ENERGY SAVINGS WITH THE EFFECT OF MAGNETIC FIELD USING R290/600a MIXTURE AS SUBSTITUTE FOR CFC12 AND HFC134a

by

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Original scientific paper
UDC: 66.045.5:537.632/.636
BIBLID: 0354-9836, *12* (2008), 3, 111-120
DOI: 10.2298/TSCI0803111M

This paper presents an experimental study on the replacement of CFC12 and HFC134a by the new R290/R600a refrigerant mixture as drop-in replacement refrigerant with and without the effect of magnetic field. Without any modification to the system components drop-in experimental tests were performed on a vapour compression refrigeration system with a reciprocating compressor, which was originally designed to operate with CFC12.The test results with no magnets showed that the refrigerant R290/R600a had 19.9-50.1% higher refrigerating capacity than R12 and 28.6-87.2% than R134a. The mixture R290/R600a consumed 6.8--17.4% more energy than R12. The coefficient of performance of R290/R600a mixture increases from 3.9-25.1% than R12 at lower evaporating temperatures and 11.8-17.6% at higher evaporating temperatures. The effect of magnetic field force reduced the compressor energy consumption by 1.5-2.5% than with no magnets. The coefficient of performance of the system was higher in the range 1.5-2.4% with the effect of magnetic field force. The R290/600a (68/32 by wt.%) mixture can be considered as an excellent alternative refrigerant for CFC12 and HFC134a systems.

Key words: *hydrocarbon mixture, alternative refrigerants, ozone layer depletion, global warming, magnetic field*

Introduction

The refrigerants chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) both have high ozone depleting potential (ODP) and global warming potential (GWP), and contributes to ozone layer depletion and global warming. Therefore these two refrigerants are required to be replaced with environmentally friendly refrigerants to protect the environment. The hydrofluorocarbon (HFC) refrigerants with zero ozone depletion potential have been recommended as alternatives. Devotta *et al.* [1] have suggested that R134a is the long-term replacement refrigerant for R12 because of having favourable characteristics. The ODP of R134a is zero, but it has a relatively high global warming potential. The issues of ozone layer depletion and global warming have led to consideration of hydrocarbon refrigerants such as propane, isobutene, n-butane or hydrocarbon blends as working fluids in refrigeration and air-conditioning systems. Hydrocarbons are designated as A3 (highly flammable) refrigerants by ASHRAE standard 34, the industry standard for refrigerant classification. Hydrocarbon (HC) refrigerants have several positive characteristics such as zero ozone depletion potential, very low global warming, non-toxicity, high miscibility with mineral oil, good compatibility with the materials usually employed in refrigerating systems. The main disadvantage of using hydrocarbon as refrigerants is their flammability [2, 3]. If safety measures are taken to prevent refrigerant leakage from the system then a flammable refrigerant could be as safe as other refrigerants.

The effect of magnetic field is not still considered as a well-known subject. It is believed that magnetic field could have an enhancement effect on heat transfer properties. Several studies have been reported on the use of magnetic elements in enhancing the performance in many applications such as oil, natural gas furnaces, diesel engines, fuel lines, and also in water treatment.

Many studies have been concentrated on the research of substitutes for CFC12. Richardson *et al.* [4] have investigated the performance of HC290/HC600a mixture in a vapour compression refrigeration system. It was shown that propane and propane/isobutane mixtures may be used in an unmodified R12 system and gave better coefficients of performance (*COP*) than R12 under the same operating conditions. Mixtures of around 50% propane and 50% isobutane have very similar saturation characteristics to R12 but *COP* would seem to improve as the proportion of propane is increased. Jung *et al.* [5] have tested the performance of R290/R600a mixture in the composition range of 0.2 to 0.6 mass fractions of R290 yields an increase in *COP* of 1.7 to 2.4% as compared to R12. R290/R600a mixture at 0.6 mass fraction of R290 showed a 3 to 4% increase in energy efficiency and a faster cooling rate as compared to R12. Baskin [6] has studied different mixtures of HC600a/HC290 performance in residential refrigerator/freezers. The 60/40% and 70/30% (isobutane/propane) were the best overall mixtures. Kuijpers *et al*. [7] have theoretically showed that 21/79 wt.% propane/isobutane mixture should be considered as a substitute to CFC12. This composition has an evaporation pressure and volumetric refrigeration capacity comparable to CFC12. Hammad *et al.* [8] have carried out experimental study with four ratios of propane, butane and isobutene as possible alternative to R12 in an unmodified R12 domestic refrigerator. The hydrocarbon mixture with 50% propane, 38.3% butane, and 11.7% isobutene showed better performance among all other hydrocarbon mixtures investigated. Experimental results of Jung *et al*. [9] have indicated that the mixture of propane and iso-butane with 60% mass fraction of propane has higher *COP*, faster cooling rate, shorter compressor on-time and lower compressor dome temperatures than R12. Akash *et al*. [10] have conducted performance test with LPG (30% propane, 55% n-butane and 15% iso-butane by mass fraction) as a possible substitute for R12 in domestic refrigerator. The cooling capacity and *COP* were comparable to those of R12.

