Experimental performance comparison of adiabatic and internally-cooled membrane dehumidifiers

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Abstract

Humidity control of indoor space using the conventional air conditioning system is energy intensive. The liquid desiccant dehumidifier, which operates on low grade energy sources, is one of the energy efficient alternatives for humidity control. Membrane dehumidifiers avoid the desiccant carryover and hence are preferred over the packed bed dehumidifiers. However, their performance is lower due to the additional resistance in the membrane. Internal cooling is one way to improve the performance of the membrane dehumidifier and the present study experimentally investigates such a dehumidifier. The operating parameters considered are specific humidity, mass flow rate, temperature and of inlet air. The performances of the adiabatic and internally cooled dehumidifiers are presented in terms of moisture removal rate and latent effectiveness. It is found that these are higher by 60 and 50%, respectively, for the internally cooled dehumidifier.

Keywords: internally cooled membrane dehumidifier; liquid desiccant dehumidification; moisture removal rate; latent effectiveness; experimental analysis

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1 INTRODUCTION

According to the International Energy Outlook 2013, building sector consumes one fifth of the total global energy consumption. India too follows the same trend. Further, more than 60% of the buildings projected for 2030 are yet to be built. These are also expected to have increased demand of thermal comfort due to both growth in urbanization and increased aspiration for better human comfort. Thus, the energy share required for controlling the indoor conditions is expected to increase to ~45% of the total building energy consumption from the present of ~25% [1]. Apart from temperature, control of humidity plays a vital role in air conditioning (AC) at tropical climate and also for many special applications such as hospitals, electronic labs, museums etc. to maintain the required low indoor humidity [2]. Cooling air below its dew point temperature to condense the water vapor is the standard method of dehumidification adopted in the conventional AC systems. Air has to be cooled to low temperature and then heated before it enters the AC room to control humidity. Therefore, the conventional AC system is energy inefficient due to overcooling followed by reheating of the air. Thus, alternative energy efficient systems have been studied for the control of humidity in many AC applications. One such prospective system is desiccant dehumidifier which utilizes the renewable low grade energy sources for its regeneration [3]. The hybrid AC system combines such a desiccant dehumidifier with the conventional cooling system.

Desiccant dehumidification is the process of removing water vapor from air by absorbing it in the desiccant, which may be liquid or solid. The former is selected for the present study due to its advantages such as high moisture holding capacity, low airside pressure drop and low regeneration temperature. Moreover, it facilitates air sterilization, operational flexibility and utilization of the low grade thermal energy sources such as solar or waste heat for its regeneration [4]. The liquid desiccant systems are classified as direct contact-packed bed and indirect contact-membrane systems. The latter is preferred to avoid the problems associated with desiccant carryover such as health hazard and corrosion of equipment [5]. While the membrane avoids direct contact between air and desiccant, its micro-pores

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allow water vapor to get transferred between them. However, its mass transfer performance is lower than that of the packed bed dehumidifier due to the additional resistance imposed by the intermediate membrane. There are many ways such as internal cooling, provision of nanofibrous membrane, providing micro-fins and so on to improve the performance [6]. Present study analyses the performance improvement of the membrane dehumidifier by internal cooling. Flat-plate configuration is selected for the present study due to its suitability for multi-stream applications, ease of assembly and less airside pressure drop over the hollow-fiber configuration [7].

Dehumidifiers are broadly divided into two types, namely adiabatic and internally cooled. Cooling of the desiccant is essential to make it absorb water vapor from air. In the adiabatic dehumidifier, the desiccant is precooled in an external heat exchanger as shown in Figure 1a, to facilitate it to absorb water vapor from the air flowing in the adjacent channel separated by the membrane. The heat of absorption raises the desiccant temperature which reducing its capacity to absorb water vapor. In the internally cooled type, the desiccant is continuously cooled as shown in Figure 1b, while it absorbs water vapor thereby improving the capacity.

Membrane dehumidifiers are developed recently as an alternative to the conventional packed bed dehumidifiers. Hence, their literature, especially with internal cooling arrangement is limited. Isetti *et al.* [8] developed the first prototype of such a dehumidifier. Potassium formate solution (desiccant) was cooled by the cooling water in a plate heat exchanger. Air flows in the hydrophobic polypropylene membrane tubes placed in the desiccant channel in cross-flow direction. The parametric study revealed that the performance of the dehumidifier was better at low inlet temperature of the cooling water. Abdel-Salam *et al.* [9] experimentally reconfirmed the influence of inlet temperature and further found that the high water flow rate enhances the performance. The paper details the issues in manufacturing of the internally cooled dehumidifier without leaks due to the additional cooling water channel. The results concluded that the internally cooled dehumidifier is better than the adiabatic dehumidifier. The results also indicate that the inlet temperature of cooling water has to be critically selected to avoid the temperature drop of desiccant in the dehumidifier. Later, the same authors extended their study [10] and analyzed the effect of inlet specific humidity of air and mass flow rate of desiccant. The results indicated that an

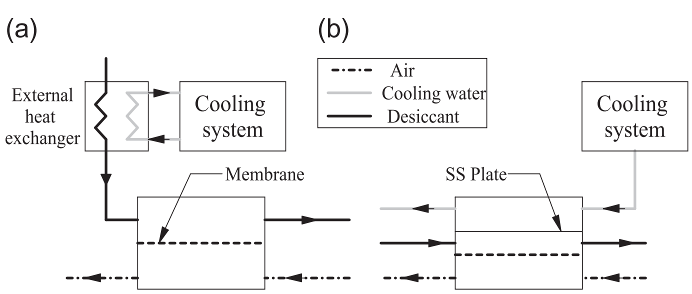

Figure 1. *Schematic diagram of operating conditions of the (a) adiabatic and (b) internally cooled membrane dehumidifiers.*

increase in such parameters increases the performance of both adiabatic and internally cooled dehumidifiers. However, the effect of mass flow rate of desiccant is significant on the former. A numerical model of the internally cooled dehumidifier is required to analyze its performance under various climatic conditions. Huang *et al.* [12] developed one such model and validated using their experimental results. The governing mass, momentum and energy equations were solved to find the Nusselt and Sherwood numbers for the heat and mass transfer processes of the dehumidifier. Woods and Kozubal [11] analyzed the influence of air, desiccant and membrane on the heat and mass transfer resistances of internally cooled membrane dehumidifier. It is reported that the air resistance accounts for 70% of the overall heat transfer resistance while the air and membrane resistances together account for 90% of the overall mass transfer resistance.

