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ENHANCING COOLING EFFICIENCY WITH LIQUID DESICCANTS

[1] S. DHIVAKARAN M. E, [2] M. CHANDRU M. E, (Ph.D.), [3] B. KARTHIK M.E,
[1] ASSISTANT PROFESSOR, [2] ASSISTANT PROFESSOR, [3] ASSISTANT PROFESSOR
[1] DEPARTMENT OF MECHANICAL ENGINEERING,
[1] ASIAN COLLEGE OF ENGINEERING AND TECHNOLOGY, COIMBATORE, TAMILNADU, INDIA

Abstract: This study presents analytical calculations for a liquid desiccant system that employs a calcium chloride solution and gauze-type structured packing as the packing material in the dehumidifier and regenerator of a Liquid Desiccant Cooling System (LDCS). The outlet parameters from the dehumidifier, such as the outlet humidity ratio, outlet air temperature, outlet air enthalpy, and outlet solution temperature, are estimated through mathematical equations and compared. A theoretical assessment of the heat and mass transfer performance of calcium chloride is performed for the conditions in Chennai, with an air flow rate of 100 CFM. The analytical results suggest that an increase in height leads to a decrease in both the humidity ratio and air temperature, which subsequently results in an increase in the size of the system**.**

Index Terms - Dehumidifier and regenerator of a Liquid Desiccant Cooling System, THIC, global warming**.**

I. INTRODUCTION

Air-conditioning systems are seen as crucial for keeping the indoor built environment comfy and livable. The approach of handling both heat and mass together is being utilized by current air-conditioning setups. As society moves forward, the old-school ways of air-conditioning are getting a nudge because folks are wanting nicer indoor vibes and better energy savings from these systems. To cut down on how much energy air-conditioning gobbles up and to make indoors more chill and pleasant, a fresh strategy has been figured out. Given what people are asking for, the THIC (temperature and humidity independent control) air-conditioning system is often thought of as a smart and doable fix. It's all about those indoor environmental control systems stepping up to ensure everyone inside feels good and healthy, by keeping things like temperature, humidity, air movement, and the quality of air just right. The vibe indoors, which is all about the weather-like conditions created by stuff like gadgets, lights, the folks hanging around, and how the air moves, plays a big role in making sure everyone's comfortable. With air-conditioning tech getting better in commercial spots, the standards for what makes air-conditioned spaces feel good have been set and are now a thing worldwide. In loads of buildings, the cost of air conditioning can munch through about 60-70% of the electricity bill. This study is all about finding a way to make air conditioning not eat up so much power, by using a liquid desiccant and the sun's help for regeneration, which could really dial down energy use.

II. GREEN REFRIGERATION CYCLES

Continuous development is underway for numerous green refrigeration cycles, aiming to combat global warming and slow down the rigorous changes in the world's climate. Among the evolving green technologies, such as absorption, adsorption, ejector, and thermo-electric systems, adsorption systems are taking the lead. This is because they're seen as having lower operational costs, a flexible approach to using waste heat and renewable energy sources, compatibility with energy storage systems, and so on. It's the use of green refrigerants like water in adsorption-based cooling systems that gives them an edge over other technologies.

There are a couple of reasons why there's a push to speed up research on adsorption refrigeration. First off, folks are on the lookout for ways to tackle the energy shortage problem. An effective strategy identified involves tapping into low-grade thermal energy, which encompasses both renewable energy and the recovery of waste heat. The second reason is the concern over the destruction of the ozone layer and global climatic changes, which are now being recognized as major environmental issues across the globe.

III. LIQUID DESICCANT COOLING SYSTEM

By a liquid desiccant air conditioner (AC), moisture and latent heat (and maybe even sensible heat) are removed from process air, thanks to a liquid desiccant material. The setup that's talked about in THIC [17], you can see it in Fig.1, has this cool scene where concentrated and chilled liquid desiccant gets poured into the absorber and then makes its way down through a packed bed filled with granular particles (or some other fancy surface that boosts mass transfer or packing).

As for the return air, it heads up through the bed, doing a little swap of both moisture and heat with the liquid desiccant going the opposite way. By the time the liquid desiccant exits the bottom of the packed bed, it's picked up water from the air, getting diluted, and off it goes into the regenerator.

Inside the regenerator, there's a heat source (could be gas or oil-fired, maybe waste heat, solar, who knows?) heating up the not-so-strong liquid desiccant solution. This solution is then sprayed over another packed bed. Thanks to the heat, the solution gives up the moisture it picked up earlier to an air-stream moving in the opposite direction, regenerating the concentrated liquid desiccant solution in the process. After making its trip from the regenerator, the liquid desiccant takes a chill pill in a cooling tower or chiller, and voilà, the cooled down liquid desiccant solution is ready to go back to the dehumidifier and do its thing again.

