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Heat and Mass Transfer Studies on 134 A-DMAC Based Falling Film Absorbers for Absorption Refrigeration System

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Abstract-: Absorber is an important component in Vapour Absorption Refrigeration System and its performance has greater influence in overall efficiency of absorption machines. Falling film heat and mass transfer in an absorber is greatly influenced by fluid properties, geometry of heat exchanger and its operating parameters. This paper presents on the results of experimental studies on the heat and mass transfer characteristics of horizontal, vertical and coiled tube falling film absorbers using 1,1,1,2-Tetrafluroethane(R-134a) and N-N Dimethyl Acetamide (DMAC) as working fluids. The effects of film Reynolds number and cooling water temperature on absorber heat load, over all heat transfer co-efficient and mass of refrigerant absorbed for the said three configurations are presented discussed and compared. The experimental values of overall heat transfer coefficient are found to be 745, 320 and 230 w/m^2 K for coil, vertical and horizontal tubes respectively. Among the configurations tested, the shell and coiled tube absorber was found to yield higher heat transfer coefficient and also more compact. When all the other parameters are kept constant, if the cooling water temperature is reduced from 30 ºC to 25 ºC, the absorber heat load and refrigerant mass absorption rate is increased by 16.3% and 15 % respectively.

Key words: Heat and mass transfer performance: falling film absorbers: R134aDMAC:
Film Reynolds Number: Overall heat transfer coefficient

1 Introduction

Simultaneous heating and cooling are required in many industries such as dairy plant pharmaceuticals chemical etc,. Absorption systems have been extensively paid attention in recent years due to the potential for CFC and HCFC replacements in refrigeration, heating and cooling applications. The absorber in any absorption machine is a key component and its characteristics have significant effects on overall efficiency of absorption machines.

The heat transfer area of absorber alone might account for 40% of the total heat transfer area in absorption machines [1]. Previous published works have developed an understanding of the transport processes in both laminar and turbulent absorber falling films. Absorption phenomena in falling film absorber have been widely investigated by many researchers [1-6] to predict the heat and mass transfer performance of various geometric configuration of absorber, with H2O-LiBr and ammonia-water as working fluids. Deng et al. [1] have conducted experimental studies on heat and mass transfer characteristics of falling film H2O-LiBr absorber, which was made up of 24 smooth horizontal tubes. They concluded that there is an spray density of solution, at which the heat transfer co-efficient, is maximum. They also found that when coolant temperature is decreased from 32° C to 30° C, the absorber flux was increased by 17%.

Jeffrey Seewald [2] has developed a model to investigate heat and mass transfer processes of H2O-LiBr Coil tube absorber. He observed that when solution flow rate is increased, the overall heat transfer co-efficient also increases and optimum value is obtained. The absorber performance was benefited from higher inlet absorbent concentration.

Kang et al. [3] proposed a modeling method for concurrent flow of vapour liquid in fluted tubes with ammonia-water solution, including heat and mass transfer in the vapour region. Their computations illustrated that the heat exchanger size is affected strongly by the temperature difference between liquid-vapour interface and vapour velocity.

Siyoung Jeong et al. [4] have found experimentally the Re-Nu relations for coiled tube absorber with ammonia-water as working fluid. Perez-Blanco [5] developed a model for the absorption of ammonia into a falling film around coiled tubes. By comparing numerical prediction with experimental results, he concluded that the mass transfer process in the falling film controlled the absorption rate so that vapour velocity must be optimized to increase the absorption rate.

Kang et al. [6] carried out experimental investigation to verify the heat and mass transfer process that occurs simultaneously in a coiled tube absorber. They examined the effects of various operating conditions in the heat and mass transfer. They also suggested experimental co-relations for Nusselt and Sherwood numbers.

Sujatha et al. [7,8] conducted experiments on a vertical tubular bubble absorber operating with HCFC22-DMF and have obtained the overall heat transfer co-efficient of 195 W/m^2 K.

