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Heat Exchanger for Hybrid Air Conditioning System

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ABSTRACT: *In the present study energy conservation in HVAC (Heating, Ventilation and Air Conditioning) system is achieved with HACS (Hybrid Air Conditioning System). Energy conservation in HVAC system is very important because of the sharp rise in fuel prices and fuel shortage. HACS is a combination of Vapor Compression System (VCS) and Liquid Desiccant (LD) System. The system can be energy efficient and environment friendly. Considerable attention has been achieved due to its inherent ability to use low grade thermal energy and reduce the cooling load. The present system has the ability to provide the required humidity and temperature for human comfort by consuming less electrical energy as compared to VCS alone. A 1 TR HACS with R22 refrigerant and calcium chloride LD was designed, fabricated and tested. This paper presents the design , fabrication and testing of an improved solution heat exchanger incorporated between the absorber and the regenerator of HACS , working with R22 refrigerant and calcium chloride LD. The simulation parameters and the experimental results with solution heat exchanger are compared.*

Keyword: *absorber, desiccant, hybrid, solution heat exchanger.*

I. INTRODUCTION

Evaporative and desiccant cooling technology for air conditioning systems has increased as an alternative to the conventional VCS.

1.1 Vapour Compression Refrigeration System (VCS)

The VCS is an improved type of air refrigeration system which uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects heat elsewhere.

In evaporator the refrigerant absorbs its latent heat from the brine which is used for circulating it around the space to be conditioned. While in condenser, it gives out its latent heat to the circulating water or air of the cooler. VCS is therefore a latent heat pump because it pumps latent heat from the brine and delivers it to the cooler.

In a conventional VCS, air is cooled below the Apparatus Dew Point (ADP) temperature (generally 7.2°C) so that the moisture can be removed and is then reheated to the desired temperature for human comfort. This results in wasted energy.

1.2 Hybrid Air Conditioning System(HACS)

HACS is a combination of vapor compression system (VCS) and Liquid Desiccant (LD) system. In HACS the moisture from the air to be conditioned is absorbed by the cool LD solution and the air gets cooled simultaneously by giving out its heat to the LD. Since the air is dehumidified by the LD, only sensible cooling is required to be handled by the VCS thereby allowing evaporator coil to be operated at higher temperatures. The ADP temperature of HACS is increased from 7.2^{o}C of conventional VCS to 15^{o}C.

Thus the hybrid system operates on less energy input than the conventional system. It eliminates the need for reheating the air which adds to energy effectiveness. Liquid Desiccants also remove microbiological contaminants from air streams to improve the indoor quality of air[1]. The process air will not reach the saturation condition at any point in the desiccant cycle and hence avoids the problems of mould, fungi, or other microbial growth in the air conditioner (Lowenstein and Dean, 1992). Howell and Peterson, in 1986 studied a hybrid system combining LD dehumidification with VCS. It was found that the hybrid system reduces area of evaporation and condensation by 34 % and power consumption by 25 %, compared with VCS alone. Parsons, in 1989 studied the gas fired air conditioning system combining vapor compression machine with solid desiccant dehumidifier and concluded that the cooling capacity of hybrid system increases by 50 % and COP increases by 40 %. However, the initial cost increases to US $ 140 / kW cooling capacity.

The solution heat exchanger between the absorber and regenerator plays a significant role in the enhancement of COP of HACS. This paper presents the design, fabrication and testing of solution heat exchanger incorporated between the absorber and the regenerator of HACS, working with R 22 refrigerant and calcium chloride LD. The simulation parameters and the experimental results with solution heat exchanger are compared.

2. Components Of HACS

2.1 Evaporator

The evaporator coil is immersed in a tray filled with LD, calcium chloride ($CaCl_2$) solution having 30% concentration by weight. The refrigerant absorbs the heat from this solution thereby reducing its temperature.

