

## Effect of Condenser Coil Diameter on Performance of a Domestic Refrigerator



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### ABSTRACT

*In systems involving heat transfer, a condenser is a device or unit used to condense a substance from a gaseous to liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchanger which has various designs and sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. For example, a refrigerator uses a condenser to discharge to the surrounding air heat extracted from the restricted space of the unit to the outside air.*

*In Domestic refrigerator the condenser coil is used to discharge the heat from the refrigerant after operating the compression to the atmosphere. In General this heat rejection rate depends is mainly on various parameters for example, ambient air temperature, dimensions of the coil, diameter of the coil. Normally in domestic refrigerator condenser coil size is restricted to some standard dimensions. In this project a condenser coil with different dimensions are placed in place of standard dimensions of the coil.*

*In the present work three different types of condenser coils has been used for this investigation by varying the diameter of the condenser coil by keeping the length as constant. For the present work a domestic*

*refrigerator having condenser coil diameter-3/16 inch (4.7650mm), length of the Coil-35 feet(8.5m) and capacity of the compressor 1/6 HP . The result obtained for different diameters are compared with calculated the standard model with respective diameter of condenser is taken to evaluate the C.O.P of the system.*

### INTRODUCTION

Vapor compression Refrigeration system is an improved type of air refrigeration system. The ability of certain liquids to absorb enormous quantities of heat as they vaporize is the basis of this system. Compared to melting solids (say ice) to obtain refrigeration effect, vaporizing liquid refrigerant has more advantages. To mention a few, the refrigerating effect can be started or stopped at will, the rate of cooling can be predetermined, the vaporizing temperatures can be governed by controlling the pressure at which the liquid vaporizes. Moreover, the vapor can be readily collected and condensed back into liquid state so that same liquid can be re-circulated over and over again to obtain refrigeration effect. Thus the vapor compression system employs a liquid refrigerant which evaporates and condenses readily. The System is a closed one since the refrigerant never leaves the system.

The coefficient of performance of a refrigeration system is the ratio of refrigerating effect to the

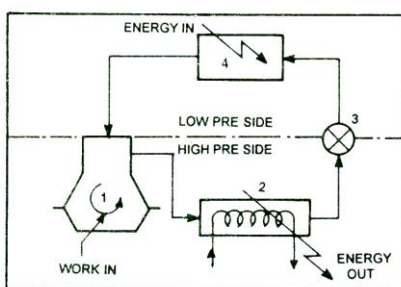
compression work; therefore the coefficient of performance can be increased by increasing the refrigerating effect or by decreasing the compression work.

The Vapor compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air-conditioning plant.

### Basic components of a vapor compression system

Basic components of a vapor compression refrigeration system are shown in Fig. 1.1. They are,

1.	Compressor	:	It is motor driven; it sucks vapor refrigerant from evaporator and compresses.
2.	Condenser	:	High pressure vapor refrigerant is condensed into liquid form in the condenser using cooling medium such as water.
3.	Expansion Valve	:	High pressure refrigerant is throttled down to evaporator pressure; rate of flow is metered.
4.	Evaporator	:	A cooling chamber in which products are placed; low pressure liquid refrigerant flows in the coils of evaporator and absorbs heat from products; the refrigerant vaporizes and leaves for compressor.



1 COMPRESSOR 2 CONDENSER 3 EXPN VALVE 4 EVAPORATOR

**Fig. 1 Schematic diagram of a vapor compression refrigeration system**

### CONDENSER

Condenser is that component which is placed next to compressor in a vapor compression refrigeration system. It is a heat exchanger that affects heat transfer between refrigerant gas, vapor or super saturated vapor coming from compressor and cooling medium such as

air or water. It removes heat absorbed by refrigerant in the evaporator and the heat of compression added in the compressor and condenses it back to liquid. The condenser abstracts the latent heat from high pressure refrigerant at the same pressure and constant temperature. For this purpose the condenser employs a cooling medium such as air or water.

Two considerations are necessary in design for effective functioning of the condenser as given below.