Muthu [9] has done experimental studies on Performance of R-134a – DMAC based absorption cooling system using low potential thermal sources. He proved that R-134a – DMAC based absorption cooling system yielded an optimum COP of 0.4, when the heat source temperature is 70 °C.

Falling film heat transfer mode provides relatively high heat transfer coefficient and is stable during operation and is easy to manufacture [5]. It has been observed that the falling vertical films have a wavy character. A wave film leads to surface renewal and mixing of fluid, which efficiently enhances the heat transfer rates. The wave frequency has strong impact on heat and mass flux of absorber [2].

In the previous works performed by the authors [1-6], it was found that the working substances used are either water-lithium bromide or ammonia-water. As ammonia has its own limitations due to its non compatibility with copper and high specific volume where as production of sub-zero temperature and crystallization are the two main demerits associated with water-Lithium bromide systems and to add upon, these two working fluids require higher heat source temperature.

R-134a-DMAC working fluid pair is having Zero Ozone Depletion Potential and negligible Global Warming Potential with a comparatively lesser heat source temperature [10]. Arivalagan et.al [11] have observed that R134a-DMAC refrigerant-absorbent combination may considered as the one of the most favorable working fluids when a half effect system is to be operated with low temperature heat sources**.**

Hence the objectives of these studies are to analyze the heat and mass transfer performance characteristics of horizontal, vertical and coiled tube falling film absorber with R-134a-DMAC as working fluid. In this study the effects of film Reynolds number, Cooling water temperature on absorber heat load, overall heat transfer co-efficient and mass of refrigerant absorbed eco-friendly working fluid (R-134a – DMAC) are presented and discussed.

2 Experimental set-up and Procedure

The experimental set up used in this investigation is depicted schematically in Fig (1).The main components are shell and coil tube absorber, horizontally cooled and vertically cooled absorbers, evaporator, generator, solution pump, condenser and strong solution tank.

2.1 Coiled tube absorber

The absorbent solution N-N-Dimethyl Acetamide (DMAC) flows down the outer surface of the coiled tube as a form of liquid film and consequently 1,1,1,2 Tetrafluoroethane (R-134a) vapour is absorbed into the liquid film. The heat of absorption is removed by the cooling water, which is flowing inside the coiled tube. The cooling water system consists of a constant temperature water tank with temperature controller, a centrifugal water pump and a water flow meter.

2.2 Vertical tube absorber

The absorbent solution N-N-Dimethyl acetamide (DMAC) flows down as a falling film through the inner surface of the vertical tube and consequently 1,1,1,2 Tetrafluoroethane (R-134a) vapour coming from the bottom of the vertical tube is absorbed into the falling liquid film. The heat of absorption is removed by the cooling water, which is flowing through the annulus space of the concentric vertical tube.

2.3 Horizontal Tube absorber

The absorbent solution N-N-Dimethyl acetamide (DMAC) flows down the outer surface of the falling film horizontal tube as a form of liquid film and consequently 1,1,1,2 Tetrafluoroethane (R-134a) vapour is absorbed into the liquid film. The heat of absorption is removed by the cooling water, which is flowing inside the tube.

For the same operating conditions, all the three configurations of falling film absorber were tested one by one by using the flow control valves fitted at the inlets and outlets of the respective absorber for the solution, cooling water and refrigerant

2.5 Test Conditions:

Table 2:Test conditions

Solution inlet conditions:	
Pressure	3.2 bar
Concentration (refrigerant)	0.43
Temperature	48^o C
Flow rate	0.012,0.0160,0.02 and 0.024 kg/s
Cooling water and Refrigerant inlet conditions:	
Flow rate	0.04 kg/s
Temperature	20 ^{o}C, 25 ^{o}C, 30 ^{o}C
Refrigerant temperature	5 ^{o}C

2.6 Test processes:

The strong refrigerant solution is first pumped to the generator, where the R-134a vapour was driven out by circulating hot water and weak refrigerant solution at specified pressure and temperature is then supplied to the absorber through a eight way solution distributor, which exactly directs the solution to the outer surface of a coiled tube, inner surface of the vertical tube and outer surface of the horizontal tube. The test absorber is equipped with proper regeneration arrangements for both refrigerant and absorbent solution. This arrangement consists of an evaporator, condenser and generator as depicted in fig (1). Absorption of R-134a vapour takes place on the wetted surface of the absorber tubes and the heat of absorption is removed away by flow of cooling water through the each absorbers. The strong refrigerant solution is collected back in the solution tank, under the absorber.