And yeah, a lot of designs throw in a counter-flow heat exchanger between the absorber and the regenerator to cut down on how much external heating and cooling is needed.

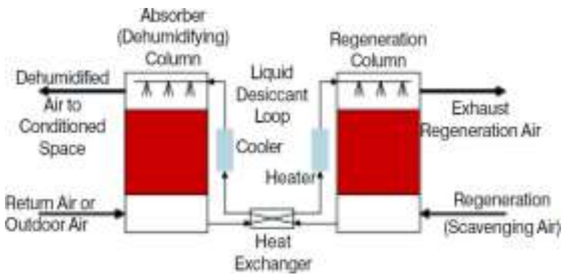


Fig.1 Basic liquid desiccant cooling system

IV. LAYOUT OF LIQUID DESICCANT SYSTEM

In Fig.2, the layout of the liquid desiccant evaporative cooling system is displayed. CaCl2, which is the liquid desiccant used, manages to dehumidify the incoming air with an efficiency ranging from 60-80%. To hit that high efficiency mark, the regeneration liquid needs to be heated up to about 55˚C, something that's usually done with a heater for experimental purposes. In real-life scenarios, though, this heat could totally come from a solar collector.

Once it's been dehumidified and if the humidity drops below what's comfy, the cold process air gets a pass through an evaporative cooler. This cooling bit is done super carefully to make sure the air that comes out has its relative humidity sitting pretty between 50-65%. After that, this air takes a trip through the cabin that needs cooling, picking up both sensible and latent load along the way. Finally, this air is pushed through a cooling tower which chills the water. This chilled water is then used to take the heat off the hot strong desiccant solution.

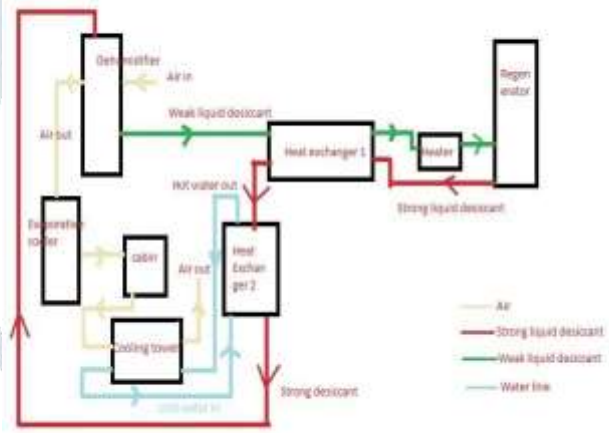


Fig.2 Liquid desiccant loop

V. WORKING OF LIQUID DESICCANT LOOP

5.1 Air cycle

The dehumidifier is where the process air is sucked in by a blower and gets dehumidified. If needed, the outlet air is sent to an evaporative cooler to hit those comfy conditions before heading into the cabin. Once it cools the cabin, the process air picks up both sensible and latent heat but still keeps a cooler temp and lower humidity compared to the outside air. That's why this air is perfect for running the cooling tower.

5.2 Liquid Desiccant-Closed cycle

The weak liquid desiccant after dehumidifying the air is pumped to the pre-heater / pre-cooler (heat exchanger) where it gets preheated. The preheated liquid desiccant is then passed to the heater, where it is heated to a little above the regeneration temperature. The hot liquid desiccant is then sent to the regenerator where the water vapor is removed from it. The concentrated liquid desiccant is now cooled in two stages. The first stage in the pre-heater / pre-cooler (mentioned above) where it loses heat to the weak liquid desiccant and then it is losing rest of the heat to the water from the cooling tower to become a strong cold liquid desiccant. This is sent back to the dehumidifier for dehumidification.

5.3 Water cycle

The air from the cabin, which usually boasts a wet bulb temperature ranging between 20-24˚ C, is interacted with by the water from the cooling tower. Therefore, water at 25˚C can be produced by a cooling tower that's rocking a 90% effectiveness. This water then gets to chill the super-hot liquid desiccant.

