Performance Enhancement of Vapour Compression Cycle Using R134+Al_2O_3 Nanorefrigerant

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Abstract- *The recent advancements in nanotechnology have originated some new heat transfer fluids i.e. nanofluids which are prepared by dispersing and suspending the solid nanoparticles in conventional heat transfer fluids. These nanofluids are having better heat transfer performance, better thermo physical, transport and radiative properties. In the past seven years, nanorefrigerant has become the input for large number of experimental and vapour compression systems because of shortage of energy and environmental consideration. In this current research of work, aluminium oxide nanoparticles of size ranging from 50 to 100 nm are added in the vapour compression cycle by mixing with conventional R134a refrigerant as a nanorefrigerant. Three concentrations of* Al_2O_3 *i.e. 0.25%, 0.375% and 0.5% of mass of refrigerant are prepared and added to the system. For every nanorefrigerant concentration experiments are carried out and results are validated. The test results mainly focus on the application of nanorefrigerant which has a positive effect on the COP and power consumption of the system for the refrigerant. Literature has reported improvement in performance of the system on application of nanorefrigerant on account of increasing the surface area and heat capacity due to smaller particle size, enhancing the thermal conductivity which results improvement in efficiency of heat transfer systems, intensifying mixing fluctuations and turbulence, enhancing the flow rates and in turn cooling capacity simultaneously reducing the compressor power. The net result is improvement in the COP of the VCC and reduction in the compressor power consumption.*

Keywords- Al2O3 nanoparticles, Energy efficient system, Nanofluids, Nanorefrigerant, R134a refrigerant, Vapour compression cycle.

I. INTRODUCTION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature.

Refrigerants are the main working mediums used in the refrigeration systems. A refrigerant is the medium of heat transfer, which absorbs heat by evaporating at low temperatures and give out heat by condensing at high temperature and pressure conditions. They are classified as CFCs, HCFCs, and HFCs etc. The refrigerants chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) both have high ozone depleting potential (ODP) and global warming potential (GWP), and contributes to ozone layer depletion and global warming. Therefore these two refrigerants are required to be replaced with environmentally friendly refrigerants to protect the environment. The hydro fluorocarbon (HFC) refrigerants with zero ozone depletion potential have been recommended as alternatives. The ODP of R134a is zero, but it has a relatively high global warming potential. The rapid industrialization has led to unprecedented growth, development and technological advancement across the globe. Today global warming and ozone layer depletion on the one hand and spiralling oil prices on the other hand have become main challenges. Excessive use of fossil fuels is leading to their sharp diminution and nuclear energy is not out of harm's way. In the face of imminent energy resource crunch there is need for developing thermal systems which are energy efficient. Thermal systems like refrigerators and air conditioners consume large amount of electric power. It is essential to developing energy efficient refrigeration and air conditioning systems with nature friendly refrigerants. By addition of nanoparticles to the refrigerant results in improvements in the thermo-physical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. This project report presents the addition Al_2O_3 nanoparticles in Vapour compression cycle with R134a refrigerant which is having ultimate aim to enhance system performance and develop an energy efficient refrigeration system.

II. VAPOUR COMPRESSION REFRIGERATION SYSTEM(VCRS)

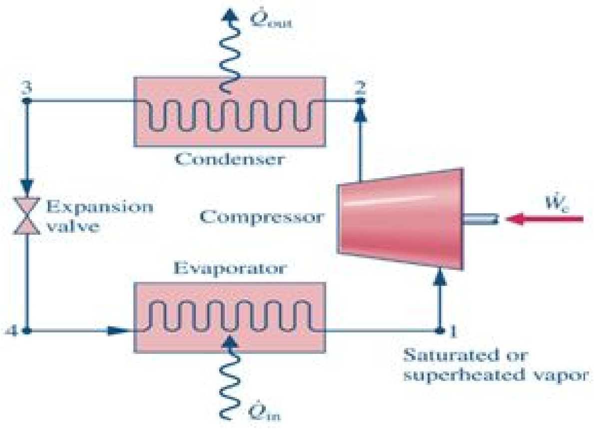

Fig. 1. Schematic of VCRS [12]

Figure. 1 depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapour and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapour is then in the thermodynamic state known as a superheated vapour and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air. That hot vapour is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool water or cool air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case).

