THERMAL BEHAVIOUR OF R407C AS AN ALTERNATE TO R22 IN A MINICHANNEL SHELL AND TUBE CONDENSER

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Abstract :
The worldwide alert about global warming has led to an increasing interest in new HVAC (heating, ventilation, and air conditioning) technologies with low environmental impact. When considering this impact, both a direct effect due to leakages of refrigerant and an indirect effect due to the energy consumption. So in order to reduce the refrigerant charge in the refrigeration system a minichannel shell and tube condenser is used. DAVIDE DEL COL uses R22 as a refrigerant to check the performance of a minichannel shell and tube condenser in the European project SHERHPA(Sustainable Heat and Energy Research for Heat Pump Applications).
But R22 is going to phase out from 2020 because of the major impact on the ozone layer depletion and global worming potential. In this project I'm replacing the R22 refrigerant by R407C to avoid ozone depletion potential, to reduce global worming potential. Because R407C has zero ozone depletion potential. So, the main theme of my project is to replace the R22 refrigerant by R407C to avoid ozone depletion potential, to reduce global worming potential and to reduce the refrigerant charge in the refrigeration system by using a minichannel shell and tube condenser.

IndexTerms – minichannel shell and tube condenser, refrigerants R22 and R407C, temperature drops, enthalpy drops and mass flow rates

1. INTRODUCTION

The main theme of my project is to replace the R22 refrigerant by R407C to avoid ozone depletion potential, to reduce global worming potential and to reduce the refrigerant charge in the refrigeration system by using a minichannel shell and tube condenser. Because in the present days global warming has led to an increasing interest in new HVAC (heating, ventilation, and air conditioning) technologies with low environmental impact. When considering this impact, both a direct effect due to leakages of refrigerant and an indirect effect due to the energy consumption and the consequent carbon dioxide emissions caused by the electricity production process must be taken into account. As a general consideration, the environmental impact of the atmospheric emissions during the whole lifetime of equipment, from manufacture to final disposal, cannot be considered negligible.

As a consequence of the phasing out of chlorinated refrigerants (i.e., chlorofluorocarbons [CFCs] and hydrochlorofluorocarbons[HCFCs]) because of their negative influence on the ozone layer, hydrofluorocarbons (HFCs) containing no chlorine are now being used by the HVAC industry in newer equipment. The gradual phasing out in automotive applications of fluids with GWP higher than 150 has been regulated in the European Community (EC) starting from 1 January 2011. In some countries new legislations have already been approved for a global phasing out of HFCs.

Some natural fluids with very low greenhouse effect impact, like hydrocarbons (HCs), ammonia, and carbon dioxide, have been suggested as substitutes for halogenated man-made refrigerants. Among the natural fluids suggested, HC refrigerants are chemically related to the halogenated ones and their use would not involve major changes in the equipment design, since their thermodynamic properties and materials compatibility are similar to those of traditionally used synthetic fluids. The main problem of the use of hydrocarbons as refrigerants is their flammability, which has prevented their use in a more extensive way.

2. NEED FOR SMALLER FLOW PASSAGES

The flow passage dimensions in convective heat transfer applications have been shifting towards smaller dimensions for the following three main reasons:

- Heat transfer enhancement.
- Increased heat flux dissipation in microelectronic devices.
- Emergence of microscale devices that require cooling.

Fluid flow inside channels is at the heart of many natural and man- made systems. Heat and mass transfer is accomplished across the channel walls in biological systems, such as the brain, lungs, kidneys, intestines, blood vessels, etc., as well as in many man-made systems, such as heat exchangers, nuclear reactors, desalination units, air separation units, etc. In general, the transport processes occur across the channel walls, whereas the bulk flow takesplace through the cross- sectional area of the channel. The channel cross-section thus serves as a conduit to transport fluid to and away from the channel walls.

3. FLOW CHANNEL CLASSIFICATION

Channel classification based on hydraulic diameter is intended to serve as a simple guide for conveying the dimensional range under consideration. Channel size reduction has different effects on different processes. According to kandlikar heat and mass transfer in mini and micro channels, the channels are classified based on the internal diameter of the tubes. They are,

- Conventional channels - $> 3mm$
- Minichannels - $3mm \geq D > 200\mu m$
- Microchannels - $200\mu m \geq D > 10\mu m$
- Transitional Microchannels - $10\mu m \geq D > 1\mu m$
- Transitional Nanochannels - $1\mu m \geq D > 0.1\ \mu m$
- Nanochannels - $0.1\mu m \geq D$
- Mesochannels - 100µm to1mm

In the case of non-circular channels, it is recommended that the minimum channel dimension; for example, the short side of a rectangular cross-section should be used in place of the diameter D. We will use the above classification scheme for defining minichannels and microchannels. This classification scheme is essentially employed for ease in terminology; the applicability of continuum theory or slip flow conditions for gas flow needs to be checked for the actual operating conditions in any channel.

4. HISTORY OF SHELL AND TUBE HEAT EXCHANGER

A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

There can be many variations on the shell and tube design. The tubes may be straight or bent in the shape of a U, called U-tubes. In nuclear power plants called pressurized water reactors, large heat exchangers called steam generators are two-phase, shell-and-tube heat exchangers which typically have U-tubes. They are used to boil water recycled from a surface condenser into steam to drive a turbine to produce power. Most shell-and-tube heat exchangers are either 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, the fluid goes in one end of each tube and out the other.

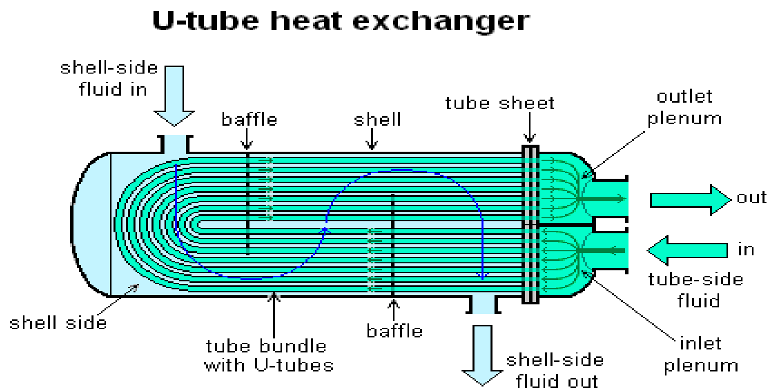

Fig.1 U-Tube Heat Exchanger

5. CONSTRUCTIONAL DETAILS OF A MINICHANNEL SHELL AND TUBE HEAT EXCHANGER

The shell-and-tube heat exchanger is named for its two major components – round tubes mounted inside a cylindrical shell. The shell cylinder can be fabricated from rolled plate or from piping. The tubes are thin-walled tubing produced specifically for use in heat exchangers. Other components include: the channels (heads), tubesheets, base plate and baffles.

Fig.2 Basic view of shell and tube condenser

Fig.3 Tube bundle with baffles

6. SPECIFICATIONS OF SHELL AND TUBE CONDENSER:

Tubes – U-type, smooth

- Tube inside diameter [m] – 0.002
- Tube outside diameter [m] – 0.004
- Tube length [m] – 1.1
- Shell internal diameter [m] – 0.265
- Tube pitch [m] – 0.008
- Number of tubes – 360
- Number of baffles – 13
- Baffle spacing [m] – 0.078

7. SELECTION OF REFRIGERANT

The selection of refrigerant is mainly based on the environmental and safety properties. In fact, at present the environment, friendliness of the refrigerant is a major factor in deciding the usefulness of a particular refrigerant. The important environmental and safety properties are:

Ozone Depletion Potential (ODP):

According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances. Refrigerants having non-zero ODP have either already been phased-out (e.g. R 11, R 12) or will be phased-out in near- future (e.g. R22).

Global Warming Potential (GWP):

Refrigerants should have as low a GWP value as possible to minimize the problem of global warming.

Total Equivalent Warming Index (TEWI):

The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming.

Toxicity:

Ideally, refrigerants used in a refrigeration system should be non-toxic. However, all fluids other than air can be called as toxic as they will cause suffocation when their concentration is large enough. Thus toxicity is a relative term, which becomes meaningful only when the degree of concentration and time of exposure required to produce harmful effects are specified. Some refrigerants such as CFCs and HCFCs are non-toxic when mixed with air in normal condition. However, when they come in contact with an open flame or an electrical heating element, they decompose forming highly toxic elements.

Flammability:

The refrigerants should preferably be non-flammable and non-explosive. For flammable refrigerants special precautions should be taken to avoid accidents.

8. DESIGN OF A MINICHANNEL SHELL AND TUBE CONDENSER:

Tube profile:

- Select line tool and draw the line of length 1.1m and with a distance of 0.008m draw another line with same length
- Draw the semi-circle
- Exit sketch

