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Behaviour of new refrigerant mixtures under magnetic field

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SUMMARY

The behaviour of some new alternative refrigerant mixtures such as R-410A, R-507, R-407C, and R-404A under various conditions of magnetic field are discussed, analysed and presented.

The effect of magnetic field on mixture behaviour varies from one mixture to another depending upon the mixture's composition and its boiling point and consequently on the thermophysical properties. Furthermore, the use of magnetic field appears to have a positive influence on the thermal capacities of the condenser and the evaporator depending upon the refrigerant mixture's thermophysical properties. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS: refrigerant mixtures; magnetic field; thermodynamic properties

1. INTRODUCTION

The effect of magnetism and the magnetic field on fluids is still considered as not a well known subject. However, it is well established that there are major changes caused by the passage of fluid through the magnetic field.

Several magnetic refrigeration devices under development by Astronautics using convention NbTi magnets have been described by Zimm and DeGrgoria (1992). The system advantages of incorporating high-temperature super conducting magnets in designs have been discussed. The authors also explained the nature of active magnetic regenerative (AMR) cycle and its requirements in refrigeration.

Research on magnetic caloric effect and its application has been discussed by Gschneidddner and Pecharsky (1999) for cooling near room temperature. The study included the relationship between the nature of magnetic transformation and the temperature dependence of the magnet caloric effect and the entropy utilized in the magneto-caloric.

The magnetic measurements to evaluate the thermodynamic behaviour of magnetic material have been presented by Foldeaki *et al.* (1995). As reported in this reference depending on the

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thermodynamic cycle selected, the isothermal magnetic entropy change temperature or the adiabatic temperature change upon the field application should be reselected as a function of temperature. This paper presented classical magnetic measurements, when evaluated within the framework of the Landau theory.

A magnetic heat pumping can be made according to Brown (1976) using a ferromagnetic material with a Curie point and an appropriate thermodynamic cycle. The regenerative magnetic cycle can approach the Carnot cycle efficiency, as reported by Brown.

Furthermore, most refrigeration and air conditioning systems experience load variation. High efficiency and high performance are greatly in demand. Among techniques employed for improvement, capacity control, optimization of vapour compression systems are the refrigerant liquid and vapour injection. However, it is believed that the magnetic field can be employed as an enhancing technique.

Several studies reported in the literature demonstrated the magnetic field and its capabilities as well as its impact on the thermodynamic characteristics. However, as the electrical hydrodynamic (EHD) technique has shown an improvement in the heat transfer on the refrigerant side (Muraki *et al.*, 2001), 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. To the authors knowledge none have been reported on the use of magnets as a performance enhancer in the refrigeration industry.

Recently, Sami and Aucoin (2003) presented the test results of the performance of new alternative refrigerant mixtures such as R-410A, R-507, R-407C, and R-404A under various conditions of magnetic field. The test results demonstrated that as liquid injection ratio increases, compressor head pressure and discharge temperature decrease. This has a positive effect in protecting the compressor. The effect of liquid injection on mixture behaviour varies from one mixture to another depending upon the mixture's composition. Furthermore, liquid injection appears to have a significant influence on R-410A behaviour compared to the other mixtures in question.

Therefore, this paper is concerned with the analysis of some refrigerant mixtures behaviour inside enhanced surface tubing air-fined heat exchangers under magnetic field at various forces of the magnetic field (gauss levels). The blends under consideration in this study are R-507 (R-125/R-143a:50/50%), R-404A(R-125/R-143a/R-134a:44/52/4%), R-410A(R-32/R-125:50/50%), and R-407C (R-32/R-125/R-134a:23/25/52%). All percentages of the aforementioned blends are based on weight.