From the above narratives, it can be concluded that most of the previous works of internally cooled membrane dehumidifiers are focused only on its initial design and development. The parametric experimental investigations on such dehumidifiers are scarce to compare their performance with those of adiabatic membrane dehumidifier. Thus, the main objective of the present paper is to experimentally investigate the performance of the internally cooled membrane dehumidifier for the hot and humid climatic conditions prevailing in the city of Chennai, India. The operating parameters considered are mass flow rate, inlet temperature and specific humidity of air. The performances of the adiabatic and internally cooled dehumidifiers are presented in terms of moisture removal rate (MRR) and latent effectiveness. The presented results are useful in the optimum design of the membrane dehumidifiers.

2 DESCRIPTION OF MEMBRANE DEHUMIDIFIER

Figure 2 shows the schematic diagram of the membrane dehumidifier. It has three channels, one each for air, desiccant and cooling water with their flow in counter-flow direction. Upward entry of desiccant is adopted to avoid flow maldistribution [13]. Flow guides are provided to make the desiccant flow direction counter to both air and cooling water. The membrane is attached to a metal mesh using double-sided foam tape and metal screws to avoid its deflection. The design details of the membrane dehumidifier are listed in Table 1. Experimental studies of both adiabatic and internally cooled dehumidifiers are carried out in the same dehumidifier, the former by switching off the cooling water pump.

3 EXPERIMENTAL SETUP AND INSTRUMENTATION

The schematic diagram and photograph of the experimental setup of membrane dehumidifier are shown in Figures 3 and 4 respectively. It consists of three circuits, namely the air,

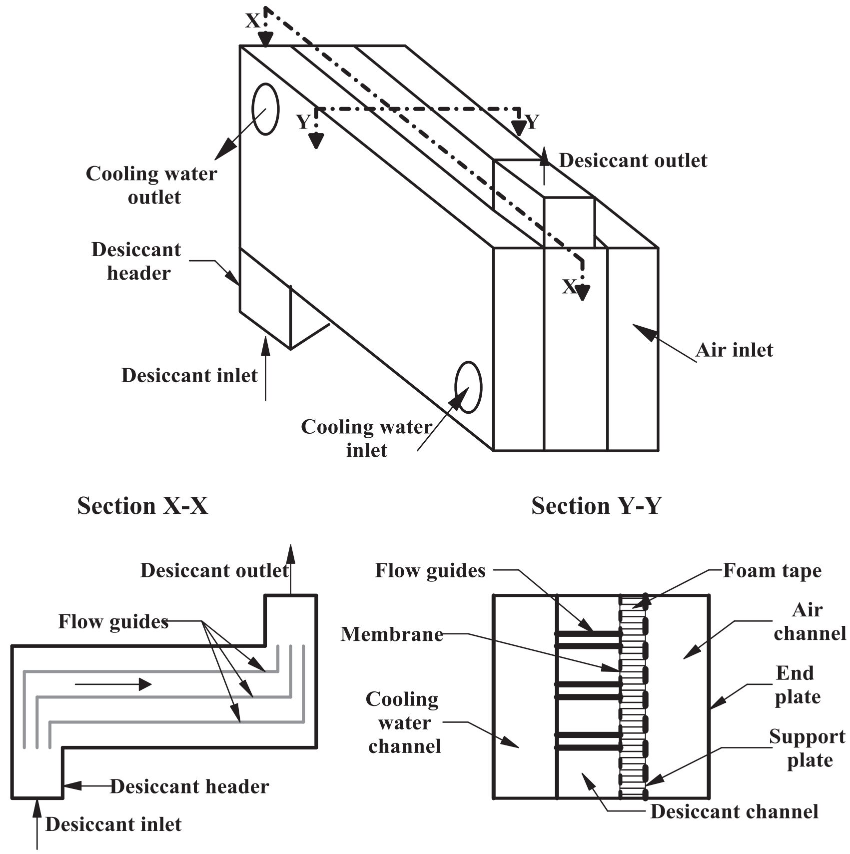

Figure 2. *Schematic diagram of the membrane dehumidifier.*

Table 1. *Design details of the membrane dehumidifier.*

Sl. No.	Parameter	Value
1	Channel spacing (mm)	5
2	Dehumidifier length (m)	1.1
3	Dehumidifier height (m)	0.55
4	Membrane material	PVDF
5	Membrane pore diameter (μm)	0.2
6	Membrane thickness (mm)	0.22
7	Plate thickness (mm)	1.2

desiccant and cooling water with the provision to control the respective operating parameters namely, (a) flow rate, inlet temperature and specific humidity for air (b) flow rate, inlet temperature and concentration for desiccant and (c) flow rate and inlet temperature for cooling water.

