

Experimental performance of a novel Liquid Desiccant Dehumidification System

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ABSTRACT: This paper presents results of experiments conducted to investigate the performance of an energy efficient, liquid desiccant dehumidification, cooling system. The system was designed to deliver conditioned air supply to buildings in highly humid climate conditions. The system could also be used to provide precondition air for commercial and industrial building, and so will help to save energy and cost by reducing compressor and/or chiller capacities in the ordinary cooling units. The system has an added value of improved indoor air quality and comfort by removing excessive humidity when used under humid climates, thus reducing the rate of mould growth and mildew that create “sick building syndrome”. The system evaluated in the study incorporates a desiccant dehumidifier, heat exchangers and an indirect evaporative cooling core. The desiccant is regenerated through heat energy produced using electrical power, but it could also be generated using recovered heat from the building, if available at the required temperature. A 4.85kW cooling capacity system has been fabricated and tested. The results show that the system is able to remove a considerable amount of moisture from the air at a thermal efficiency of 68.5%. A temperature difference of 7°C and relative humidity difference of 27.6 % between the ambient and the supply air have been achieved during the test.

Key words: Energy efficient, liquid desiccant dehumidifier, evaporative cooling.

1.0 INTRODUCTION

Air conditioning using desiccant is a process in which that air is dehumidified using an absorbent, cooled through a sensible heat exchange and finally cooled to the desired temperature using an evaporative process.

Desiccant cooling systems have been introduced as alternative to conventional vapour compression systems due to their advantages of utilizing low – temperature energy. They also provide an environmental – conscious operation [1]. Furthermore desiccant cooling when integrated with evaporative cooling offers opportunity of extended the climate range of the simple evaporative cooling.

Development of the related technologies have been advanced rapidly [2, 3] since 1950s. Desiccant cooling is achieved by dehumidifying the incoming air stream by passing the air through a desiccant material where the water vapour in the air is absorbed and then drying the air to the desired indoor temperature. To make the system work continuously, water vapour absorbed by the desiccant must be driven out of the desiccant material in a process known as regeneration. This is done by heating the desiccant to its temperature of regeneration which is dependent on the nature of the desiccant material used. A desiccant cooling system, therefore, comprises principally three main

components, namely the regeneration heat source, the dehumidifier (desiccant

material), and the cooling unit as shown in figure 1[4].