Sami *et al.* [11] have presented the test results of the performance of new alternative refrigerants such as R410A, R507, R407C, and R404A under various conditions of magnetic field. They reported that the increase in magnetic field force, increases compressor head pressure and discharge temperature slightly as well as less liquid refrigerant was boiling in the compressor shell. The magnetic field was applied to the working fluid in the liquid phase to disrupt intermolecular forces in the working fluid and enhance expansion of the working fluid molecules. This reduces the amount of residual liquid that is boiled in the compressor shell, lowering the power consumption of the compressor and improving the performance of the system. They also reported that the increase in the magnetic field force (Gauss level) enhances the *COP* of the system. Sami *et al.* [12] have presented the test results of the performance of new alternative refrigerants such as R410A, R507, R407C, and R404A under various conditions of magnetic field. They reported that the effect of magnetic field on refrigerant mixture varies from one mixture to another depending upon the mixture's composition, boiling point, and thermo physical properties. They also reported that the use of magnetic fields have influence on thermal capacities of the condenser and evaporator.

Figure 1 shows the saturated vapour pressure *vs*. temperature for R12, R134a, and R290/R600a (68/32 by wt.%) mixture. It was observed from fig. 1 that the saturated vapour pressure curve for propane/isobutane mixture of propane concentration equal to 68% is very close to the vapour pressure curves of the refrigerant R12 and R134a, and can be used as a potential retrofit refrigerant. The R290/R600a (68/32 by wt.%) is a zeotropic blend with temperature glide of 7.6 °C at 101 kPa and it shows different vapour and liquid compositions when in equilibrium. Mixtures with temperature glide about 5 °C or larger offer a theoretical potential to improve the performance of the vapour compression systems. In this work the refrigerant R290/R600a (68/32 by wt.%) was selected and studied in a vapour compression refrigeration system with and without the effect of magnetic field force and compared with R12 and R134a. The refrigerant propane/isobutane mixture is being sold under different brand names as substitutes for CFC12. But this R290/R600a (68/32 by wt.%) mixture is a new HC blend composed of propane 68% and isobutane 32% on mass basis and performed better than other propane/isobutene mixtures. Initially the system was checked for leakage and then the refrigerant R290/R600a (68/32 by wt.%) mixture was charged in the liquid state to assure proper mixture.

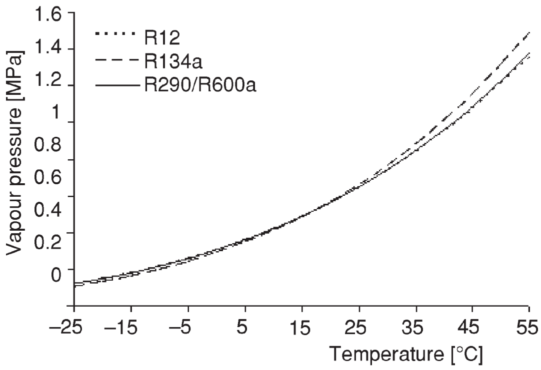

Figure 1. Vapour pressure curves for R12, R134a, and R290/R600a (68/32)

Experimental apparatus

An experimental setup of a vapour compression refrigeration system was built to investigate the performance R12, R134a, and R290/R600a (68/32 by wt.%) mixture. A schematic diagram of the experimental setup is shown in fig. 2. It consisted of two loops; a main loop and a secondary loop. The main loop was composed of compressor, condenser, a filter-drier, refrigerant flow meter, sight glass, expansion valve, and evaporator. The compressor was an open, reciprocating type. The rotating speed of the compressor was 855 rpm and its speed could be changed by a variable diameter belt pulley of the electrical motor.