The air circuit consists of an ultrasonic humidifier, cooler and heater by which the desired climatic conditions (temperature and humidity) can be achieved. The cooler is supplied with water at the desired temperature from a constant temperature water bath. The air circuit has fan, inlet static mixer and flow straightener before the dehumidifier. The flow rate of air is adjusted using fan speed control. The inlet and outlet headers facilitate uniform air distribution in the rectangular channel of the dehumidifier. Temperature, relative humidity and flow rate are measured at all the key locations as shown in Figure 3. Aqueous solution of lithium chloride is used as desiccant [14] and its circuit consists of supply and storage tanks, and a peristaltic pump. Sufficient quantity of desiccant with desired concentration is filled in the supply tank. It is maintained at the desired temperature using water from the constant temperature water bath. The desiccant flow rate to the membrane dehumidifier is adjusted by controlling the speed of the pump and its flow rate is measured. Desiccant density and temperature are measured both at inlet and outlet of the dehumidifier as shown in Figure 3 and the respective concentrations are calculated [15]. The cooling water circuit contains a constant temperature bath and a peristaltic pump to control the water inlet temperature to the dehumidifier and its flow rate respectively. Inlet and outlet temperatures, and flow rate of the water are measured. The details of the instruments used in the experimental setup are listed in Table 2. The data acquisition system records all the experimental data namely temperature, relative humidity, mass flow rate and density at regular intervals.

All the sensors and instruments are pre-calibrated. The temperature sensors are calibrated using a constant temperature bath for their entire working range. The relative humidity probes are calibrated using a dew point meter in a controlled

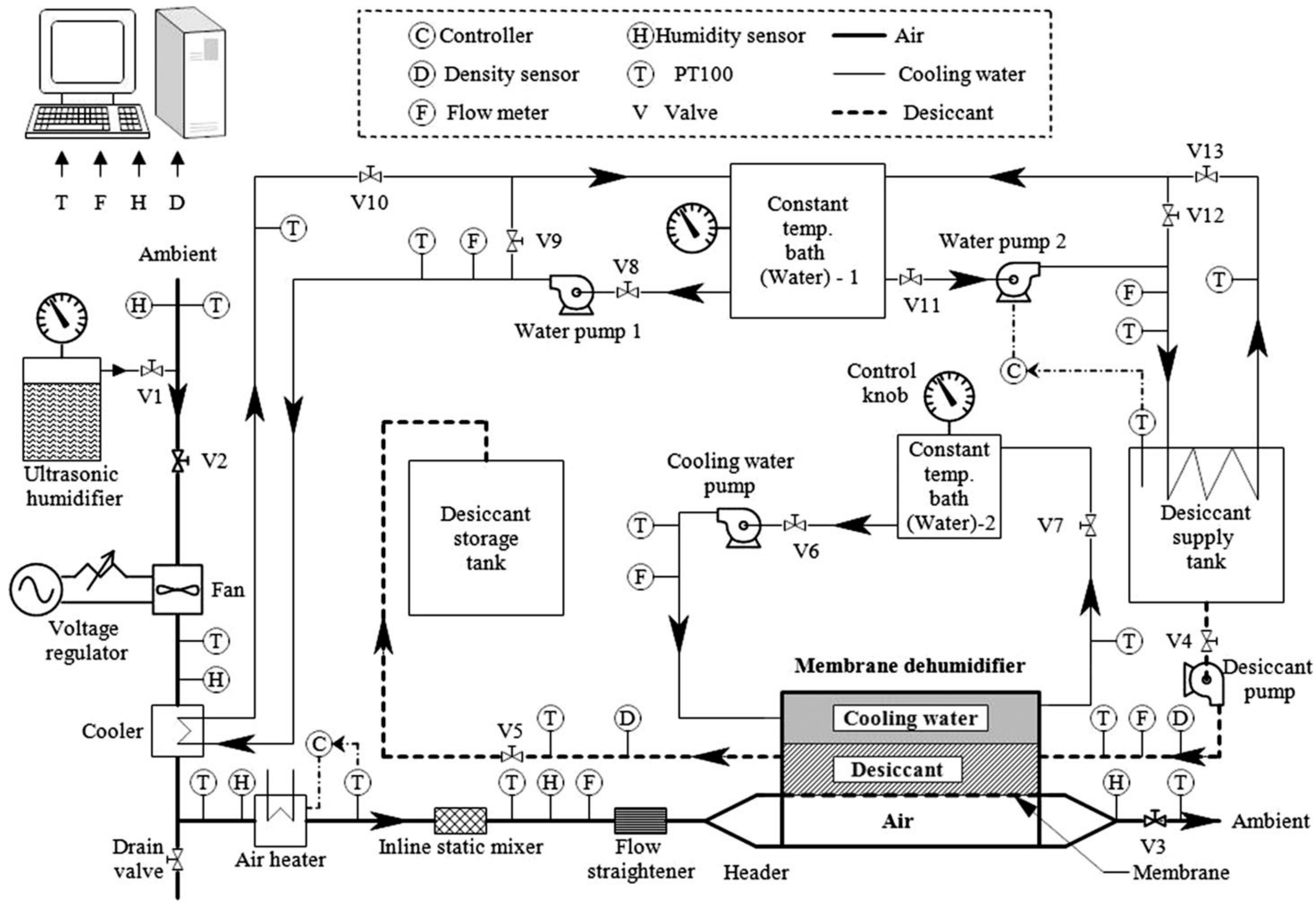

Figure 3. *Schematic diagram of the experimental setup.*

environment chamber for their entire humidity range at different temperatures. A detailed error analysis [16] has been done estimating the uncertainty in the two performance parameters, namely MRR and latent effectiveness, which are found to be within ±5% and ±6%, respectively.

4 EXPERIMENTAL PLAN

4.1 Experimental procedure

The experimental procedure for the internally cooled dehumidifier is as follows.

