Enhancement of COP in Vapour Compression Refrigeration System

M. Krishna Prasanna[#1]
M.E student, Heat Transfer studies in Energy Systems
Department of Mechanical Engg., Andhra University
Visakhapatnam-530003, A.P, India.

P. S. Kishore[*2]
Ph.D, Professor, Department of Mechanical Engg.,
Andhra University
Visakhapatnam-530003, A.P, India

Abstract: **Experimental analysis on vapour compression refrigeration (VCR) system with R-12 refrigerant was done and their results were recorded. The effects of the main parameters of performance analysis such as mass flow of refrigerant, degree of sub cooling and super heating on the refrigerating effect, coefficient of performance (COP) and power required to run the compressor for various evaporating temperatures, percentage increase in COP and percentage reduction of power required to run the compressor for VCR are dealt. Further the investigations are carried out by introducing shell and coil heat exchanger at the end of compressor.**

Keywords: Vapour compression refrigeration, Heat exchanger, COP, power.

I. INTRODUCTION

Vapour compression refrigeration system is based on vapour compression cycle. Vapour compression refrigeration system is used in domestic refrigeration, food processing and cold storage, industrial refrigeration system, transport refrigeration and electronic cooling etc. So improvement of performance of system is too important for higher refrigerating effect or reduced power consumption for same refrigerating effect. By sub-cooling using heat exchanger at condenser inlet refrigerating effect increases and power consumption or work input decreases. Thus performance of cycle is improved. Along with this waste heat also recovered. The essential quantity of heat recovered is not the amount but it is value.

Lokapure and Joshi [1] In their article dealt energy conservation by using technique of utilizing waste heat from air-conditioning system and increasing COP. They said that the refrigeration heat recovery device is indirect type of system in which a refrigerant to water heat exchanger is installed between the host refrigeration system compressor and condenser. In this case they achieved their goal by recovering energy and improving COP up to 13%. Khurmi and Gupta [2] in their book gave evidence that the process of under cooling is also brought about by employing a heat exchanger. This increases refrigerating effect and finally improved coefficient of performance in vapour compression refrigeration system. Domanski [3] investigated the effect of LLSL-HX (Liquid line/ Suction line heat exchanger) on system performance by taking liquid refrigerant from condenser to exchange heat with vapor refrigerant from evaporator. They reported that coefficient of performance was increased after installing LLSL-HX. Jain et al. [4] analyzed a complex system in order to utilize waste heat rejected by condenser to the atmosphere by installing additional water cooled condenser. Baskaran and Mathews [5] described systems including various refrigerants improved by analyzing the effect of the super heating / sub cooling case. Better performance coefficient values (COP) than those of non-super heating /sub cooling case are obtained. Rajput [6] in his book concluded that sub-cooling results in increase of C.O.P and said that no further energy has to be spent to obtain the extra cold coolant. Thirumaleshwar [7] proposed correlations for overall heat transfer coefficient for parallel and counter flow heat exchangers. Coronel and Sandeep [8] determined convective heat transfer coefficient in both helical and straight tubular heat exchangers under turbulent flow conditions. The experiments were conducted in helical heat exchangers and their study shows that the heat transfer coefficient in coiled tubes is higher than that in straight tubes.

II. SYSTEM DESCRIPTION AND DESIGN

Heat flows naturally from hot to colder body. But, in refrigeration system there is opposite phenomena i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant. The refrigerant (R-12) absorbs heat and hence evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. Thus, heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source. The refrigeration cycle can be broken down into the following stages as in Fig 1.

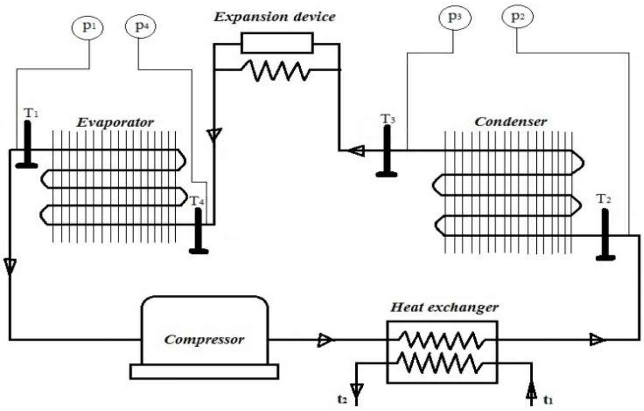

Fig.1: Schematic diagram of a proposed VCR System

Considering Fig.2,

1-2, the saturated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.

