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Conditioning of outdoor air using rotating disk type liquid desiccant-air contacting device

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ABSTRACT: *Liquid desiccant (LD) based air conditioning technology is a promising eco-friendly technology with valuable features like high density energy storage and electrical energy saving. Air is dehumidified in air-LD contacting device in this system. Performance of rotating disk type contacting device (RDCD) is simulated in this work using aqueous potassium formate solution as LD. Finite difference method is used for this purpose and suitable heat and mass transfer models and empirical correlations are used. This work would be helpful in choosing the right parameters for RDCD for the given performance criterion.*

Keywords – *Air Conditioning, Contacting Device, Dehumidification, Liquid Desiccant*

1. Introduction

1.1 Liquid desiccant based air conditioning systems

Liquid desiccants (LDs) are hygroscopic aqueous solutions of various substances like lithium chloride, calcium chloride, potassium formate and glycols. When strong and low temperature LD is brought in contact with humid air, it can absorb moisture from it. Thus, LD can be used to remove latent heat from air in a component called dehumidifier. Sensible cooling may be provided with cooling tower water and/or by converting a part of latent cooling to sensible cooling using evaporative cooling. LD becomes weak by absorbing moisture from air and should be regenerated, i.e. water absorbed should be removed in order to work in a cycle. This is done in a component called LD regenerator [1]. Regenerator as well as dehumidifier is a LD-air contacting device.

1.2 Liquid desiccant-air contacting devices

Various LD-air contacting devices are studied in literature viz. spray tower, packed bed and falling film [2]. These devices are illustrated in Fig. 1. In case of spray tower, the surfaces of tiny droplets of LD provide contact area between air and LD. In case of packed bed, the surface of packing material provides large area for contact. In case of falling film type device, LD is distributed over parallel plates, whose surfaces provide the required contact area. The pressure drop on air side is generally low in this device, but distribution of liquid over multiple plates and complete plate area could be tricky.

Most researchers have used adiabatic contacting devices, but it is advantageous to cool LD during the process dehumidification process. If LD is cooled during dehumidification process, it will retain lower water vapor pressure up to a lower concentration value. This will allow higher concentration range and lower flow rate of LD in cycle helping to reduce electrical power consumption in the system in this thermally activated system. The size of the equipment will be small for same capacity of cooling. The falling film type contacting device illustrated in Fig. 1 is an internally cooled contacting device. Another novel type of diabatic contacting device is a rotating disk type contacting device [3, 4].

1.3 Rotating disk type contacting device

Fig. 2 shows end view of a rotating disk type of contacting device in which several disks are mounted on a shaft, which is rotated with the help of a motor. Strong LD enters from one end of trough and moves along the axis of shaft. Disks remain partially dipped into the LD pool in trough. The upper part of rotating disk remains outside the LD pool and offer contact area between air and LD. LD is continuously cooled with cooling water flowing co-current with LD through channels provided in trough. When disks are rotated, they bring strong, cool LD in contact with the air passing through the gaps between them. The water vapor pressure exerted by LD is lower than that of air, so water vapor transfer takes place from air to LD. LD becomes dilute by absorption of moisture and comes out from the other end of the trough. Air is drawn into the device using a fan as shown in the Figure.

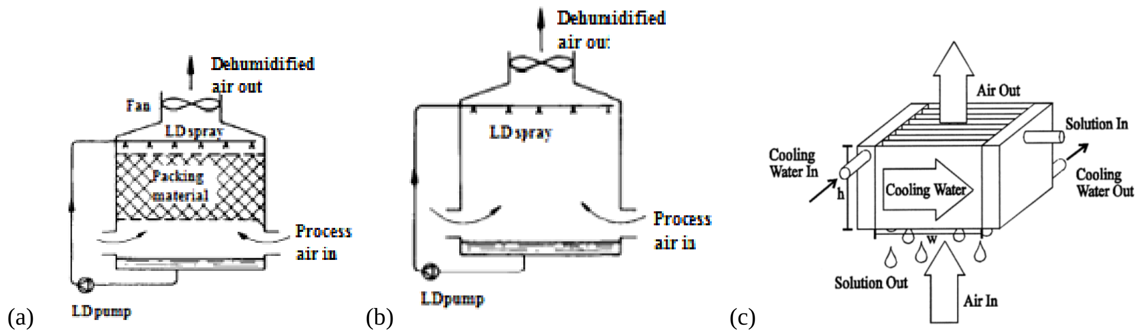

Fig. 1: Various types of LD-air contacting devices (a) Packed bed (b) Spray tower (c) Falling film