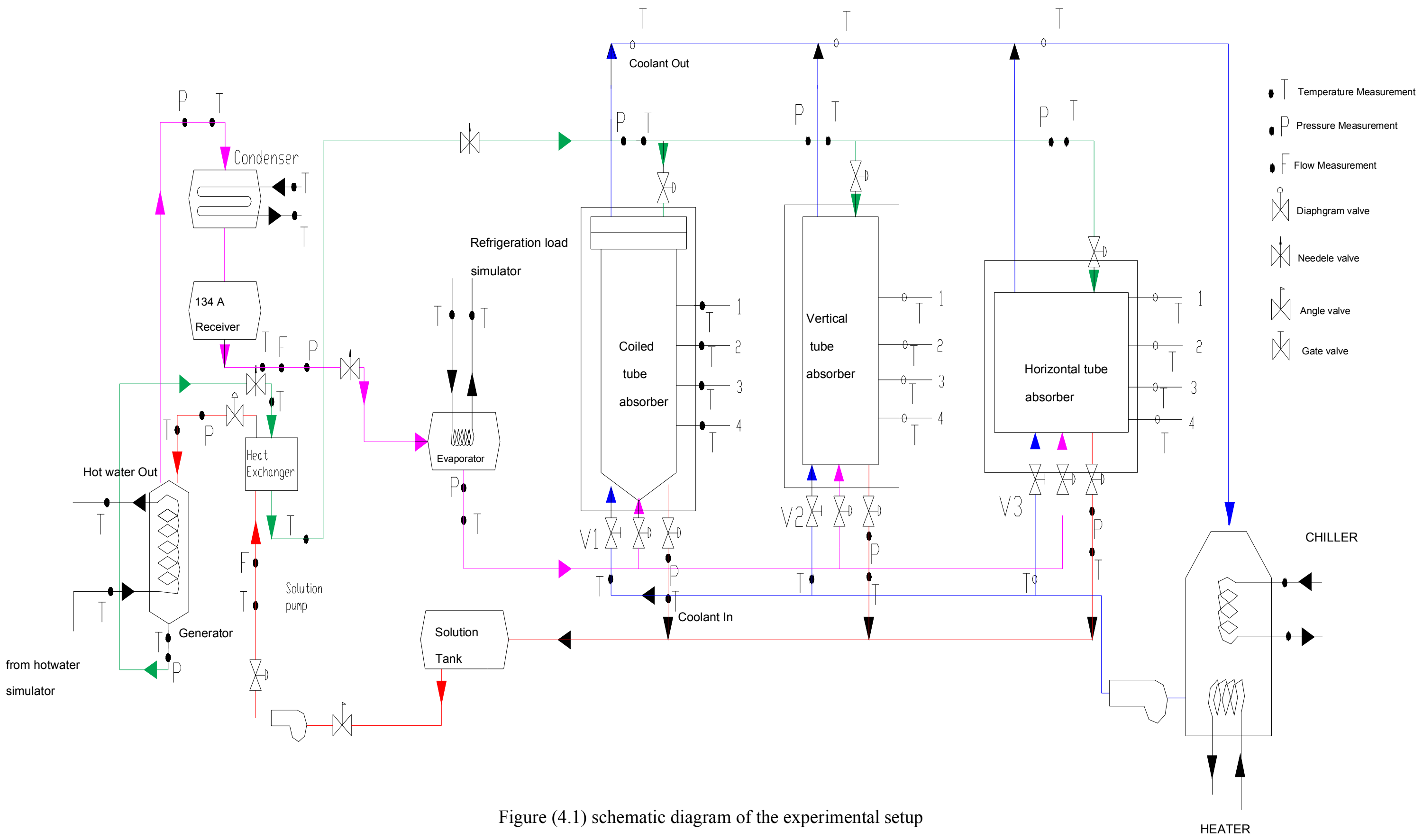

Figure (4.1) schematic diagram of the experimental setup

2.4 Details of the Absorber

Table 1 Specifications of the three configurations of falling film absorber

Type of Absorber	Shell and coil tube absorber	Shell and horizontal tube absorber	Vertical tube-in- tube absorber
Fluid circuit	Solution flows over the coil and cooling water inside the tube	Solution flows over the horizontal tube and cooling water flows inside the tube	Solution flows inside of inner tube and cooling water flows through annulus of the concentric tube
Material & specifications			
Shell	MS 152 mmdia and 400mm length	MS 300 mm dia 1.5 m length	Double pipe arrangement 25.54 mm OD 12.7mm OD length 1.1 m
Tube	Copper Outer dia 12.7 mm Inner dia 10.7 mm Length 3.3 m Coil dia 120 mm	Copper Outer dia 12.7 mm Inner dia 10.7 mm Length 3.3 m	Copper Outer dia 12.7 mm Inner dia 10.7 mm Length 3.3 m
Solution distributor	8 nos of 3mm dia nozzles, which directs the solution over the coiled tube downward	15 nozzles, dia 3 mm each, which directs the solution over the horizontal tube downward	Perforated tube, 2mm dia holes which direct the solution through the inside surface of the inner tube.
Refrigerant distributor	8 nos of 3mm dia nozzles which directs the 134a vapour over the liquid film upward	8 nos of 3mm dia nozzles which directs the 134a vapour over the liquid film upward	Perforated tube, 2mm dia holes which direct 134a vapour over the liquid film upward

The acquired data at the inlet and outlet of the test absorber included the temperatures and flow rates of the solution and cooling water and absorber pressure.. T-type thermocouples (with an uncertainty of 0.5^0C) and Bourdon tube type pressure gauges (with an uncertainty of 0.2 bar) were used to measure temperatures and pressures at salient locations. Flow measurement of the refrigerant was recorded by the rotameter type flow meters (with an uncertainty of 0.00025 kg/s). Solution flow rate was varied by varying the stroke length of diaphragm type pump