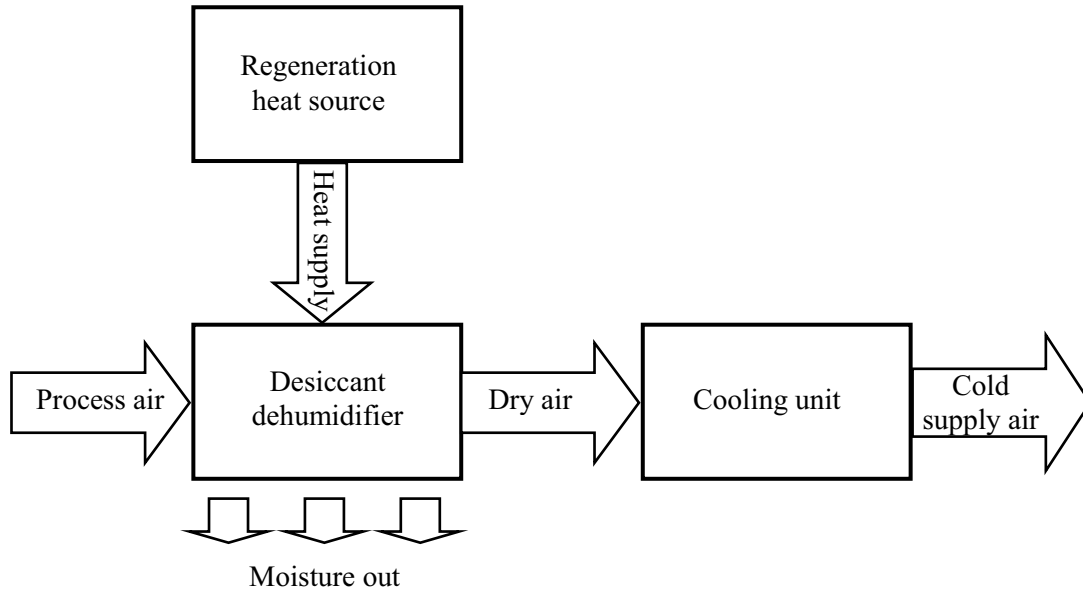


Figure 1: Components of desiccant cooling unit

The efficiency of desiccant system depends strongly on the Sensible Heat Ratio (SHR). The SHR is defined as the ratio of the sensible heat gain to the sensible and latent heat gain of the space being conditioned. A low value of this quantity means that the total cooling load is predominately the latent load, in which situation the desiccant cooling is characterised as effective and economical [4, 5]. The possible configurations and/or the composition of each of the three components can vary largely according to the nature of the desiccant material employed as follows:

The desiccant dehumidifier – if the desiccant employed in its solid state, the desiccant dehumidifier could take a form of a slowly rotating desiccant wheel or a periodically regenerated adsorbent bed. When a liquid desiccant is employed, the dehumidifier (absorber) is the vessel in which the liquid desiccant is brought into contact with the process air stream.

Possible configurations of this could include finned-tube surface, coil-type absorber, spray tower or a packed tower. The dehumidifier and the regenerator are generally referred to as contactors. The packing mode of packed towers could take a regular (structured) or random (irregular) structure [6].

The cooling unit – this could take a form of an evaporator of a traditional air conditioner, an evaporative cooler or a cold coil. The role of the cooling unit is handling of the sensible load while the desiccant removes the latent load. When a desiccant wheel system is considered, a heat exchanger is normally used in order to pre-cool the dry and warm air stream before its further cooled in the evaporative section. The heat exchanger together with the evaporator cooler or the cold coil constitutes the cooling unit in this case [7].

The regeneration heat source - This supplies the thermal energy necessary for driving out the moisture that the desiccant

had taken up during the sorption phase. The major advantage of desiccant cooling is its potential energy saving and the reduced rate of fossil fuels consumption. The electrical energy requirement could be very low compared with the conventional refrigeration systems. Because of the low thermal energy source requirement, a variety of potential energy sources can be utilised including solar energy, waste heat and natural gas burners. The system also has the possibility of energy recovery within the system [8]. In the case of a liquid desiccant cooling, the heat of regeneration is furnished to the desiccant solution inside the structure of a regenerator where a scavenger air stream is concurrently blown to carry away the moisture desorbed under the heating.

The liquid desiccant absorbs moisture from the air depending on vapour pressure difference between the air and the solution. The equilibrium vapour pressure of the solution depends on the temperature and concentration of the solution. The weak solution of the absorption process needs to be regenerated before reuse.

Advantages of the current design are that the system is compact, due to the integrated nature of the desiccant pads and indirect evaporative-cooling pads. The system is relatively lightweight due to the novel cellulose fibre and the plastic materials. The cost of the system is also low due to the novel material used and the maintenance requirement is also low due to the readily replaceable low-cost absorber core.

The absorber does not allow liquid desiccant to escape (i.e., zero-carryover absorber) will bring liquid-desiccant technologies in line with market expectations.

The system could be used in buildings where air conditioning is required and driven by waste heat, solar power, natural gas or hybrid sources waste heat/electricity, thus lowering the peak electric demand. Using the Dehumid system will serves a

number of societal policy objectives such as reducing the residential electricity demand in humid region, the environment will obviously benefit as liquid desiccant dehumidifier saves energy, thus reducing pollution.

The system Operate without the use of the ozone –depletion chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) and employing only environmentally friendly refrigerant water avoiding the use of green house effect.

Desiccant dehumidification cooling systems can substantially lower humidity levels and hence reduce the rate of growth of mould and mildew that create “thick building” by circulating spores through air conditioning systems with high humidity levels so hospitals, nursing homes, hotels, etc. can be safe and a healthy workplace and living environment for residents. Desiccant dehumidification systems are particularly cost effective for application where latent loads are large relative to sensible loads or supply dew points must be very low (supermarket, pools), High humidity causes significant property damage (hotels, warehouses and other storage areas) and where high cooling demand is difficult to meet (older buildings require additional cooling, buildings with high occupancy, but intermittent usage, e.g., church and arenas.

