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Study of R404a - Oil Mixture in Vapour Compression System

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ABSTRACT

In this investigation the heat transfer characteristics R404a with polyol ester oil at different oil concentration in vapour compression refrigeration system using C-type serpentine condenser were analyzed experimentally and their results were compared. The result shows that R404a with 3% oil mixture works better in case of COP, heat transfer coefficient & freezing capacity than R404a with 5% oil concentration. Due to the consistent performance, it can be preferred for the domestic appliances as well as commercial applications.

1. INTRODUCTION

Refrigeration is define as a process of removing heat from a space or substance and transfers that heat to another space or substance. In refrigeration process, refrigerant is the working fluid employed as the heat absorber or cooling agent. The refrigerant absorbs heat by evaporating at low temperature and pressure and removes heat by condensing at a higher temperature and pressure. As the heat is removed from the refrigerated space, the area appears to become cooler.

Vapour compression refrigeration system is the most commonly used among all refrigeration systems. In this system, the working fluid is mentioned in the state of liquid and vapour. It must readily evaporate and condense or change alternately between the vapour and liquid phase without leaving the system.The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary and an evaporator arranged as shown in the figure.

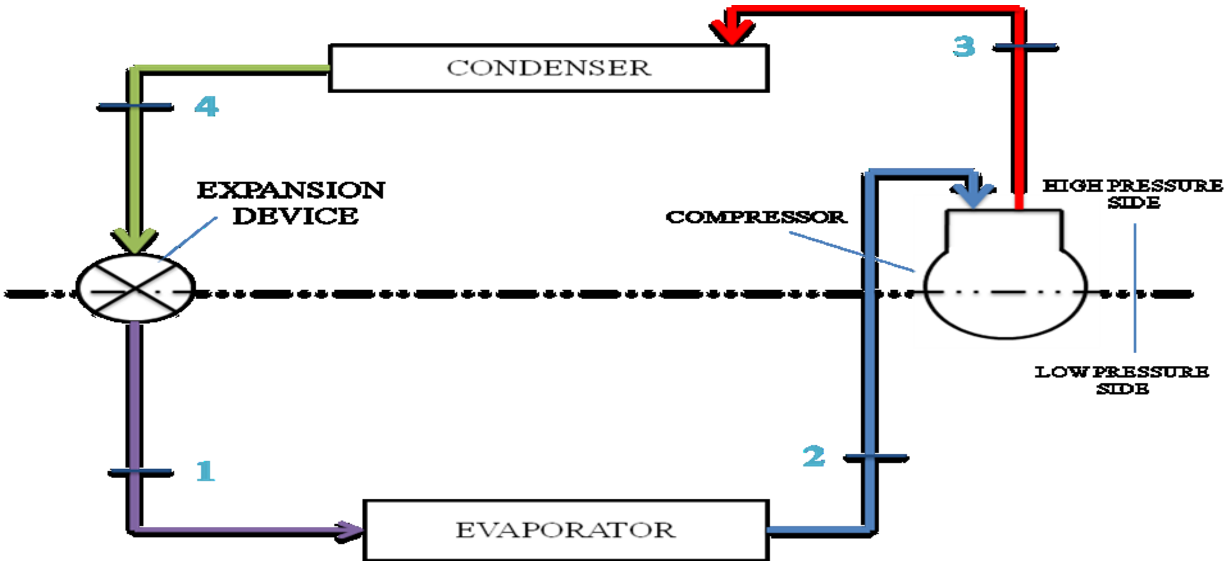

Fig 1.1 Schematic Representation of Vapour Compression System

The refrigeration cycle is shown in above figure and can be broken down into the following stages:

1 – 2.Low-pressure liquid refrigerant in the evaporator absorbs heat from itsSurroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2 – 3.The superheated vapour enters the compressor where its pressure is raised. The temperature will also increase, because a proportion of the energy put into the compression process is transferred to the refrigerant.

3 – 4.The high pressure superheated gas passes from the compressor into the condenser.

A lubrication agent is necessary in the refrigeration vapour compression systems, particularly for the correct operation of the compressor. A certain portion of the oil always circulates with the refrigerant through the cycle.

The oil circulation is the main factor for the deviation from the theoretical behavior ofpure refrigerant. Its main role is to ensure the existence of a thin oil film allowing the lubrication of the mechanical moving parts such as pistons, connecting rod/crank and valves to protect them against wear.