2.2 Absorber

The low temperature LD flows through the contacting device i.e. absorber, forming a layer over the surface of these meshes. The air to be conditioned is forced to flow through these meshes in horizontal direction by using a fan. The air while flowing across the meshes comes in contact with the cool LD, flowing in vertical direction. The $CaCl_2$ solution absorbs the moisture from the flowing air and there is a simultaneous cooling of air as it comes in contact with the cool LD. The $CaCl_2$ solution becomes weak after absorbing the moisture from the air as its concentration by weight falls.

2.3 Condenser

This weak $CaCl_2$ solution from the absorber then flows under gravity to the other tray in which the condenser coils of VCS are immersed. The refrigerant used in the VCS rejects its heat to the condenser coil. The temperature of the $CaCl_2$ solution rises as it absorbs the heat rejected to the condenser coil.

2.4 Regenerator

Regenerator is a contacting device. This high temperature weak $CaCl_2$ solution then flows through the regenerator, forming a layer over its surface. While flowing, the $CaCl_2$ solution rejects its moisture to the ambient air that is forced to flow in perpendicular direction. The mass transfer of the moisture from the $CaCl_2$ solution to the ambient air takes place because of the partial pressure difference of $CaCl_2$ in the solution and the air. The air also takes away the heat from the $CaCl_2$ solution lowering its temperature. The $CaCl_2$ solution leaving the regenerator is now strong as concentration by weight of $CaCl_2$ in the solution increases as a result of moisture removal from the $CaCl_2$ solution.

2.5 Solution Heat Exchanger

In the heat exchanger the hot, strong $CaCl_2$ solution gives away its heat to the weak solution coming from the absorber.

The regenerated hot and concentrated LD flowing to absorber is cooled in the solution heat exchanger by the cool stream of weak LD flowing in the counter flow direction to the regenerator.

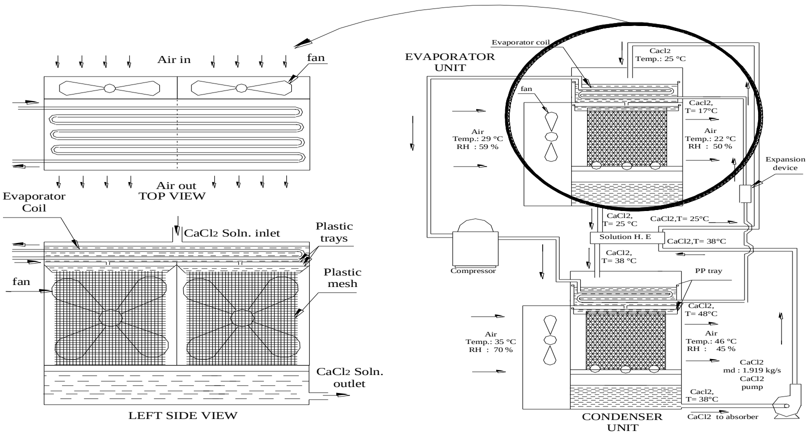

Figure 1.Schematic layout of HACS[5]

3. Design of Solution Heat Exchanger

Heat Exchanger is process equipment designed for effective transfer of heat energy between two fluids; a hot fluid and a coolant. The heat transferred in the heat exchanger may be in the form of latent heat or sensible heat. The solution heat exchanger helps in increasing the cooling effect as well as reducing the regenerator requirement. The effectiveness of solution heat exchanger will play a significant role in improving the overall COP of the system[8]. A heat Exchanger is designed, fabricated, tested and compared with the simulation parameters in this paper.

3.1 Heat Exchanger

Selecting copper as the material for inner tube and stainless steel as the material for outer tube.