2-3, the high pressure superheated vapour passes from the compressor into the condenser. There will be decrease in temperature due to condensation process. The cooling for this process is usually achieved by using air. After condensation, refrigerant enters the expansion device.

3'-3, shell and coil heat exchanger is installed between the host refrigeration system compressor and condenser. Water is circulated through one side of heat exchanger and hot refrigerant gas from the compressor is routed through the other side. Heat is transferred from the hot refrigerant gas to the water thus refrigerating effect increases and power consumption or work input decreases. Thus performance of cycle is improved. Along with this waste heat also recovered.

3-4, the high-pressure liquid refrigerant passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

4-1, Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

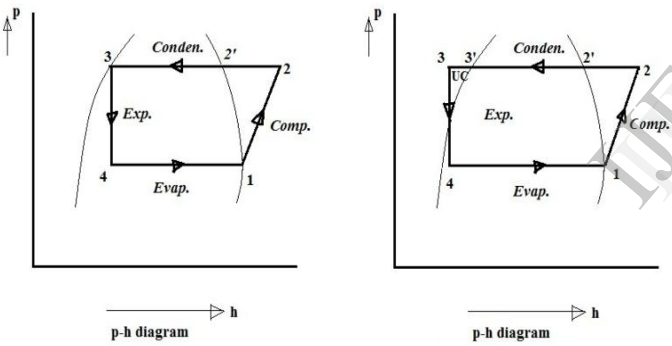

Fig.2: p-h diagram of a basic VCR and VCR with heat exchanger

(A) Shell and Coil Heat Exchanger:

Heat transfer in curved and helical circular tubes has been the subject of several studies due to the relatively high heat transfer coefficients associated with them. Flow in curved tubes is different from flow in straight tubes because of the presence of centrifugal forces. The centrifugal forces generate a secondary flow, normal to the primary direction of flow, with circulatory effects, that increases both the friction factor and the rate of heat transfer. The helically coiled heat exchangers generate a lot of turbulence thus a higher heat transfer coefficient obtained. If the unit is vertically installed, this reduces space requirements. Fig.3 shows heat exchanger coil which is modeled in Pro-E.

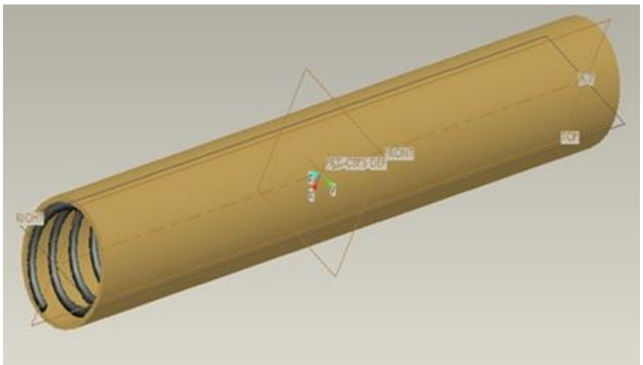

Fig.3: HEAT EXCHANGER COIL (modeled in Pro-E)

(B) Heat Exchanger Unit:

1) Overall heat transfer coefficient.

$$1/U = 1/hi + 1/ho + dx/k + F_r + F_w \quad (1)$$

2) Outlet temperature of water

$$t_2 = (Q/ (m\ C_p))+ t_1 \quad (2)$$

3) Log mean temperature difference. $=\Delta T_m$

$$\Delta T_m = \Delta T_1 - \Delta T_2 / \ln (\Delta T_1/\Delta T_2) \quad (3)$$

4) Area of Heat Exchanger

$$A = Q/ U \times \Delta T_m \quad (4)$$

5) Length of the Tube,

$$L = A / \pi \times D_o \quad (5)$$

III. ANALYSIS OF THE PROBLEM

Based on T-s diagram of basic VCR as shown in Fig.4

1. Refrigerating effect $=h_1-h_{f3'}$ (6)
2. Degree of superheat $= T_2 - T_3$ (7)
3. $h_{2\,sup}=h_{2'} + C_{pv}\,(T_2-T_{2'})$ (8)
   where h_{2sup}=enthalpy of vapour at superheated state C_{pv} (specific heat at constant pressure for the superheated vapour)
4. Compressor work (W_{comp}) $= h_{2\,sup}-h_1$ (9)