2.0 DESCRIPTION OF THE SYSTEM

The system is fabricated using desiccant pads/ Indirect Evaporative Cooling (DP/IND), Micro Heat & Mass Cycle (MHM3C), supply and exhaust air fans, water and desiccant basin and two pumps. The basic principle is shown in Figure 2; the Fresh Air (FA) at point 1 is dehumidified and cooled by desiccant in the MHM3C unit at point 2. It is then passed into the DP/IND to get further dehumidified to Supply Air (SA) at point 3. The Return Air (RA) at point 4 passes

Through the MHM3C device to the desiccant, regenerated through point 5, and then passes the DP/IND to be humidified. It absorbs heat from the dehumidification process and became Exhaust Air (EA) at point 6. The desiccant basin and the water basin are located under the DP/IND and the

desiccant is cycled in one channel of the DP/IND, and the water is cycled in another separate channel of the DP/IND. The desiccant basin exchanges desiccant with the regenerator and the water basin need to be top up.

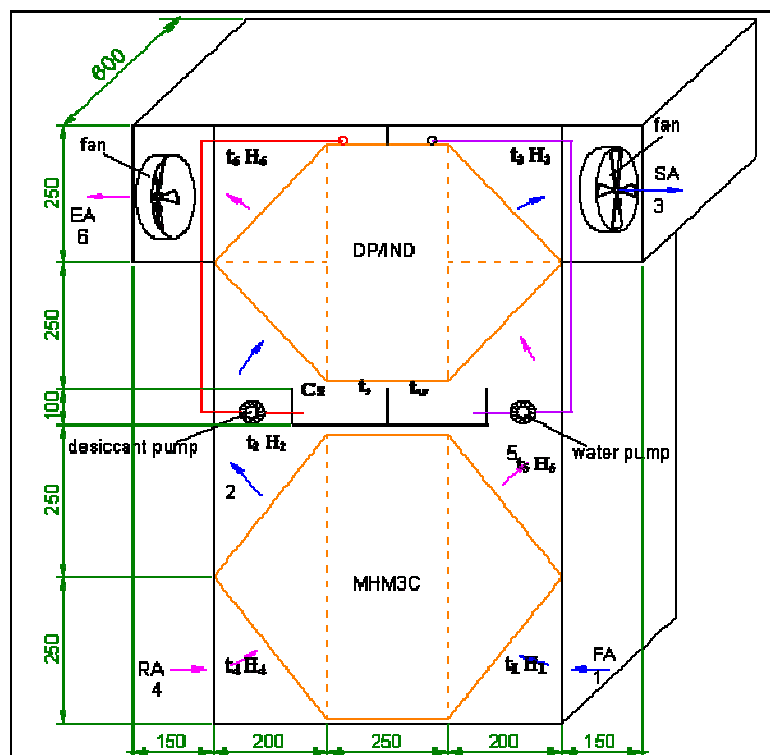


Figure 2: system operation descriptions

As shown in Figure 3, the ambient air at point 1 passes through the heat exchanger and extract heat until reach point 2, it then passes the desiccant pads (DP) while it is humidified. At the same time it passes through the desiccant regeneration to reach point 3 and then passes through the heat exchanger to release its heat and exhaust at point 4.

The regenerator is highly efficient because of the counter - flow heat and mass transfer of air and desiccant. The desiccant pad has a unique specification because of the combined feature of the plastic and special paper. The paper has a good wicking and high temperature features, the material also has good structure strength and temperature endurance.