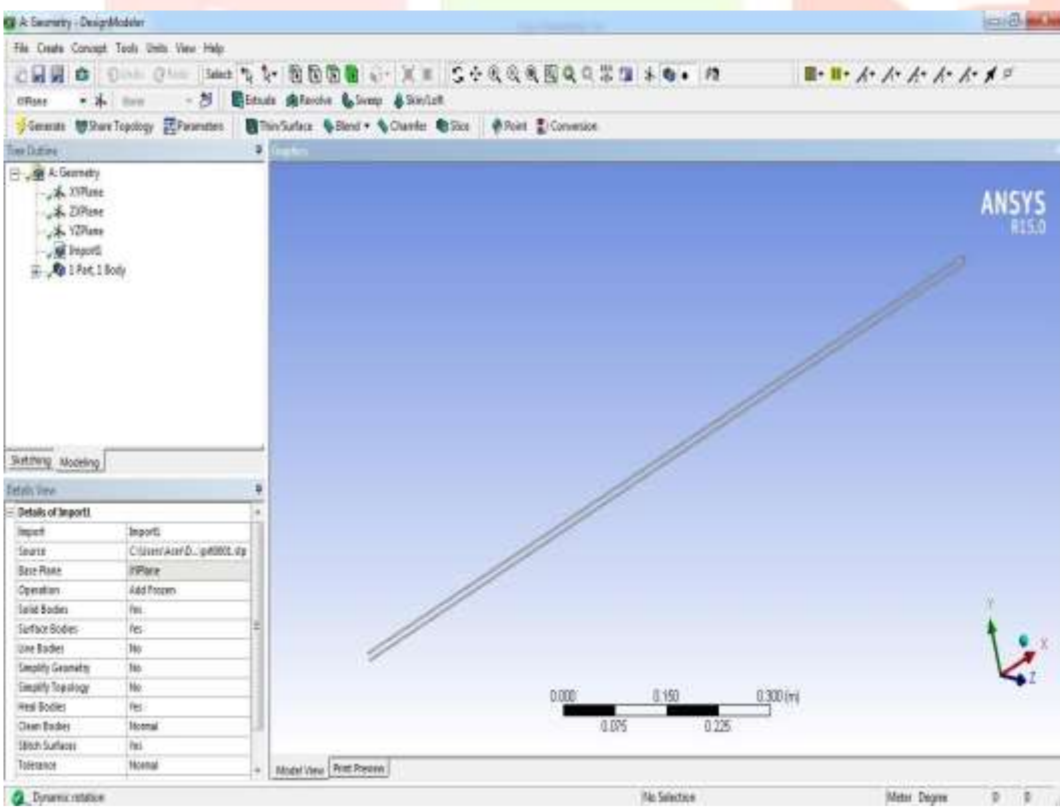

Fig.4 single U-Tube

Assembly of all tubes with baffles:

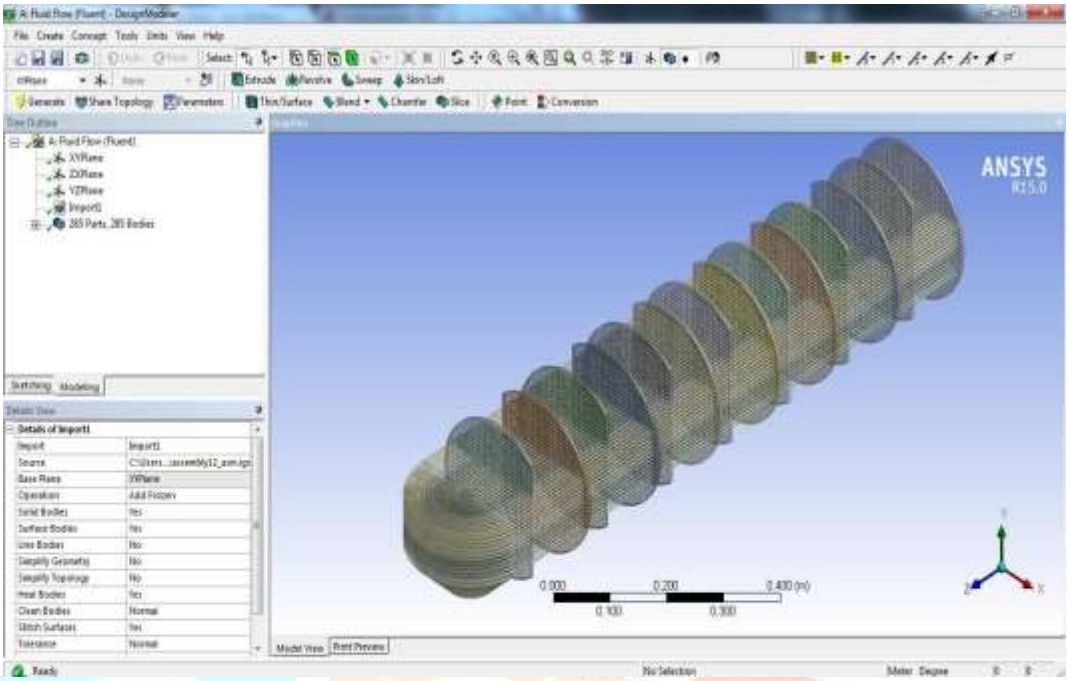

Fig.5 Assembly of U-Tubes

9. *C.F.D ANALYSIS OF MINICHANNEL SHELL AND TUBE CONDENSER*

Properties of refrigerant R22:

Density	-	1083.1 kg/m^3
Specific heat	-	785.34 J/kgK
Thermal conductivity	-	0.1W/mk
Viscosity	-	0.00011832 kg/ms

Wall – thermal convection heat transfer coefficient – 44.08 W/m^{2}K

FOR R22 REFRIGERANT (2mm inner diameter)