- Effective temperature differential
- High heat transfer coefficient

There are different types of condenser and selection of condenser depends upon the capacity of the system, refrigerant used and medium of cooling available. There are three types of condensers.

### Types of Condensers

- Air cooled condensers
- Water cooled condensers
- Evaporative condensers
- Air Cooled Condensers

An air cooled condenser is one in which the removal of heat is done by air. It consists of steel or copper tubing through which the refrigerant flows. The size of tube usually ranges from 6 mm to 18 mm outside diameter, depending upon the size of condenser.

Generally copper tubes are used because of its excellent heat transfer ability. The condensers with steel tubes are used in ammonia refrigeration systems. Following are the two types of air cooled condensers.

- Natural convection air cooled condenser
- Forced convection air cooled condenser

### Natural convection air cooled condenser

Natural convection air cooled condenser. In natural convection air cooled condenser, the heat transfer from the condenser coils to the air is by natural convection. As the air comes in contact with the warm condenser tubes, it absorbs heat from the refrigerant and thus the

temperature of air increases. The warm air being lighter, rises up and the cold air from below rises to take away the heat from the condenser. This cycle continues in natural convection air cooled condensers.

### Forced convection air cooled condenser

Forced convection air cooled condenser. In this air cooled condenser the condenser is mounted on the common chassis along with motor-compressor assembly. This integrated unit is generally called a condensing unit.

High pressure hot refrigerant gas or vapor from the compressor enters the top header of the condenser. The vapor flows down into finned tubes while a motor driven fan propels air on to these pipes. Fins increase the surface area of tubes and

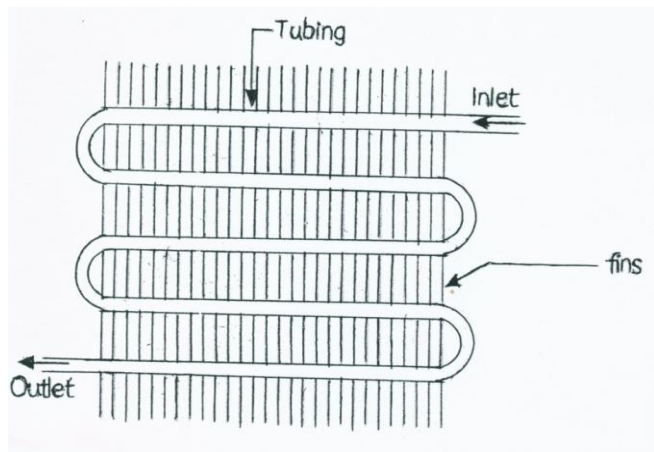


Fig2 Natural convection air cooled condenser

## SELECTION OF CONDENSER FOR A VCR SYSTEM

### Condenser

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temperature. For this purpose the condenser employs a cooling medium such as air or water.

### Selection of condenser

The condenser is one of the most important components of a refrigeration system. Its function is to dissipate heat absorbed by the refrigerant during evaporation (refrigeration effect) and compression (Heat of compression).

There are three different types of condensers classified on the basis of cooling used to dissipate heat. These are.

- Air cooled
- Water cooled
- Evaporative type

Air-cooled condenser can be natural convection type or forced convection type. This chapter is devoted only to the air-cooled condenser which is the most common type in use.

Before sizing a condenser, careful evaluation should include, consideration of initial cost, operating cost, service life and type of load. A condenser that is too large can be expensive and create operating problems in lower ambient conditions; an undersized condenser can cause operating problems in higher ambient conditions. It is therefore important to consider the following factors before sizing a condenser.

- Gross heat rejection
- Ambient temperature
- Condensing temperature
- Temperature difference (TD)
- Air flow

### Gross Heat Rejection

The refrigeration effect and the heat rejection rate of the system will vary depending on the actual balance to evaporator, compressor and condenser. Once the compressor and evaporator are selected to perform the required cooling it is essential that the condenser be selected on the basis of the capability of these components. Thus, the selection is made not on the heat gain, but rather on the actual load on the

condenser. It is also important to anticipate overload conditions on the evaporator and compressor that may occur at start-up, pull down, or unusual loading so that these may be considered in the condenser selection.