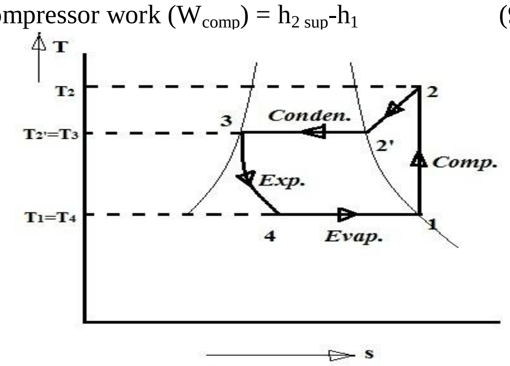

Fig.4: T-s diagram of basic VCR

5. COP_1 $= \dfrac{\text{Refrigeration Effect}}{\text{Work done by compressor}}$

$$= \frac{(h_1 - h_{f3'})}{(h_{2\,sup} - h_1)} \quad (10)$$

COP_1 = coefficient of performance of vapour compression refrigeration system without heat exchanger

6. Mass flow of refrigerant,

$$m_R = \frac{\text{Refrigerating capacity}}{60 \times W_{comp} \times COP_1} \quad (11)$$

Where W_{comp}= Compressor work

7. Heat available for desuperheating

$$(Q) = m_R (h_{2\,sup} - h_{2'}) \quad (12)$$

8. Outlet temperature of water in heat exchanger

$$(t_2\,°C) = (Q/\,(m\,C_p)) + t_1 \quad (13)$$

Where C_p is specific heat of water
t_1= inlet temperature of the water
t_2= outlet temperature

9. Degree of under cooling(DUC) = t_2-t_1 (14)
10. $h_{f3} = h_{f3'} - C_{pl} \times DUC$ (15)

Where h_{f3}=Enthalpy of liquid refrigerant (VCR with heat exchanger)
C_{pl} =Specific heat at constant pressure for the superheated liquid

11. $$COP_2 = \frac{\text{Refrigeration Effect}}{\text{Work done by compressor}} = \frac{(h_1 - h_{f3})}{(h_{2\,sup} - h_1)} \quad (16)$$

Where COP_2 = coefficient of performance of vapour compression refrigeration system with heat exchanger

12. $$\%\text{ increase in COP} = \frac{(COP_2 - COP_1)}{COP_1} \times 100 \quad (17)$$

13. $$m_{R1} = \frac{\text{Refrigerating capacity}}{60 \times W_{comp} \times COP_2}$$
14. (18)

m_{R1}=Mass flow of refrigerant when VCR with heat exchanger

15. $$P_1 = \frac{\text{Refrigerating capacity}}{60 \times COP_1} \quad (19)$$

Where P_1= Power required to run the compressor when VCR without heat exchanger

16. $$P_2 = \frac{\text{Refrigerating capacity}}{60 \times COP_2} \quad (20)$$

Where P_2= Power required to run the compressor when VCR with heat exchanger

17. % reduction of power required to run the compressor =

$$\frac{(P_1 - P_2)}{P_1} \times 100 \quad (21)$$

The results are extended to refrigerating capacity of 2 TR

IV. RESULTS AND DISCUSSION

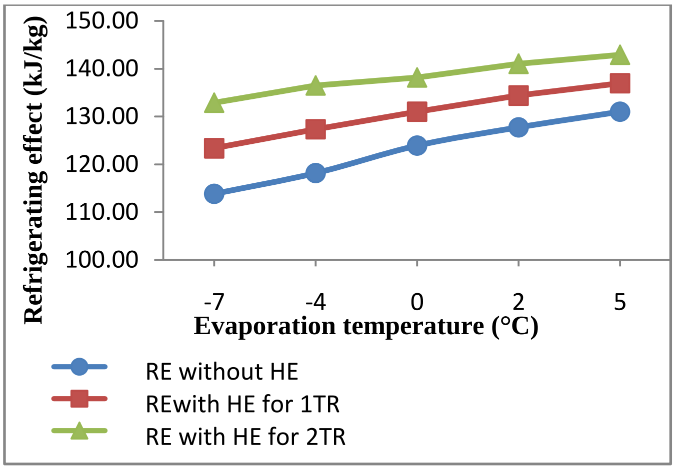

Fig.5: Evaporation temperature (°C) Vs Refrigerating effect (kJ/kg)