Variations of temperature, pressure and enthalpy at 2bar

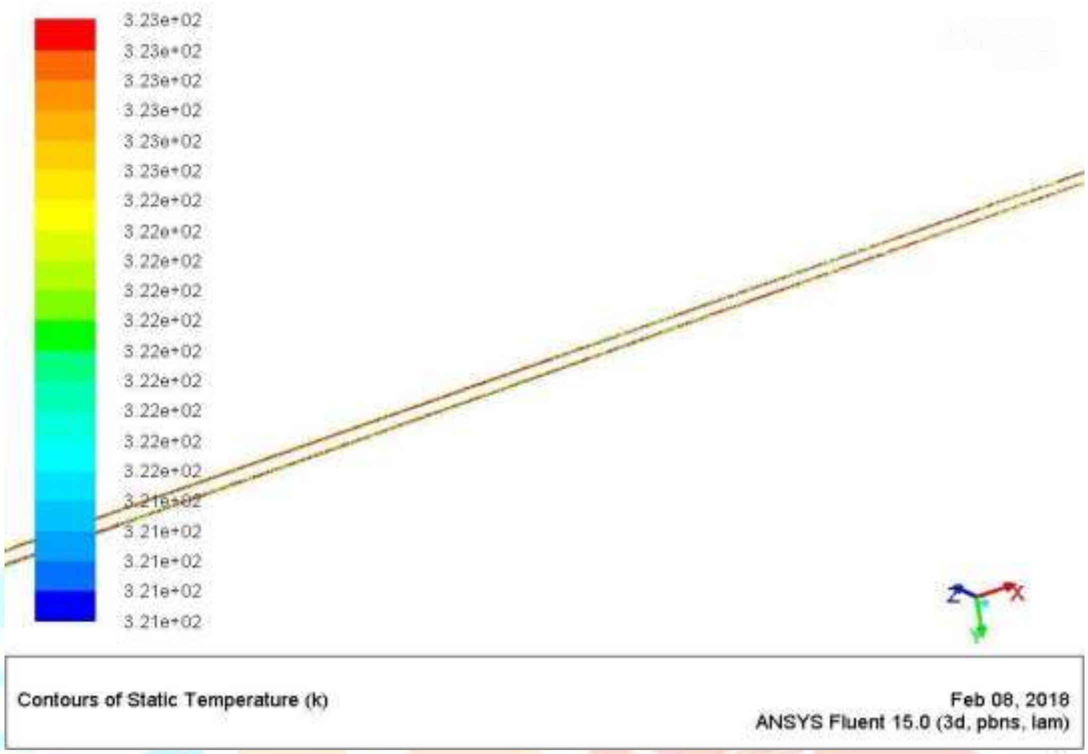

Fig.6 Temperature variations at 2bar

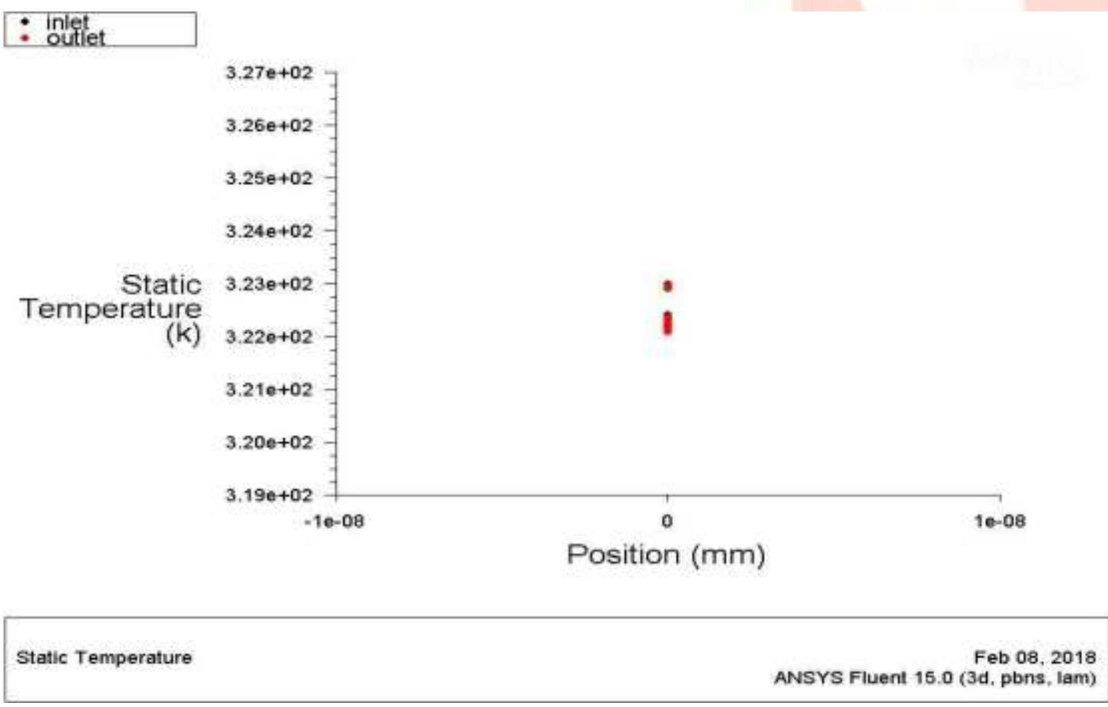

Fig.7 Temperature drop at 2bar

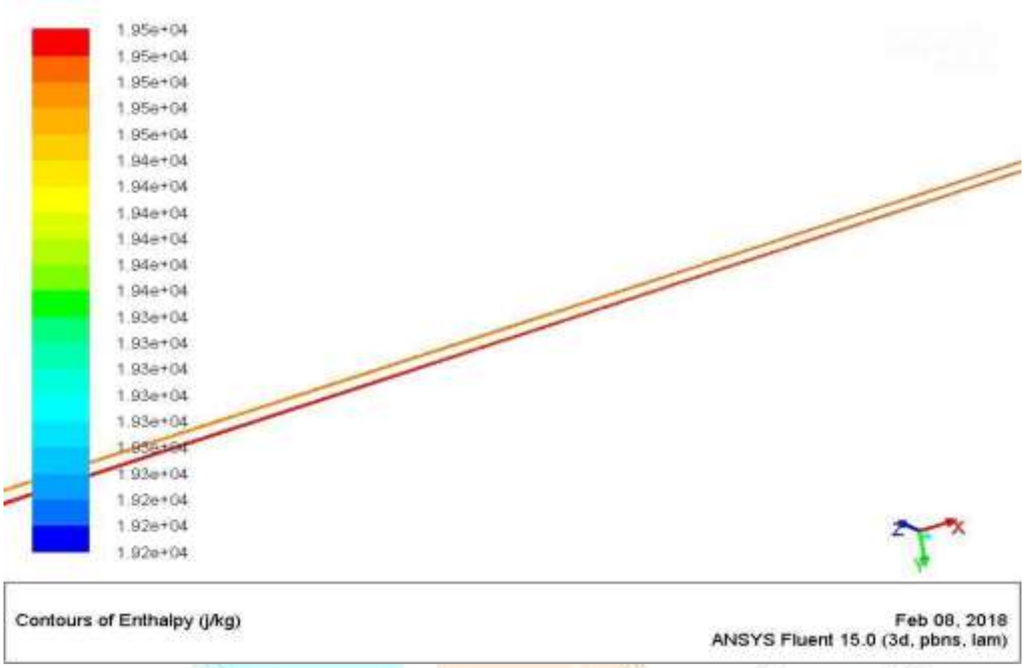

Fig.8 Enthalpy variation at 2bar

Variations of temperature, enthalpy and pressure at 0.4kg/s

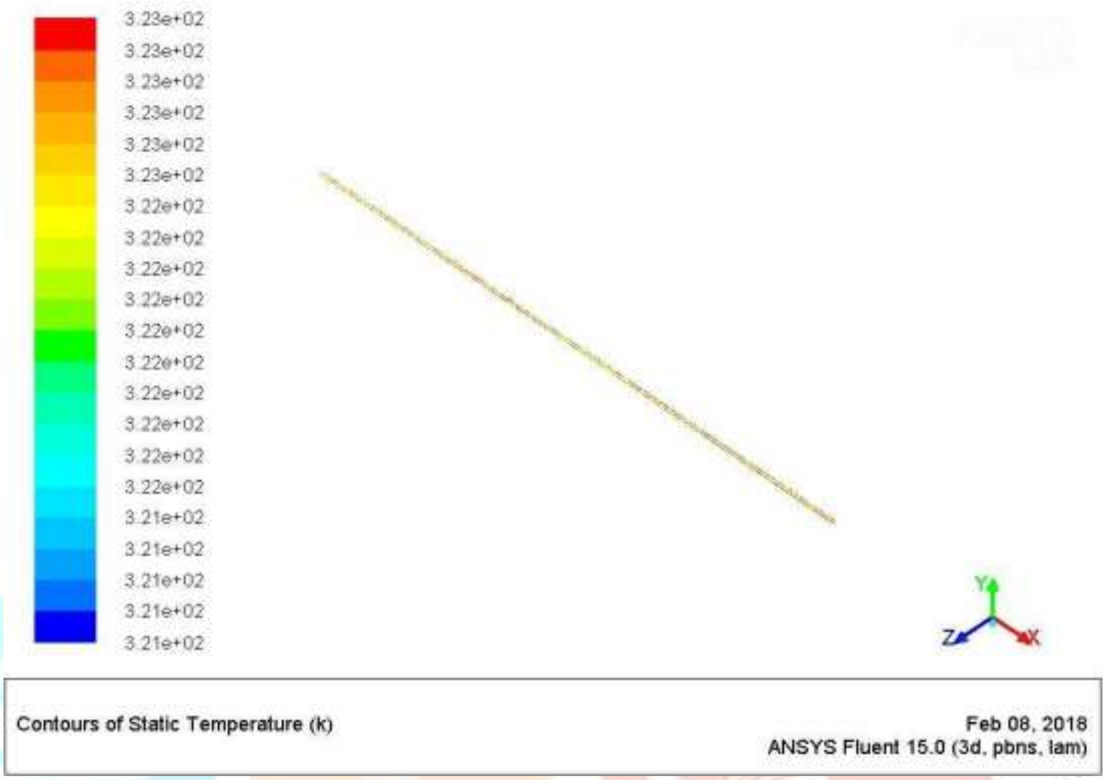

Fig.9 Temperature variations at 0.4kg/s

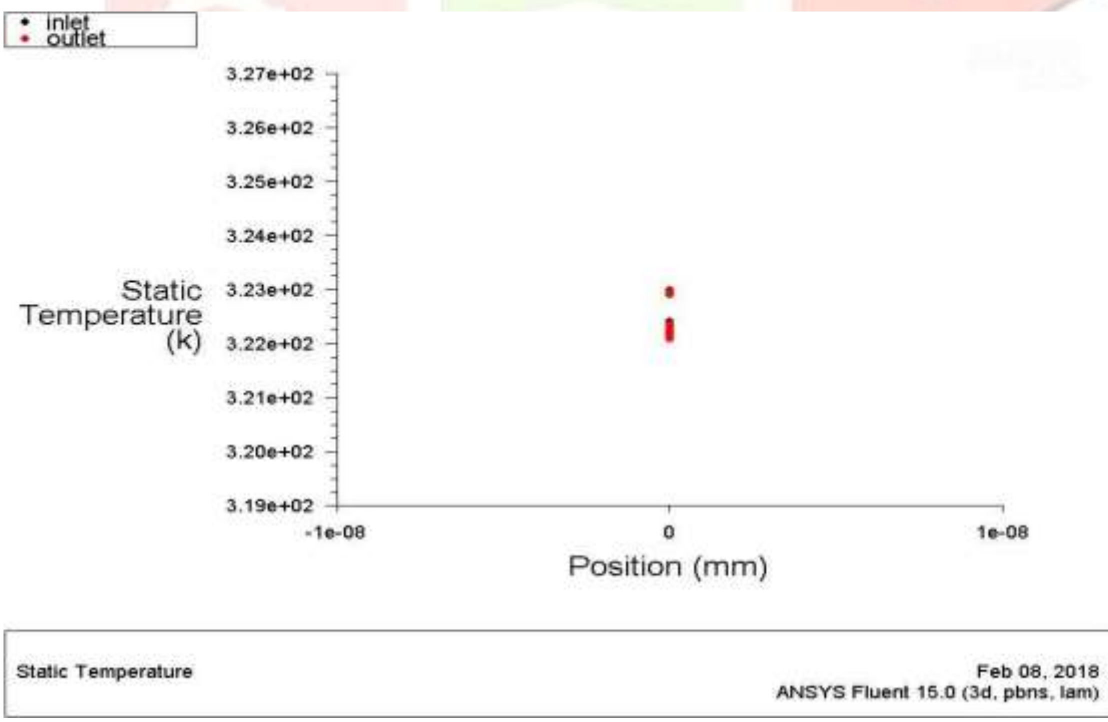

Fig.10 Temperature drop at 0.4kg/s

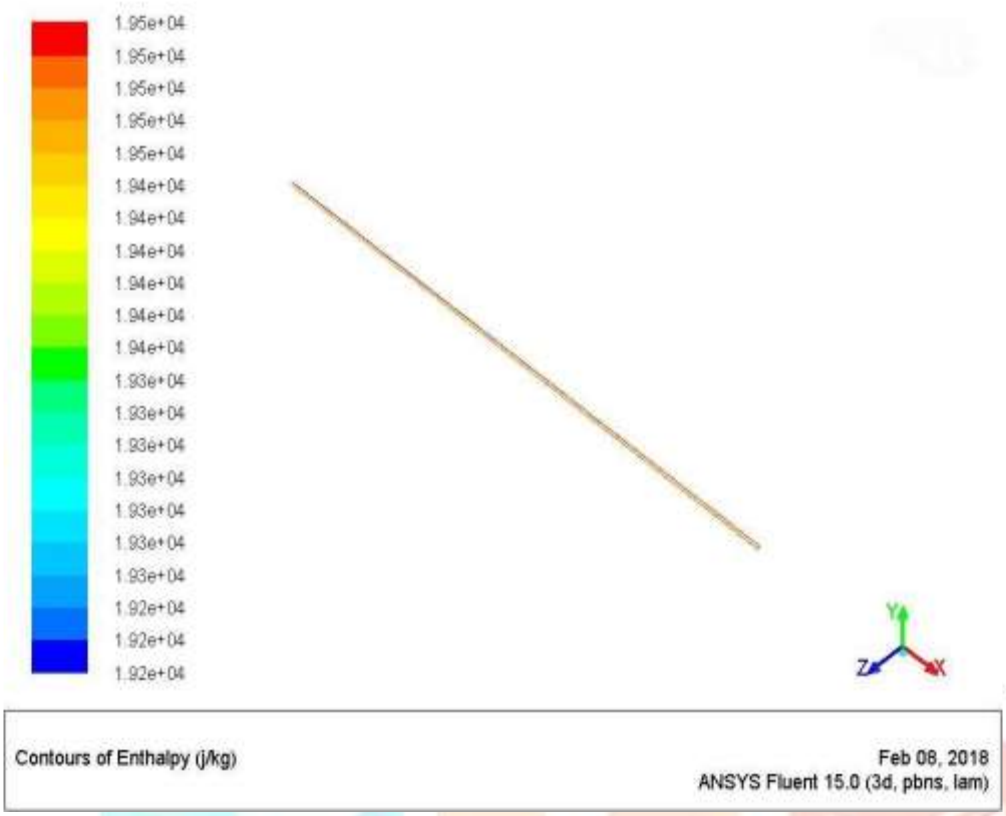

Fig.11 Enthalpy variation at 0.4kg/s

FOR R407C REFRIGERANT (3mm inner diameter)