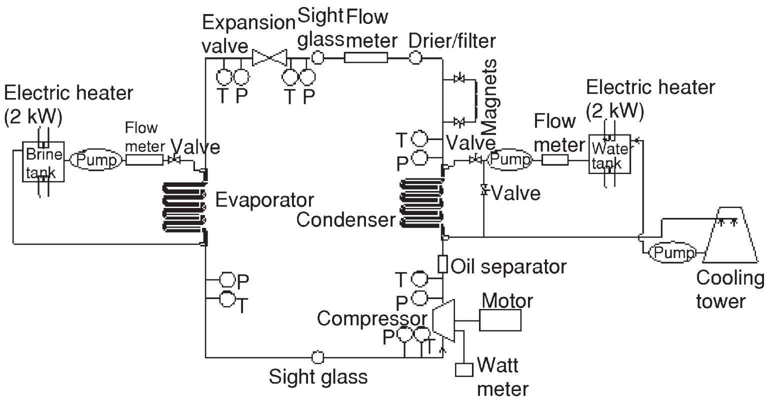

Figure 2 . Schematic diagram of the experimental setup

The condenser and evaporator were of both copper double tubes. In the double tube condenser, the refrigerant flows through the inner tube while the cooling water flows through the annular space between the inner and outer tubes. In the double tube evaporator the brine solution (calcium chloride/water solution) flows through the inner tube and the refrigerant flows through the annular space between them. For minimizing the heat loss, the outer tube was well insulated. Two sight glasses were incorporated into the system, one in the liquid line at the condenser outlet and another in the vapour line at the evaporator outlet in order to give a visual indication of the refrigerant circulation. The secondary loops were composed of a pump, a flow meter, and an electrically heated unit within the insulated tank. One tank was filled with cooling water and circulated through the condenser tubes while the other tank was filled with brine solution and circulated through the evaporator tubes. The hot water coming out of the condenser tube was supplied to a cooling tower to be cooled. This cooled water was pumped to the cooling water tank via a separate pump. Six magnetic elements with a Gauss level of 4000 each were employed in this study. The dimensions of the magnets are 25 25 10 mm. These magnets were placed on the refrigerant full liquid line at condenser outlet. This is confirmed by observation through the sight glass.

Experimental procedure

The main objective of this study is to compare the compressor energy consumption and system coefficient of performance with and without the effect of magnetic field. Rotameters were used to measure the flow rates of the cooling water and brine solution with an accuracy of 0.05 L per minute. The refrigerant flow meter was used to measure the refrigerant flow rate with an accuracy of ±0.0125 kg per minute. RTD type thermocouples were used to measure the temperatures with an accuracy of 0.1 °C and pressures were measured using calibrated pressure gauges with an accuracy of 1 psi. Each sensor was calibrated to reduce experimental uncertainties. The range and accuracy of equipment used in the experimental test setup are summarized in tab.1. The temperatures and pressures of the refrigerant and secondary fluid temperatures were measured at various locations in the experimental setup as shown in fig. 2. The compressor power consumption was measured using a wattmeter. The accuracy of rotation of wattmeter disc was 1 s for 10 revolutions. An expansion device was used to regulate the mass flow rate of refrigerant and to set pressure difference. The refrigerant was charged after the system had been evacuated.

Table 1. Range and accuracy of the measuring equipment used in the test setup

Measuring equipment	Range	Accuracy
Temperature sensor	–100 to 100 °C	0.1 ºC
Pressure gauge 1	0-300 psi	1 psi
Pressure gauge 2	0-150 psi	1 psi
Refrigerant flow meter	0-2.3 kg per minute	0.0125 kg per minute
Rotameter	0-5 L per minute	0.05 L per minute
Wattmeter disc rotation	10 revolutions	1 s
Electronic balance weight	0-50 kg	1 g

The working fluids were R12, R134a, and R290/R600a (68/32 by wt.%). Drop-in experiments were carried out without any modifications to the experimental apparatus. The experiment was started with R12 to set up the base reference for further comparisons with the other two refrigerants. The desired evaporating temperatures (T_e) and condensing temperatures (T_c) were obtained by adjusting all the other parameters in the system such as cooling water flow rate and its temperature, refrigerant flow rate, and brine solution flow rate, and its temperature. The thermodynamic properties of the refrigerants were taken from the NIST [13] REFPROP database. The readings were taken after the system had reached steady-state conditions. The absolute errors in the refrigerating capacity (*RC*), compressor energy (*CE*), and *COP* estimated by the single sample analysis according to ASHRAE Guideline 2 [14] were 0.044, 0.015, and 0.123, respectively.