2. EXPERIMENTAL APPARATUS AND MEASUREMENTS

An experimental set-up, which is an air-source vapour compression heat pump, has been employed in this study, which is mainly composed of a 3 kW compressor, oil separator, condenser, pre-condenser, post-condenser, pre-evaporator, adjustable expansion device, capillary tubes, and evaporator. Three magnetic elements with gauss level of 4000 each have been employed in this study. These magnets were intended for gasoline fuel line of 1/4 in diameter; they were clamped at the refrigerant line of the same diameter. The units were single type with two brackets strapped around the pipe. They were clamped on the refrigerant liquid line at the post condenser outlet at various distances, before the capillary tube/thermal expansion valve used as a flow control device. During the course of this experimental study, series of three magnets were used totalling 12 000 gauss levels. The magnets were placed at three locations of the outlet of the post-condenser.

The oil content in the refrigerant loop was estimated to be about 1% using gas chromatography and refrigerant parameters such as pressure, temperature and flow rate were measured and recorded. Readers interested in details of the set-up and measuring stations are advised to consult reference Sami and Aucoin (2003).

Data collection was carried out using a computer equipped with a data acquisition system. This enabled us to record, at a single scan, the local properties such as pressure drops, pressure, temperature, and flow rates as well as power consumption for energy balance verifications.

In order to evaluate the blend's performance, the thermodynamic properties of pure and zeotropic refrigerant mixtures should be known. REFPROP (Sami and Aucoin, 2003) version 6.01 was used to evaluate the mixture's characteristics. Furthermore, the thermophysical properties such as the viscosity, thermal conductivity and specific heat were calculated using this version and ASHRAE Fundamentals ASHRAE (2001). Test conditions and coil specifications of the heat exchangers used employed in this study are given in Tables I and II. The geometrical parameters of the micro-fin tubes are also presented in Table III.

Table I. Air coils specifications.

Tube outer diameter	3/8 in
Rows deep	4
Fin per inch	12
Fin depth	3.46 in
Fin height	20 in
Fin length	30 in
Fin thickness	0.0045 in
Rifled tubes	Micro-fins

Table II. Test conditions.

1	Temperature of air of the condenser inlet	21°C
2	Temperature of air at the evaporator inlet	−15 to +8°C
3	Air flow rate	7.07×10^{-2}–$9.4 \times 10^{-2}\,\mathrm{m^3\,s^{-1}}$
4	Refrigerant mass flow rate	8–$40\,\mathrm{g\,s^{-1}}$
5	Condenser pressure	600–1800 kPa
6	Evaporator pressure	170–450 kPa
7	Standard relative humidity at condenser inlet	45%

Table III. Geometry of micro-fin tubes (round tip geometry).

Outside diameter	0.375 in
Root diameter	0.344 in
Tip diameter	0.331 in
Fin height	0.0074 in
Pitch	0.016 in

3. RESULTS AND DISCUSSION

The test conditions were condenser pressure varied between 600 and 1800 kPa, and the condenser refrigerant temperature was between 28 and 38°C. The evaporator pressure ranged from 170 to 450 kPa, and the refrigerant evaporator temperature was between −20 and −6°C. Under these conditions, and at each test, the following parameters have been measured: thermal capacities at evaporator and condenser sides, power consumed by compressor, refrigerant flow rates, coolant flow rates, and refrigerant quality at both evaporator and condenser sides. These parameters are necessary for evaluating the coefficient of performance (COP) under heating and cooling modes.

The COP and heat absorbed/released at system heat exchangers are calculated as follows:

$$\mathrm{COP} = \frac{\text{Heat absorbed/Released}}{\text{Compressor power}} \tag{1}$$

and

$$Q_{a/r} = \dot{m}x\, C_{p,\mathrm{f}} \cdot \Delta T \tag{2}$$

$$Q_{a/r} = \dot{m}x\, \Delta H \tag{3}$$

where $\dot{m}$ and ΔT represent the air mass flow rate, and air temperature differences across the evaporator/condenser coils. $C_{p,\mathrm{f}}$ is the specific heat for airflow and ΔH gives the total air enthalpy difference across the heat exchangers.