The lubricant simultaneously ensures several secondary roles among which serving as a tightness element, limiting the noise, or helping the evacuation of chemical impurities or deposits that may be present in the system. Lastly, in many situations, the oil is also used as a heat transfer medium for cooling the compressor. All these favorable actions of oil show that oil is definitely useful in refrigeration units.

However, the presence of a lubricant is also accompanied by several drawbacks, among which the most often cited is a reduction in heat transfer coefficients in the two-phase heat exchangers such as condenser and evaporator. The presence of oil also induces changes in the flow configurations, increases pressure drops, modifies the thermodynamic equilibrium and thermodynamic properties of the refrigerant (liquid–vapour equilibrium, enthalpy, viscosity, surface tension, etc.).

For all these reasons, many oil-related researches in the field of refrigeration have been conducted over the last years.Many researchers concentrated their studies on the behavior of refrigerant flows contaminated with lubricating oil (refrigerant-rich mixtures) with the objective of analyzing the influence of the oil in the mixture flow and heat transfer dynamics in compressors, evaporators, condensers and capillary tubes.We propose to analyze them in this research.

In this investigation the heat transfer characteristics of R134a-oil mixture and R404a-oil mixture in vapour compression refrigeration system were analyzed experimentally and their results were compared.

2. LITERATURE REVIEW

Several research works aim at evaluating the performance of a refrigerating system as a function of the oil type and characteristics, circulation ratio, operating conditions, etc. It is usually relevant to consider the COP or evaporator refrigerating power.Mainly in the 80s and 90s, several studies related to oil–refrigerant mixture started being developed.

Bambachet al (1995) [1] and Spauschus et al (1963) [2] demonstrated that the performance of the refrigeration system depends upon the quantity and the type of compressor oil, circulating in the system with the refrigerant. Some of these works were directed towards the determination of the thermo physical properties of the mixtures. Other researchers concentrated their studies on the behavior of refrigerant flows contaminated with lubricating oil (refrigerant-rich mixtures) with the objective of analyzing the influence of the oil in the mixture flow and heat transfer dynamics in compressors, evaporators, condensers and capillary tubes.

Schlager et al (1987) [3] have studied the evaporation and condensation of the R22 refrigerant - Naphthenic base mineral oil (viscosity of 150 SUS) mixture ,both in a smooth and micro-fin tube. The test section was a counter-flow, concentric-tube of 3.66m length with water flowing in the annulus. The oil mass concentration was varied from 0% to 5 % and the mass fluxes were tested over the ranges of 125to 400 kg m-2 s-1. It was observed that for both smooth and micro-fin tubes, small quantities of oil at approximately 1% to 3% were found to enhance the evaporation heat transfer in comparison with pure refrigerant evaporation.

Hambraeus et al (1995) [4] reported a study of evaporation inside two horizontal smooth tubes of 12mm inner diameter with a length of 4 and 10m using the R134a refrigerant and with oil-refrigerant mixtures. The heat flux was varied from 2 to10 kW m-2 and the oil content was varied from 0 to 2.5 mass percentages (synthetic oil, EXP 0275). It was found that the oil - free R134a had a higher heat transfer coefficient than R22 at the same heat and mass fluxes. It was found that at 2 and 4 kW m-2 the heat transfer coefficient had a maximum value for an oil content of around 0.5 mass percentages and no increase was registered for a heat flux of 6 kW m-2. The heat transfer coefficients for the pure refrigerant were also compared with the two existing correlations.

Haitao Hu et al (2010) [6] Two-phase heat transfer characteristics of R410A–POE oil mixture and R22-mineral oil mixture flow boiling inside a horizontal C-shape curved smooth tube were investigated. The test results show that, and the ratios of the heat transfer for R410A–oil mixture and R22–oil mixture are within 0.46 – 0.74 and 0.74–0.90.

BartoszDawidowicz et al (2012) [7] The experimental data for pure R22, R134a, R407C and their mixtures with polyester oil FUCHS Reniso/Triton SEZ 32 in a tube with porous coating and smooth, stainless steel reference tube are presented. Mass velocity varied from about 250 to 500 kg/m2s.

Winandy and Cuevas (2003) [8] monitored and analyzed the oil level of two

Compressors linked with line allowing for the pressure andoil-level equalization, with various ON/OFF conditions foreach compressor cycle.

