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PERFORMANCE ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM KEEPING VOLUME OF THE CAPILLARY TUBE AS CONSTANT

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ABSTRACT

The design of capillary tube plays a very important role in the performance of a vapor compression refrigeration system. Optimized design is possible through theoretical calculations, however may fail due to the reason that the uncertainties in the formulation of pressure drop inside the capillary tubes. Hence experimental investigations are the best in terms of optimization of certain design parameters. Components of the vapour compression refrigeration system never work in isolation; change in performance of one component affect the performance of the other components and in turn overall performance of the system. Performance of the system also depends on the type, quantity of the refrigerant charged. In the present work, an attempt is made to optimize Length of capillary tube for refrigeration unit of capacity 30lts; with R-134a as refrigerant and hermetic sealed compressor of capacity 0.14H.P.and this study examined the effects of lengths capillary tubes on the performance of a vapor compression refrigeration system. It is found that 4.5feet Length of capillary tube gave a better performance.

1. INTRODUCTION

GENERAL

In 1972, Du Pont, one of the leading Chloro-Fluoro Carbon (CFC) manufacturers, discussed the effect of their products on the environment. Ray McCarthy summarized that fluorocarbons are intentionally or accidentally vented to the atmosphere which may be either accumulating in the atmosphere and/or returning to the land or sea in pure form or as decomposed products. Du pont, investigated the effect of these compounds due to its presence in the atmosphere on living beings, plants etc.As a result CFC manufacturers formed the fluorocarbon panel to investigate the environmental impact of the CFC's. Molina and Rowland, inferred that CFC's could destroy the stratospheric ozone. The atmospheric research programmed confirmed that CFC's were likely to deplete stratospheric ozone as predicted by Rowland and Molina, at the rate of 3% per decade. It was concluded that CFC's should be phased out, but that this could occur over a long period to minimize the economic impact on the CFC users.

In 1984, a remarkable and totally unpredicted phenomenon was discovered by the British Antarctic survey, called "ozone hole". In 1987, government negotiated in the Montreal Protocol, the first international treaty and subsequently in other international protocols to protect the global environment. This agreement originally mandated in reduction in CFC production and consumption, but, importantly allowed for future revision in light of new scientific evidence. After the Montreal Protocol, the atmospheric concentrations of the most important chlorofluorocarbons and related chlorinated hydrocarbons have either leveled off or decreased. Halon concentrations have continued to increased, as the halons presently stored in fire extinguisher are released, but their rate of increase has slowed down and their abundances are expected to decline by about 2020. Also, the concentration of the hydro-chloro-fluorocarbons (HCFCs) increased drastically at least partly due to the fact that usages of CFCs (e.g. used as solvents or refrigerating agents) were substituted with HCFCs. While there have been reports of attempts by individuals to circumvent the ban, e.g. by smuggling CFCs from undeveloped to develop nations, the overall level of compliance has been high.

Unfortunately, the hydro chlorofluorocarbons (HCFCs) and hydro fluorocarbons (HFCs) are now thought to contribute to anthropogenic global warming. On a molecule for molecule bases, these compounds are up to 10,000 times more potent greenhouse gases than carbon dioxide, and their increased use significantly increases the danger that human activity will change the climate. The Montreal and subsequent Protocols currently call for a complete phase-out of HCFCs by 2030, but does not place any restriction on HFCs. Ozone can be destroyed by a number of free radical catalysts, the most important of which are the hydroxyl radical (OH), the nitric oxides radical (NO) and atomic chlorine (Cl) and bromine (Br). All of these have both natural and anthropogenic sources; at the present time, most of the OH and NO in the stratosphere is of natural origin, but human activity has dramatically increased the chlorine and bromine. These elements are found in certain stable organic compounds, especially chlorofluorocarbons (CFCs), which may find their way to the stratosphere without being destroyed in the troposphere. Once in the stratosphere, the Cl and Br atoms are liberated from the parent compounds by the action of ultraviolet light, and can destroy ozone molecules through a variety of catalytic reactions. In the simplest example of such a reaction, a chlorine atom reacts with an ozone molecule, taking an oxygen atom with it (forming ClO) and leaving a normal oxygen molecule.A free oxygen atom then takes away the oxygen from the ClO, and the final result is an oxygen molecule and a chlorine atom, which then reinitiates the reaction. A single chlorine atom would

