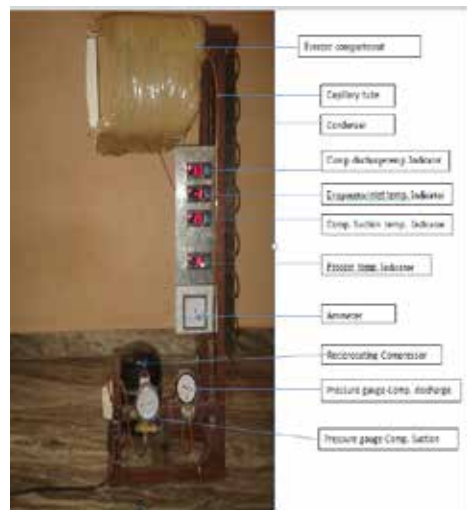


Figure 1 Schematic diagram of the investigation unit and apparatus

The experimental setup of the household refrigerator used in the experiment is shown in Fig4.4. The domestic refrigerator consists of an evaporator, wire mesh air-cooled condenser and hermetically sealed reciprocating compressor. The 165 liters domestic refrigerator of tropical class originally designed to work with HFC134a was taken for this study.

The refrigerator was instrumented with two pressure gauges at the inlet and outlet of the compressor for measuring the suction and delivery pressure, four temperature sensors are mounted to measure the compressor inlet temperature, compressor delivery temperature, evaporator inlet temperature and the freezer temperature. An ammeter is mounted at the inlet of the compressor to measure the power supply.

As per the refrigerator manufactures recommendation quantity of charge requirement for HFC134a was 100 g. In the experiment, refrigerant charge is 10% higher due to the presence of instruments and connecting lines etc. To optimize the mixed refrigerant charge, the refrigerator is charged with 80g. The refrigerator was charged with 110 g of R134a and the base line performance was studied. After completing the base line test with R134a, the refrigerant was recovered from the system and charged with 80g of mixed refrigerant and the performance was studied. The refrigerant charge requirement with hydrocarbons is very small due to their higher latent heat of vaporization.

Since the hydrocarbons are having flammability R134a is added to these hydrocarbon mixtures in some percentages. During the experimentation the atmospheric is maintained at 28 ± 2 oC. The experimental procedures were repeated and take the reading for different mixtures from the various modes. Service port is installed at the inlet of expansion valve and compressor for charging and recovering the refrigerant. The liquid refrigerant at low-pressure side enters the evaporator. As the liquid refrigerant passes through the evaporator coil, it continually absorbs heat through the coil walls, from the medium being cooled.

III.RESULTS AND DISCUSSIONS

The refrigerating effect is the main purposes of the refrigeration system. The experiment was performed on the household refrigerator purchased from the market, the components of the refrigerator was not changed or modified. This indicates the possibility of using mixed refrigerant as an alternative of HFC-134a in the existing refrigerator system.

The COP, refrigeration effect, work done, and cooling time of the household refrigerator using R-134a as a refrigerant was considered as benchmark and the COP, refrigeration effect, work done, and cooling time of mixed refrigerant compared. The properties are calculated using the software REFPROP. The temperature versus COP, temperature versus refrigeration effect were plotted at the refrigerant R-134a and mixed refrigerant-1, mixed refrigerant-2 mixed refrigerant-3 mixed refrigerant-4 mixed refrigerant-5 (without load & without load) in the different graphs.

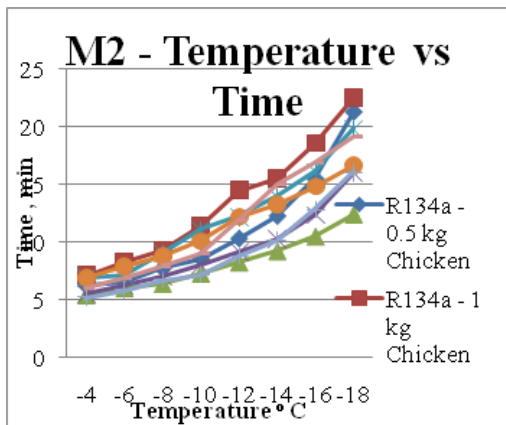


Figure 2 R134a & Mixed Refrigerant 2 – With Load (Temp. vs Pressure)

Figure 2 shows the observed values for R134a and mixed refrigerants at different load condition. i.e., 0.5kg, 1 kg Chicken and 0.5kg, 1 kg vegetables. For this observation, 0.5kg vegetable reach -18oC in a short duration of 12 minute for R134a.Using R134a, 1 kg chicken will take maximum time of 23 minutes to reach -18oC. At the same time the involvement of mixed refrigerant 1kg of chicken reaches -18oC in duration of 17minutes. Based on the above graph, we observe a drastic change of while using a mixed refrigerant compared with R134a.