Equations (2) and (3) represent the heat exchanger sensible and latent heats, respectively. Equation (3) is employed particularly during cooling load calculation. Only heating tests were considered in this study.

Samples of the test results at the condenser side used as base line data with no magnets were plotted in Figure 1 at various entering air temperatures to the evaporator. As expected, the results plotted in this figure show that the COP heating, increases at higher air temperature

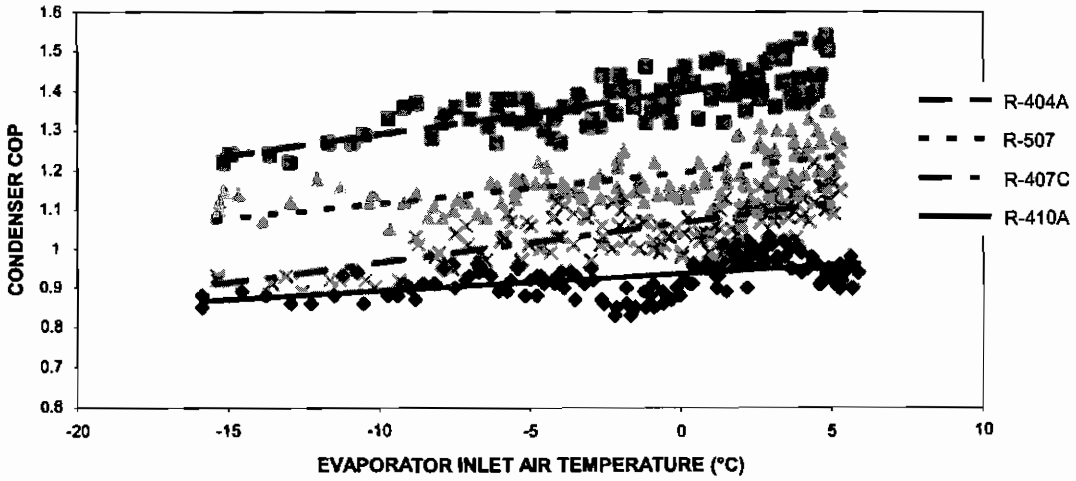

Figure 1. Condensor COP vs evaporator inlet air temperature with no magnets.

entering at the evaporator side. The results also demonstrate that R-404A has the highest COP among the mixtures under investigation.

To demonstrate the influence of number of magnets on the behaviour of the refrigerant, mixtures and the system performance samples of the test results were plotted at various conditions in Figures 2 and 3. It appears from the sample results displayed that the magnets accelerated the increase in the COP compared to the no magnets results.

It is quite clear from Figure 3 that the evaporator COP was enhanced depending on the type of mixture used and its boiling point. It is quite clear from the data in Figure 3 that R-404A behaviour is significantly influenced by the magnetic field force (gauss levels) and power of the magnets.