- Check all the electrical connections for safety and switches for OFF position.
- Check all the valves for their closed position.
- Switch on the electric power supply to the main control panel.
- Switch on the electric power supply to the data acquisition system, sensors and instruments.
- Set the data acquisition system to record data from the instruments and sensors.
- Open Valves V2 and V3.
- Switch on the fan and regulate it for the desired air flow.
- Open Valves V8, V9 and V10, and switch on Water pump 1.
- Switch on Constant temperature water bath 1 and adjust it for the required inlet water temperature to the cooler.
- Switch on the inline air heater and set the desired air temperature in its automatic temperature controller.
- Open Valve V1. Switch on and adjust the ultrasonic humidifier for the desired specific humidity of air.
- Fill sufficient quantity of desiccant of desired concentration in the supply tank.
- Open Valves V11, V12 and V13.
- Switch on the automatic temperature controller of the desiccant supply tank and set it for the desired desiccant temperature (the set temperature is maintained by on/off control of Water pump 2 with the signal from the temperature controller).

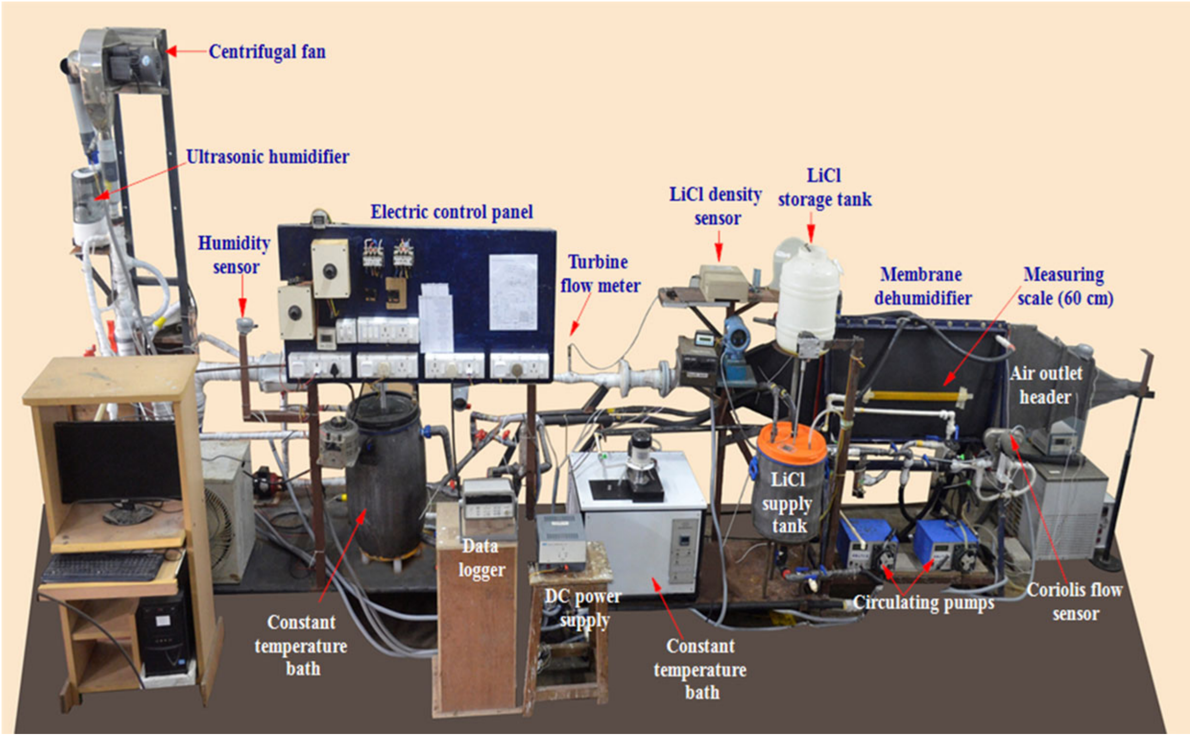

Figure 4. *Photographic view of the experimental setup.*

Table 2. *Details of the measuring instruments.*

Sl no.	Parameter	Instrument	Range	Accuracy
1	Temperature	PT100 Sensors	0–100°C	±0.1°C
2	Air flow rate	Turbine flow meter	0–20 m^3/hr	±1%
3	Air relative humidity	Humidity sensors	5–95 %	±1.5%
4	Desiccant flow rate	Coriolis flow meter	0–30 kg/hr	±1%
5	Desiccant density	Density meter	0–3 g/cm^3	±0.0001 g/cm^3
6	Water flow rate	Rotameter	0–2 lpm	±3%

Table 3. *Values of the fixed parameters.*

Sl no.	Parameters	Value
1	Mass flow rate of cooling water (kg/h)	15
2	Inlet cooling water temperature (°C)	15
3	Mass flow rate of desiccant (kg/h)	5
4	Inlet desiccant concentration	0.35
5	Inlet desiccant temperature (°C)	20[a]/28[b]

[a]Adiabatic dehumidifier.
[b]Internally cooled dehumidifier.

- Switch on Constant temperature water bath 2 and set it for the desired cooling water temperature.
- Allow sufficient time for various parameters to reach their respective set values such as air temperature before dehumidifier, desiccant temperature in the supply tank and cooling water temperature in Constant temperature water bath 2 and so on.
- Open Valves V4 and V5.
- Switch on the desiccant pump and adjust its speed to maintain the desired desiccant flow rate.
- Open Valves V4 and V5.
- Switch on the cooling water pump and adjust its speed to maintain the desired cooling water flow rate.
- Allow sufficient time for the experimental setup to attain steady state condition.
- Record all the final data for the performance analysis.