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keep on destroying ozone for up to two years. On basis of per atom, bromine is even more efficient than chlorine at destroying ozone, but there is much less bromine in the atmosphere at present. As a result, both chlorine and bromine contribute significantly to the overall ozone depletion or creating a hole in ozone called "ozone hole". Ozone layer depletion is expected to increase surface UVB levels, which could lead to damage, including increases in skin cancer. Although decrease in stratospheric ozone are well-tied to CFCs, and there are good theoretical reasons to believe that decrease in ozone will lead to increase in surface UVB. An increase of UV radiation would also affect crops. A number of economically important species of plants, such as rice, depend on cyanobacteria residing on their roots for the retention of nitrogen. Cyanobacteria are very sensitive to UV light and they would be affected by its increase.Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases. When sunlight reaches earth's surface some light is absorbed and warms the earth and then it re- radiates heat at longer wavelengths. Some of these longer wavelengths are absorbed by greenhouse gases in the atmosphere before they are lost to space. This absorption of long wave radiation warms up the atmosphere. Greenhouse gases also emit long wave radiation both upward to space and downward to the surface. The downward part of this long wave radiation emitted by the atmosphere is the "greenhouse effect".This effect results in global warming and increase in average temperature of earths atmosphere and oceans. In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations. The largest contributing source of greenhouse gas is the burning of fossil fuels. Increasing global temperatures are expected to cause a broad range of changes. Sea levels are expected to rise due to thermal expansion of the ocean, in addition to melting of land ice. Amounts and patterns of precipitation may probably change. Changes in temperature and precipitation patterns are likely to increase the frequency, duration, and intensity of other extreme weather events, such as floods, droughts and heat waves.

2. ALTERNATIVE REFRIGERANTS

Refrigerant R134a is hydro fluorocarbons (HFC) that has zero potential to cause the depletion of the ozone layer and very little greenhouse effect. Let us see the various properties of this refrigerant and how it replaces R12.

i. Refrigerant R134a

The refrigerant R134a is the chemical compound tetra fluoro ethane comprising of atoms of carbon, two atoms of hydrogen and four atoms of fluorine. Its chemical formula is CF_3CH2F.The molecular weight of refrigerant R134a is 133.4 and its boiling point is -15.1degree F.

Refrigerant R134a is a hydro fluorocarbon (HFC) that has zero potential to cause the depletion of the ozone layer and very little greenhouse effect. R134a is the noninflammable and non-explosive, has toxicity within limits and good chemical stability. It has somewhat high affinity for the moisture. The overall physical and Thermodynamic properties of refrigerant R134a closely resemble with that of refrigerant R12. Due to all the above factors, R134a is considered to be an excellent replacement for R12 refrigerant.

ii. R134a as Replacement for R12

Refrigerant R12 is the most widely used of all the refrigerants for different refrigeration and air conditioning applications. It is indeed very tough that any refrigerant will be able to replace this highly versatile refrigerant in different operating conditions. However, R134a has been able to replace R12 successfully in number of applications. Let us see how R134a compares well with R12.

1) Power required per ton of refrigeration:

For the evaporator temperatures of -7 degree C and above the isentropic discharge temperature from the compressor for both the refrigerants is same. The total horsepower required per ton of refrigeration is also same. For the temperatures below -7degree C, if R12 is replaced by R134a there will be significant loss of the refrigerating effect, and in such cases it is advisable to use the blends of refrigerants as the replacement instead of using R134a.

2) Low temperature application:

For the instance where the saturation temperature is -15.08 degree F at the standard barometric pressure, and if the evaporator temperature is below 0 degree F, the pressure in the evaporator will be still well above the vacuum. Thus the refrigerant R134a can be used for the low temperature application also without the need to produce vacuum in low pressure side of the refrigerant system.

3) Heat transfer coefficients:

The heat transfer coefficients for refrigeration R134a are higher than R12 in different conditions depending on the temperature. If the refrigerants exist in single liquid phase the heat transfer coefficient of R134a is higher by 27 to 37% and if they are in gaseous phase, the heat transfer coefficient for R134a is higher by 28 to 34% in the evaporator and 35 to 41% in the condenser. Etc.,

In view of the above, a need for alternative refrigerants arises, which can minimize the impact. Availability of performance of alternative refrigerant 404A in small capacity systems in the literature is scanty. Refrigerant 404A is a ternary blend and is considered to be a zero ODP replacement for R502 and R22. Snelson et al have conducted experiments on this mixture using an open type compressor.