Variation of temperature and enthalpy at 2bar

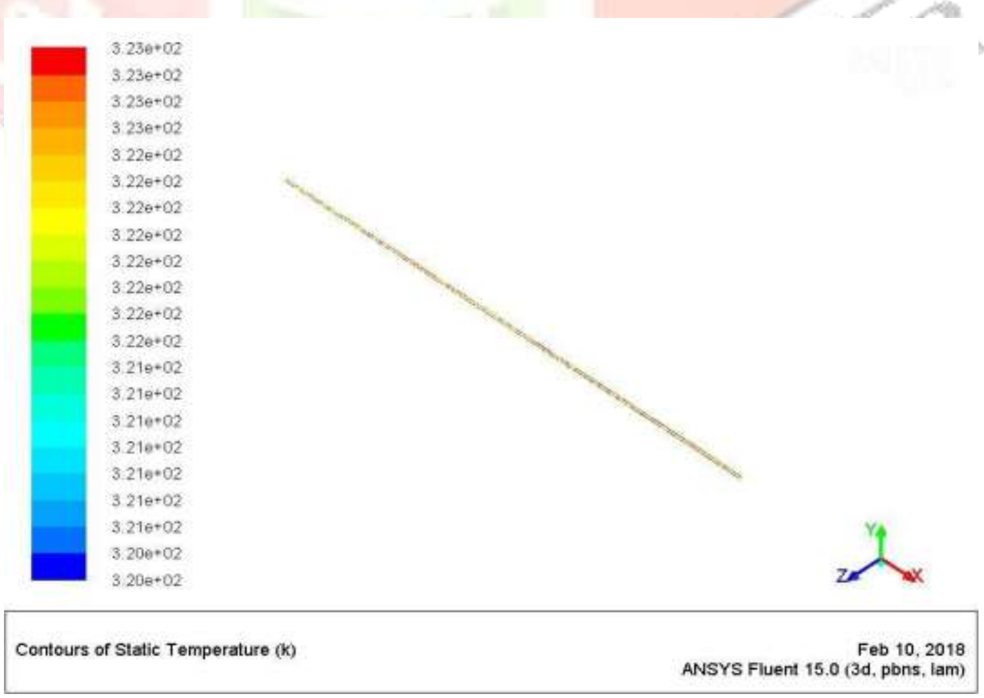

Fig.12 Temperature variations at 2bar and 0.4kg/s

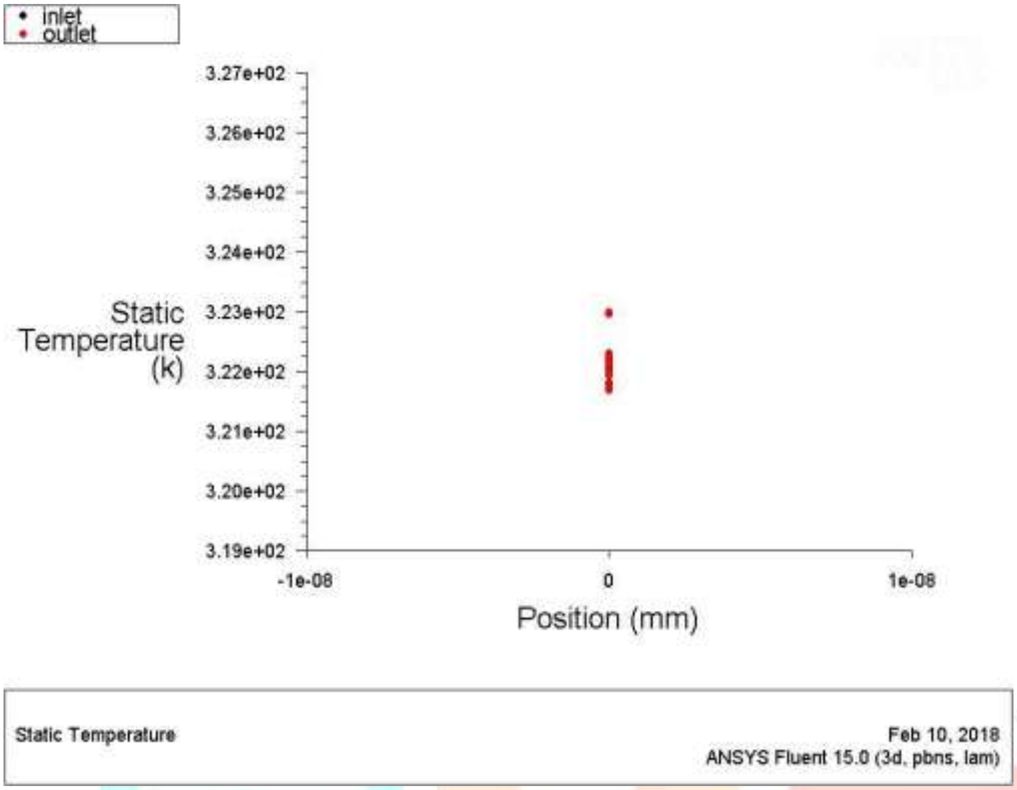

Fig.13 temperature drop at 2bar and 0.4kg/s

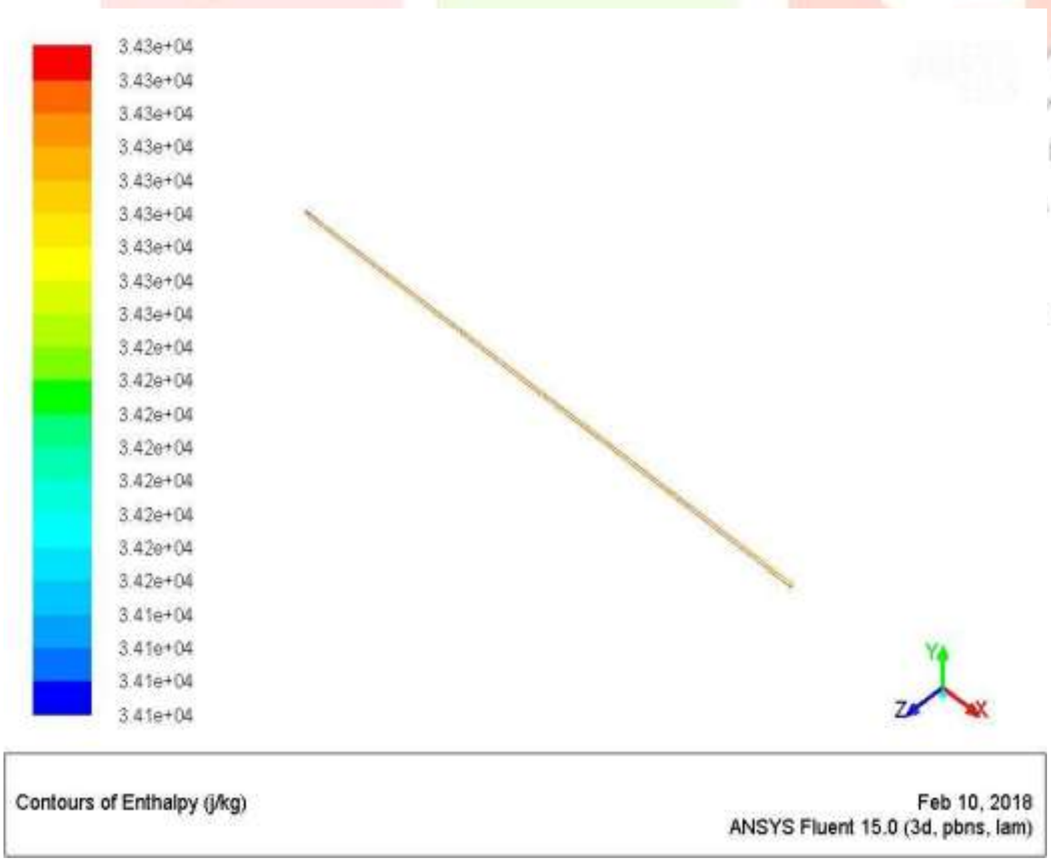

Fig.14 Enthalpy change at 2bar and 0.4kg/s

Variation of temperature and enthalpy at 3bar

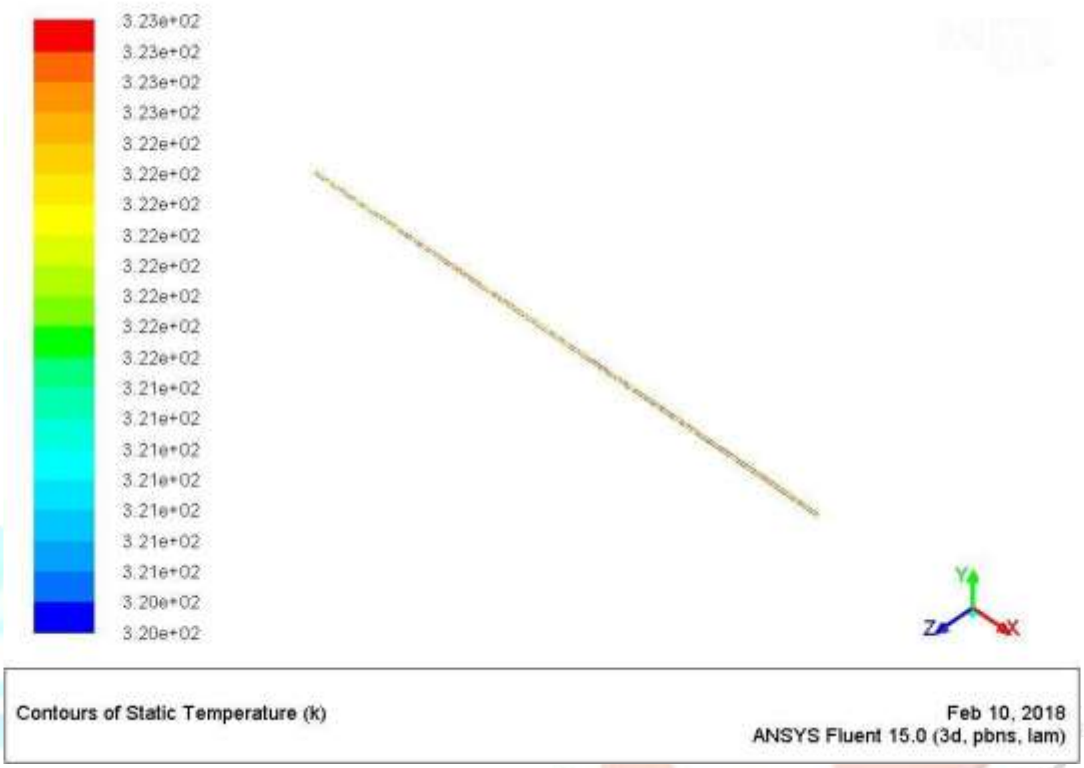

Fig.15 Temperature variations at 3bar and 0.4kg/s

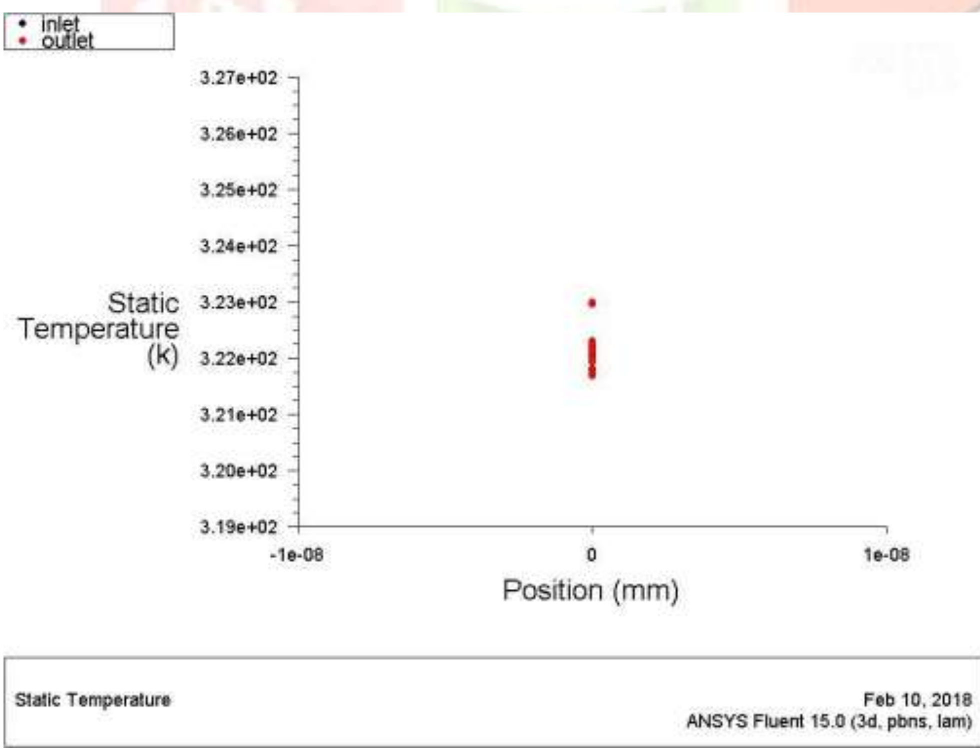

Fig.16 Temperature drop at 3bar and 0.4kg/s

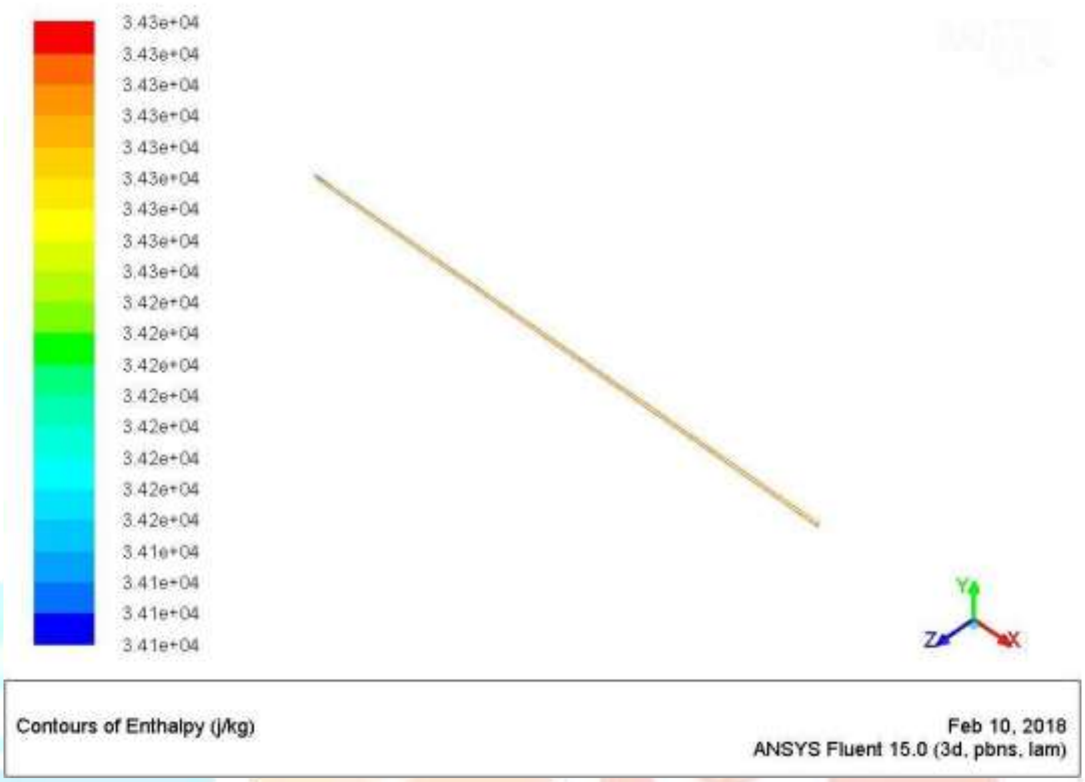

Fig.17 Enthalpy change at 3bar and 0.4kg/s

10. RESULTS AND DISCUSSIONS

FOR R22 REFRIGERANT IN (2mm ID):

Variation of temperature drop for different pressures

S.NO	INLET PRESSURES (KPa)	TEMPERATURE DROP(K)
1	200	0.9
2	300	1.2
3	500	1.96