The experimental procedure for the adiabatic dehumidifier is similar to the procedure mentioned above except that Steps 15, 19 and 20 are not to be included.

4.2 Fixed parameters

Experiments are carried out to explore the influence of operating parameters pertaining only to air on the performance of the dehumidifiers. Therefore, other potential operating parameters pertaining to cooling water and desiccant are held constant as listed in Table 3. The desiccant is precooled in the case of the adiabatic dehumidifier (Figure 1). Hence, its inlet temperature is lower than that in the case of the internally cooled dehumidifier.

Table 4. *Range and default values of the airside operating parameters.*

Sl no.	Parameters	Default value	Range
1	Inlet specific humidity (g/kg_{da})	22.5	15–25
2	Inlet temperature (°C)	36	28–40
3	Mass flow rate (kg/h)	5	3.5–8.7[a]

[a]Converted from volume flow rate.

4.3 Orating parameters

The selected operating parameters are mass flow rate, temperature and specific humidity of air at the inlet of the dehumidifier. The range and default values of these parameters are listed in Table 4. The conditions of inlet temperature and specific humidity of air are selected based on the standard climatic conditions of Chennai (13.0827° N, 80.2707° E), India [17]. While the membrane dehumidifier has many air channels, its testing needs only one channel with corresponding air flow rate. Each operating parameter is varied to study its effect by keeping the rest at their respective default value during the experimentation.

4.4 Performance parameters

Performance comparison between the adiabatic and internally cooled dehumidifiers is presented using the following two parametric indices.

4.4.1 *Moisture removal rate*

The MRR is defined as the total amount of water vapor transferred from air to the liquid desiccant [14]. Thus,

$$MRR = m_a \times (W_{a,in} - W_{a,out}) \quad (1)$$

where m_a is the mass flow rate of air while $W_{a,in}$ and $W_{a,out}$ are the inlet and outlet specific humidities of air, respectively.

4.4.2 *Latent effectiveness (ε_w)*

The latent effectiveness is defined as the ratio of total specific humidity drop of air in the dehumidifier to the maximum possible drop that can take place [14]. Thus,

$$\varepsilon_w = \frac{W_{a,in} - W_{a,out}}{W_{a,in} - W_{s,in}} \quad (2)$$

where $W_{s,in}$ is the inlet equivalent specific humidity calculated as function of temperature and concentration of desiccant [15].

5 RESULTS AND DISCUSSION

The performances of the adiabatic and internally cooled dehumidifiers are compared for the varying specific humidity, mass flow rate and temperature of inlet air.

5.1 Effect of inlet specific humidity of air

Figure 5 shows the effect of inlet specific humidity of air on the performance of the dehumidifiers. The Moisture Removal Rate

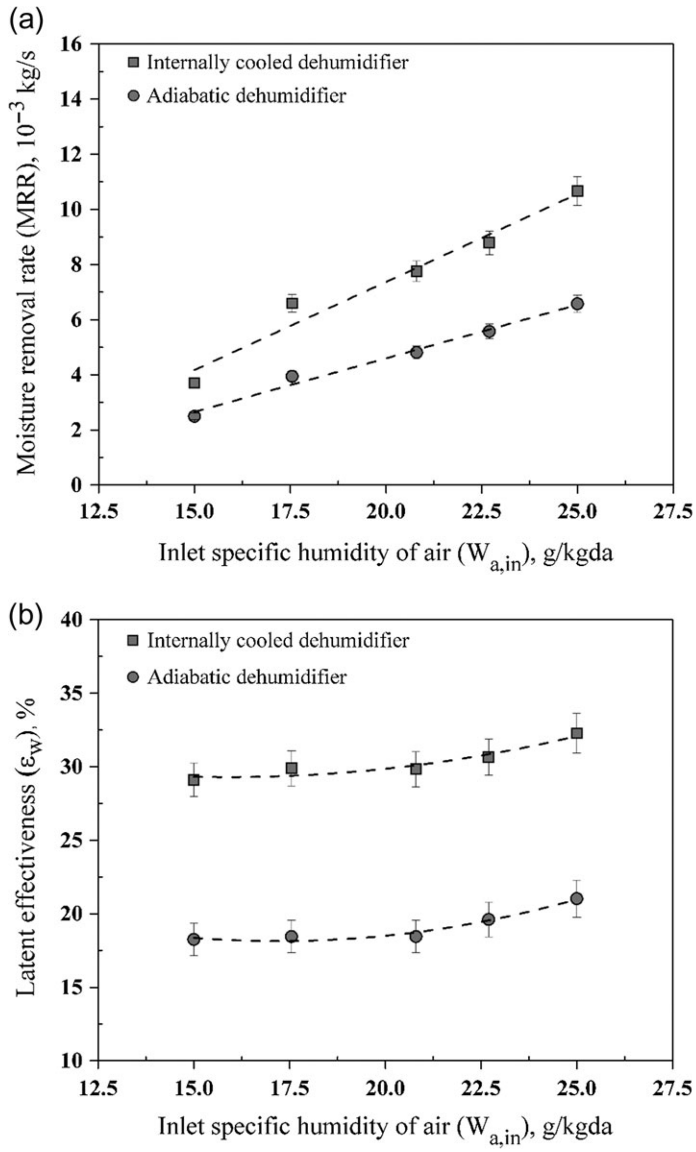

Figure 5. *Effect of inlet specific humidity of air on (a) moisture removal rate and (b) latent effectiveness.*

(MRR) is found to increase linearly with the inlet specific humidity of air for both the dehumidifiers. This is due to increase in the mass transfer potential, i.e. pressure difference between the partial pressure of water vapor in the air and that in the air–desiccant interface of the dehumidifier. When the inlet specific humidity of the air increases, the partial pressure of water vapor in the air also increases, which in turn increases the mass transfer potential for the dehumidifiers. Moreover, Figure 5(a) shows that the MRR of the internally cooled dehumidifier is not only higher but also increases at a higher rate than that of the adiabatic dehumidifier. It increases from 3.7 to 10.6 g/s (186%) when the inlet specific humidity of air is increased from 15 to 25 g/kg_{da}. This is due to the continuous removal of the exothermic heat (heat of absorption) by the cooling water that is released during the mass transfer process. This continuous cooling restricts the desiccant from heating up thereby limiting the equivalent specific humidity (i.e. specific humidity of air in equilibrium with the desiccant) of the desiccant.