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapour refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated. The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapour mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser. To complete the refrigeration cycle, the refrigerant vapour from the evaporator is again a saturated vapour and is routed back into the compressor.[16]

III. REFRIGERANT R134a

R134a is also known as Tetrafluoroethane (CF3CH2F) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement. It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressors. It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive. Currently it is also being widely used in the air conditioning system in newer automotive vehicles.

Table. 1. R134a properties.[13] [14]

Sr No	Properties	R134a
1	Boiling Point	-14.9°F or -26.1°C
2	Auto-Ignition Temperature	1418°F or 770°C
3	Ozone Depletion Level	0
4	Solubility in Water	0.11% by weight at 77°F or 25°C
5	Critical Temperature	252°F or 122°C
6	Cylinder Color Code	Light Blue
7	Global Warming Potential	1200

IV. NANOPARTICLES

Nanoparticles and nanoparticle-based devices are of interest in numerous industrial applications due to their unique and often advantageous properties. The high surface-to-volume ratio together with size effects (quantum effects) of nanoparticles introduces many size-dependent phenomena such as chemical, electronic, magnetic and mechanical properties. In nanotechnology, a particle is defined as a small object that behaves as a whole unit with respect to its transport and properties. Particles are further classified according to their diameter. Coarse particles cover a range between 10,000 and 2,500 nanometres. Fine particles are sized between 2,500 and 100 nanometres. Ultrafine particles or nanoparticles are sized between 1 and 100 nanometres.

A. Aluminium Oxide (Al_2O_3) Nanoparticles

This article discusses the properties and applications of aluminum oxide nanoparticles. Aluminum is a Block P, Period 3 element, while oxygen is a Block P, Period 2 element. The morphology of aluminum oxide nanoparticles is spherical, and they appear as a white powder. Aluminum oxide nanoparticles (both liquid and solid forms) are graded as highly flammable and an irritant that can cause serious eye and respiratory irritation. Size of the nanoparticles added in the system is ranging from 50 to 100 nm.

Chemical composition of elements in Al_2O_3:
Aluminum = 52.92%
Oxygen = 47.04%

B. Properties of Aluminum Oxide (Al_2O_3)

1. Chemical Properties:

- Chemical symbol : Al_2O_3
- CAS No. : 1344-28-1
- Group Aluminum : 13
- Oxygen : 16

2. Physical properties

Properties	Metric	Imperial
▪ Density	3.9 g/cm3	0.140 lb/in3
▪ Molar mass	101.96 g/mol	-

3. Thermal properties

Properties	Metric	Imperial
▪ Melting point	2040°C	3704°F
▪ Boiling point	2977°C	5391°F

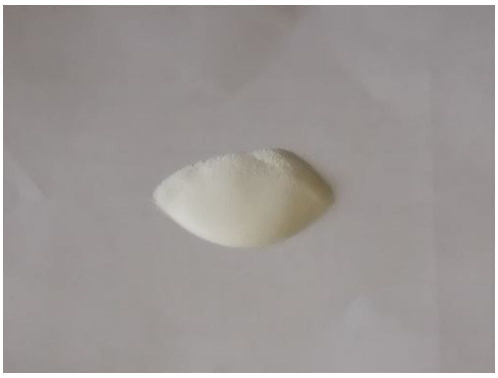

Fig. 2. Al_2O_3 nanoparticles concentration [15]