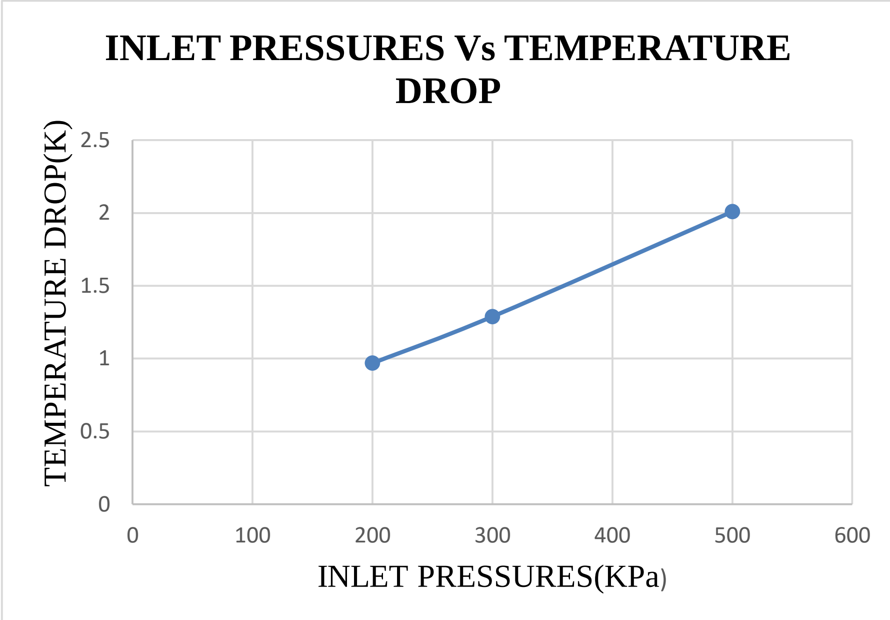

Fig.18 Inlet pressures Vs Temperature drops for 2mm ID at 0.4kg/s

According to DAVID DEL COL the temperature drop at 0.4kg/s mass flow rate is 0.92K. But by conducting the experiments on 2mm ID tube, I get 0.9K temperature drop at 2bar on R22 refrigerant. And it goes on increasing by increasing the inlet pressures of the condenser.

Variation of temperature drop for different mass flow rates

S.NO	MASS FLOW RATES(kg/s)	TEMPERATURE DROP(K)
1	0.4	0.9
2	0.5	1.1
3	0.6	1.5

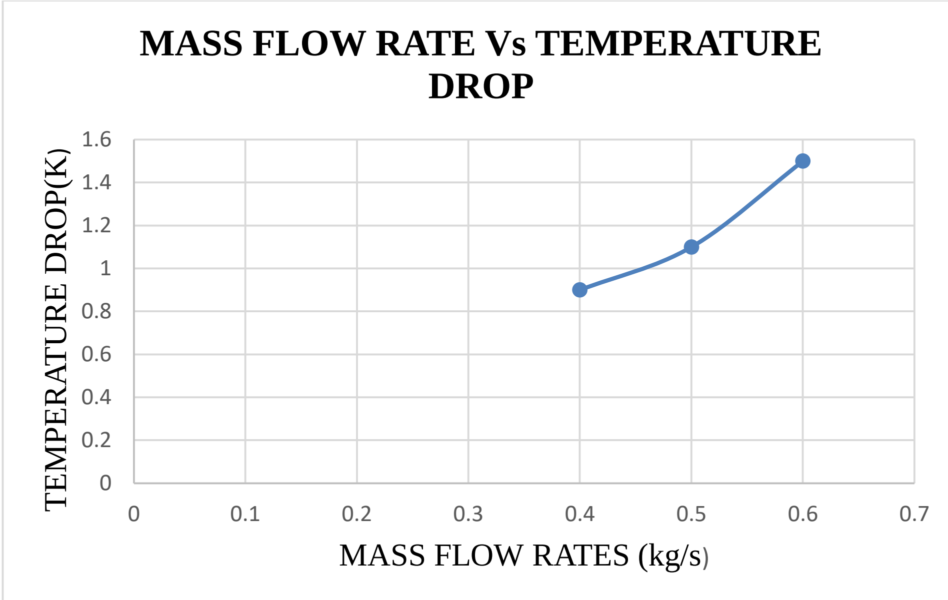

Fig.19 Mass flow rates Vs Temperature drop for 2mm ID at 2bar

By increasing the mass flow rates of the refrigerant R22 the temperature drops of the refrigerant also increases at constant pressure 2bar. The variation of temperature drops for different mass flow rates are shown in the figure.