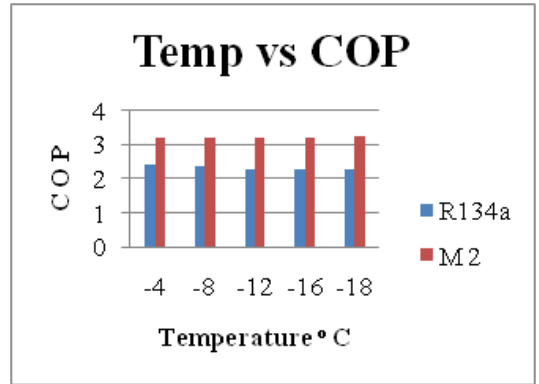


Figure 3 R134a & Mixture 2– Load condn. (Temp. vs COP)

Figure 3 shows the observed values of COP for R134a and mixed refrigerants at different temperatures. COP of the Mixed Refrigerant shows more COP compared to Refrigerant R134a.

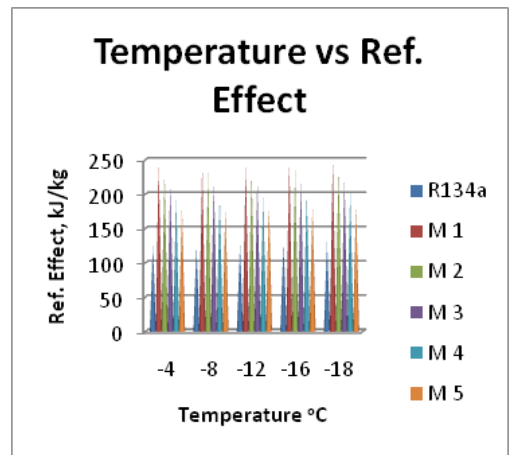


Figure 4 Temperature vs Refrigeration Effect

Fig 4 shows the observed values for R134a and different mixtures for temperature vs Refrigeration Effect From the graph we can identify that Mixture 2 has more refrigeration effect for the corresponding temperature than basic refrigerant and other mixtures.

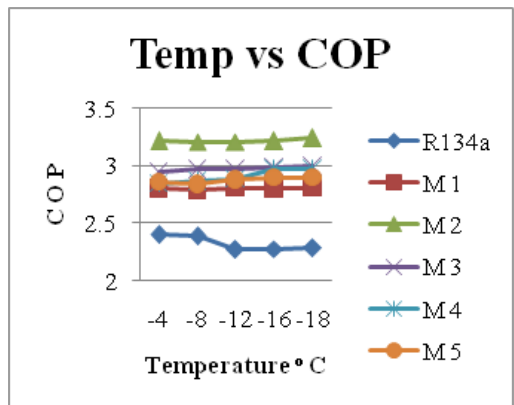


Figure 5 R134a& Mixures. (Temp. vs COP)

Figure 5 shows the observed values of COP for R134a and mixed refrigerants at different temperatures. COP of the Mixed Refrigerants shows more COP compared to Refrigerant R134a. COP of Mixture 2 has more COP for the corresponding temperature than other mixtures.