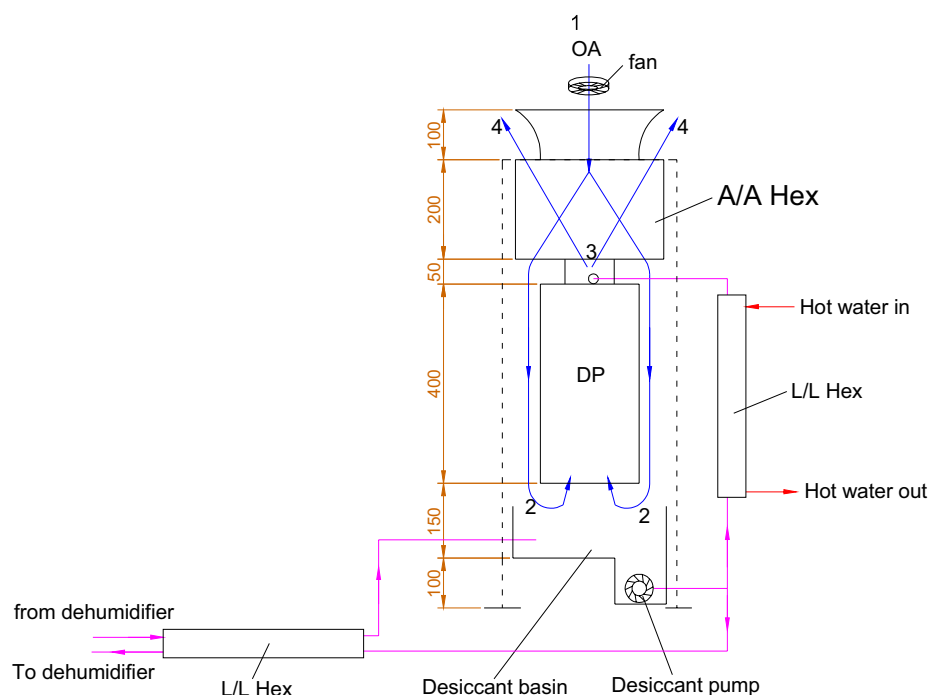


Figure 3: The regenerator cycle

Figure 4 illustrate the whole system liquid flow cycle and shows the transfer of

the desiccant and water between the dehumid parts and the regenerator.

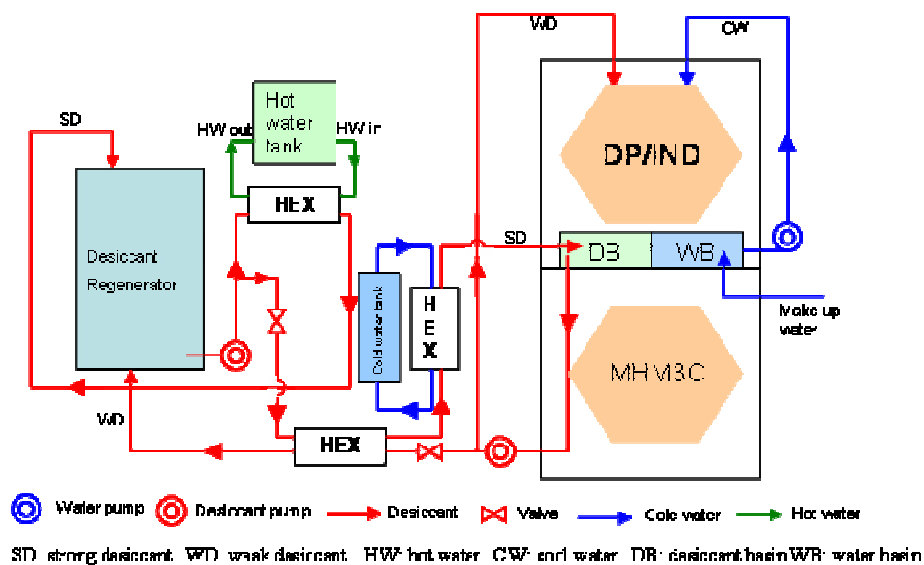


Figure 4: system Liquid flow diagram.

3.0 EXPERIMENTAL SETUPS AND TESTING

Lithium chloride (LiCl) is used in this system as it produces better performance compared to Lithium Bromide (LiBr) [9].

Lithium chloride solution is excellent liquid desiccant because it has essentially zero vapour pressure during the test therefore it can be regenerated at high temperatures with no loss of lithium chloride and cannot evaporate into the supply air stream.

However because LiCl is only suitable for applications where no LiCl droplets carryover (i.e., zero carryover), and because of its corrosive nature a non-metal material is used in the absorber unit. The absorber used is cellulose fibre arranged in a packed bed. The cooling of the desiccant solution was also integrated into the absorber surface, this help to a void LiCl droplet carryover.