Variation of Enthalpy drop for different pressures

S.NO	INLET PRESSURES(Kpa)	ENTHALPY DROP(KJ/kg)
1	200	1
2	300	1.2
3	500	1.5

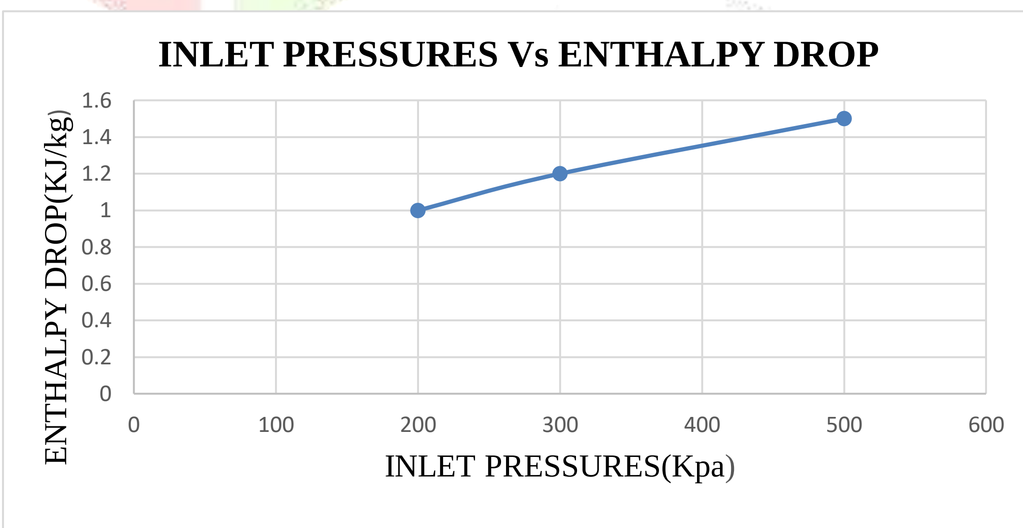

Fig.20 Inlet pressures Vs Enthalpy drops for 2mm ID at 0.4kg/s

The variation of enthalpy drop for different inlet pressures at constant mass flow rate is shown. By increasing the inlet pressures of the refrigerant the enthalpy drops of the refrigerant also increases at constant mass flow rate i.e., 0.4kg/s.

FOR R22 REFRIGERANT IN (3mm ID):

Variation of temperature drop for different pressures

S.NO	INLET PRESSURES(Kpa)	TEMPERATURE DROP(K)
1	200	0.93
2	300	1.25
3	500	1.98

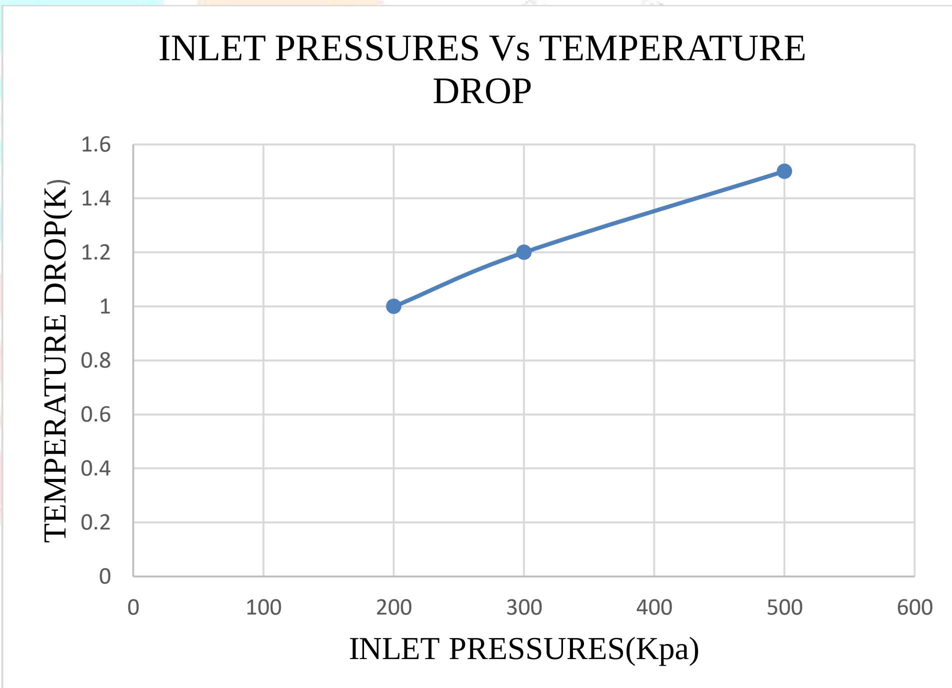

Fig.21 Inlet pressures Vs Temperature drops for 3mm ID at 0.4kg/s

The variations of temperature drop at different inlet pressures for a 3mm ID tube on a refrigerant R22 is shown. If the inlet pressures of the refrigerant increases then the temperature drop of the refrigerant also increases at constant mass flow rate. So the cooling effect increases.

Variation of Enthalpy drop for different pressures

	INLET PRESSURES(Kpa)	ENTHALPY DROP(KJ/kg)

S.NO		
1	200	1.1
2	300	1.4
3	500	1.7

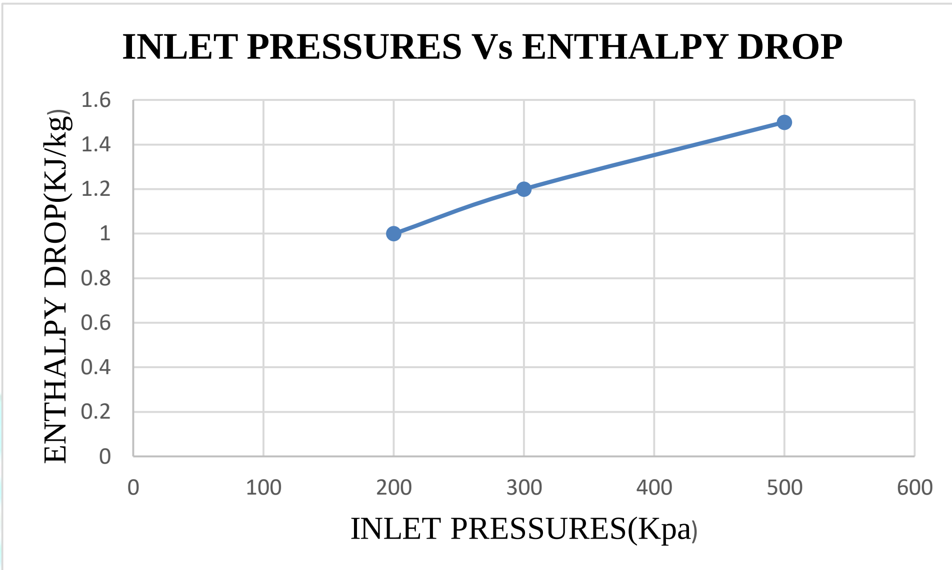

Fig.22 Inlet pressures Vs Enthalpy drops for 3mm ID at 0.4kg/s

The variations of enthalpy drop at different inlet pressures for a 3mm ID tube on a refrigerant R22 is shown. By increasing the inlet pressures of the refrigerant at constant mass flow rate the enthalpy drop of the refrigerant R22 also increases. So the heat transfer rate also increases.

FOR R407c REFRIGERANT IN (3mm ID):

Variation of temperature drop for different mass flow rates at 2bar

SNO	MASS FLOW RATES (kg/s)	TEMPERATURE DROP(K)
1	0.4	1.3
2	0.5	1.4
3	0.6	1.6

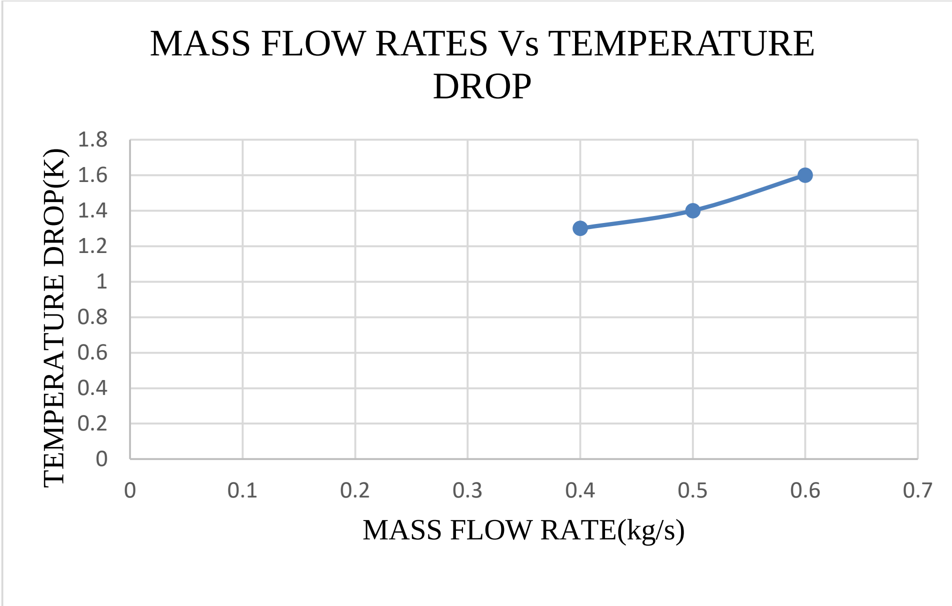

Fig.23 Mass flow rates Vs Temperature drop for 3mm ID at 2bar

The variations of temperature drop at different mass flow rates for a 3mm ID tube on a refrigerant R407c is shown. By increasing the mass flow rate of the refrigerant at constant pressure the temperature drop of the refrigerant R407c also increases. So the temperature drops of the refrigerant R407c is more when compared to the refrigerant R22 for 3mm ID at constant pressure. So the cooling capacity of the condenser with R407c is more.