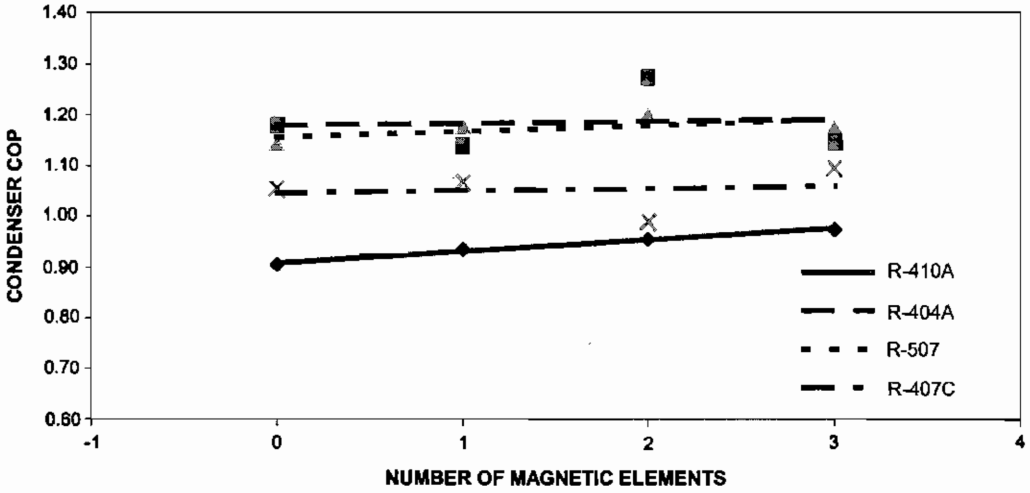

Figure 2. Condensor COP vs number of magnetic elements at constant temperature (0°C).

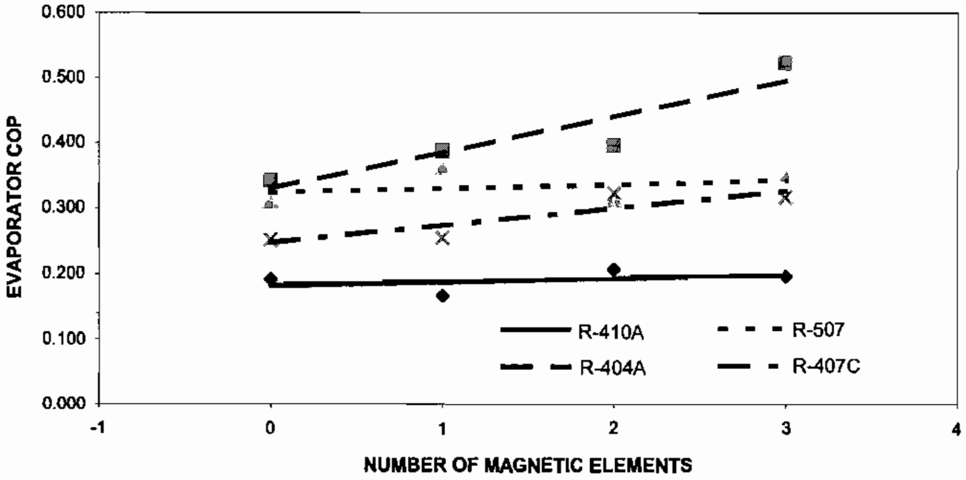

Figure 3. Evaporator COP vs number of magnetic elements at constant temperature (0°C).

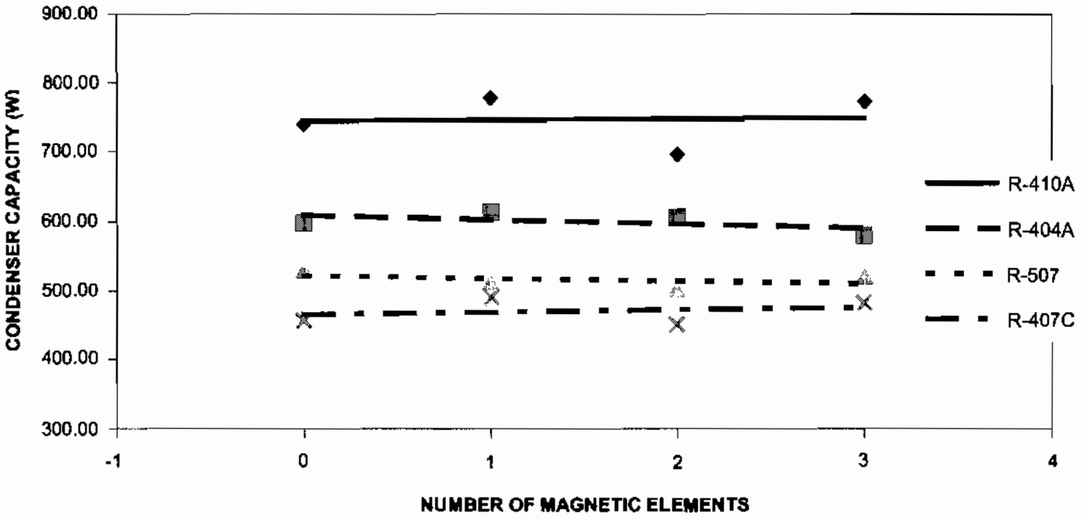

Figure 4. Condenser capacity vs number of magnetic elements at constant temperature (−15°C).