Among the variables that have a major impact on the operation performance and effectiveness of a desiccant dehumidification system, and which have been evaluated in this test are:

- 1- Process air moisture temperature.
- 2- Reactivation air temperature.
- 3- Velocity and moisture load of air passing through the desiccant.
- 4- Amount of desiccant presented to the reactivation and process air streams.
- 5- Desiccant adsorption properties.

The system is controlled manually as well as automatically, to allow any control problems in the logic sequence to be overridden and the system to work using specific ratings of components (i.e. pumps and fans in order to operate at full capacity).

The level of LiCl in the basins of the dehumidifier and the regenerator was adjusted by means of valves.

Figure 5 shows the testing of the dehumid and the regenerator, humidity and temperature sensor used for the purpose of measurements during the test. Flow meters were used to adjust the desiccant flow, as this is an open circuit, flow system from the dehumidifier must always be equal to the flow to the dehumidifier to avoid desiccant over flow at the basins.

Desiccant meter flow rates were set at 0.55 l/m during the test for both the dehumidifier and the regenerator units.

A 12 kW heater was used in the water tank to maintain the temperature required to the desiccant regenerator. Relative humidity and temperature has been measured using humidity sensors and

thermocouples at different points of the regenerator. The moisture content at the fresh air inlet during the test was controlled by continuing boiling water at the inlet of the air.



Figure 5: aphoto showing the experimental rig and measuring transducers.

The equations used to perform the calculation are as follow:

$$Q = V \times S \quad -1$$

Where Q is flow rate (m^3/h), V is the velocity (m/h) and S is the area of the duct (m^2).

$$\Delta D = \rho Q (D_x - D_s) \quad -2$$

Where ΔD is the dehumidification (kg), ρ is the density ($1.2 \text{ kg}/\text{m}^3$), Q is air flow (m^3/h), D_x is the fresh air moisture content (kg/kg) and D_s is the supply air moisture content (kg/kg).

$$Z = \rho Q (H_x - H_s) \times 3600 \quad -3$$

Where Z is the cooling load (KW), ρ is the density ($1.2 \text{ kg}/\text{m}^3$), Q is the air flow (m^3/h), H_x is the fresh air enthalpy (kJ/kg) and H_s is the supply air enthalpy (kJ/kg).

$$L = S q_w (t_{in} - t_{out}) \quad -4$$

Where L is the is the heat input (kW), S is the specific heat of water of average T of t_{in} and t_{out} ($^\circ\text{C}$), q_w is the water flow rate (kg/s), t_{in} is inlet temperature of heat exchange ($^\circ\text{C}$) and t_{out} is the outlet temperature of the heat exchange ($^\circ\text{C}$).

The air flow rates of the fresh air and return air were measured using an airflow meter.

A number of measurements have been taken at the inlet of the fresh air where the

average velocity was 8.516 m/s. This gives air flow rate of 516 m³/minute.

Cross section:

$$S = 3.14/4 \times 0.15 \times 0.15 = 0.0176 \text{ m}^2 \text{ (}\phi 150 \text{ circle)}$$

The heat input to the system regenerator was calculated where the inlet temperature is measured at the point “hot water in” and the outlet temperature is measured at the point “hot water out” indicated in Figure 3. The water temperature results are presented in table 2.

4.0 RESULTS OF THE TESTS & DISCUSSIONS

The aims of the experimental to determined the optimum flow rates for the interacting fluids i.e., air, water and lithium chloride. The test also discussed the short- and long-term performance of the combined absorber-cooler pads and examined the potential of zero-carryover LiCl.

Desiccant and water flow were measured during the test, they were 1 litre every

39.95 second and 1 litre every 41 second respectively.