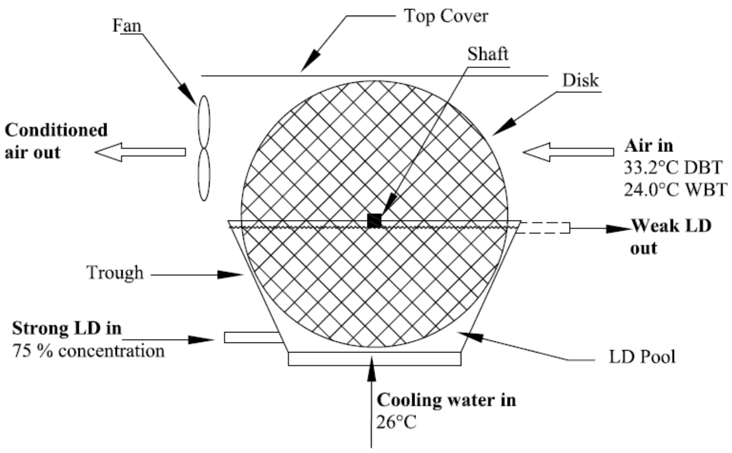

Fig. 2: Rotating disk type contacting device along with process parameters used in this work

2. Simulation of Performance of RDCD

Ambient design conditions for cooling for Ahmedabad at 2% probability (33.2°C DBT and 24.0°C WBT) are taken as the inlet condition of air. This weather represents typical summer conditions in tropics, particularly India. The performance of RDCD is evaluated for outdoor air dehumidification in this work and not for conditioning of recirculated room air. The device is thus evaluated as a dedicated outdoor air conditioning unit, which is mainly responsible for enthalpy reduction of outdoor air in a central air conditioning unit. Most part of this enthalpy reduction would come from moisture removal, but a small part may also come from sensible cooling, generally provided by cooling tower water.

The design variables for this device are: diameter of disk, gap between the disks / disk pitch and speed of rotation of disk assembly. Disk thickness is taken 1 mm and thickness of film is 0.125 mm as measured by Mehta (2013) for a 150 mm aluminum expanded metal mesh disk [5]. Half the disk dips into the pool and the other half remains exposed to air. LD used is aqueous potassium formate solution due to its good compatibility with common metals like steel, aluminium and copper [6]. The solution enters the device at 75% concentration, practically highest value that can be used without risk of crystallization. Taking cooling tower approach equal to 2 K with wet bulb temperature, cooling water is assumed to enter into the RDCD at 26°C.

The flow rate of water would be adjusted such that there is maximum temperature rise of 2 K in the RDCD. LD and cooling water flow co-currently and LD always remains at 2 K higher than cooling water temperature.

Air flows through the gap between the disks (Fig. 3). Flow of air through this gap is considered to be flow through a channel. Diameter of the disk is the total depth of the channel, but the height of the channel varies as the air moves through it. The depth of channel (diameter of disk along air flow direction) is divided into several parts and LD and air flow are assumed to flow counter-current as the direction of rotation of disk is opposite to the air flow. Flow rate of air is taken 200 kg/h. Properties of LD are found based on the modified Pitzer model [7]. Calculation of relevant non-dimensional numbers is done for each strip. The flow of air through the channel is laminar as Re < 2300 in all cases. For a given strip, first the flow pattern is determined based on Gratz number criterion. If flow is not fully developed, but is in developing zone, Nusselt number (Nu) is given by following formula [8]:

$$Nu = 7.54 + \frac{0.03\left(D_h/_L\right)RePr}{1+0.016\left[\left(D_h/_L\right)RePr\right]^{2/3}} \quad \ldots (1)$$

D_h is hydraulic diameter, L is characteristic length, Re is Reynolds number and Pr is Prandtl number. For fully developed flow, Nusselt number is a constant and the function of aspect ratio for the channel [9].