C. Applications

- In integrate circuit base boards
- Transparent ceramics, high-pressure sodium lamps, and EP-ROM window
- In YAG laser crystals
- As cosmetic fillers
- Single crystal, ruby, sapphire, sapphire, and yttrium aluminum garnets
- High-strength aluminum oxide ceramic and C substrates
- Packaging materials, cutting tools, high purity crucible, winding axle, and furnace tubes
- Polishing materials, glass products, metal products, semiconductor materials
- Plastic, tape, and grinding belts
- Paint, rubber, plastic wear-resistant reinforcement, and advanced waterproof materials
- Catalyst, catalyst carrier, analytical reagents
- Aerospace aircraft wing leading edges
- Vapor deposition materials, special glass, fluorescent materials, composite materials and resins

In cases where aluminum oxide nanoparticles are used in the liquid form such as:

- an aqueous dispersion, the key applications are as follows:
- Plastics, rubber, ceramics, refractory products
- To improve ceramics density, smoothness, fracture toughness, creep resistance, thermal fatigue resistance, and polymer products wear resistance.

V. SYSTEM FABRICATION, INSTALLATION, CHARGING AND TESTING

The entire components of test rigs are mounted on the sheet metal panels. Sheet metal panels are powder coated. Base panel having size 1000 mm x 600 mm and vertical panel of 1200 mm x 1000 mm are bolted together. All the basic components compressor, condenser, condenser cooling fan and evaporator are mounted on the base panel. All these components are bolted with the base panel with the help of different size of nut and bolts. Vertical panel is used to mount all the measurement related equipment which consist of pressure gauges and temperature indicator. All the electric switches, temperature indictor's knob, capillaries and dryer is mounted on the vertical panel. Stirrer is provided for keeping the water temperature in the evaporator uniform. After the installation the following operations are carried out, often the success or failure of the installation depends on the care with which these things are done.

- Testing the installation for leaks
- Removal of Air or Evacuation
- Adding proper quantities of refrigerants

A. Testing the Installation for Leaks

Testing for the leakage of refrigerant from the refrigeration unit is very important. A very minute leakage may lead to the loss of refrigerant during the operations. In this system Soap leak detection method is used for leak detection. A soap solution can be used when you know the approximate area where a leak may exist. Area such as pipe joints and connector joints are applied with soap solution if the bubble are appeared the leak is present in that area. Tightening of connectors and applying brazing on detected leakages system is made leak proof. The second method used is pressure testing method. The system is pressurized with R134a and then the decrease in the pressure is measured against overnight time. As the pressure does not drop considerably hence the system is considered as leak proof. There are minute changes in the pressure as the temperature around the system is not constant throughout the testing time. Tightening of connectors and applying brazing on detected leakages system is made leak proof.

Fig. 3. Evacuation or air removal [15]

B. Removal of Air or Evacuation

Air is removed from the evaporator and lines by charging the refrigerant and forcing the air out. R134a is used to force the air out. For creating vacuum in the system separate vacuum pump is employed. Vacuum pump is connected with suction port of the compressor. Vacuum pump is run till the vacuum is not shown on the pressure indicators. As the vacuum is achieved and if the system is retained for about an hour on vacuum the system is considered as leak proof.

C. Adding proper quantities of refrigerants

The quantity of refrigerant to be added to the system for initial charge or recharging depends on the size of the equipment and the amount of refrigerant to be circulated. In this system, the refrigerant is weighed by keeping the refrigerant cylinder on the weighing machine. The charged amount of refrigerant is found out by noting down the reduction in weight of refrigerant cylinder. The quantity of refrigerant to be added to the system for initial charge or recharging depends on the size of the equipment and the amount of refrigerant to be circulated.

I. The refrigerant cylinder is put on the weighing machine
II. The cylinder and compressor suction port are connected through the hoses
III. The cylinder valve is opened and the gas is drawn into the system.
IV. Cylinder weight is observed.
V. When the correct charged has been added the valve on the refrigerant cylinder is closed and suction port is capped.

Fig. 4. Charging Nanorefrigerant in the system [15]

D. Adding Al_2O_3 nanoparticles to the system.

I. After taking the trial on the system with refrigerant R134a alone, the readings are taken and corresponding calculations are done.