Results and discussion

The experimental results of the refrigerants with no magnets were used as a baseline for this study. When a test with one particular refrigerant was completed, the system was evacuated and then recharged with the preferred refrigerant. This procedure was followed for every alternative refrigerant. The performance was calculated using the coolant brine mass flow rate and the difference of coolant temperatures across the evaporator coil.

Refrigerating capacity

The figs. 3, 4, and 5 show the variation of refrigerating capacity against evaporating temperature for the condensing temperatures (T_c) of 35, 40, and 45 °C, respectively, with and without magnetic field effect. The reduced specific volume of the refrigerant vapour increases the refrigerant circulated per unit of time. As a result, the refrigerating capacity obtained from all the refrigerants increases with increasing evaporator temperature. It was observed that the re-

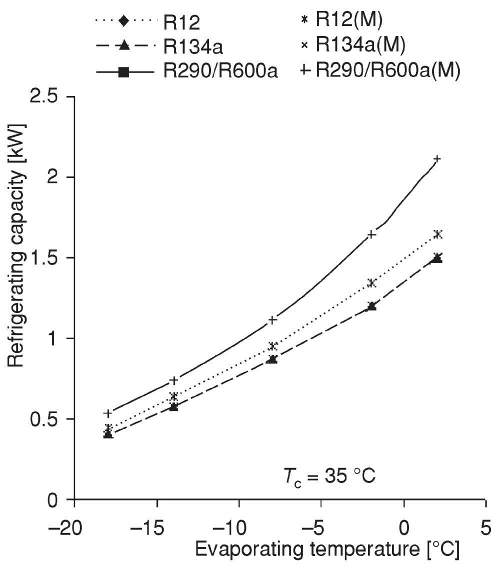

Figure 3. *RC vs.* T_e with (M) and without magnetic field effect for T_c = 35 °C

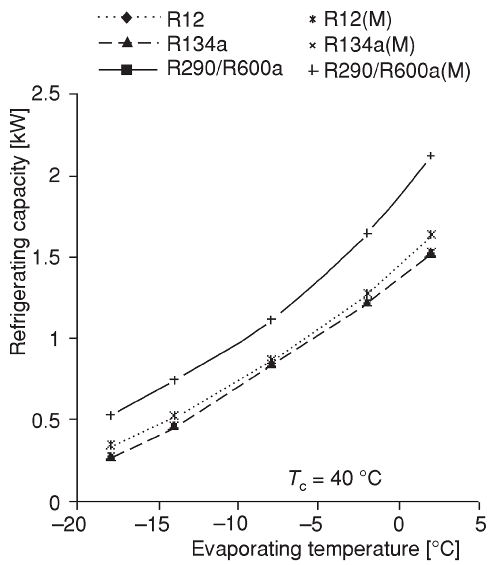

Figure 4. *RC vs.* T_e with (M) and without magnetic field effect for T_c = 40 °C

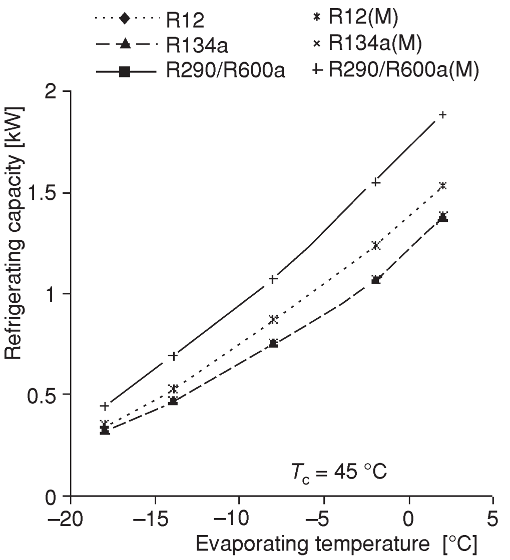

Figure 5. ***RC vs.*** ***T_e*** **with (M) and without magnetic field effect for** ***T_c*** **= 45 °C**

frigerant mixture R290/R600a (68/32) had a higher refrigerating capacity than R12 and R134a due to its higher latent heat of evaporation.