The lubricating oil used is polyol ester oil because of the presence of R134a in the mixture. Results show that refrigerating capacity of R404A is nearly same and has about 2-4 % higher pressure ratio. In spite of this, it has 5-6 ^{0}C lower compressor discharge temperature which would make it a suitable substitute for R502 and R22 in high compression ratio applications. Two important characteristics of refrigerants from a safety standpoint are its flammability and toxicity. The selected refrigerant is non-flammable and non-toxic in nature.

Advantages of Capillary tube Some of the advantages of a capillary tube are:

1. Usage of capillary tube has the following advantages over the other methods of expansion.
2. Predominant enough for universal acceptance of factory sealed systems.
3. Simple and have no moving parts.
4. Inexpensive and are compact in size.
5. Capillary tubes allow the pressures in the system to equalize during the off cycle.
6. It does not have any moving parts hence it does not require maintenance
7. Capillary tube provides an open connection between condenser and the evaporator hence during off-cycle, pressure equalization occurs between condenser and evaporator. This reduces the starting torque requirement of the motor since the motor starts with same pressure on the two sides of the compressor. Hence, a motor with low starting torque (squirrel cage Induction motor) can be used.

3. LITERATURE REVIEW

INTRODUCTION

Review of the literature gives an insight into the developments in the field of study and helps to identify the problem, techniques and methodologies to be adapted. Developments in the area of fluid flow in straight as well as coiled capillary tubes are presented in this chapter. Also, in this chapter, various developments about, physical models and parametric studies using various working fluids reported in the literature are presented in this chapter.

FLOW THROUGH CAPILLARY TUBES

Vapour compression refrigeration system has been in use for many decades in many engineering applications. Even though there are many types of expansion devices, capillary tube is the most commonly used device for low capacity systems. Physical models aid mathematical models in representing the physical phenomena taking place in the flow and transfer processes and in improving the accuracy of prediction. Empirical correlations are also necessary to predict the mass flow rate for a given capillary and the operating conditions.Bolstad and Jordan [1948] performed the first major study on capillary tube flow and tried to explain that an undetermined error of flow rate prediction of refrigerant in an adiabatic capillary tube might be due to the assumption of the thermal equilibrium in two-phase flow. Authors also presented an analytical solution for adiabatic capillary tubes based on the homogeneous flow and constant friction factor. The flow equations were solved using simplified methods based on the conservation of mass, energy and momentum. Later, authors did a similar study by using liquid viscosity for the calculation in place of two-phase Reynolds number.

Mikol and Dudley [1963] reported experimental study of adiabatic single-phase and two-phase flow in capillary tubes. Their work involved visual studies of refrigerant flow in glass capillary tubes and data collection while using copper capillary tubes. Authors first obtained typical distributions of pressure and temperature along the adiabatic capillary tube, which included the region of meta stable flow. Mikol and Dudley [1964] used photographic means to improve upon the observations of Cooper *et al*. [1957]. In their experiments, the maximum length of the meta stable flow was 0.7 m. Their major finding on meta stable flow is summarized below:

i) Meta stable flow must be considered in capillary tube design, since meta stable conditions occurred in all of their visual and data runs in adiabatic capillary tubes;
ii) Flow in the capillary tube could be described as a stable mode of sub cooled liquid flow, meta stable liquid flow, an inception of vaporization that started with vapor bubbles appearing at the tube wall and merging into a vapor core surrounded by liquid.

During 1970s, research on meta stable flow in capillary tubes had attracted more people. Rezk and Awn [1979] also obtained the distribution curves of pressure and temperature along an adiabatic capillary tube by means of experiment. Although the length of meta stable flow and the superheated degree (or under pressure of vaporization) for the experimental case could be determined, correlation for the meta stable flow was not provided. The distribution curves were only used for qualitative analyses.

Li *et al*. [1989 and 1990] and Chen *et al*. [1990] published the most complete work on meta stable flow of refrigerant in adiabatic capillary tubes. During their experiments R-12 system using capillary tubes with an inside diameter of 0.66 and mm has been studied. Effect of inlet temperature, inlet pressure, mass flow rate and back pressure, were analyzed, and it was concluded that:

i) Larger the diameter of the capillary tube, lower the under pressure vaporization, and shorter the length of the meta stable flow;
ii) Under pressure vaporization Increases with an increase in the refrigerant mass flow rate; Increase in the inlet sub cooling decreases the under pressure vaporization;
iii) Effect of the change in back pressure on the under pressure vaporization was small.