The results in above Fig.5 reveal that refrigerating effect increases when the heat exchanger is attached to VCR. This refrigerating effect further increases as the refrigerating capacity is increased from 1 TR to 2 TR.

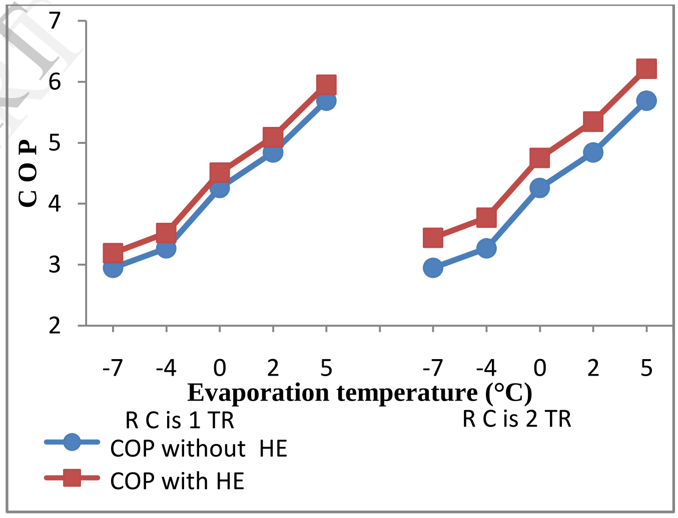

Fig.6: Evaporation temperature (°C) Vs C O P

The results in above Fig.6 reveal that the coefficient of performance increases when the VCR is connected to heat exchanger. This is further increases when the refrigerating capacity (RC) increased from 1 TR to 2TR.

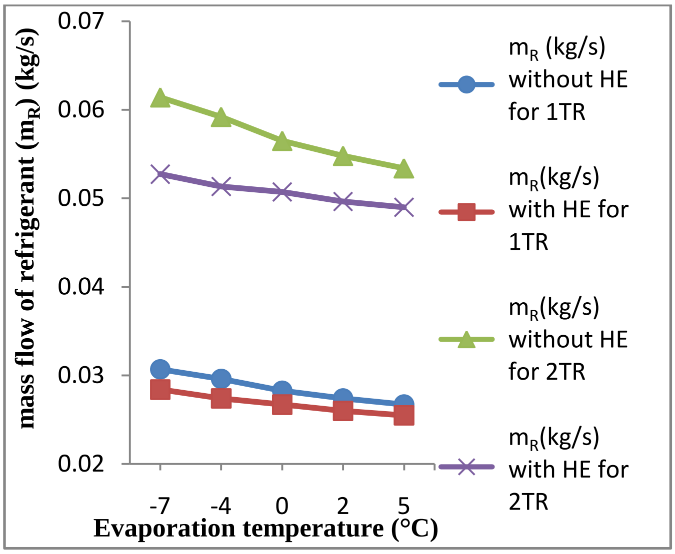

Fig.7: Evaporation temperature (°C) Vs Mass flow of refrigerant (kg/s)

The results in above Fig.7 reveal that Mass flow of refrigerant is decreases when the VCR is connected to heat exchanger. This graph is plotted by taking VCR without heat exchanger, with heat exchanger for refrigerating capacities of 1 TR and 2 TR.