The mass transfer coefficient is found using Chilton-Colburn analogy.

$$h_m = \frac{h}{\rho c_p}\left(\frac{D_{AB}}{\alpha}\right)^{2/3} \quad \ldots (2)$$

h and h_m are heat and mass transfer coefficients respectively. D_{AB} is binary diffusion coefficient for water in air. ρ, c_p and α are density, specific heat and thermal diffusivity respectively.

The mass flow rate of LD over disk could be as high as 30 times that of air, so concentration as well as temperature change across a given segment can be safely neglected. The thickness of LD over disk also can be considered to remain unchanged as mass of moisture removed in one rotation is very small. The water vapor pressure difference between air and LD is the driving force for moisture transfer. Based on heat transfer and mass of moisture absorbed; humidity ratio, temperature and enthalpy of air at outlet of segment are calculated. Outlet condition of one segment becomes inlet conditions of next segment over the disk.

As LD absorbs moisture from air, its concentration reduces. Thus, the concentration of LD at inlet to the disk reduces along the length of the device. Cooling water temperature also rises along the length of the device, increasing the temperature of LD also. To take care of this change in LD condition, the total length of the device is also divided into ten equal parts. These parts are considered in series for LD flow and in parallel for air flow. Outlet condition of LD at for first segment becomes inlet condition for second segment and so on. Parameters like moisture removal rate, total cooling rate, condition of air and LD at outlet of the device are found per unit length of device. The moisture removal as well as cooling rate for the next segment is slightly lower as LD is now weaker and there is temperature rise of 0.2^{o}C per longitudinal segment. Condition of air at outlet of the device is the state resulting after mixing the air coming out of all ten longitudinal segments.

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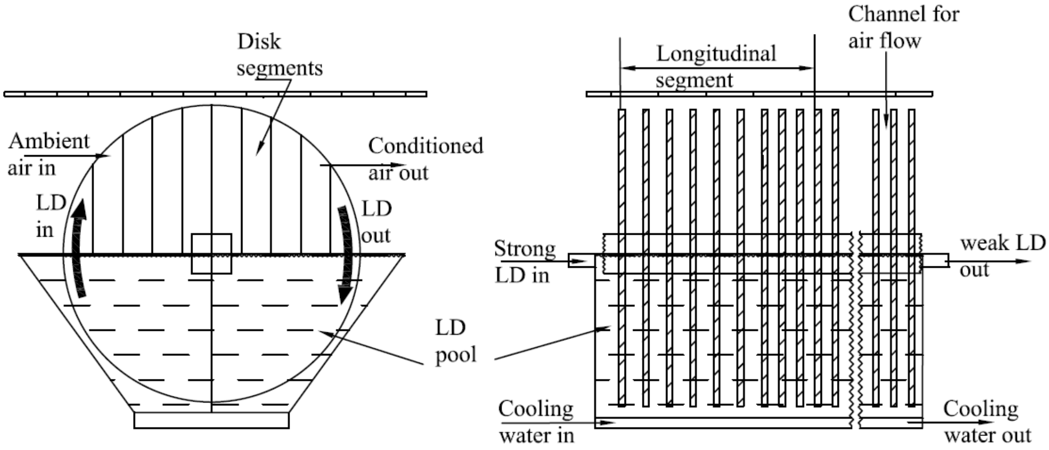


Fig. 3: Configuration and methodology of simulation for RDCD

3. Results and Discussions

The disk diameter was divided into 200 parts and heat and mass balance equations were applied to each part, considering them to be in series for air and LD flow, moving in countercurrent fashion. Humidity ratio is the most important property to be tracked, whose variation along the disk diameter (depth of channel) for various disk diameters for 2 mm pitch are shown in Fig. 4. The curve becomes flat very fast for higher disk diameters. This shows that higher disk diameter results in underutilization of surface area and volume of the contacting device and is thus less preferable for smaller pitch.

Fig. 5 shows that 150 mm diameter disk assembly will provide highest cooling rate (~1.5 kW/m). Increase in surface area by pitch reduction does not help much in increasing the cooling rate. Thus, it may be more economical to use higher pitch at this diameter as material and labor cost are proportional to disk area and number of disks respectively. Smaller pitch should be used for smaller disk diameters in order to get higher cooling rate per unit length of the device. As seen from Fig. 6, 50 mm diameter disk with 2 mm pitch will provide highest cooling rate per unit surface area of disk. 3 and 4 mm pitch should be used for disk diameters exceeding 75 and 100 mm respectively to get high cooling rate per unit surface area.