Theoretical evaluation of the performance resulting from the installation of a liquid suction line heat exchanger is done by Domanski and Didion [1994]. It examines cycle parameters and refrigerant thermodynamic properties that determine whether the installation results in improvement of coefficient of performance (C.O.P) and volumetric capacity. Benefit of application of intracycle heat exchange between them depends on the combination of the operating conditions and fluid properties like heat capacity, latent heat and coefficient of thermal expansion. Fluids that perform well in the basic cycle are affected marginally by the liquid suction heat exchanger (LS-HX) and the impact of C.O.P. Fluids performing poorly in the basic cycle benefit from the LS-HX installation for increasing the C.O.P. and volumetric capacity. These results are based on theoretical evaluations using thermodynamic properties with the assumption of isentropic compression, negligible pressure drop in the heat exchangers and liquid -suction heat exchangers.

Wong and Ooi [1995] discussed the effects of the various two phase viscosity correlations on the homogeneous flow model and compared with the predicted pressure drops along the capillary tubes from the available data. Their results showed that the homogeneous flow model may be used to predict the pressure distribution in the two phase capillary tube flow condition. Prediction may be improved by employing a more suitable two phase mean viscosity.

Flow characteristics of R-12 and R-134a in capillary tube were predicted by using numerical model developed by Wong and Ooi [1996]. They showed that even with minor differences in refrigerant properties between CFC-12 and HFC-134a creates considerable difference in flow characteristics. Comparison of flow characteristics of CFC-12 and HFC-134a revealed that HFC-134a gives higher pressure drop than CFC-12 in both the subcooled liquid region and two phase region. Thus with the same operating conditions HFC-134a always settled with a shorter tube length. This results also confirmed that for the same tube dimensions and conditions, CFC-12 can accommodate a higher mass flow rate before the flow reaches the choked flow conditions.

An empirical model was developed to size an adiabatic and non-adiabatic capillary tubes for small vapor compression refrigeration systems. An elemental approach has been employed by Bansal and Rupa Singhe [1996] to develop simple correlations for sizing both adiabatic and non-adiabatic capillary tubes. This model is based on the assumption that length of the capillary tube is dependent on five primary variables namely tube inner diameter, mass flow rate, pressure difference between the high side and low side, sub cooling at capillary inlet and relative roughness of the material. These correlations were based on the available experimental data over a range of operating conditions.

4. EXPERIMENTAL STUDY

Experimental study on a system helps to evaluate its performance experimentally under varying operating conditions. Comparing this performance with that of the theoretical studies help in understanding the acceptability limits. In this line, the performance of the helical capillary tubes is studied experimentally. Effects of various parameters like mass flow rate, inner diameter, length, coil diameter, etc over a

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range of operating conditions are studied. The detailed description of the experimental system, various components of the system, controls and measurement systems and experimental procedure are presented in this chapter.

DESCRIPTION OF THE EXPERIMENTAL SETUP

Test rig is a single stage vapour compression refrigeration system of 165 LTRS capacity. Figure 4.1 shows the schematic diagram of the experimental setup.

This test rig mainly consists of

1. Compressor
2. Condenser
3. Expansion device and
4. Evaporator

The high-pressure gas from compressor flows through an oil separator where the compressor lubricant oil and refrigerant are separated and oil is fed back to the compressor. Compressed high-pressure gas is condensed in an air cooled condenser. A sight glass is provided to see the condition of refrigerant

Channel no.	Measuring location
T1	Compressor inlet
T2	Compressor outlet
T3	Condenser outlet
T4	Evaporator inlet

Table 4.1 Temperature measuring location

entering to the expansion valve. The liquefied and subcooled refrigerant from the receiver enters into the expansion valve. A manually controlled needle valve with a capillary in parallel is used to maintain constant pressure in the evaporator.

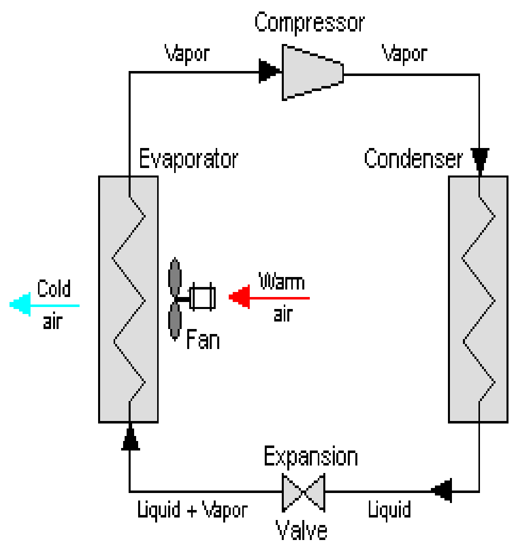

Fig. 4.1 Schematic diagram of the experimental setup

A refrigerant flow meter is provided at the inlet of the expansion valve to measure volume flow rate of the refrigerant. A water tank with the facility for controlling temperature of the content with temperature sensors was used to reduce the temperature of coolant water at high temperature. Evaporator pressure is controlled by varying the electrical load. Temperatures at various locations were measured using digital thermo meter. Various locations at which temperature was measured are shown in Table 4.1