(Wellore make [0.04 kg/s full stroke] with uncertainty of [0.0015 kg/s]). The output from the T- type thermocouple was read and recorded by a data acquisition system. The concentration of the solution at the inlet and outlet of the absorber should either be measured directly or by measuring the pressure and temperature of the solution. In this study, because of practical difficulties in the in-line measurement of concentration directly, the pressure and temperature of the solution are measured and P-T-X relation developed by Borde et al. [10] is used to determine the concentration. Hence it is assumed that the solution is in equilibrium at the prevailing absorber pressure and temperature at the liquid-vapour interface.

The saturation pressure of R-134a at an evaporation temperature of 5^0C is 3.2 bar and the optimum generator temperature for this working fluid is 75^0C [10] and hence the inlet concentration is 0.43.

3. Data reduction

3.1 Heat and mass transfer equations

In a steady state and steady flow process the heat, mass and concentration balance equations for the system with refrigerant vapour absorption can be written as follows.

3.1.1 Calculation of Overall Heat transfer co-efficient

The rate of heat transfer from the solution to coolant is calculated from inlet and outlet coolant temperatures and coolant flow rate. The overall heat transfer co-efficient can be determined by using the following relation, if temperatures of the coolant and solution at the inlet and outlet of the absorber are known. The following expressions were referred from the literature [6].