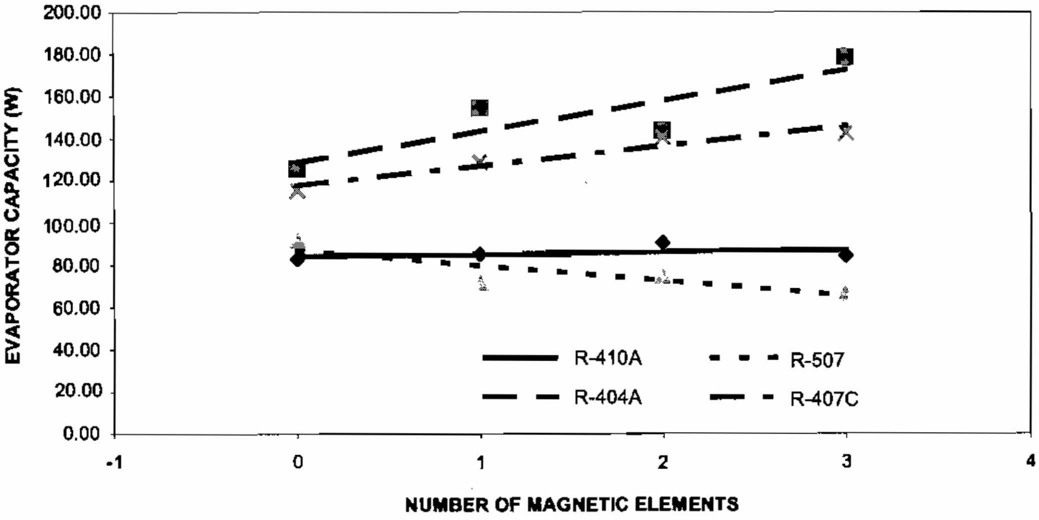

Figure 5. Evaporator capacity vs number of magnetic elements at constant temperature (−10°C).

To demonstrate the impact of the magnetic field on the condenser capacity, Figure 4 has plotted for the refrigerant mixture in question. A slight increase in the condenser capacity was observed. Figure 5 shows the evaporator capacity under various gauss levels. The data presented in this figure clearly demonstrated the enhancement of the evaporator capacity with the increase in the number of magnetic elements used.

In order to understand the effect of magnetic field on refrigerant and refrigerant mixtures behaviour, the chemical formula, chemical structure, thermophysical properties such as