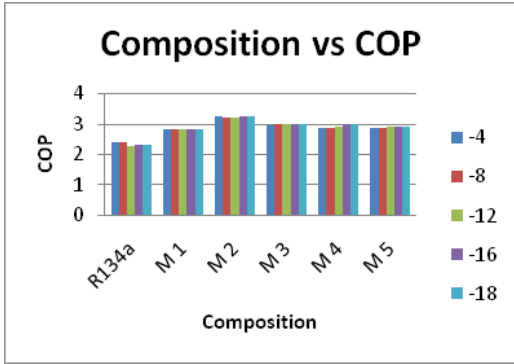


Figure 6 Composition vs COP

Figure 6 shows the observed values for R134a and different mixtures for COP Vs Composition. As the percentage of R134a in the ternary mixture was increased, corresponding saturation pressures are matching closely with the pure R134a as shown in Figure 6 which reflects the proposed alternative mixture can be used as drop in replacement for R134a. The COP started increasing with the increasing percentage R134a and reach a maximum value at 15% of R134a (Mixture-2) and then started decreasing with a further increase in R134a mass fraction.

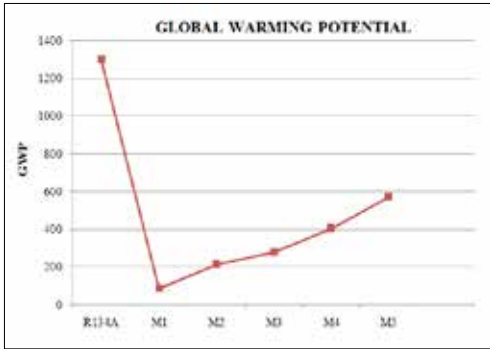


Figure 7 Global Warming Potential vs Mixtures.

Figure 7 shows the observed values of Global Warming Potential vs Different Refrigerant Mixtures. From the graph it is observed that Refrigerant R 134a has maximum GWP of value 1300. Mixture 1 has GWP of about 80 which is less than 100. Mixture 2 has GWP about 135 which is less than 200. Mixture 3 has GWP about 260 which is less than 300. Mixture 4 has GWP about 380 which is less than 400 and Mixture 5 has GWP about 560. If we increase the usage of Refrigerant R 134a, the Global warming Potential is increasing randomly.

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. They are usually used to address problems that are intractable or cumbersome to solve with traditional methods. They can also be used as an alternative approach to obtain a simple mathematical correlation between input and output values with high accuracy.

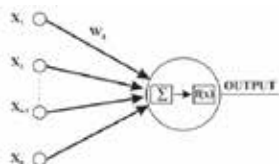


Figure 8 Operation of a neuron

We have used various ratios of refrigerant mixtures such as R134a, R290, R600a, and R600. They were used as inputs while the COP calculated shown us below, were the outputs. There were 5 inputs and 5 outputs for the system. The input parameters are R134a, R290, R600a, and R600. The output parameters were COP values. 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.

$$X = [\text{Mixture 1, Mixture 2, Mixture 3, Mixture 4, Mixture 5,}]$$

$$Y = [\text{COP}]$$

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 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

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.

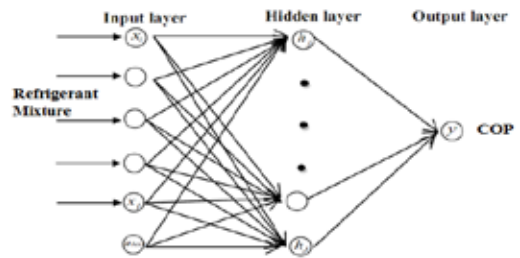


Fig 9 Architecture of Neural Network

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

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

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

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

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

Table 1 Input and output (i.e. COP) samples for the network

MIXTURE NO	R134a	R290	R600a	R600	COP
1	5	45	45	5	2.78
2	15	40	40	5	3.20
3	20	37.5	37.5	5	3.1
4	30	32.5	32.5	5	3.09
5	40	27.5	27.5	5	3.0

The back propagation algorithm is used in feed forward single hidden layer network. The back propagation algorithm has different variants. The back propagation algorithms gradient descent and gradient descent with momentum are too slow for practical problems because they require small learning rates for stable learning. 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.