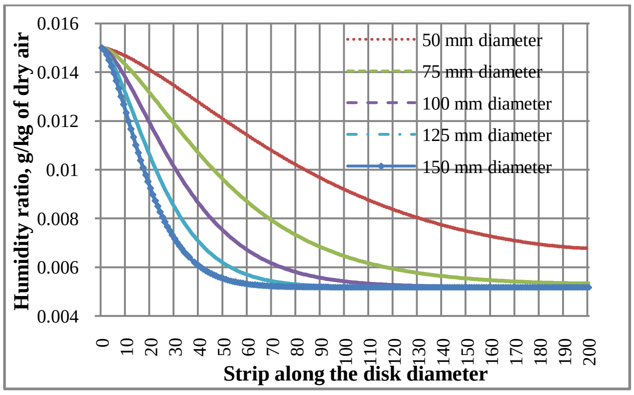


Fig. 4: Variation of humidity ratio of air along the diameter of the disk (depth of the channel)

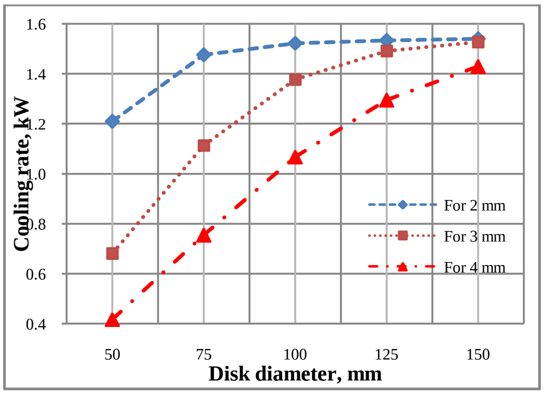
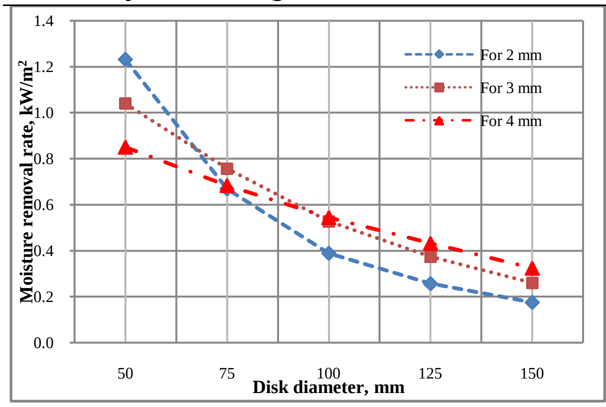


Fig. 5: Cooling rate per unit length of device for various diameters and pitch of disk



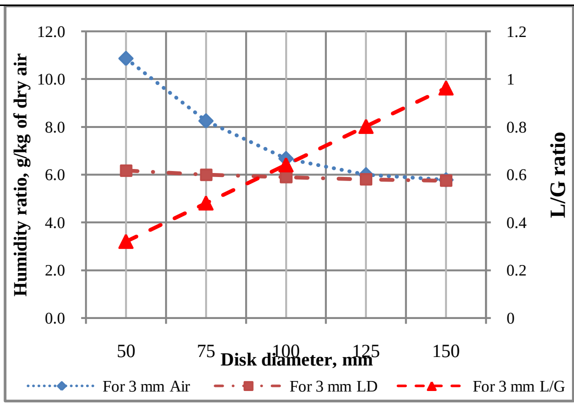


Fig. 6: Cooling rate provided by RDCD per unit length at various disk diameter and pitch

Fig. 7: Variation of humidity ratio for various disk diameters and L/G (liquid to gas flow) ratio

4. Conclusion

Higher disk diameter provides higher cooling rate per unit length of device for RDCD. Larger pitch should be used for higher disk diameters for better economy. An RDCD with 150 mm disk diameter can provide cooling at a rate of 1.5 kW/m using aqueous potassium formate as LD. Smaller disk with small pitch gives highest cooling rate per unit area (~1.2 kW/m^2 for 50 mm disk with 2 mm pitch), but air quality would be inferior. So, using multiple RDCD in series for air flow may be preferable when smaller disk diameter is used.

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