Thus the average mass transfer potential of the internally cooled dehumidifier is higher than that of the adiabatic dehumidifier. Therefore, the increment in MRR of the latter is comparatively less at 160% (2.5–6.5 g/s) for the same variation in the inlet specific humidity. As discussed, the increase in the inlet specific humidity of air increases the mass transfer potential. This increases the drop in specific humidity of air $W_{a,in} - W_{a,out}$ while it passes through the dehumidifier. This in turn increases the heat of absorption, which increases the temperature of the desiccant. Consequently, the equivalent specific humidity of desiccant also increases thereby its absorption capacity reduces. Therefore, the increase in the inlet specific humidity of air simultaneously increases the specific humidity drop of air and decreases the absorption capacity of the desiccant. The effect of the former is slightly higher in the present case. Therefore, the latent effectiveness increases slightly by 17% and 15%, respectively, for the internally cooled and adiabatic dehumidifiers as shown in Figure 5(b). As expected, the latent effectiveness of the former is relatively higher due to the continuous removal of heat of absorption.

5.2 Effect of mass flow rate of air

Figure 6 shows the effect of mass flow rate of air on the performance of the dehumidifiers. It illustrates that the increase in the mass flow rate of air enhances the MRR for both the dehumidifiers. While it is more for the internally-cooled dehumidifier as discussed above, its rate of increase is lower (102%) than that of adiabatic dehumidifier (128%) for the increase in mass flow rate of air from 3.5 to 8.7 kg/h. An increase in the mass flow rate of air decreases its residence time in the dehumidifier which in turn decreases the drop in specific humidity of air $W_{a,in} - W_{a,out}$ while it passes through the dehumidifier. As a result, the average specific humidity of air in the dehumidifier increases. Consequently, the mass transfer potential of the dehumidifier also increases. Even though the air flow regime is laminar, the increase in its mass flow rate is expected to increase the mass transfer coefficient between the air and desiccant due to the flow disturbance caused by the membrane support [18]. It is observed from Figure 6(a) that the rate of increase of MRR in the internally cooled dehumidifier is lower at higher mass flow rates of air. This is due to increase in the cooling requirement of the desiccant. At high mass flow rate of air, the amount of water vapor transferred from air to the desiccant increases, which in turn increases the amount of exothermic heat released from the desiccant. However, the cooling water cannot remove all the heat and therefore, the average temperature of the desiccant increases. Consequently, it increases the average equivalent specific humidity of the desiccant, which decreases the mass transfer potential at high mass flow rate of air. As a result, the rate of increase in MRR gradually decreases with mass flow rate of air as shown in Figure 6(a). As discussed, an increase in the mass flow rate of air decreases the drop in specific humidity of air $W_{a,in} - W_{a,out}$ in the dehumidifier due to its less residence time.

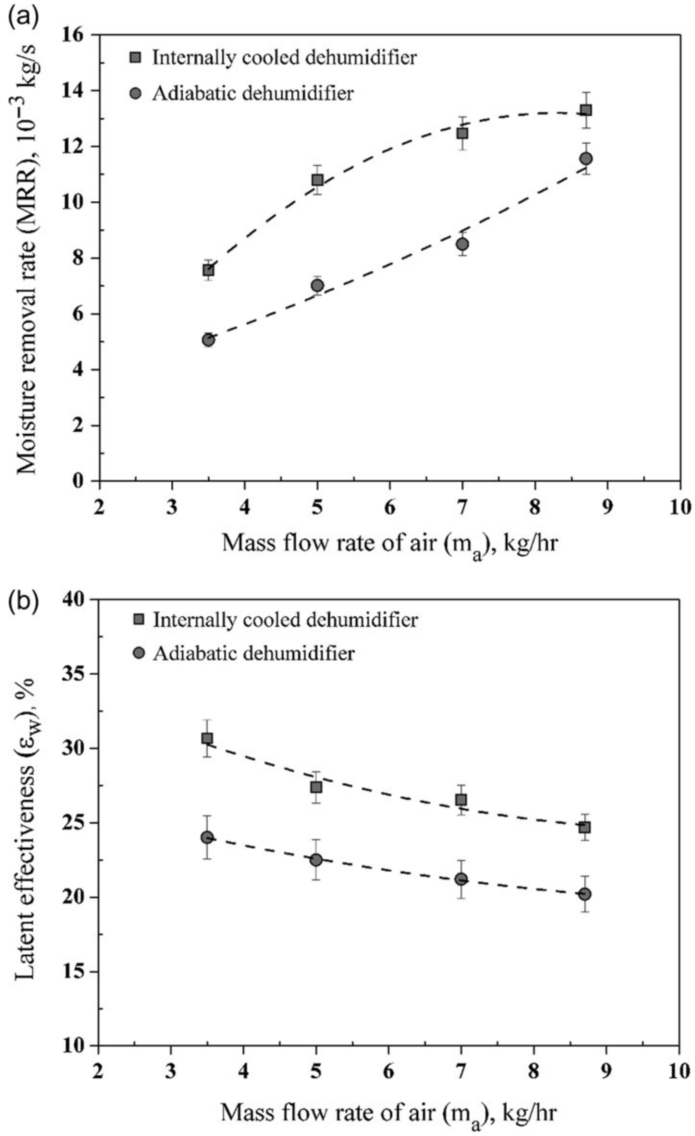

Figure 6. *Effect of mass flow rate of air on (a) moisture removal rate and (b) latent effectiveness.*

Therefore, the latent effectiveness decreases by 28% and 15%, respectively, for the internally cooled and adiabatic dehumidifiers as shown in Figure 6(b). As expected, the latent effectiveness of the former is higher due to the continuous removal of heat of absorption. In addition, it decreases faster for the internally cooled dehumidifier due to the increase in the cooling requirement of desiccant at higher mass flow rate of air.