II. In order to add the nanoparticles in the system, preparations are done.

III. Three concentrations of the nanoparticles are prepared i.e. 0.25 %, 0.375 % and 0.5 % of the weight of refrigerant i.e. 350 gm. The size of the nanoparticles is ranging from 50 to 100 nm.

IV. Now the same procedure is repeated which includes removal of the existing refrigerant, testing the installation for the leaks, air evacuation by applying vacuum pump.

V. Before adding nanoparticles to the system, charging setup is prepared.

VI. For insertion of nanoparticles in the charging line of the setup, one copper tube is used. The copper tube is flared on both the ends with flare nuts at its ends. Flaring is done with the help of flaring kit. The flare nut can be directly screwed to the charging line of the compressor.

Fig. 5. Flared copper tube along with flare nuts [15]

VII. After connecting one end of the copper tube to the charging line, first concentration of the nanoparticles is added in the tube. The other end of the tube is connected to the intake manifold of charging setup.

VIII. The intake manifold consist of a cross pipe joint. The cross pipe joint is connected at its four ends with pressure gauge, one end of flared copper tube, rubber hose connected to the R134a cylinder and one knob of opening and closing the flow.

IX. The R134a cylinder is connected with a valve on its cylinder head. Now the refrigerant with nanoparticles is added is the system by opening both the valves i.e on charging line and refrigerant cylinder and also the knob on the cross pipe joint.

X. The refrigerant is charged in steps by observing the pressure gauges. The standing inlet pressure required is 25 psi. The refrigerant is charged till the inlet pressure gauge shows 25 psi reading.

XI. After the required pressure is achieved the charging is stopped and the charging set up is removed. The main system valve is closed and fitted with flare not at the charging line.

XII. The readings are taken on the system with nanorefrigerant. The further concentrations are tested by repeating the above procedure.

VI. OBSERVATION TABLE

We have conducted experiments on our vapour compression refrigeration test rig. We have taken temperature reading after achieving steady state of the system. The readings are taken on the setup which is running for two hours. The readings are taken on the setup which is having R134a refrigerant only at first and also simultaneously with all the three concentrations of Al_2O_3 i.e. 0.25 %, 0.375 %, 0.5 %.

A. Observation table of R134a refrigerant in the set up

Table. 2. Observation Table[13] [14]

Parameters	% Concentration of Al_2O_3 in R134a			
	R134a alone	0.25 %	0.375 %	0.5 %
P_1	24	24	24	25
P_2	125	130	130	130
T_1	14.1	23.2	23.3	18.1
T_2	66.1	70.1	66.3	67.1
T_3	35.5	35.1	35.5	34.8
T_4	0.9	-0.5	-1.4	-0.9
T_5	6.2	5.9	3.9	4.2

Where,

P_1 = Pressure at compressor inlet in psi

P_2 = Pressure at compressor outlet in psi

T_1 = Temperature at evaporator outlet in ^{0}C

T_2 = Temperature at condenser inlet in ^{0}C

T_3 = Temperature at condenser outlet in ^{0}C

T_4 = Temperature at evaporator inlet in ^{0}C

T_5 = Water temperature in degree Celsius.

VII. CALCULATIONS

Sample calculations are done for the steady state reading in the table no 1

1) Saturation Temperature and Pressure in Condenser

$$(P_c)_g = \frac{psi}{14.46} = \frac{125}{14.46}$$

$$(P_c)_g = 8.644 \text{ bar}$$

$(P_c)_{abs} = (P_c)_g + P_{atm}$
$(P_c)_{abs} = 8.644 + 1.01325$ bar
$(P_c)_{abs} = 9.6577$ bar

The Saturation Pressure in Condenser = 9.6577 bar
From the saturation properties of R134a (or from p-h chart)
The Saturation Temperature in Condenser = 38.068 ^{0}C.
$(T_C)_{sat} = 311.068$ k

2) Saturation Temperature and Pressure in Evaporator

$(P_e)_g = \frac{psi}{14.46} = \frac{24}{14.46}$

$(P_e)_g = 1.6597$ bar
$(P_e)_{abs} = (P_e)\ g + P_{atm}$
$(P_e)_{abs} = 1.6597 + 1.01325$ bar
$(P_e)_{abs} = 2.6730$ bar

The Saturation Pressure in Evaporator = 2.6730 bar
From the saturation properties of R134a, (or from p-h chart)
The Saturation Temperature in Evaporator =
-2.575 ^{0}C.
$(T_E)_{sat} = 270.42$ K.