VI. MATHEMATICAL MODELING OF DEHUMIDIFIER ANDREGENERATOR

6.1 *Geometry and dimension of structured packing*

The variable that affects the heat and mass transfer coefficients for this type of packing is an equivalent diameter of a flow channel in the packing, which is calculated by takingthe arithmetic average of the hydraulic radius of different flowcross sections. In this geometry as mentioned in Al-Farayedhi[1] the cross section of the channel through which the air flows alternates between a triangle and a diamond as shown inFig.3. To simplify the calculation, triangular and diamond- shaped geometry, as shown in Fig.4 is used to estimate the hydraulic radii and equivalent diameter. To obtain a periodic redistribution of the air and the liquid flowing between adjacent sheets, the axis of the air flow channel is inclined 60° from the horizontal

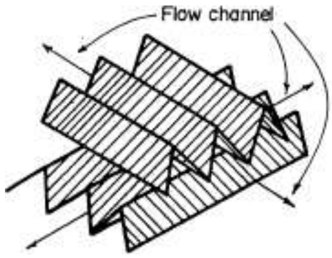


Fig.3 Flow arrangement

Fig.4.Geometry of flow channels [1]

6.2 Correlations to calculate effectiveness and other outletconditions of air liquid desiccant

In order to define all the parameters involved in the modeling Al-Farayedhi [1] approach is used. Hydraulic radius of triangular shaped channel [1] is given by

$$r_{hi} = \frac{BY}{2(B+2S)} \qquad (1)$$

Hydraulic radius of diamond shaped channel [1] is given by

$$r_{hd} = \frac{\mathrm{BY}}{4S} \qquad (2)$$

The arithmetic average of these two hydraulic radii[1] and isgiven by

$$\mathrm{d=BY}\left[\frac{1}{2S} + \frac{1}{(2S+B)}\right] \qquad (3)$$

The void fraction of structured packing [1] is given by

$$\varepsilon = 1 - \frac{4t}{d} \qquad (4)$$

The total available packing surface area per unit volume [1] is

$$a_p = \frac{4\varepsilon}{d} \qquad (5)$$

The effective gravity [1] is given by

$$g_e = g\left[\left(\frac{\rho_L - \rho_G}{\rho_L}\right)\left(1 - \frac{\frac{\Delta P}{\Delta Z}}{1025}\right)\right] \qquad (6)$$

The total holdup [1] is given by

$$H_{tot} = \left(4\frac{C_{tot}}{s}\right)^{\frac{2}{3}}\left[\frac{3\mu_L U_L}{\rho_L \varepsilon sin\theta g_e}\right]^{\frac{1}{3}} \qquad (7)$$

Where c_{tot} is a correction factor for total holdup in termsof available interfacial area

$$c_{tot} = \frac{29.12(\mathrm{We_L Fr_L})^{0.15}(\mathrm{S})^{0.359}}{\mathrm{Re}_l^{0.2}\varepsilon^{0.6}(1 - 0.93\cos\gamma)(\sin\theta)^{0.3}} \quad (8)$$

The dimensionless numbers [1] are given by

$$W_{eL} = \frac{U_L^2 \rho_L S}{\sigma} \quad (9)$$

$$R_{eL=} \frac{U_L^2}{S_g} \quad (10)$$

$$R_{eL} = \frac{U_L^2 \rho_L S}{\mu_L} \quad (11)$$

A relative velocity [1] of gas to liquid is defined as the sum ofeffective air velocity and effective liquid film velocity

$$U_r = U_{Le} + U_{Ge} \quad (12)$$

The effective air velocity is given by

$$U_{Ge} = \frac{U_G}{\varepsilon(1 - H_{tot})\sin\theta} \quad (13)$$

The effective liquid film velocity is given by

$$U_{Le} = \frac{U_L}{\varepsilon H_{tot}\sin\theta} \quad (14)$$

The effective interfacial area [1] for gauze surfaces is given by

$$a = a_p\left[1 - 1.203\left(\frac{U_L^2}{S_g}\right)^{0.111}\right] \quad (15)$$

The gas phase mass transfer coefficient [1] is given by

$$F_G\, a = 0.55(U_{Le})^{0.1}(U_{Ge})^{0.79}\exp(-0.0293T_G) \quad (16)$$

Where F is gas phase mass transfer coefficient per unit area and is given by

$$F_G = \frac{F_G a}{a} \quad (17)$$

The effectiveness based on gas phase mass transfer coefficient is given by

$$\varepsilon = 1 - \exp\left(\frac{F_G \times a \times dZ}{U_G}\right) \quad (18)$$