Lottin (2004) [9] showed numerically that there exists anoptimal suction superheat that allows to maximize the COPor the power. This superheat depends on the oil circulationratio, and it is not possible to maximize both the power andCOP simultaneously.The COP decreases when increasing the oil circulationratio.

3.EXPERIMENTAL SET UP AND TEST CONDITIONS

3.1.Experimental Test Rig

Fig 3.1 Experimental **Setup**

Compressor	-	1/8 HP reciprocating compressor
Condenser	-	Serpentine condenser
Expansion devices	-	Capillary tube diameter (0.036 inches)
Expansion devices	-	Capillary tube Length-10 feet
Evaporator	-	Coil diameter- ¼ inch length
Evaporator	-	Length 11 feet
Evaporator	-	4 litres flask capacity
Heat exchanger	-	2 feet
Refrigerant used	-	R404a

DESIGN OF CONDENSER TUBE

- Inner Diameter of Refrigerant tube - 6.35mm
- Outer diameter of Refrigerant tube - 8mm
- Inner Diameter of water flow tube - 12.7mm

- Outer diameter of water flow tube - 14mm

3.2. Experimental Procedure

The experimental apparatus consisted of compressor, condenser, expansion valve and evaporator. The system also consists of two main flow loops: a refrigerant loop and heat source water for condensing loop.The heat exchanger (test section) is shown in Fig. 2. The outer and inner diameter of the inner tube (copper) is 6.35 mm, 8 mm, and outer and inner diameters of the outer tube (copper) are 12.7 mm and 14 mm respectively. The experiment was performed on steady state after conditions control, temperature at the evaporator is the only parameter varied with respect to time. The system was charged with the help of charging system and evacuated with help of vacuum pump to remove the moisture. After charging each refrigerant, data were collected at different evaporator temperatures and the performance parameters were obtained. All the observations are taken for the corresponding temperature drop rate at the evaporator.

3.3. Experimental Conditions

Working fluid	R404a
Evaporating temperature (K)	30^oC to -3^oC
Inner tube diameter (mm)	6.35mm
Mass of refrigerant used	80gms
Chilled water	
Inlet temperature (K)	30^oC
Mass flow rate (kg/h)	164-170kg/h
Compressor oil	Zed Plus (Polyester oil)

3. 4. Experimental method

In this paper, we used R-404a (Pentafluoroethane/1,1,1-Trifluoroethane/1,1,1-Tetrafluoroethane (44/52/4% by weight)) as working fluids. To examine the condensation heat transfer characteristics, the data (temperature of refrigerant, heat source water and outer wall) are measured at the heat exchanger. In addition the pressure between inlet and outlet of heat exchanger are measured as well. Validating parameters are shown below.

3.5 VALIDATION

3.4.1 Condensation Heat Transfer Coefficient

$$h=q/(T_s-T_w)\ W/m^{2o}C$$

Where, q- Average heat flux at test section calculated from temperature difference across the test section & flow rate of water.
Ts- Saturation temperature of refrigerants.
Tw- Wall temp.

$$\text{Heat flux, } q= Q_w/\pi DL\ W/m^2$$

Where, D- Inner diameter of water tube in metres, L-Length of test section in metres

$$Q_w = m_w c_{pw}(T_{w,out} - T_{w,in})\ \ W$$

Where, m_w- flow rate of water Kg/s
$T_{w,in}$&$T_{w,out}$- Inlet and Outlet temperatures of water in double tube condenser.
C_{pw}- Specific heat of water KJ/Kg^{o}C

6.4.2 Pressure Drop Penalty Factor

$$PF = \Delta P_{oil}/\Delta P_{pure}$$

where, ΔP_{oil}- Pressure drop in the condenser coil with oil.
ΔP_{pure}- Pressure drop in the condenser coil without oil.