Cu Tube: Diameter: 1inch

Thermal Conductivity: 401W/mK, Length=800mm

SS Tube: Diameter: 1.5 inches

Thermal Conductivity: 16W/m, Length=750mm

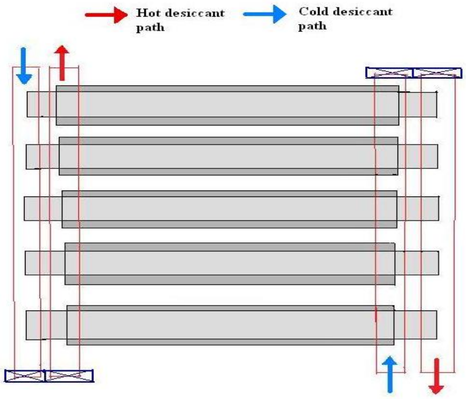

Figure 2. Flow diagram of heat exchanger

Figure 3.Assembly of heat exchanger

The assembly consists of tube in tube arrangement. They are assembled in Cu-in-SS arrangement with the help of PVCs T shaped connectors. For connection and sealing araldite solution along with M seals is used. All the connectors used in the entire HACS assembly are replaced with PVC connectors. The weak desiccant that has absorbed moisture in the absorber enters the heat exchanger through the inlet from top. The solution enters into header of 1.5 inches SS tubes and moves further into condenser unit. At the same time the desiccant solution that has been regenerated in regenerator unit is pumped from bottom into the header of 1 inch Cu tube and enters the evaporator unit. The arrangement made here is such that the solution flow is counter flow since flow rate is different inside both tubes. This results in maximum heat exchange. The flow diagram of heat exchanger is shown in figure 2. Figure 3 shows complete assembly of the solution heat exchanger.

The heat exchanger designed is based on thermal conductivity and the demand for higher heat tranfer rate. The liquid desiccant is highly corrosive hence the material selected should be such that it is unaffected by corrosion. As steel and copper showed to some extent the resistance for corrosion, hence steel and copper are chosen as the material for heat exchanger.A tube in tube circular cross section heat exchanger is designed , fabricated and tested.

3.2 Calculation Of Heat Transfer Based On Area

Parameters :

Mass flow rate of liquid desiccant (M_{flow}) = 0.144 kg/s

For Copper tube:

Inner Diameter (I.D) = 23.8 mm

Outer Diameter(O.D) = 25.4 mm

For Steel tube :

Inner Diameter (I.D) = 36 mm

Outer Diameter(O.D) = 38 mm

Length of inner tube = 0.8m

Length of outer tube = 0.75m

The values of the average heat transfer coefficients for hot and cold fluids are calculated in the following way:

Density of cold desiccant(ρ_c) = 1200 kg/m^3

Density of hot desiccant (ρ_h) = 1120 kg/m^3

Viscosity of hot desiccant(μ_h) = 2.15×10^{-3} kg/m sec

Viscosity of cold desiccant(μ_c) = 3.26×10^{-3} kg/m sec

Thermal conductivity of copper(K_{Cu}) = 401 W/mK

Thermal conductivity of steel(K_{SS}) = 16 W/mK

Thermal conductivity of brass(K_{br}) = 109 W/mK

Thermal conductivity of liquid desiccant(K_{ld}) = 0.67 W/mK

Specific heat of hot desiccant(Cp_h) = 2.78 KJ/kg K

Specific heat of cold desiccant(Cp_c) = 2.78 KJ/kg K

To find out the heat transfer coefficient for hot liquid desiccant:

Velocity (V_h) = M_{flow} /($A_{i\,*}\,\rho_h$)

$= 0.144*4/(\pi*0.0138^2*1120)$

= 0.859 m/s

Reynold's number:

$Re_h = (\rho_{h\,*}\,V_{h\,*}\,Dh_i)/\,\mu_h$

$= (1120*0.859*0.0138)/(\,2.15\times10^{-3})$

= 6175.21

Prandtl number:

$Pr_h = (\mu_{h\,*}\,Cp_h\,)/\,K_{ld}$

$= (2.15\times10^{-3}*2780)/0.67$

= 8.92

Nusselt number:

$Nu_h = 0.023 * Re^{0.8} * Pr^{0.4}$

$= 0.023 * (6175.21)^{0.8} * (8.92)^{0.4}$

= 59.48

Convective heat transfer coefficient:

$h_h = Nu_h * Di_h^{-1} * K_{ld}$

$= 59.48 * (0.0138)^{-1} * 0.67$

$= 2887.79$ W/ m^2K

To find out the heat transfer coefficient for cold liquid desiccant:

Velocity $(V_c) = M_{flow} /(A_{i\,*}\,\rho_c)$

$= 0.144*4/(\pi*(0.036^2 -0.0254^2)*1120)$

$= 0.234$ m/s

Reynold's number:

$Re_c= (\rho_{c\,*}\,V_{c\,*}\,Dc)/\ \mu_c$

$= (1120*0.234*(0.036-0.0254))/(3.26\times10^{-3})$

$= 913.03$

Prandtl number:

$Pr_c = (\mu_{c\,*}\,Cp_c\,)/\ K_{ld}$

$= (3.26\times10^{-3} *2780)/0.67$

$= 13.526$

Nusselt number:

$Nu_c = 0.023 * Re^{0.8} * Pr^{0.4}$

$= 0.023 * (913.03)^{0.8} * (13.526)^{0.4}$

$= 15.22$

Convective heat transfer coefficient:

$h_c = Nu_c * Dc^{-1} * K_{ld}$

Hence,

$h_h = 2887.79$ W/m^2 K

$h_c = 962.39$ W/m^2 K

By using electrical analogy thermal resistances were calculated:

$R_1 = (h_h * A_1)^{-1}$

$= (2887.79 * 3.14 * 0.0138 * 0.8)^{-1}$

$= 0.00998$ K/W

$R_2 = \ln (r_1 / r_2) / (2 * 3.14 * K_{br} * L)$

$= \ln(238/138)/(2 * 3.14 * 109 * 0.8)$

$= 9.93 \times 10^{-4}$ K/W

$R_3 = \ln (r_3 / r_2) / (2 * 3.14 * K_{Cu} * L)$

$= \ln(254/238)/(2 * 3.14 * 401 * 0.8)$

$= 3.225 * 10^{-3}$ K/W

$R_4 = (h_c * A_2)^{-1}$

$= (962.39 * 3.14 * 0.036 * 0.75)^{-1}$

$= 0.0122$ K/W

$R_5 = \ln(r_4 / r_5) / (2 * 3.14 * K_{SS} * L)$

$= \ln(38/36)/(2 * 3.14 * 16 * 0.75)$

$= 7.17 * 10^{-4}$ K/W

The total resistance was found out:

$R = R_1 + R_2 + R_3 + R_4 + R_5 = 0.0271$ K/W

Temperature difference between hot and cold fluids: dT = 12 K

Heat transfer rate = dT/R = 12/0.0271 = 0.442KW

II. RESULTS AND DISCUSSIONS

The amount of heat to be transferred from hot and strong solution from the regenerator to the cold weak solution flowing from absorber is found to be 0.442 KW. The simulation result is shown in the table below.

Table 1 Comparison of Simulation and Experimental Results

Sr No.	**Process**	**Change in solution temperature (^oC)**	
		Simulation results	**Experimental results**
1.	Absorption	17 – 25	20- 26

2.	Heat gain in solution heat exchanger	25 – 38	26 –38
3.	Heat gain in condenser	38 – 48	38– 42
4.	Regeneration	48 – 38	42– 38
5.	Heat lost in solution heat exchanger	38 – 25	38– 26
6.	Heat lost in evaporator	25 – 17	26 – 20

III. CONCLUSION

The pressure ratio of the cycle decreases thereby increasing the COP and cooling effect provided by the cycle. The use of external heat source for the regeneration of the liquid desiccant is eliminated. The simulation parameters and the experimental results that are taken for the design of HACS are compared. The rigorous testing of the system with the solution heat exchanger is needed to find the performance of the HACS.

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