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Fig.4.2 A view of Digital thermometer

Pressures of the refrigerant are measured using pressure gauges at 6 locations in the system as given below.

- Discharge pressure of compressor
- Suction pressure of compressor
- Pressure at the outlet of condenser
- Pressure at the capillary tube inlet
- Pressure at the capillary tube outlet
- Pressure at the inlet of evaporator.

Fig 4.3 Discharge pressure gauge

5. RESULTS AND DISCUSSIONS

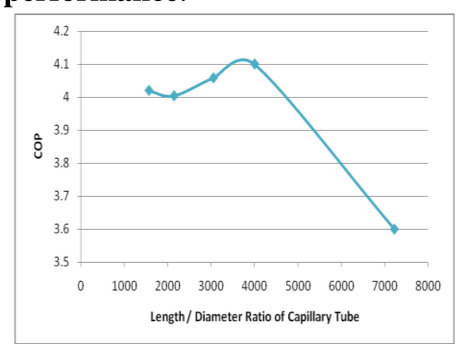
5.1 Results Summary

Performance of a simple Compression Refrigeration Cycle:

The performance of vapour compression refrigeration cycle varies considerably with the length/diameter ratio of capillary tube has greater effect. To illustrate these effects the calculated values for different length/diameter ratio of capillary tube have been plotted on the graphs. The relationships between length/diameter ratio of capillary tube and performance parameter have been compared and shown in the following graphs.

5.1 RESULTS AND DISCUSSIONS FROM THE FOLLOWING GRAPHS:

1. Effect of Length/Diameter of capillary tube on coefficient of performance:



Graph.1 Effect of L/D of capillary tube on coefficient of performance

Referring to graph-1, it is seen that the performance of the Refrigeration system increases as the length & diameter of the capillary tube increases. But at the length/diameter=4000 the performance of the system starts to decrease, because of further increase in pressure due to friction, the specific volume, and velocity increase in

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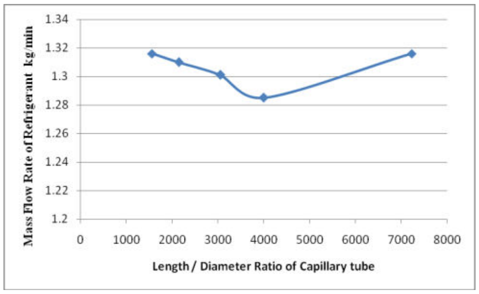
the capillary tube. It increases the mass flow rate of refrigerant and unbalanced conditions can be avoided.

2. Effect of length/diameter of capillary tube on the mass flow rate of refrigerant:



Graph.2 Effect of L/D of capillary tube on Mass flow rate of refrigerant

Effect of length & diameter of capillary tube on the mass flow rate of refrigerant:

Referring to the graph-2, it is seen that mass flow rate of refrigeration system decreases as the length/diameter ratio of capillary tube increases.

CONCLUSIONS

Experimental investigation:

Experimental investigations were made on domestic refrigerator of 165 lts capacity. In the present work l/d ratio of capillary tube is varied from 1560 to 7226 keeping the volume of the capillary tube as constant at 1225mm^3. The standard l/d ratio of capillary tube is 3048 (l=2.438m, d=0.8mm) and standard volume is 1225mm^3. The diameter is varied in steps of 0.1mm above and below the value of the standard system.

It found that the optimum l/d ratio is 4000 instead of standard value 3048 i.e., given by the manufacturer. The improvements are shown below:

1. Refrigerator effect is increased by 1.2%.
2. Compressor power is reduced by 1%.
3. Coefficient of performance is increased by 1.5%.
4. Heat reduction in condenser is increased by 1.1%.

It is recommended that for a domestic refrigerator of 165 lts capacity, the length of the capillary tube as 2.80 m and the diameter as 0.7 mm for the maximum COP of the refrigerator.

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