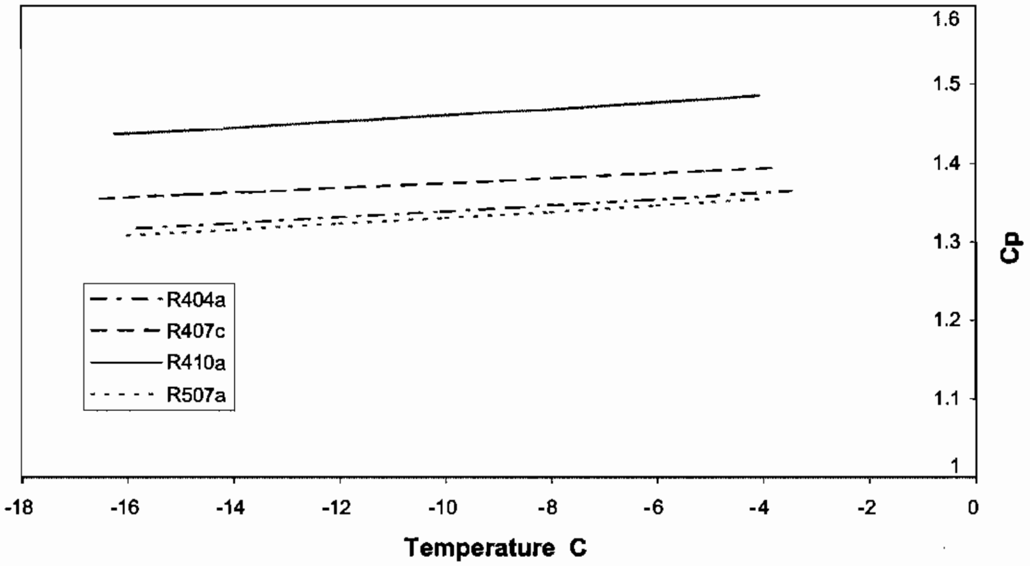

Figure 6. Refrigerant mixtures specific heats.

viscosity, thermal conductivity, thermal capacity as well as the surface tension were examined and analysed over the range investigated.

To analyse the impact of magnetic field upon fluids that go through a phase change, it is important to examine the chemical substance structure, chemical bond formed by sharing a pair of electrons, which is called a covalent bond. Electronic pairs shared between two different atoms are not necessarily shared equally. The stability of a molecule can be related to the strengths of the covalent bonds it contains. The strength of a covalent bond between two atoms is determined by the energy required to break that bond (Brown *et al.*, 1994).

Covalent bonds are forces within molecules, that influence molecular shape, bond energies, and chemical behaviour. The thermophysical properties of molecular liquid and solids are largely due to intermolecular forces that are strong enough to hold molecules close together. The molecules of the liquid must overcome their attractive forces that exist between the molecules. Liquids have intermolecular attractive forces that are strong in order to separate and go through a change of phase. The state of the refrigerant depends on the balance between the kinetic energies of the particles and the interparticle energies of attraction. Any change of phase is conditional to overcome intermolecular forces. Enhancement of the change of phase process will require overcoming the residual bonds or intermolecular forces.

The refrigerant or refrigerant mixture complex is held together with their weak bonds that have internal vibrations of certain frequency. This frequency depends upon the total mass of the number of water molecules and the strength of the bonds between the molecules. The lower the frequency of internal vibration the higher the thermal heat characteristics such as specific heat and thermal conductivity. The higher thermal properties, specific heat and thermal conductivity of the refrigerant mixture are less likely to respond to magnetic treatment. Figures 6 and 7 present the variation of specific heat ($\mathrm{kJ\,kg^{-1}\,K^{-1}}$) and thermal conductivity ($\mathrm{mW\,m^{-1}\,K^{-1}}$) with boiling or condensing temperatures (°C). These findings have been confirmed by the data