Great variation in compression heat occurs with variation in the ratio of the suction pressure and the discharge pressure. Large compression ratio needs more compression work. However, the heat loss from the compressor body, discharge gas piping are neglected in this energy as these are very small.

Since the heat transfer through the condenser is by conduction, condenser capacity is a function of the fundamental heat transfer equation.

$$Q_c = U.A. (LMTD)$$

Where

$$Q_c = \text{Condenser capacity in KJ/Sec. (Ref. Effect Heat of Comp. + Motor Wdg. Heat)}$$

$$U = \text{Overall heat transfer coefficient KJ/h-m}^2 \text{ } ^\circ\text{K}$$

$$A = \text{Effective surface area in m}^2$$

$$LMTD = \text{the log mean temperature difference between the condensing refrigerant and condensing medium } ^\circ\text{K}$$

From the above equation it is evident that for any fixed value of 'U' the capacity of condenser is directly proportional to the surface area of the condenser and to the temperature difference between the condensing refrigerant and condensing medium.

### Ambient Temperature

While selecting suitable ambient temperature in condenser sizing, it is kept in mind that the value of ambient temperature in working out the TD is not taken at a very conservative value. The realistic one is always found to be more accurate and economical in final selection of a condenser. In the normal course while sizing condenser the ambient air temperature of 38°C has been found satisfactory.

### Condensing temperature

The condensing temperature depends on the type of refrigerant, the type of condenser, and the compressor capability. The type of refrigerant influences the condensing pressure, the superheated gas temperature, and mass flow required. The condensing pressure and the gas temperature in turn affect the power consumption and the cooling capacity of the system. It is, therefore, necessary to select a condensing temperature based on the recommendation of compressor manufactures more on realistic basis than on conservative basis in which case condenser size will work out to be too large.

### Temperature Difference (TD)

Air cooled condensers are normally rated on the basis of initial temperature difference (TD) which is the difference between the saturated temperature of the condensing refrigerant and the entering dry bulb air temperature. The capacity of the condenser is proportional to the temperature difference so that an increase in temperature difference increases the capacity of the condenser. Therefore, a higher temperature difference means that a physically smaller condenser may be adequate for necessary heat dissipation.

The proof of a good condenser selection comes only during the operating season when satisfactory operation without problems at various conditions.

$$TD = 0.6(CT_{max} - t_a)$$

**Table1: Realistic and Conservative Method**

	Realistic	Conservative
Ambient temperature $^{\circ}\text{C}$ (max. recorded for conservative 10% level for realistic)	38 $^{\circ}\text{C}$	46 $^{\circ}\text{C}$
Condensing temperature $^{\circ}\text{C}$ (Assumed value of 55 $^{\circ}\text{C}$ for conservative, max. for compressor 63 $^{\circ}\text{C}$ for realistic)	63 $^{\circ}\text{C}$	55 $^{\circ}\text{C}$
Design temperature difference (Condensing temperature minus max. recorded for conservative)	15 $^{\circ}\text{C}$	9 $^{\circ}\text{C}$
Relative equipment size	1.00	1.7

Whereas  $CT_{max}$  = maximum condensing temperature for compressor selected,  $^{\circ}\text{C}$ .

$t_a$  = ambient air temperature at 10% design level  $^{\circ}\text{C}$  DB



A 10% design temperature level means that the temperature is exceeded 10% of all the hours, day and night during the four summer months; March through June. This adds up to 2928 hrs and 1% temperature level is equated or exceeded a total of 292 hours, (0.1 x 2928) during an average summer period. This basis has been found very satisfactory and economical.

### Air Flow

For an air cooled condenser a definite relationship exists between size (face area) of condenser and the quantity of air circulated. The velocity of air through the condenser is critical within certain limits. Good design prescribes the minimum air velocity that will produce turbulent flow and high heat transfer coefficient. Increasing the air velocity beyond this point causes an excessive pressure drop through the condenser and results in an unnecessary increase in the power requirements of the fan and noise level.