5.3 Effect of inlet temperature of air

Figure 7 shows the effect of inlet temperature of air on the performance of the dehumidifiers. As the inlet temperature of air increases, the amount of heat transfer from the air to the desiccant also increases due to the increase in the temperature difference. This increases the temperature of the desiccant and consequently its equivalent specific humidity. Thus, the mass transfer potential of both the dehumidifiers decreases which in turn decreases their MRR and latent effectiveness. However, these performance parameters are independent of the inlet temperature of air in the present study as shown in Figure 7. This is due to the fact that the intermediate membrane which is made up of polyvinylidene difluoride has low thermal conductivity and therefore the heat transfer potential of the dehumidifiers is almost unaffected. As a result, the influence of inlet temperature of air on the desiccant temperature difference ($T_{s,out} - T_{s,in}$) is low. As illustrated in Figure 8, when the inlet temperature of air increases from 28°C to 40°C, the increase in the desiccant temperature difference is less than 1°C for both the cases. Therefore, the increase in inlet temperature of air does not significantly increase the equivalent specific humidity of the desiccant. Consequently, the mass transfer potential of the dehumidifiers remains almost unaffected. As a result, MRR and latent effectiveness of both the membrane dehumidifiers become independent of the inlet temperature of the air as shown in Figure 7. It can be concluded that such membrane dehumidifiers are suitable for the regions where the ambient temperature fluctuates over a wide range. It is also observed from Figure 7 that both MRR and latent effectiveness of the internally cooled dehumidifier are higher than those of the adiabatic dehumidifier. This is due to the continuous removal of heat of absorption in the former.

The liquid desiccant system requires a control system to ensure desirable temperature and specific humidity of air from the dehumidifier irrespective of the variation in ambient temperature and specific humidity. The performance of either dehumidifier is found to remain unchanged with variation in the inlet temperature of air as shown in Figure 7. As a result, the liquid desiccant system requires a control system only for variation in the specific humidity of ambient air. This, in turn, increases its reliability and reduces its size and cost.

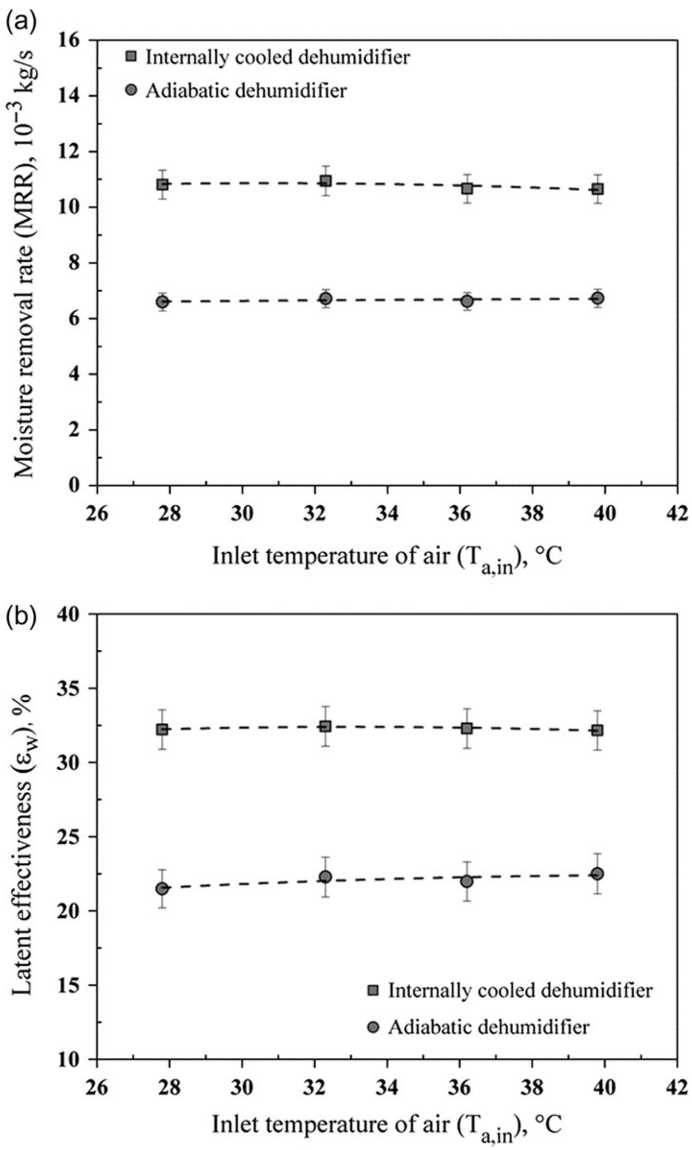

Figure 7. *Effect of inlet temperature of air on (a) moisture removal rate and (b) latent effectiveness.*

5.4 Performance comparison at equal heat transfer area

Cooling of the desiccant is essential to make it absorb water vapor from air. Therefore, it is continuously cooled during the mass transfer process in the case of internally cooled dehumidifier whereas, in the case of adiabatic dehumidifier, it is