The heat transfer area is kept constant at 0.13 $m^2$for all the three configuration of the absorbers

$$U = Q_a / A\Delta T_m \qquad (1)$$

$$\Delta T_m = \frac{(T_{si} - T_{cwo}) - (T_{so} - T_{cwi})}{\ln\{(T_{si} - T_{cwo})/(T_{so} - T_{cwi})\}}$$

$$Q_a = m_{cw}\, C_{pw}\, (T_{cwo} - T_{cwi}) \qquad (2)$$

$$Q_e = m\, C_p(T_{ei} — T_{eo}) \qquad (3)$$

Calculation of refrigerant mass absorption rate

$$m_{si} + m_r = m_{so} \qquad (4)$$

$$m_{si}X_{si} + m_rX_r = m_{so}X_{so} \qquad (5)$$

$$Q_a = (m_{si}h_{si} + m_rh_r - m_{so}h_{so}) = m_{cw}Cp_{cw}\,(T_{cwo}-T_{cwi}) \qquad (6)$$

On combining equations (4) and (5). The mass of refrigerant absorbed is

$$m_r = m_{si}\,(X_{so}-X_{si}) / X_{si} \qquad (7)$$

The temperature and concentration satisfy the phase equlibrium relationship that is expressed as P-T-X relation, developed by Borde.I and Jeleneik [10]

$$X=f\,(p,t) \qquad (8)$$

4 Results and Discussions

4.5 Effects of Film Reynolds number on overall heat transfer Co-efficient and absorption Heat load.

The heat and mass transfer characteristics of the three falling film absorber configurations was studied at the film Reynolds number from 170 to 440, at various inlet cooling water temperatures It is observed from Figs 3(a) ,3 (b), 4(a) ,4 (b), 5(a) and 5 (b). that for a constant inlet cooling water and solution temperatures, the overall heat transfer Co-efficient and absorber heat load increase with increase in solution flow rate, for all the three configurations

Coiled Tube Absorber

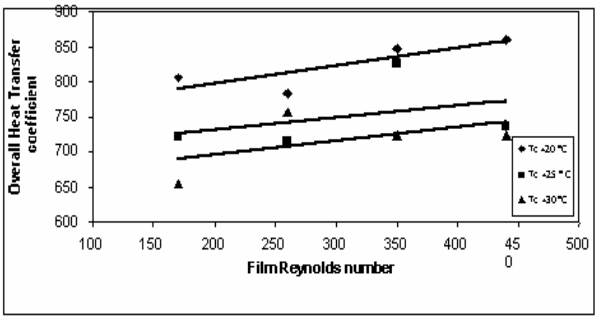

Fig 3(a) Effects of Film Reynolds number and cooling water temperature on overall heat Transfer co-efficient Tsi=48 ºC, Mcw =0.04 kg/ s

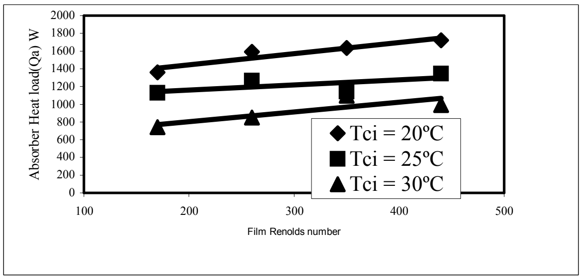

Fig 3 (b) Effects of Film Renolds number and cooling water temperature on absorber heat Load Tsi=48 ºC, m_{cw}=0.04 kg/s.

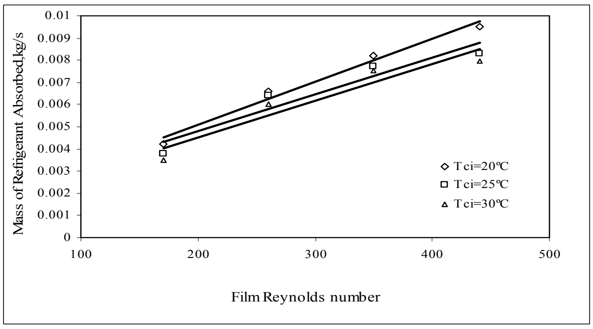

Fig 3 (c) Effects of Film Reynolds number and cooling water temperature on Mass of refrigerant absorbed Tsi=48 ºC, m_{cw}=0.04 kg/s.