The artificial neural network used in SAR modeling was made in the MATLAB (version 7.9.0 (R2009B)) environment using a neural network tool box. The available data obtained from the experimental observations are divided into training and testing sets. The range of input data used for the ANN modeling is shown in Table 1. The data set consists of 20 input values. From these data sets are used for training and the remaining is used for testing the network. The performance parameters of the network with log-sig transfer function and different variants are shown in

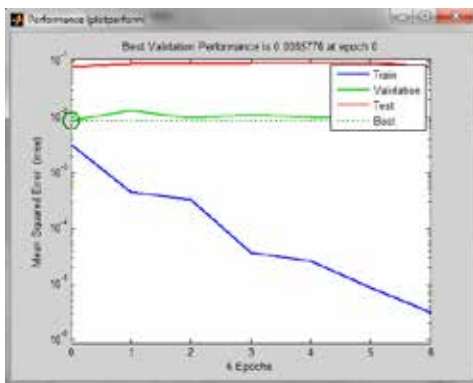


Fig 10 Chart showing best performance

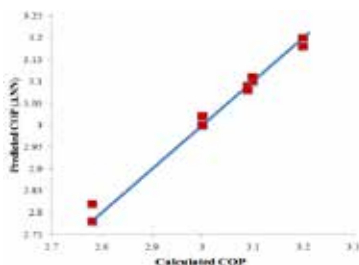


Figure 11 Comparison of calculated and predicted COP

The field of neural networks is vast and interdisciplinary. Speed of calculation, capability of learning from examples and simplicity are the advantages of the ANNs. These features enable the ANNs to be used in thermal systems. Reducing the time and effort spent for the numerical studies using our approach for other mixture ratios, the COP and the TI values can be achieved. The above chart shows the same values for the training data. As shown, corroboration once again occurs. From above table some COP calculations have been shown in respect of the learning algorithms and hidden numbers.

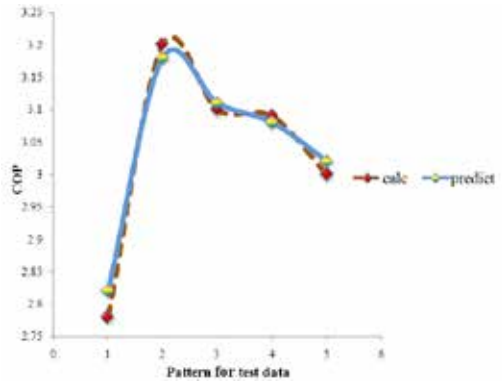


Figure 12 Pattern for the test data.

The above chart shows the results corresponding to test data: the calculated and predicted COP values are very close to each other.

V. CONCLUSION

The performance parameters investigated are the refrigeration effect, the evaporator temperature and the coefficient of performance (COP). The refrigerator worked efficiently when mixed refrigerant was used as refrigerant instead of R134a. The evaporator temperature reached -21°C with COP value of 3.24 and an ambient temperature of 30°C in the mixture-2(15%R134a/40%R290/ 40%R600a/5% R600) is used as alternate refrigerant to the traditional refrigerant R134a. The results of the present work indicate the successful use of this mixed refrigerant as an alternative to R134a in domestic refrigerators.

1. Every mode of mixed refrigerant yields higher COP than R-134a.
2. From using the mixed refrigerant in domestic refrigerator, we were observed the freezer temperature lower than that of the R134a.
3. When the evaporator temperature increases, COP will be increases and the condenser temperature decreases, COP will also increases.

The aim of this analysis is to show the possibility of the use of neural networks for the calculation of the performance of a vapor-compression refrigeration system using refrigerant mixtures. Results, the networks can be used as an alternative way in these systems. The RMS error values are smaller than 0.002 and R2 values are about 0.99999, which can be considered to be excellent.

The statistical values corresponding to both the test data and COP predictions obtained from different learning algorithms and varying hidden number of neurons. Although the LM, the SCG—except for the 3hidden layer neurons (and the CGP) with the 7hidden layer neurons—have produced fine values; the LM algorithm with 5neurons has produced the best results.

The maximum error level in this algorithm is 0.85% in training and 0.18% in testing; the mean error level is 0.07% in the training and 0.08% in the testing, and the RMS value is

0.00024 in the training and 0.00022 in the testing sessions. The results with the SCG (3hidden numbers) and CGP (with 3,4,5,6 hidden neurons) produced maximum mean error percentages of 0.71. Even this value is regarded as within the acceptable ranges in different applications found in the literature. Therefore, we can comfortably say that the network is accepted, because, as it can be seen from Table3, the R2 approximates to unity.

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