The outlet humidity ratio with respect to effectiveness is givenby

$$\omega_a{}^o = \omega_a{}^i - \varepsilon(\omega_i - \omega_E) \quad (19)$$

The gas phase heat transfer coefficient is given by

$$h_G\, a = 13.0(U_{Le})^{0.1}(U_{Ge})^{0.79}\exp(-0.026T_G) \quad (20)$$

Where h_G is gas phase heat transfer coefficient per unit areaand is given by

$$h_G = \frac{h_G a}{a} \quad (21)$$

The effectiveness [1] based on gas phase mass transfercoefficient is given by

$$\eta = 1 - exp\left(\frac{h_g \times a \times dz}{U_G\left(1.005 + 1.88\ \omega_G^i\right)}\right) \quad (22)$$

The outlet air enthalpy is given by

$$ha, o = (Cp\,TG, o) + \omega a, o\,(2500 + 1.88TG,o) \quad (23)$$

Where outlet air temperature is given by

$$TG, o = hG - \eta\,(TG, i - TL, i) \quad (24)$$

The liquid phase heat transfer coefficient [1] is given by

$$h_L a = 15.7(U_{Le})^{0.4}(U_{Ge})^{0.07}\ e^{-0.031\ T_L}\ e^{0.0025\ \xi} \quad (25)$$

Where hL is liquid phase heat transfer coefficient per unit area and is given by

$$h_L = \frac{h_L a}{a} \quad (26)$$

The liquid phase mass transfer coefficient [1] is given by

$$F_L a = 6.27(U_{Le})^{0.4}(U_{Ge})^{0.07}\ e^{-.0033\ T_L}\ e^{0.0066\ \xi}\ ) \quad (27)$$

Where FL is liquid phase mass transfer coefficient per unit area and is given by

$$F_L = \frac{F_L a}{a} \quad (28)$$

The mass flow rate of desiccant flowing out from the dehumidifier is given by

$$m_{L,o} = F_L \times a(F_G - \omega_{G,o}) \times m_G + m_L \quad (29)$$

The temperature of desiccant [1] flowing out from thedehumidifier is given by

$$T_{L,O} = \frac{(m_L \times C_{PL} \times T_{Li}) + h_L m_a(h_{G,i} - h_{G,O})}{F_{La} \times C_{PL}} \quad (30)$$

Table 1

Properties of Gauze type structured packing

Crimp height(y)	0.005 m
Channel base(B)	0.033 m
Channel side (S)	0.01 m
Equivalent diameter(d)	0.0113 m
Film thickness(t)	0.0025 m
Void fraction(ε)	0.88
Crimp angle from horizontal(θ)	60°

Table 2

Properties of air and desiccant at inlet conditions

Inlet air Temperature	38	°C
Area of flow	0.09	m²
Density of air	1.23	kg/s
Air flow rate	0.0549	kg/s
Air flow rate	0.045	m³/s
Air flow rate	0.5	m²/s
Inlet desiccant temperature	23	°C
Inlet air humidity ratio	16.7	g/kg of dry air
Equilibrium humidity ratio	10.8	g/kg of dry air

Inlet air enthalpy	81.1	KJ/kg
Concentration of solution	0.4	
Specific heat capacity of desiccant	2.4375	KJ/kgK
Density of desiccant	1360	kg/m3
Liquid desiccant flow rate	0.00018	m^3/s
Liquid desiccant flow rate	0.25	kg/s
Liquid desiccant flow rate	0.002	m^2/s
Viscosity of desiccant	0.0075	Ns/m^2
Surface tension of desiccant	0.0936	N/m
Crimp height	0.005	m
Channel base	0.033	m
Channel side	0.01	m
Equivalent diameter	0.0113	m
Void fraction	0.88	
Crimp angle from horizontal	60°	

VII. RESULTS AND DISCUSSION

The dehumidification effectiveness depends on the time of contact of ambient air with the liquid desiccant solution. The tower height determines the NTU of the system because to attain high drop in humidity ratio and air temperature, the tower height increases which directly increases the NTU of thesystem as shown in Fig.8. The variation of humidity ratio withrespect to height of gauze type structured packing is shown in Fig.5.The graph shows that as tower height increase humidity ratio decreases gradually and beyond 0.6m it gradually attains constant valu