Vertical tube absorber

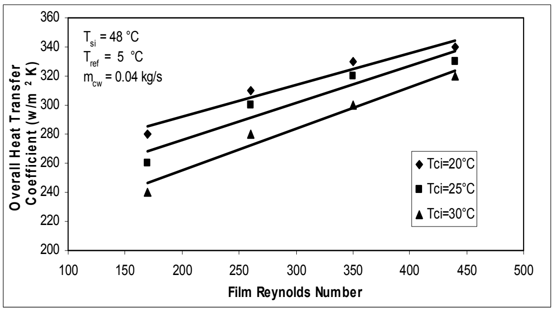

Fig 4(a) Effects of Film Reynolds number and cooling water temperature on overall heat transfer coefficient

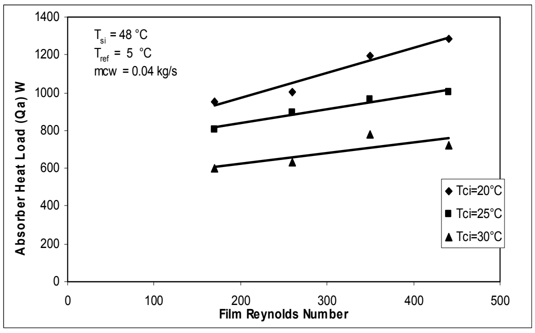

Fig 4(b) Effects of Film Reynolds number and cooling water temperature on Absorber heat load

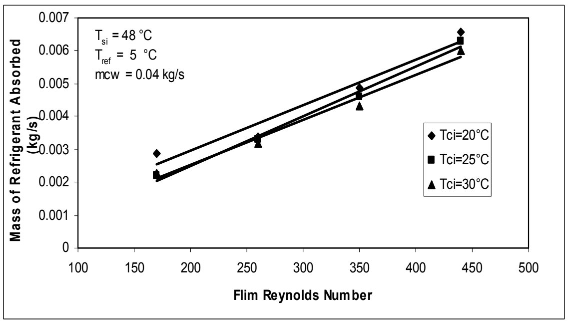

Fig 4(c) Effects of Film Reynolds number and cooling water temperature on Mass of refrigerant absorbed

Horizontal tube absorber

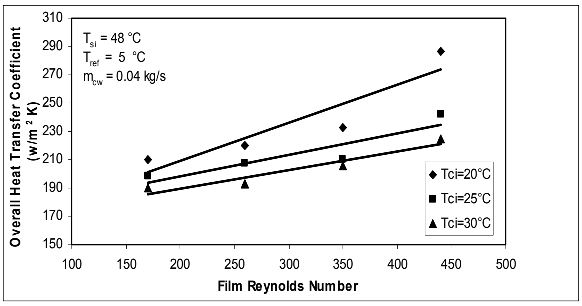

Fig 5(a) Effects of Film Reynolds number and cooling water temperature on overall heat transfer coefficient

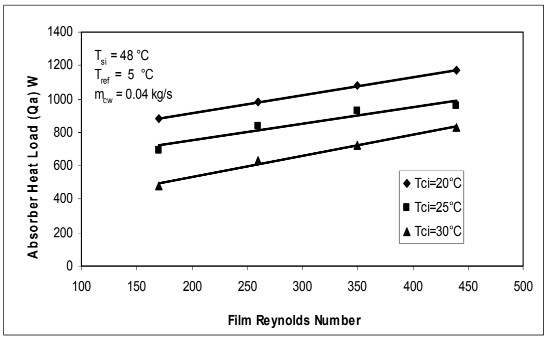

Fig 5(b) Effects of Film Reynolds number and cooling water temperature on Absorber heat load