The quantity of air passing through an air-cooled condenser is a function of face area of the condenser and the air velocity. Normally the air velocities over air-cooled condenser are between 2 meters to 6 meters per second depending upon the application. By establishing the air quantity and air velocity the face area of the condenser can be calculated using the following equation.

$$\text{Face area} = \frac{\text{Air quantity m}^3/\text{sec}}{\text{Air velocity m/sec}}$$

### EXPERIMENTAL SETUP

In vapor compression refrigerating system basically there are two heat exchangers. One is to absorb the heat which is done by evaporator and another is to remove heat absorbed by refrigerant in the evaporator and the heat of compression added in the compressor and condenses it back to liquid which is done by condenser.

This project focuses on heat rejection in the condenser this is only possible either by providing a fan or by extending the surfaces. The extended surfaces are

called fins. The rate of heat rejection in the condenser depends upon the number of fins attached to the condenser.

This project investigated the performance of condenser using helical condenser in the present domestic refrigerator galvanized iron steel material fins are used. In this project mild steel material fins are replaced and galvanized iron steel are used for the condensers.

The performance of the condenser will also help to increase COP of the system as the sub cooling region incurred at the exit of the condenser. The performance of the condenser is also investigated by existing and modification condenser. In general domestic refrigerators have no fans at the condenser and hence extended surfaces like fins play a very vital role in the rejection of heat.

In order to know the performance characteristics of the vapor compression refrigerating system the temperature and pressure gauges are installed at each entry and exit of the component. Experiments are conducted on helical condenser having fins.

Different types of tools are also used like snips to cut the plated fins to required sizes, tube cutter to cut the tubes and tube bender to bend the copper tube to the required angle. Finally the domestic refrigerator is fabricated as for the requirement of the project. All the values of pressures and temperatures are tabulated.

### Pressure Gauges

Pressure gauge indicates pressure in the system. Most commonly used gauges in Refrigeration and Air-conditioning installation are

- High pressure Gauges
- Compound pressure Gauges

### High Pressure Gauges:

As the name suggests, this gauge is employed on the high pressure side of the vapor compression system. It

is equipped with dial for measuring pressures from 0 to 500 psi.

**Compound Pressure Gauges:**

A compound pressure gauge can measure pressures both above and below the atmospheric pressure. It is used on the low pressure side of the vapor compression refrigeration system. A standard compound gauge's dial is graduated to record a pressure range from -30 to 250 psi.



Fig 3: Pressure gauges

**Temperature Gauges**

Temperature gauges used in this invention have electronic thermostat at the probe which senses and records the temperature.

Fig. 5.2 shows the Temperature gauges which are used in the experimental setup.



Fig 4 Temperature gauges





Fig 5 Proposed System With Pitch Angle 180°.



Fig 6 Proposed System with Pitch Angle 90° & Rectangular Shaped Fin.

### EXPERIMENTAL PROCEDURE

The following procedure is adopted for experimental setup of the vapor compression refrigeration system

- The domestic refrigerator is selected, working on vapor compression refrigeration system.
- Pressure and temperature gauges are installed at each entry and exit of the components.
- Flushing of the system is done by pressurized nitrogen gas.
- R 134a refrigerant is charged in to the vapor compression refrigeration system by the following process:

The systematic line diagram for charging is shown in the fig. it is necessary to remove the air from the refrigeration unit before charging.

First the valve  $V_2$  is closed and pressure gauge  $P_2$ , vacuum gauge  $V$  are fitted as shown in the fig. the valve  $V_5$  is also closed and valves  $V_1$ ,  $V_4$ ,  $V_6$  and  $V_3$  are opened and the motor is started thus the air from the condenser receiver and evaporator is sucked through the valve  $V_1$  and it is discharged in to atmosphere through the valve  $V_6$  after compressing it in the compressor the vacuum gauge  $V$  indicates sufficiently low vacuum when most of the air is removed in the system. The vacuum reading should be at least 74 to 75 cm of Hg. If the vacuum is retained per above an hour it may be concluded that the system is free from the air.