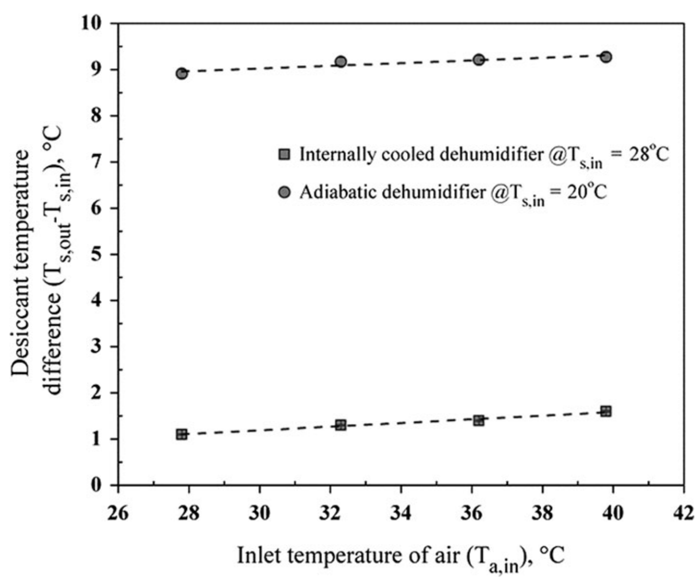

Figure 8. *Effect of inlet temperature of air on the temperature difference of desiccant in the dehumidifiers.*

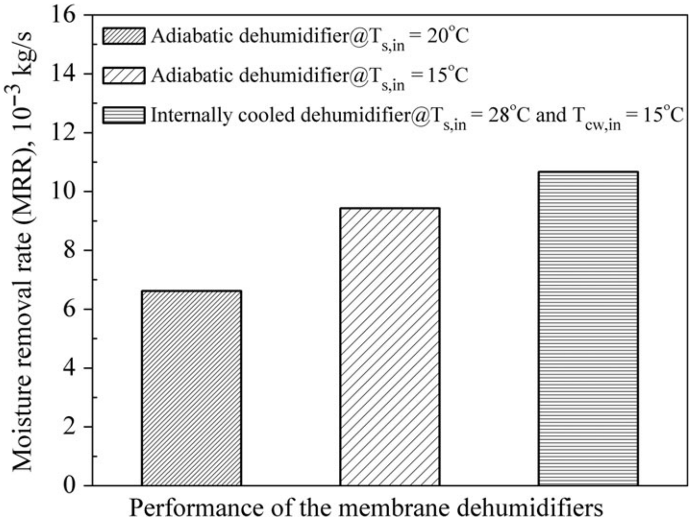

Figure 9. *Performance comparison of the dehumidifiers at both level playing ground and practical conditions.*

precooled in the external heat exchanger (Figure 1). Therefore, in the present study, the inlet temperatures of desiccant for the former and latter are selected as 28°C and 20°C, respectively. In addition, these are the recommended values for the high humid climatic conditions [19]. However, the performance comparison of the dehumidifiers with these desiccant inlet temperatures will not be on an equal basis. The level playing ground would be 15°C and 28°C, respectively, the latter with 15°C chilled water for internal cooling. With 15°C chilled water, it is theoretically possible to precool the desiccant to 15°C for the adiabatic dehumidifier. In the case of membrane-based internally cooling dehumidifier, the heat exchanging area between the desiccant and chilled water is equal to that of the membrane. This is larger than that of the external heat exchanger. If one provides the same area for the both, the effectiveness of the exchanger will be close to 1. With $(mc_p)_d > (mc_p)_{cw}$, the terminal temperature difference at the cold end will be zero and thereby the assumption for the level playing ground is justified.

Figure 9 compares the performance of internally cooled and adiabatic dehumidifiers, the latter with the inlet desiccant temperature of both 15°C (level playing ground) and 20°C (practical). Even with the inlet desiccant temperature of 15°C, the performance of the adiabatic dehumidifier falls short by 13% of that of the internally cooled one. The performance of the adiabatic dehumidifier for practical cases is still poorer. Thus, the provision for internal cooling arrangement is desirable for the membrane dehumidifier to improve its mass transfer performance.

6 CONCLUSIONS

An experimental study is carried out to compare the performance of membrane-based adiabatic and internally cooled dehumidifiers for the hot and humid climatic conditions prevailing in Chennai, India. The operating parameters considered are specific humidity, mass flow rate and temperature of air. The performances of the dehumidifiers are presented in terms of MRR and latent effectiveness. It is found that while the performance trends with the operating parameters are similar, the performance of the internally cooled dehumidifier is better than that of the adiabatic dehumidifier at all the operating conditions. Both inlet specific humidity and mass flow rate of air are found to increase the MRR. For the fixed mass flow rate of air, the latent effectiveness of the dehumidifiers is found to be independent of change in the ambient conditions, i.e. both temperature and specific humidity. The observations pertaining to the effect of inlet temperature of air confirm that the membrane dehumidifiers are suitable for regions where the ambient temperature fluctuates over a wide range.

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NOMENCLATURE

c_p	Specific heat capacity	(kJ/kg.K)
m	Mass flow rate	(kg/h)
T	Temperature	(°C)
W	Specific humidity	(kg/kg_{da})
Greek symbol		
ε	Latent effectiveness	
Subscripts		
a	Air	
a,in	Air inlet	
a,out	Air outlet	
cw	Cooling water	
cw,in	Cooling water inlet	
s	Desiccant	
s,in	Desiccant inlet	
s,out	Desiccant outlet	
W	Latent	
Abbreviations		
AC	Air conditioning	
MRR	Moisture removal rate	

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