The refrigerating capacity of R290/R600a (68/32) mixture was 19.9-50.1% higher than R12 and 28.6-87.2% higher than R134a for the lower evaporating temperatures while 21.2-28.5% higher than R12 and 30.7- 41.3% higher than R134a for the higher evaporating temperatures with and without magnets. R134a showed a slightly lower refrigerating capacity than R12 for all the operating conditions. There was no significant change in the refrigerating capacity with magnetic field effect. It can be seen from these figures that the refrigerating capacity decreases with increasing condensing temperature for the mixtures, R12 and R134a due to their reduced mass flow rate.

Compressor energy

Figures 6, 7, and 8 show that the energy consumed by the compressor increases as the evaporating and condensing temperature increases with and without the effect of magnetic field. It is found that when the evaporator temperature increases the power consumed by the compressor increases for all the selected refrigerants. This is due to the increased mass flow rate of the refrigerants at higher evaporating temperatures. It can be seen from these figures that the increase

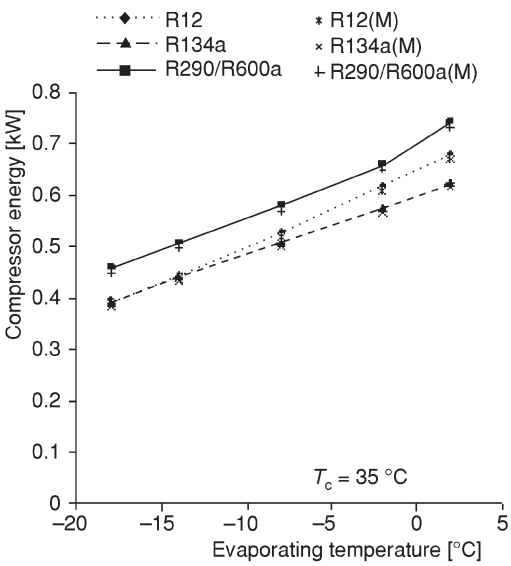

Figure 6. ***CE vs.*** ***T_e*** **with (M) and without magnetic field effect for** ***T_c*** **= 35 °C**

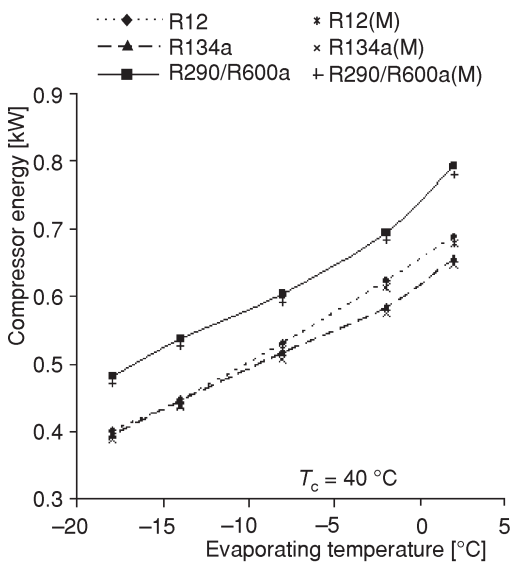

Figure 7. ***CE vs.*** ***T_e*** **with (M) and without magnetic field effect for** ***T_c*** **= 40 °C**

of condensing temperature causes the increase of compressor energy due to the increase in the work of compression per unit mass. Test results showed that the energy consumed by the system with R290/R600a (68/32) mixture was higher by 6.8-17.4% than R12 and 8.9-20% higher than R134a for all the operating conditions without the magnetic field effect. The energy consumed by the system with R134a was slightly lower than R12 at higher evaporating temperatures while at lower evaporating temperatures both R12 and R134a consumed nearly the same energy with no magnets. For a specific evaporating temperature the R290/R600a mixture consumes more power than that of R12 and R134a due to its higher latent heat of evaporation.