After removing the air the compressor is stopped and valves  $V_1$  and  $V_6$  are closed, the valves  $V_5$ ,  $V_2$  and  $V_7$  of the refrigerant cylinder are opened and then the compressor is started whenever the sufficient quantity of refrigerant is taken in to the system which will be noted in the pressure gauges. The compressor is stopped. The valves  $V_7$  and  $V_5$  are closed and valve  $V_1$  is opened the refrigerant cylinder is disconnected from the system the pressure gauge is used to note the pressure during the charging the system.

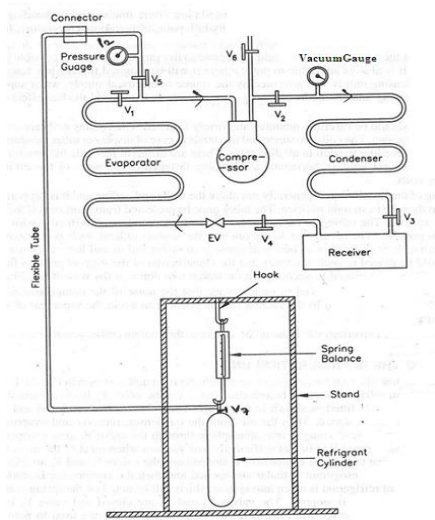


Fig. Charging of Refrigeration System.

### Fig7 charging of refrigeration system

- Leakage tests are done by using soap solution, In order to further test the condenser and evaporator pressure and check purging daily for 12 hours and found that there is no leakages which required the absolutely the present investigation to carry out further experiment.
- Switch on the refrigerator and observation is required for 1 hour and take the pressure and temperature readings at each section.
- The performance of the existing system is investigated, with the help of temperature and pressure gauge readings.
- The refrigerant is discharged out and helical condenser is located at the inlet of the capillary tube.

### Existing System

#### Temperatures

Compressor Suction Temperature $T_1$	=	27.6°C
Compressor Discharge Temperature $T_2$	=	59.2°C
Condensing Temperature $T_3$	=	36.2°C

Evaporator Temperature $T_4$	=	-10°C
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#### Pressures

Compressor suction pressure $P_1$	=	1.048 bar
Compressor discharge pressure $P_2$	=	12.275 bar
Condenser pressure $P_3$	=	12.275 bar
Evaporator pressure $P_4$	=	1.048 bar

#### Enthalpies

From pressure-enthalpy chart for R-134a, enthalpy values at state points 1,2,3,4. The state points are fixed using pressure and temperature and each point.

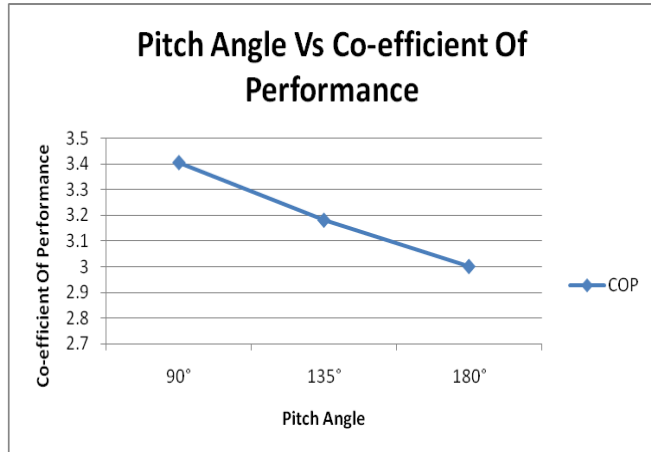
$h_1$	=	394 kJ/kg
$h_2$	=	436 kJ/kg
$h_3$	=	252 kJ/kg
$h_4$	=	252 kJ/kg