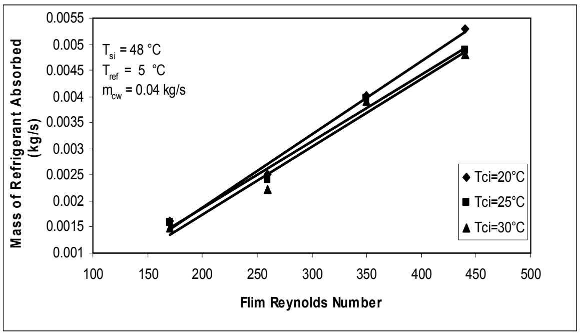

Fig 5(c) Effects of Film Reynolds number and cooling water temperature on Mass of refrigerant absorbed

Comparison of Three types of absorbers

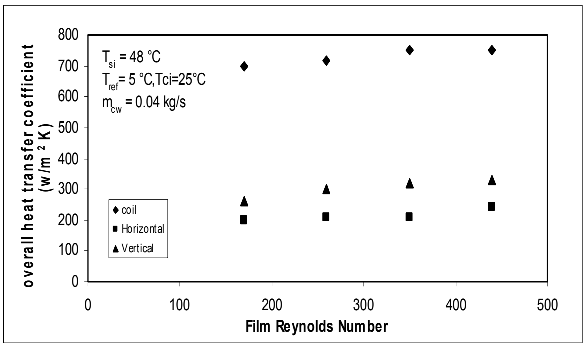

Fig 6(a) Effects of Film Reynolds number on overall heat transfer coefficient of three types of absorbers

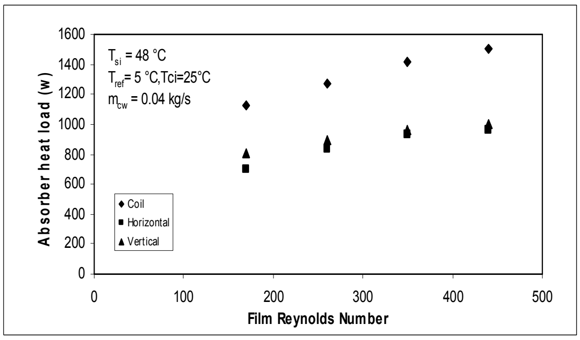

Fig 6(b) Effects of Film Reynolds number on Absorber heat load coefficient of three types of absorbers

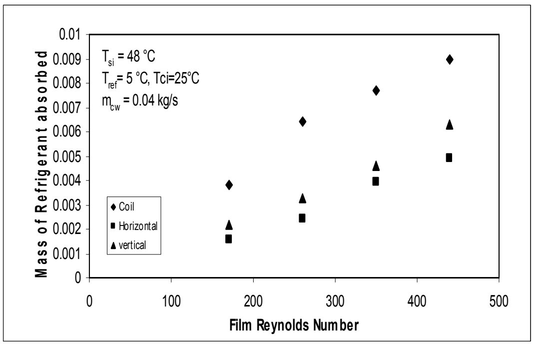

Fig 6(c) Effects of Film Reynolds number on Mass of refrigerant absorbed of three types of absorbers

This phenomenon can be explained as follows. Increase in Film Reynolds number improves the fluid characteristics and wet ratio of the heat transfer area, which contribute to the enhancement of heat and mass transfer.

In the present study, the overall heat transfer co-efficient and absorber heat load for a coil absorber operating with R-134a DMAC was found to be 745 w/m^{2}k 1080 W respectively, for a film Reynolds number of 350 and inlet cooling water temperature of 25 ºC. Similarly the overall heat transfer coefficient for vertical tube and horizontal tube absorbers are found to be 320 and 230 W/m^2 K respectively

It is learnt from Fig 6(a) that the Overall heat transfer co-efficient is relatively higher for coiled tube configuration, which is due to the fact that the coolant side heat transfer co-efficient is relatively higher for coil tube absorber than the straight tube, which improves the overall heat transfer co-efficient.