3) Carnot COP

$(COP)_{Carnot} = \frac{TL}{TH-TL}$

$(COP)_{Carnot} = \frac{(TL)sat}{(TC)sat-(TE)sat} = \frac{270.42}{311.068-270.42}$

$(COP)_{Carnot} = 6.65.$
$(COP)_{Carnot} = 6.65.$
The Carnot COP of the system is 6.65.

4) Theoretical COP

The Saturation Temperature in Evaporator = -2.575 ^{0}C.

The Evaporator outlet temperature of the refrigerant = 14.1 ^{0}C.

As the evaporator outlet temperature of the refrigerant is greater than saturation temperature, therefore point 1(Outlet condition of the refrigerant from evaporator) is in superheated region.

The Saturation Temperature in Condenser = 38.068 ^{0}C.

The Condenser outlet temperature of the refrigerant = 35.3 ^{0}C.

As the condenser outlet temperature of the refrigerant is less than saturation temperature, therefore point 3(Outlet condition of the refrigerant from condenser) is in sub cooled region.

Assuming isentropic compression in the compressor, point 2 is obtained at the intersection of the constant entropy line passing through point 1 and condenser pressure line. Plotting the cycle on p-h chart gives the following enthalpies of the refrigerant at different points.

$h_1 = 412$ kJ/kg
$h_2 = 449$ kJ/kg
$h_3 = h_4 = 248$ kJ/kg [10]

$(COP) = \frac{h1-h4}{h2-h1}$

$(COP) = \frac{412-248}{449-412}$

(COP) = 4.43

The COP of the system is 4.43

Inthe same way, COP for reading no. 2, 3 and 4 is calculated and results are given below in result table no. 3 and 4. [13]

VIII. RESULT AND DISCUSSION

A.Comparison of coefficient of performance obtained with R134a and different nanoparticle concentration.

Table. 3. Result table of COP [13] [14]

Concentration	R134a alone	0.25 % Al_2O_3	0.375 % Al_2O_3	0.5 % Al_2O_3
Coefficient of performance (COP)	4.43	5.375	5.931	4.859

B. Comparison of Carnot coefficient of performance obtained with R134a and different nanoparticle concentration.

Table. 4. Result table of Carnot COP [13] [14]

Concentration	R134a alone	0.25 % Al_2O_3	0.375 % Al_2O_3	0.5 % Al_2O_3
Carnot COP	6.65	6.443	6.443	6.578

C. Graph comparing COPs obtained with different concentrations

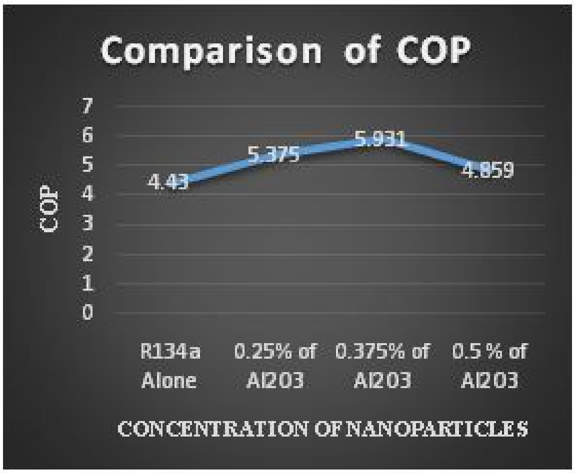

Fig. 6. Graph comparing COPs [13] [14]

IX. CONCLUSION

As we conducted test on Vapour Compression Refrigeration System with and without using nanorefrigerant and further analyzed the results, the test results shows that the application of nanorefrigerant has positive effect on the COP of the system. The study has been able to validate the reported phenomena of improvement in COP of refrigeration systems on application of Al_2O_3 nanoparticles in the working refrigerant i.e R134.