Variation of Enthalpy drop for different mass flow rates at 2bar

S.NO	MASS FLOW RATE(kg/s)	ENTHALPY DROP(KJ/kg)
1	0.4	0.3
2	0.5	1.4
3	0.6	2.2

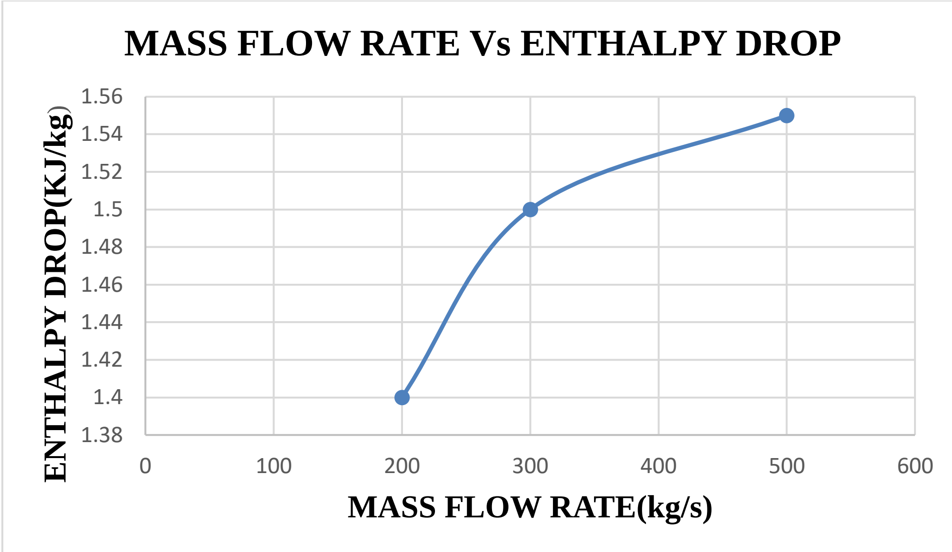

Fig.24 Mass flow rates Vs Enthalpy drop for 3mm ID at 2bar

The variations of enthalpy drops at different mass flow rates for a 3mm ID tube on a refrigerant R407c is shown. By increasing the mass flow rate of the refrigerant at constant pressure the enthalpy drop of the refrigerant R407c also increases. So the enthalpy drops of the refrigerant R407c is more when compared to the refrigerant R22 for 3mm ID at constant pressure. So the heat transfer rate of the condenser is more by using R407c as a refrigerant.

Variation of temperature drop for different mass flow rates at 3bar

S.NO	MASS FLOW RATE(kg/s)	TEMPERATURE DROP(K)
1	0.4	1.45
2	0.5	1.5
3	0.6	1.57

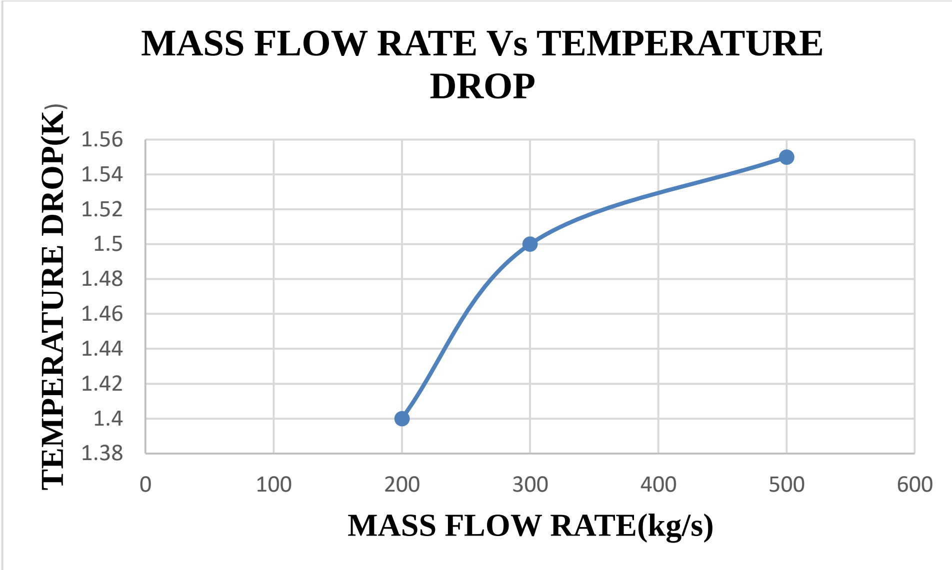

Fig.25 Mass flow rates Vs Temperature drop for 3mm ID at 3bar

The variations of temperature drop at different mass flow rates for a 3mm ID tube on a refrigerant R407c at 3bar is shown. By increasing the mass flow rate of the refrigerant at constant pressure the temperature drop of the refrigerant R407c also increases. So the temperature drops of the refrigerant R407c at 3bar is more when compared to the refrigerant R407c for 3mm ID at 2bar. So the cooling capacity of the condenser with R407c is more by increasing pressure.

Variation of Enthalpy drop for different mass flow rates at 3bar

S.NO	MASS FLOW RATE(kg/s)	ENTHALPY DROP(KJ/kg)
1	0.4	0.8
2	0.5	1.5
3	0.6	2.2

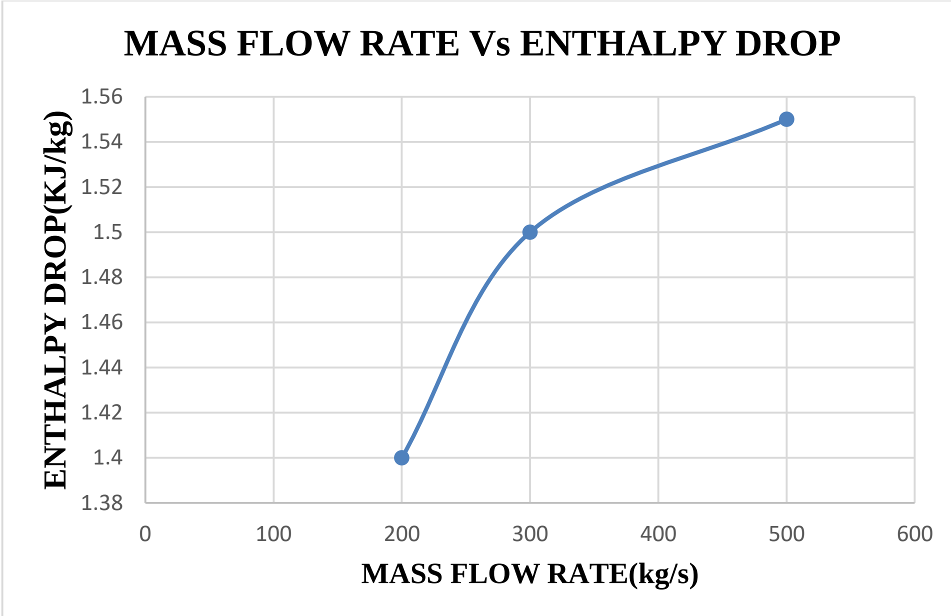

Fig.26 Mass flow rates Vs Enthalpy drop for 3mm ID at 3bar

The variations of enthalpy drops at different mass flow rates for a 3mm ID tube on a refrigerant R407c at 3bar is shown. By increasing the mass flow rate of the refrigerant R407c the enthalpy drop of the refrigerant R407c also increases. So the enthalpy drops of the refrigerant R407c at 3bar is more when compared to the refrigerant R407c at 2bar for 3mm ID. So the heat transfer rate of the condenser is more by using R407c as a refrigerant at 3bar.

Variation of temperature drop for different pressures at 0.4kg/s

S.NO	INLET PRESSURES(Kpa)	TEMPERATURE DROP(KJ/kg)
1	200	1.3
2	300	1.4
3	500	1.5

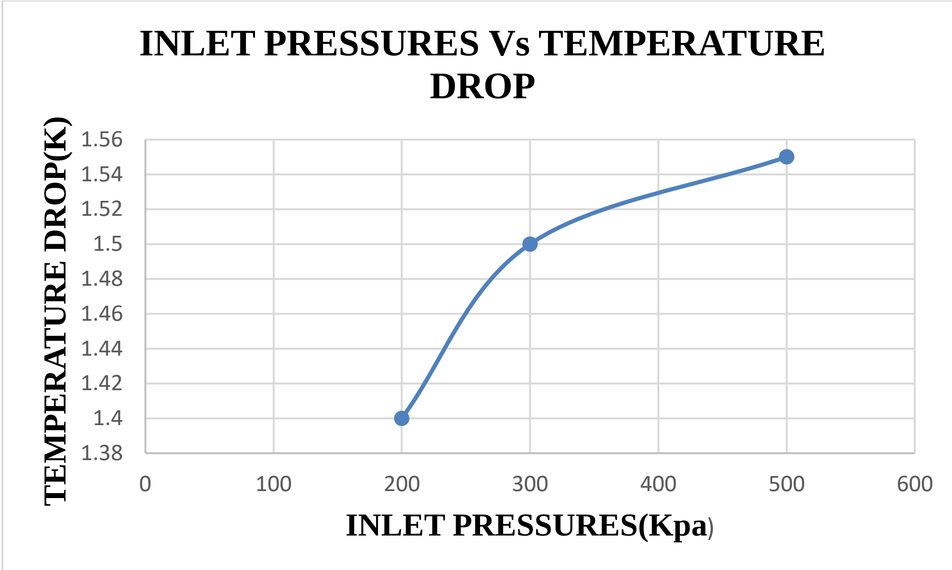

Fig.27 Inlet pressures Vs Temperature drop for 3mm ID at 0.4kg/s

The variations of temperature drops at different inlet pressures for a 3mm ID tube on a refrigerant R407c at 0.4kg/s mass flow rate is shown. By increasing the inlet pressures of the refrigerant R407c the temperature drop of the refrigerant R407c also increases. So the temperature drops of the refrigerant R407c at 0.4kg/s is more when compared to the refrigerant R22 at 0.4g/s for 3mm ID.