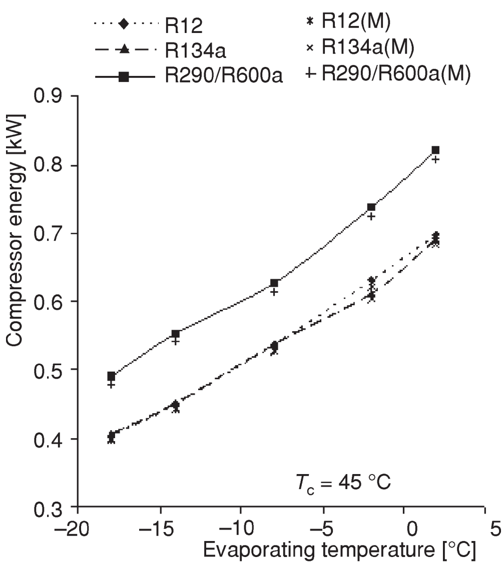

Figure 8. ***CE vs.*** T_e **with (M) and without magnetic field effect for** T_c **= 45 °C**

The vapour compression refrigeration system consumes a significant amount of energy. The energy consumed by the compressor in a vapour compression refrigeration system is often limited by incomplete or inefficient evaporation and condensation of the refrigerant. When evaporation of the refrigerant is incomplete, some of the refrigerant enters the compressor in the liquid phase. The compressor must consume additional energy to boil the liquid refrigerant that enters the compressor. The application of magnetic field to the working fluid in a vapour compression refrigeration system disrupts the intermolecular forces in the working fluid. The magnetic field is applied to the fluid before the fluid is conveyed through an expansion valve to enhance vaporization of the fluid. This reduces the energy consumption of the compressor. Experimental results with the effect of magnetic field force showed that the compressor consumed 1.5-2.5% less energy than that with no magnets for all the operating conditions. Previous studies have shown that the decrease of the power consumption was around 8% [11]. It is observed that the magnets reduce slightly the power consumption of the compressor and it depends on the impact of the Gauss levels of the magnets. It is observed that increasing Gauss levels decreases the compressor power and therefore enhance the *COP*. The behaviour of refrigerants varies from one refrigerant to another depending upon the mixture's composition and its boiling point.

Coefficient of performance

The figs. 9, 10, and 11 show the *COP* for R12, R134a, and R290/R600a (68/32 by wt.%) mixture for various evaporating temperatures with condensing temperature of 35, 40, and 45 °C, respectively, with and without magnetic field effect. The *COP* of all the selected refrigerants increases with increasing evaporating temperature. This is because the increase of refrigeration capacity is more than that of the compressor work. It was observed that the *COP* of R290/R600a (68/32 by wt.%) mixture was 3.9%-25.1% higher than R12 at the lower evaporating temperatures while 11.8-7.6% higher than R12 at the higher evaporating temperatures without magnetic field effect. The *COP* of R134a was lower than R12 for all the operating conditions. It can be seen from the figures that the increase of condensing temperature causes the

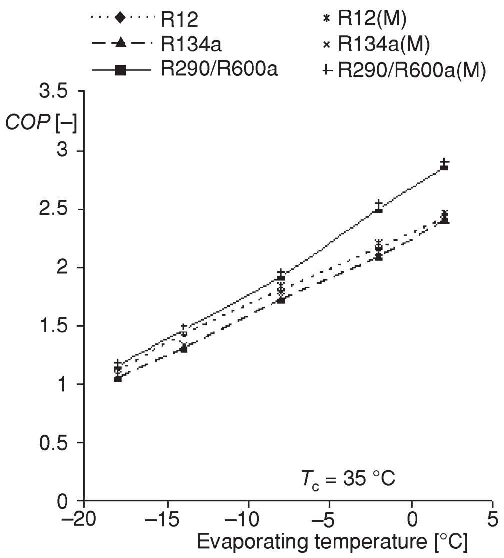

Figure 9. *COP vs.* T_e with (M) and without magnetic field effect for T_c = 35 °C