The analysis shows that the average COP of system without using nanorefrigerant is 4.43. The COP of the system with using 0.25 % of Al_2O_3 is 5.375. The COP of the system with 0.375 % and 0.5 % of Al_2O_3 is 5.931 and 4.895 respectively. Hence we can conclude that among the three concentrations, concentration with 0.375 % of Al_2O_3 is leading to highest COP as compared to others. 0.5 % is the highest concentration and it leads to slight increase of COP when compared with result of R134a alone and it is much less than the COP obtained with 0.375 %. Hence the optimum concentration among the three is 0.375 % of Al_2O_3. The concentration of nanoparticles in refrigerant is having a great impact on the performance of the system. Slightly less or more than the optimum can affect the system performance.

The advantageous properties of nanoparticles found helpful in improving system working by enhancement of heat transfer rates in both the heat exchangers and also it is requiring less pumping power for nanorefrigerant.

X. ACKNOWLEDGEMENT

We would like to give our special thanks to our Head of Dept. Prof. N. P. Sherje and my institution SKNCOE who supported me at every bit and without whom it was impossible to complete the task.

REFERENCES

[1] D. Sendil Kumar1, Dr. R. Elansezhian “Experimental Study on Al2O3-R134a Nano Refrigerant in Refrigeration System.” International Journal of Modern Engineering Research (IJMER) Vol. 2, Issue. 5, Sep.-Oct. 2012 pp-3927-3929.

[2] R.K AdyansheePattanayak , NilamaniSahoo , Prasheet Mishra “Performance Analysis of a Domestic Refrigerator using Al2O3 Nanoparticles.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. IV (Jul. - Aug. 2015).

[3] Pravesh Kumar Kushwaha, PavanShrivastava, Ashish Kumar Shrivastava “Experimental Study of Nanorefrigerant (R134a+Al2o3) Based On Vapor Compression Refrigeration System. International Journal of Mechanical and Production Engineering.” ISSN: 2320-2092, Volume- 4, Issue-3, Mar.-2016.

[4] R.Reji Kumar, K. Sridhar, M.Narasimha “Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al2O3 as working fluid.” International Journal of Computational Engineering Research||Vol, 03||Issue, 4||.

[5] V.K. Dongare, Jyoti Kadam, AmrutaSamel, RupaliPawar, SampadaSarvankar “Enhancement of Vapour Compression Refrigeration System Using Nanofluids” International Research Journal of Engineering and Technology (IRJET). Volume: 04 Issue: 04 | Apr -2017.

[6] N. KamarajA.Manojbabu “Experimental analysis of Vapour Compression Refrigeration System using the refrigerant with Nano particles.” International Conference on Engineering Innovations and Solutions (ICEIS—2016).

[7] Gupta H.K, Agrawal G.D, Mathur J “An overview of Nanofluids: A new media towards green environment.” International Journal of Environmental Sciences Volume 3, No 1, 2012.

[8] Kuljeet Singh, Kundan Lal “An Investigation into the Performance of a Nanorefrigerant (R134a+Al2O3) Based Refrigeration System.” IJRMET Vol. 4, Issue 2, Spl- 2 May - October 2014.

[9] www.egr.msu.edu

[10] www.imperial.ac.uk

[11] www.basicmechanicalengineering.com

[12] https://www.slideshare.net/KDPatel9034/simple-vapour-compression-system

[13] Academic Lab manual of Refrigeration and Air conditioning, SKNCOE, pune

[14] A textbook of Refrigeration and Air conditioning, R.S. Khurmi, J.K. Gupta.
[15] Photographs of the apparatus and test rig components taken while experiments