Variation of Enthalpy drop for different pressures at 0.4kg/s

S.NO	INLET PRESSURES(Kpa)	ENTHALPY DROP(KJ/kg)
1	200	0.3
2	300	0.8
3	500	1

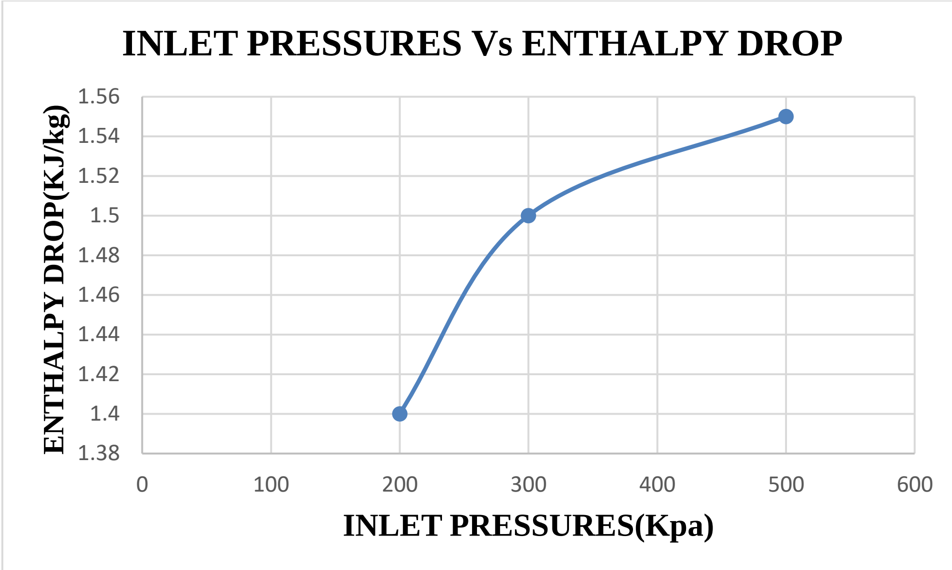

Fig.28 Inlet pressures Vs Enthalpy drop for 3mm ID at 0.4kg/s

The variations of enthalpy drops at different inlet pressures for a 3mm ID tube on a refrigerant R407c at 0.4kg/s mass flow rate is shown. By increasing the inlet pressures of the refrigerant R407c the enthalpy drop of the refrigerant R407c also increases. So the enthalpy drops of the refrigerant R407c at 0.4kg/s is more when compared to the refrigerant R22 at 0.4kg/s for 3mm ID.

Variation of temperature drop for different pressures at 0.5kg/s

S.NO	INLET PRESSURES(Kpa)	TEMPERATURE DROP(K)
1	200	1.4
2	300	1.5
3	500	1.7

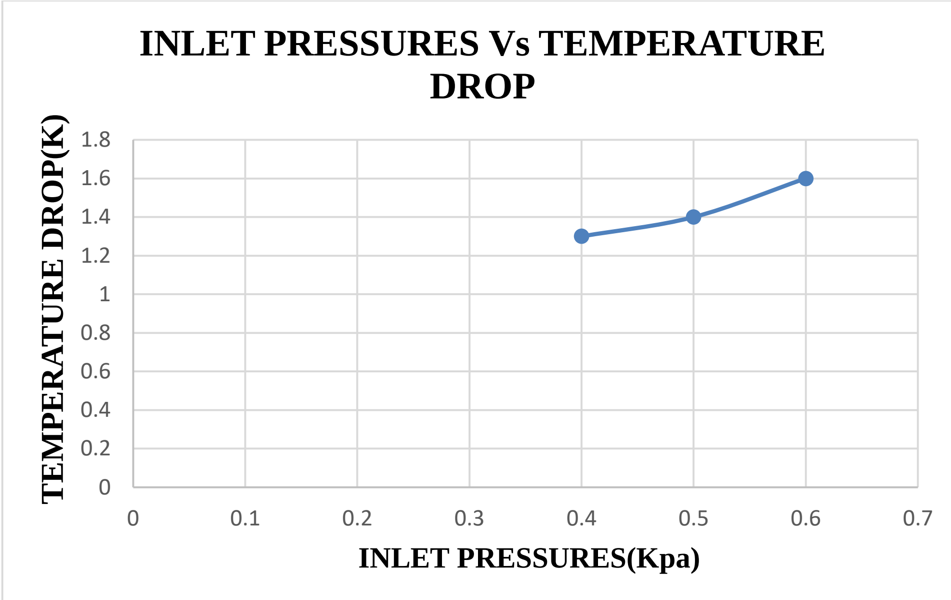

Fig.29 Inlet pressures Vs Temperature drop for 3mm ID at 0.5kg/s

The variations of temperature drops at different inlet pressures for a 3mm ID tube on a refrigerant R407c at 0.5kg/s mass flow rate is shown. By increasing the inlet pressures of the refrigerant R407c the temperature drop of the refrigerant R407c also increases. So the temperature drops of the refrigerant R407c at 0.5kg/s is more when compared to the refrigerant R407c at a mass flow rate of 0.5kg/s for 3mm ID. So the cooling capacity of the refrigerant R407c at 0.5kg/s is more.

Variation of Enthalpy drop for different pressures at 0.5kg/s

S.NO	INLET PRESSURES(Kpa)	ENTHALPY DROP(KJ/kg)
1	200	1.4
2	300	1.5
3	500	1.55

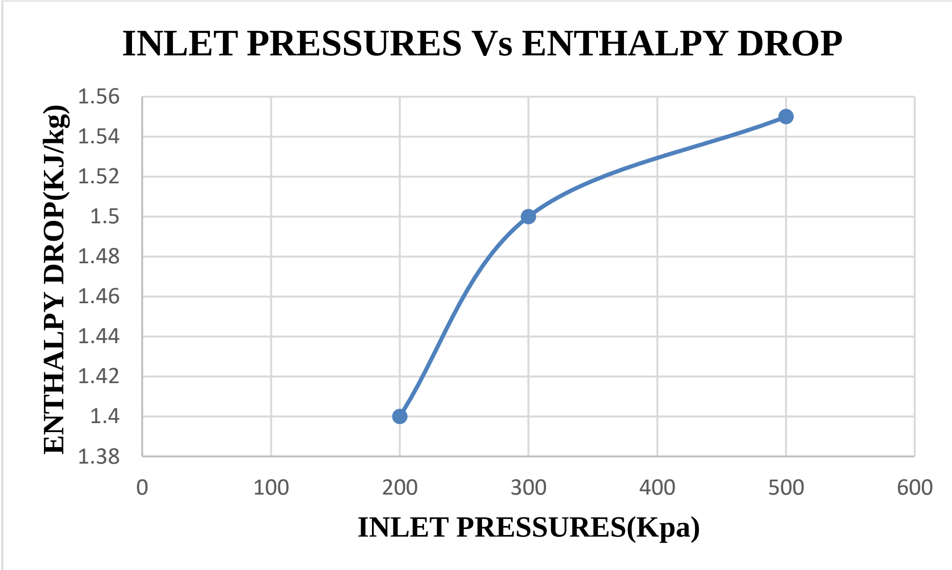

Fig.30 Inlet pressures Vs Enthalpy drop for 3mm ID at 0.5kg/s

By observing the above results, the refrigerant R407c gives the better temperature and enthalpy variations for different mass flow rates and pressures than the refrigerant R22. In the refrigerant R407c the temperature and enthalpy drops are more when compared to the refrigerant R22. So the heat transfer to the water is high when R407c is used. Also, the thermal conductivities, densities and viscosities of both the refrigerants R22 and R407c are almost same. So the refrigerant R22 can be replaced by the refrigerant R407c in the existing refrigerants.

CONCLUSION:

By conducting several tests at different mass flowrates and pressures, the refrigerant R407c shows better results than the refrigerant R22. In the refrigerant R407c the temperature and enthalpy drops are more when compared to the refrigerant R22. So the heat transfer to the water is high when R407c is used. Also, the thermal conductivities, densities and viscosities of both the refrigerants R22 and R407c are almost same. So the refrigerant R22 can be replaced by the refrigerant R407c in the existing refrigerants. And also by using a minichannel shell ad tube condenser, the charge needed for the condensation will be low. If we go for the micro channels, the pressure drops will be more and also the refrigerant may stagnate within the condenser.

So a minichannel shell and tube condenser with 3mm inner diameter gives the better condensation effect for the refrigerant R407c.

FUTURE SCOPE:

According to Montreal protocol, the refrigerants containing chlorine and bromine content will be phased out from 2020 because of their adverse effects on the ozone depletion potential and global warming potential. So the refrigerant R22 (difluoromonochloromethene) will be phased out because of his chlorine content and it will be replaced by the refrigerant R407c (it is a blend of R32, R125, R134a). The refrigerant R407c will be the best alternate to the refrigerant R22 because of the thermal conductivities, densities and viscosities of both the refrigerants are almost same. In most of the industries R22 already replaced and tested by R407c. so in order to reduce the environmental effects R407c will be used and it is the best alternative refrigerant for the refrigerant R22.

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