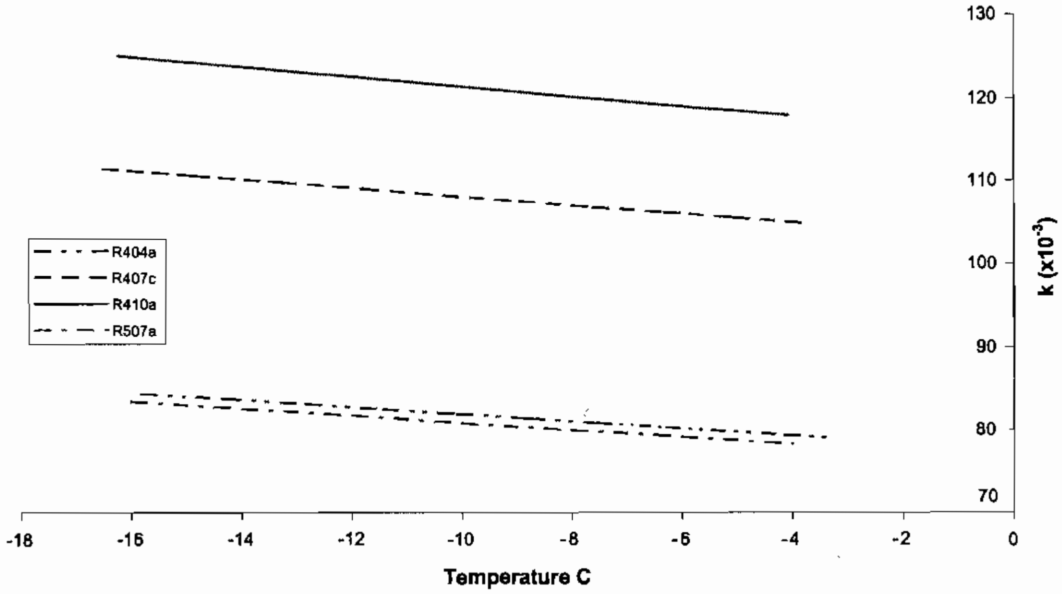

Figure 7. Thermal conductivity of refrigerant mixtures.

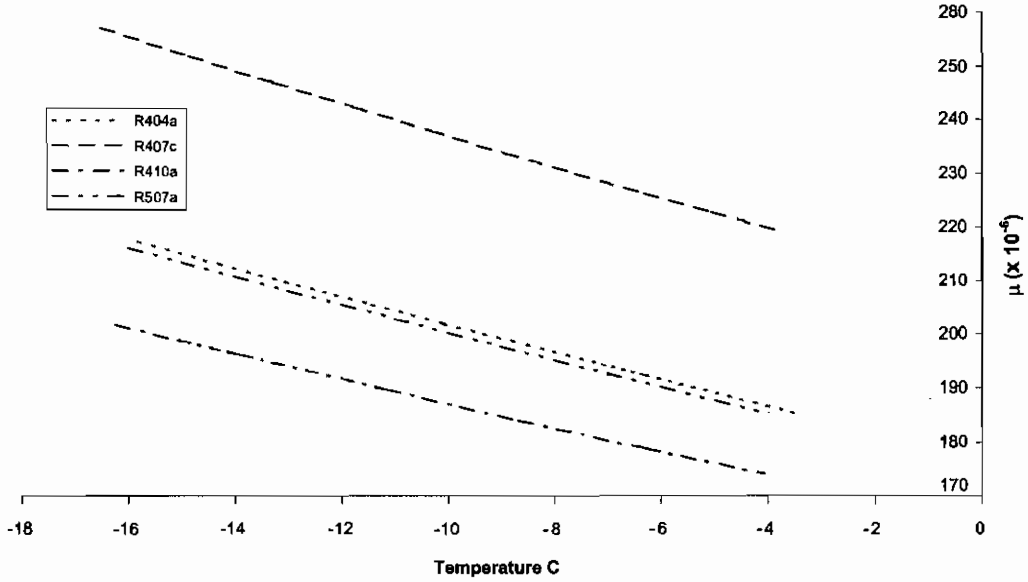

Figure 8. Viscosity of refrigerant mixtures.

displayed in Figures 4 and 5, where R-410A has the highest thermal conductivity and specific heat and has weak response to magnetic treatment. On the other hand, experimental data on refrigerant mixtures R-404A, R-407C and R-507 indicate that they have lower thermal properties compared to R-410A and respond well to magnetic treatment.

Furthermore, the higher the viscosity of the refrigerant mixture the more probable its response to the magnetic treatment. Figure 8 demonstrates this observation of the refrigerant mixture viscosity (μ Pa s). The comparison between R-407C viscosity and the other refrigerant mixtures under investigation clearly shows that this refrigerant mixture responded very well to the magnetic treatment.

4. CONCLUSIONS

During the course of this experimental study, the performance characteristics of some new proposed substitutes under various magnetic field levels have been investigated, analysed and compared to that of no magnet condition. The test results under heating conditions demonstrated that increasing the magnet capacity has a positive effect on the COP. The study showed that the effect of magnetic field on the mixture behaviour varied depending upon the mixture's composition and its boiling point.

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