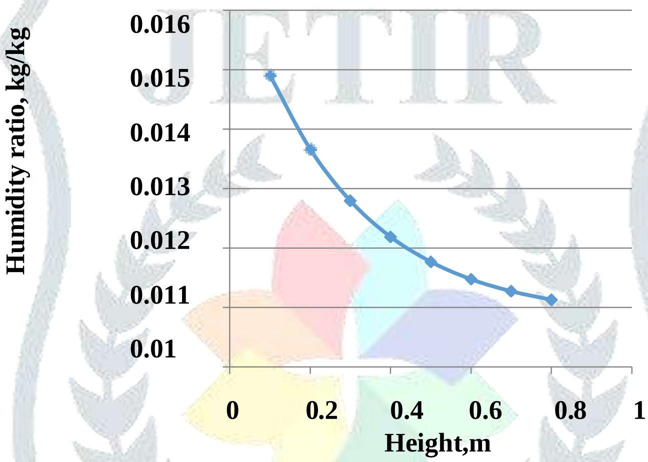
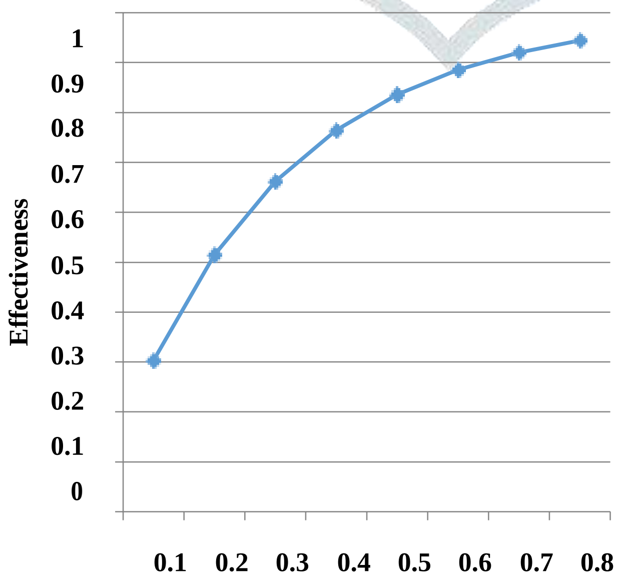


Fig.5.Variation of tower height with humidity ratio

The effectiveness is a function of inlet humidity ratio and equilibrium humidity ratio. The effectiveness increases as height increases as shown in Fig.6.The effectiveness reaches 0.9 between the tower heights 0.6m to 0.7m. Upon increasing the height beyond 0.7m the size of the dehumidifier and regenerator becomes large.



Height,m Fig.6.Variation of effectiveness with tower height

The temperature of the ambient air from 38°C decreases gradually to 30°C and remains almost constant at a height of 0.7m as shown in Fig.7.The inlet desiccant temperature isaround 22°C and heat transfer takes place between air and liquid desiccant.

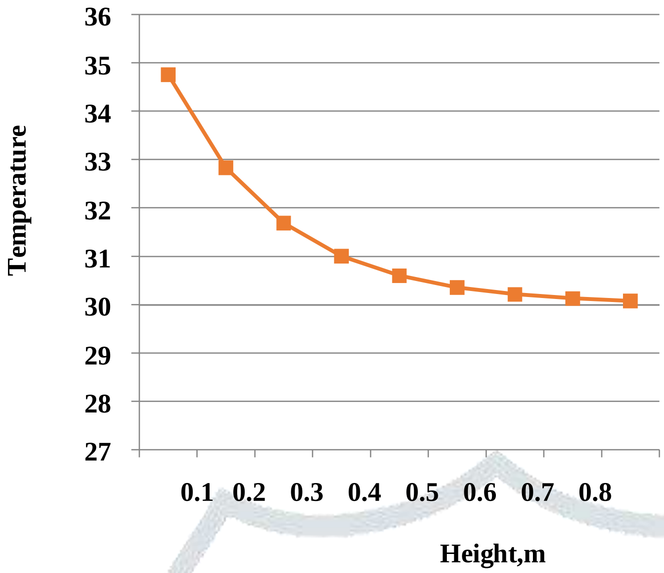


Fig.7.Variation of temperature with tower height

we can conclude that at a height of 0.6m to 0.7m the humidity ratio of air, outlet air temperature and effectiveness are found have an optimum value. Hence the height of gauze type structured packing is found to be 0.7m with a cross sectional area of 0.3m*0.3m for calcium chloride desiccant as it is the cheapest desiccant compared to lithium chloride and lithium bromide.

VIII. CONCLUSION

In this paper a suitable procedure to find the tower height ofgauze type structured packing material for the calcium chloride liquid desiccant is found using heat and mass transfer correlations. Height determination plays a major role in determining the size of the dehumidifier and regenerator as it increases the NTU of the system. Further validation and comparison of experimental data with analytical data has to be done and optimization has also to be done to reduce the height for the outlet humidity ratio.

IX. ACKNOWLEDGMENT

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