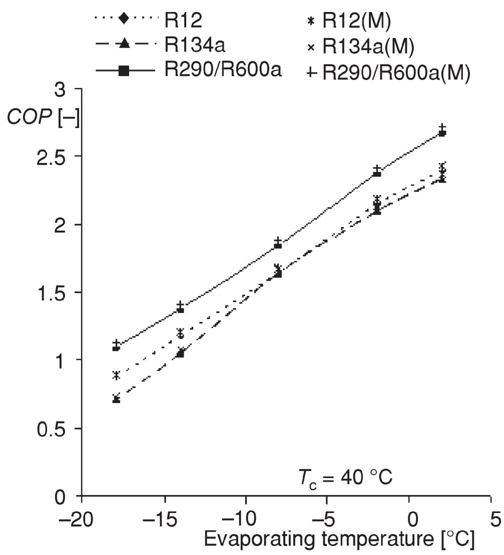

Figure 10. *COP vs.* T_e with (M) and without magnetic field effect for T_c = 40 °C

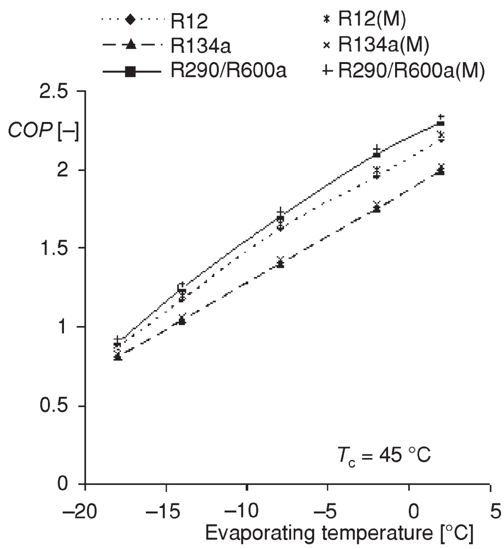

Figure 11. *COP vs.* T_e with (M) and without magnetic field effect for T_c = 45 °C

reduction of *COP* of R12, R134a, and R290/R600a (68/32). This is due to the increased work of compression at higher condensing temperatures.

For a specific evaporating temperature the R290/R600a (68/32) mixture refrigerant shows higher *COP* than that of R12 and R134a. This is due to the rate of increase in refrigerating capacity of R290/R600a (68/32) mixture refrigerant is higher than the rate of increase of compressor work than that of the refrigerants R12 and R134a. The effect of magnetic field force increased the *COP* of the system in the range 1.5-2.4% for all the operating conditions due to the reduced work of compression than that with no magnets.

Conclusions

An experimental study on a vapour compression refrigeration system with the new propane and iso-butane mixture as substitute for CFC12 and HFC134a was made under the effect of magnetic field force and compared with that of no magnetic field condition.

The propane-isobutane mixture has been identified as a drop-in replacement refrigerant for conventional CFC12 and HFC134a.

Refrigerating capacity of R290/R600a (68/32 by wt.%) mixture was higher in the range 19.9-50.1% in the lower evaporating temperatures and 21.2-28.5% in the higher evaporating temperatures than R12 without magnetic field effect.

Refrigerating capacity of R290/R600a (68/32 by wt.%) mixture was higher in the range 28.6-87.2% in the lower evaporating temperatures and 30.7- 41.3% in the higher evaporating temperatures than R134a without the effect of magnetic field. There was no significant influence of magnetic field force on the refrigerating capacity.

The power consumed by R290/R600a (68/32) mixture was lower in the range 1.5-2.5% for all the operating conditions with the effect of magnetic field force.

The *COP* of R290/R600a (68/32 by wt.%) mixture was 3.9-25.1% higher than R12 without magnetic field effect. The effect of magnetic field force increased the *COP* of the system in the range 1.5-2.4% for all the operating conditions.

The magnetic field force had no significant influence on discharge temperature and discharge pressure for all operating conditions.

During the experimental test R290/R600a mixture were found to be safe. However care should be taken when using R290/R600a mixture in a refrigeration/heat pump system. From the two major environmental impact (ozone layer depletion and global warming) point of view this R290/R600a (68/32 by wt %) mixture can be used as a drop-in replacement refrigerant for CFC12 and HFC134a.

Nomenclature

CE – compressor energy, [kW]
CFC – chlorofluorocarbon
COP – coefficient of performance, [–]
GWP – global warming potential
HCFC – hydrochlorofluorocarbon
HFC – hydrofluorocarbon
HC – hydrocarbon
ODP – ozone depletion potential
RC – refrigerating capacity, [kW]
T – temperature, [°C]

Subscripts

c – condensing/condenser
e – evaporating/evaporator

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Paper submitted: November 17, 2007
Paper revised: April 1, 2008
Paper accepted: May 2, 2008