6.4.3 Co-Efficient Of Performance

$$C.O.P = R_n/W$$

Where, R_n – Net refrigeration effect in KW
W – Work required (or) work done in KW

$$\textbf{Refrigeration Effect} = \{m * c_p * (\Delta T)\}/t\ \ \textbf{KW}$$

Where, m - Mass of water used for cooling in Kg
c_p- Specific heat of water in KJ/Kg^{o}C
t - Time in seconds

$$\textbf{Work Required} = (E_f - E_o)/t\ \ \textbf{KW}$$

Where, E_f- Final energy meter reading in KWh
E_o- Initial energy meter reading in KWh
t - Time in hours

5. Results and Discussion

Temperature of the water at the evaporator is dropped from 30^{o}C to -3^{o}C. Temperature drop at various points are noted and their corresponding time is recorded which is shown in Fig

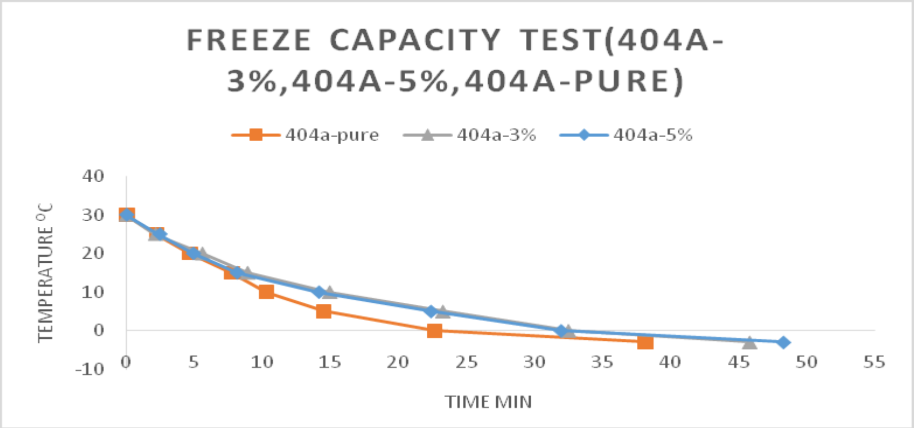

Fig Freeze Capacity Test for R404a-pure, 3% & 5%oil

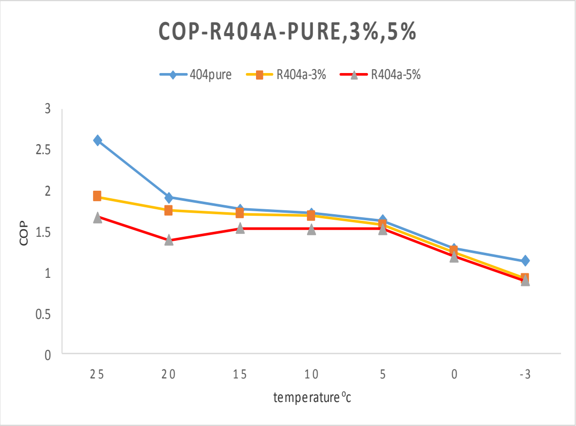

Fig COP Test-R404a-pure, 3%&5% oil

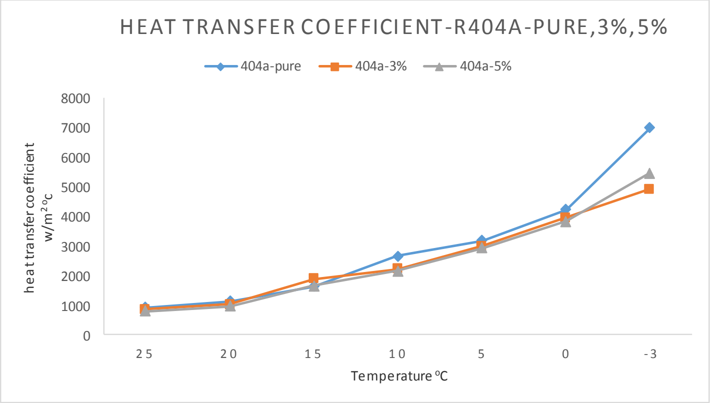

Fig Heat transfer Test-R134a-pure, 3%, 5%oil

The result shows that R404a works better with 3 % oil concentration in case of COP, heat transfer coefficient & freezing capacity than R404a with 5 % oil concentration.

6.1CONCLUSION

The results are very clear that the compressor oil has a major influence in the COP, heat transfer rate, and pressure drop in the system. The current study covered the effect of compressor oil in the refrigerants namely R404a with POE oil. The result shows that R404a with 3 % oil concentration works better in case of COP, heat transfer coefficient & freezing capacity than R404a with 5% oil concentration. So it can be preferred for vapour compression system.

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