Similar experimental studies for ammonia-water coil absorber by Siyoung jeong et.al [4] yielded that the overall heat transfer co-efficient in the film Reynolds number range of 100 to 400, was found to vary from 200 to 650 w/m^{2}k. A model developed by Jeffrey S.Seewald [2] to predict performance of water-liBr coil absorber indicated that the value of overall heat transfer co-efficient was 700 w/m^{2}k.

4.6 Effects of Film Reynolds number on mass of refrigerant absorbed:

From the Figs 3(c), 4(c)and 5(c), When inlet cooling water temperature and absorber pressure is constant, the refrigerant mass absorption rate increases with increase with increase in Film Reynolds number. The experimental value for coil, vertical and horizontal is 0.007, 0.0046, and 0.0035 respectively. This is because, for a constant inlet concentration, the mass balance across absorber revealed that the mass absorbed is proportional to solution flow rate and hence Film Reynolds number. It is also observed from fig 6(c) that, at a constant solution flow rate and inlet solution and cooling water temperatures the mass absorption rate is higher for coiled tube configuration followed by vertical tube and horizontal tube absorbers. This is due to the higher value of overall heat transfer coefficient of coiled tube absorber which causes the relatively faster rate of heat transfer from the solution to the cooling water.

4.7 Effects of cooling water temperature on heat transfer co- efficient, absorber load and mass absorption rate

It is learnt from in Figs 3(a, b, c), 4(a, b, c) and 5(a, b, c). All the three parameters followed a similar trend when the inlet cooling water temperature is increased from 20 to 30ºC, the heat and mass transfer performance was found to decline. This can be explained as follows. At lower cooling water temperature, the heat transfer rate from solution to coolant is increased, which improves the absorption rate. When all the other parameter are kept constant if the cooling water temperature is decreased from 30 to 25 ºC, the overall heat transfer coefficient is improved by 11%, 15 % and 5 % for coiled tube, vertical tube and horizontal tube absorbers respectively. Similar improvements are also absorbed in absorber heat load and mass of the refrigerant absorbed.

The error in heat transfer coefficient absorber heat load etc., is calculated using the method proposed by Kline and McClinltock [12]. Uncertainty in overall heat transfer coefficient is 4% and absorber heat load is 3.7%.

5. Conclusions

Three configurations of falling film absorbers with R134a-DMAC as working fluid was designed and built to suit 1kW cooling capacity evaporator and their heat and mass transfer characteristics were investigated and the results are compared.

The effects of film Reynolds number and cooling water temperature on absorber heat load, over all heat transfer co-efficient and mass of refrigerant absorbed for the said three configurations are presented. The experimental values of overall heat transfer coefficient are found to be 745, 320 and 230 w/m2 K for coil, vertical and horizontal tubes respectively. For the same heat transfer surface area, among the configurations tested, the shell and coiled tube absorber was found to yield higher heat transfer coefficient and also more compact.

The effect of cooling water temperature is significant in the design of absorbers When all the other parameters are kept constant, if the cooling water temperature is reduced from 30 ºC to 25 ºC, the absorber heat load and refrigerant mass absorption rate is increased by 16.3% and 15 % respectively.

These results can be used as a reference in designing actual absorption chiller, heat pump and heat transformers, operating with R134a- DMAC as working fluids.

6. **Nomenclature**

m	- Mass flow rate in kg/s
X	- Concentration by weight
Q	– Absorber heat load in kW
h	– Enthalpy in kJ/kg
Cp	– Specific heat in kJ/kg k
U	– Overall heat transfer co-efficient in kW/ m^2k
A	– Heat transfer area in m^2
ΔT_m	- Log Mean Temperature difference (LMTD) in k
Re	– Reynolds Number
K	- Thermal Conductivity in W/m k
d	– diameter of tube in m
D	– Diameter of coil in m
T	- Temperature, ºC

Subscripts

a	– Absorber
r	– Refrigerant
ei	- evaporator inlet
eo	- evaporator inlet
si	- Solution Inlet
so	– Solution Inlet
cwo	– cooling water outlet
cwi	- cooling water inlet
g	-generator

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