#### Calculation Performance Parameters

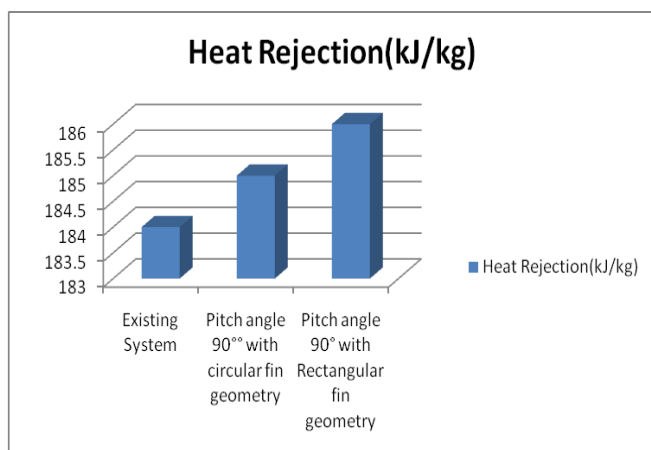
- Net Refrigerating Effect (NRE) =  $h_1 - h_4$   
=  $394 - 252 = 142$  kJ/kg
- Mass flow rate to obtain one TR, kg/min.
- $m_r = 210 / \text{NRE} = 210 / 142 = 1.48$  kg/min.
- Work of Compression =  $h_2 - h_1$  =  $436 - 394 = 42$  kJ/kg
- Heat Equivalent of work of compression per TR
- $m_r \times (h_2 - h_1) = 1.48 \times 42 = 62.16$  kJ/min
- Theoretical power of compressor =  $62.16 / 60 = 1.036$  kW
- Coefficient of Performance (COP) =  $(h_1 - h_4) / (h_2 - h_1) = 142 / 42 = 3.38$
- Heat to be rejected in condenser =  $h_2 - h_3$  =  $436 - 252 = 184$  kJ/kg
- Heat Rejection per TR =  $(210 / \text{NRE}) \times (h_2 - h_3) = 1.48 \times 184 = 272.32$  kJ/min
- Heat Rejection Ratio =  $272.32 / 210 = 1.296$
- Compression Pressure Ratio =  $\frac{\text{Discharge Pressure } P_d}{\text{Suction Pressure } P_s} = \frac{12.275}{1.048} = 11.75$



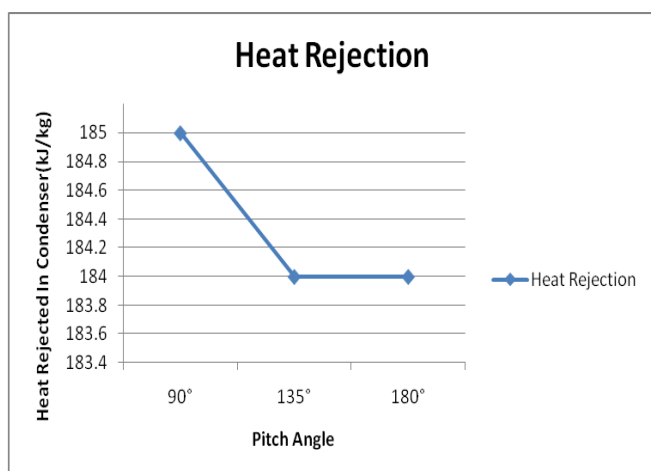
**GRAPHS**



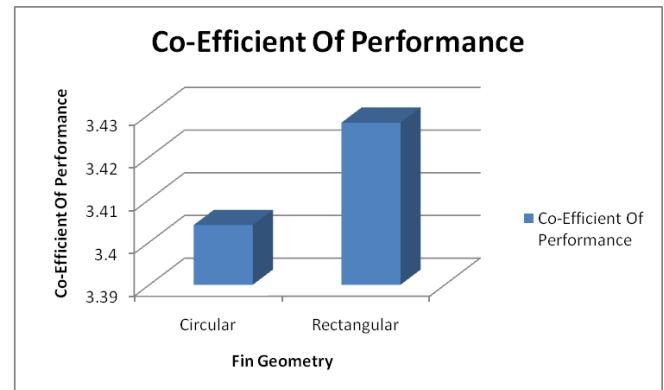
**Graph1 Pitch angle of the coil Vs COP**



**Graph2 Existing Vs Proposed System Heat rejection**



**Graph3 Pitch Angle of the coil Vs Heat rejection in condenser**



**Graph4 Fin Geometry Vs COP**

**CONCLUSIONS**

In the present work experiments are conducted for the helical design condenser, pitch of the coil of the condenser of a vapor compression refrigeration system used for a domestic refrigerator of 215 liters capacity.