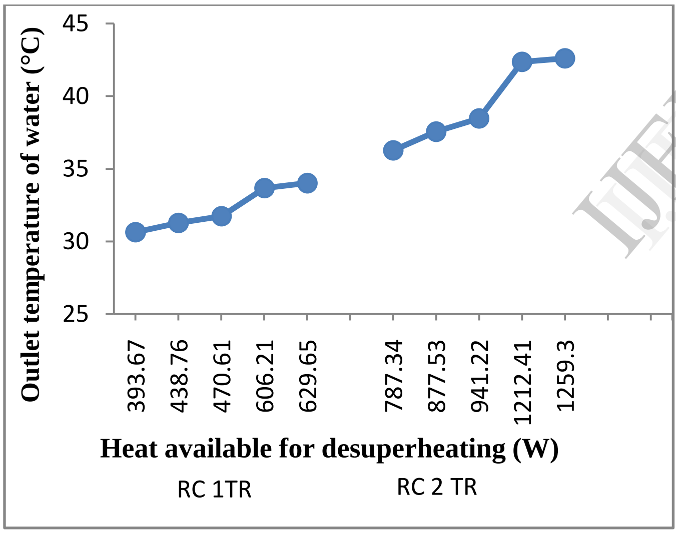

Fig.8: Heat available for desuperheating (W) Vs Outlet temperature of water (°C)

The results in above Fig.8 reveal that as the heat available for desuperheating increases, the outlet temperature of water in heat exchanger also increases.

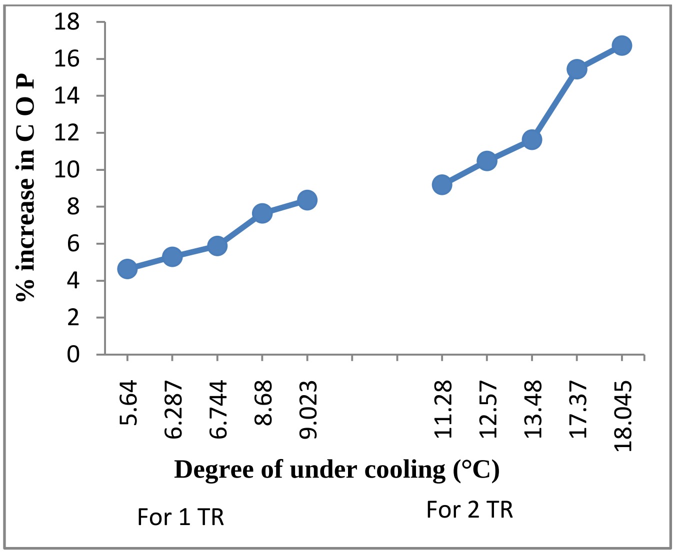

Fig.9: Degree of under cooling (°C) Vs percentage increase in C O P

The results in above Fig.9 reveal that as the degree of under cooling increases the % increase in coefficient of performance also increases up to 16%. This is plotted by taking refrigerating capacities of 1 TR and 2TR.

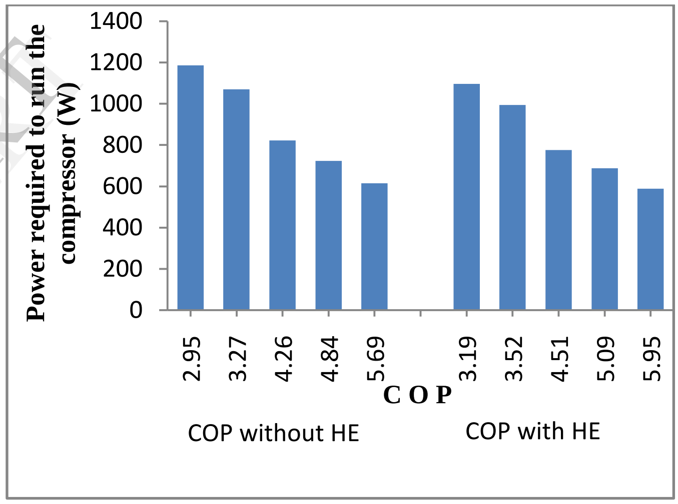

Fig.10: C O P Vs Power required to run the compressor (W)

The power required to run the compressor is reduced up to 7.5% when the VCR (having refrigerating capacity of 1 TR) is attached to heat exchanger. The power required to run the compressor for a VCR without heat exchanger and VCR with heat exchanger both were plotted and shown in Fig.10

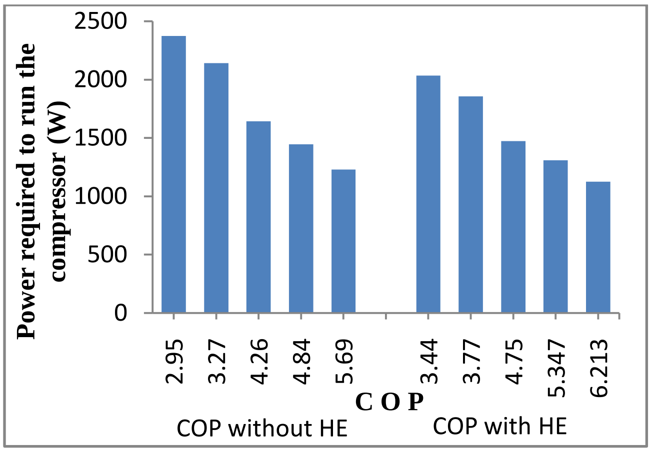

Fig.11: C O P Vs Power required to run the compressor (W)

The power required to run the compressor is reduced up to 14% when the VCR (having refrigerating capacity of 2 TR) is attached to heat exchanger. The power required to run the compressor for a VCR with and without heat exchanger were plotted and shown in Fig.11

V. CONCLUSIONS

The following conclusions are arrived from the VCR system connected with heat exchanger when the evaporation temperature decreases to -7°C:

1. The refrigeration effect of the system is increased up to 16% using the heat exchanger with vapour compression refrigeration system.
2. The C O P (coefficient of performance) of the system is increased up to 16% using the heat exchanger with vapour compression refrigeration system.
3. Mass flow of refrigerant (m_R) is reduced up to 14% using the heat exchanger with vapour compression refrigeration system.
4. Heat available for desuperheating (Q) increases as the evaporation temperature decreases. So by attaching heat exchanger to the vapour compression refrigeration system and regulating water into heat exchanger, outlet temperature of the water (t_2) in heat exchanger increases. That hot water can be used for useful purpose.
5. Power required to run the compressor is reduced up to 14% by using the heat exchanger with vapour compression refrigeration system.

ACKNOWLEDGMENT

We, authors express gratitude to all the anonymous reviewers for their affirmative annotations among our paper. Thanks to every reviewer for reviewing our paper and give valuable suggestions.

REFERENCES

[1] R.B. Lokapure and J.D.Joshi., Waste Heat Recovery through Air Conditioning System, International Journal of Engineering Research and Development, Vol 5, Issue 3, pp: 87-92, Dec 2012.
[2] R.S.Khurmi and J.K. Gupta., Refrigeration and Air Conditioning, Eurasia publishing house Pvt Ltd, New Delhi, 2006.
[3] P.A Domanski, Evaluation of Suction-Line/Liquid-Line Heat Exchanger in the Refrigeration Cycle, pp. 10-11, USA, 1995.
[4] Rakesh Jain, Devendra Dandotiya and Abhishek Jain,Performance improvement of a Boiler through Waste Heat Recovery from an Air Conditioning Unit, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 2, pp: 405-412, Feb 2013.
[5] A.Baskaran and P.Koshy Mathews., A Performance Comparison of Vapour Compression Refrigeration System using Eco Friendly Refrigerants of Low Global Warming Potential, International Journal of Scientific and Research Publications, Vol. 2, Issue 9, pp: 4-7, Sept 2012.
[6] R.K.Rajput, Thermal Engineering, Laxmi publications Pvt Ltd., 2006.
[7] M. Thirumaleshwar, Fundamentals of Heat and Mass Transfer, Pearson Publications, New Delhi, 2006.
[8] Pablo Coronel, K.P. Sandeep.,Heat Transfer Coefficient in Helical Heat Exchangers under Turbulent Flow Conditions, International Journal of Food Engineering, Vol 4, Issue 1,pp. 1-5, 2008
[9] Yunus A.Cengel, Heat and Mass Transfer, Third Edition, Tata McGraw-Hill Publication, 2000.
[10] Frank P.Incropera and David P. Dewitt., Fundamentals of Heat and Mass Transfer, Wiley India Pvt Ltd, 2010