The data was obtained from the experimental set-up fabricated by the present investigation and is used to analyze the performance of vapor compression refrigeration system with existing condenser and with helical condenser.

The COP of the system is 1.40% is increased and to compare with existing condenser and as a result of 1.408% increased in refrigeration effect and there is no any affect to the compressor work then existing.

In this work it is also tried to verify the performance of the system by varying the pitch angle of the coil is to be taken 90°, 135° & 180° variation. According to this 90° pitch angle with rectangular shaped fins performance is increased and better compared to other pitch angles.

An improvement of COP of 0.7% is obtained for the rectangular plate fin geometry. Because the plate rectangular plate fins has more surface area therefore more heat transfer rate occurs. Due to this sub cooling region increases at the exit of the condenser. Therefore the performance of the system increases. Compare

with Circular fin geometry Rectangular Fin geometry enhance the heat transfer rate by 5.33%.

### REVIEW OF LITERATURE

In study of applied thermo dynamics all the while we have been observing heat transfer from a system at higher temperature to that at lower temperature. Now in the study of refrigeration we will be observing various methods of cooling the objects and maintaining the temperature of bodies at values lower than surrounding temperature.

According to American society of Heating, Refrigeration and Air-conditioning Engineers (ASHARE) "Refrigeration is the science of providing and maintaining temperature below that of the surrounding (ambient) temperature".

In the olden days around 2500 years B.C. Indians, Egyptians, etc., were producing ice by keeping water in the porous posts open to cold atmosphere during the night period. The evaporation of water in almost cool dry air accompanied with recitative heat transfer in the clear night caused the formation of ice even when the ambient temperature was above the freezing temperature. Further references are available which support the use of ice in China 1000 years BC. Nero, the emperor, was using ice for cooling beverages. Further, the East Indians were able to produce refrigeration by dissolving salt in water as early as 4<sup>th</sup> century A.D., of course, on very small scale. The use of evaporative cooling is another application of refrigeration used olden days. The cooling of water in earthen pots for drinking purpose; is the most common example where the evaporation for water through the pores of earthen pot is accompanied with cooling of water.

### REFERENCES

1. Akintunde, M.A. 2004b. Experimental Investigation of The performance of Vapor Compression Refrigeration Systems. Federal University of Technology, Akure, Nigeria.

2. Eckert, E.R.G.; Goldstein, R.J.; Ibele, W.E.; Patankar, S.V.; Simon, T.W.; Strykowski, P.J.; Tamma, K.K.; Kuehn, T.H.; Bar-Cohen, A.; Heberlein, J.V.R.; (Sep 1997), Heat transfer--a review of 1994 literature, International Journal of Heat and Mass Transfer 40-16, 3729-3804.
3. Performance enhancement of a household refrigerator by addition of latent heat storage International Journal of Refrigeration, Volume 31, Issue 5, August 2008, Pages 892-901 Azzouz, K.; Leducq, D.; Gobin, D.
4. Akintunde, M.A. 2004b. Experimental Investigation of The performance of Vapor Compression Refrigeration Systems. Federal University of Technology, Akure, Nigeria.
5. Kays WM, London AL. Compact heat exchangers. New-York: McGraw-Hill, 1984.
6. Seshimo Y, Fujii M. An experimental study of the performance of plate fin and tube heat exchangers at low Reynolds numbers. ASME/JSME Thermal Engineering Proceedings, ASME 1991;4:449-54.
7. By James R. lines .Helically Coiled Heat Exchangers offer Advantages GRAHAM MANUFACTURING CO. INC.
8. [HTTP:WWW.CHANGPUAK.CH /ELECTRONICS\CALC\\_21.PHP](http://www.changpuak.ch/electronics/calc_21.php) The Continental united states from Buchanan MI49107,improvement@coppertubecoils.com