Dehumidification measurement result and cooling load of the system has been calculated using the measurement of the fresh, return and supply air and is presented in table 1.

$$\begin{aligned} \Delta D &= 1.2Q (D_x - D_s) / 1000 \text{ (kg)} = \\ &1.2 \times 516 \times (21.6 - 12.4) / 1000 = 5.7 \text{ kg} \\ Z &= 1/3 Q_x (H_x - H_s) / 1000 \text{ (kW)} = \\ &1/3 \times 516 \times (91.6 - 63.4) / 1000 = 4.85 \text{ kW} \end{aligned}$$

Table 1 shows the average temperature obtained for the fresh air temperature (T_{xg}), the fresh air wet bulb temperature (T_{xs}), the fresh air moisture content (D_x), the fresh air enthalpy (H_x), the return air temperature (T_{hg}), the return air wet bulb temperature (T_{hs}), the return air moisture content (D_h), the return air enthalpy (H_h), the supply air temperature (T_{sg}), the supply air wet bulb temperature (T_{ss}), the supply air moisture content (D_s) and the supply air enthalpy (H_s).

Table 1: Temperature variation of the fresh, return and supply air

Test	Fresh air				Return air				Supply air			
No of test	T_{xg}	T_{xs}	D_x g/kg	H_x kJ/kg	T_{hg}	T_{hs}	D_h g/kg	H_h kJ/kg	T_{sg}	T_{ss}	D_s g/kg	H_s kJ/kg
Average	35.8	28.3	21.6	91.6	24.3	20.3	13.2	58.2	31.5	21.6	12.4	63.4

Enthalpy efficiency η (%) of the system has been calculated as follow:

$$\begin{aligned} \eta &= (H_x - H_s) / (H_x - H_h) \% \\ &= (90.2 - 73.7) / (90.2 - 66.2) \% = 68.46\% \end{aligned}$$

$$\Delta T = \Sigma \Delta T / 7 = 5.14$$

$$Q_{\text{water}} = \Sigma Q_{\text{water}} / 7 = 0.4036 \text{ ton/h}$$

$$1 \text{ ton} = 1000 \text{ kg}$$

$$L = 1.16 * Q_{\text{water}} * \Delta T$$

$$= 1.16 * 0.4036 * 5.14 = 2.4 \text{ KW}$$

Table 2: water temperature results

Test	Inlet water temp.	Outlet water temp.	Water flow tonnes/h
Average	80.43	75.29	0.4036

Figure 6 and Figure 7 present the result of the temperature and relative humidity of the fresh and supply air. A temperature

difference of 7°C and RH 27.6 % different have been achieved.

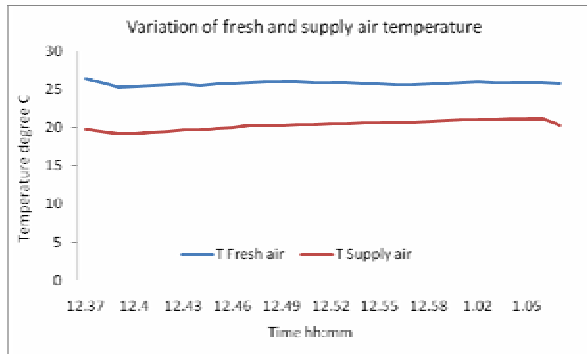


Figure 6: Variation of Fresh and supply air temperature

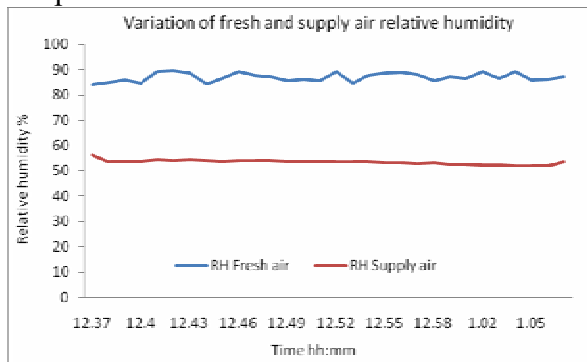


Figure 7: Variation of the RH of the fresh and supply air

5.0 CONCLUSIONS

The test has revealed that the system has many advantages, as the corrosion problem is eliminated and the cellulose fibre is unaffected by LiCl. Carryover of LiCl droplets which was one of the main concern is reduced, as liquid droplets adhere better to cellulose fibre surfaces compared to metal surfaces and further reduction of droplets carryover is achieved by U-trapping of the system pipelines.

Frequency and the time required for maintenance are both reduced, as the cellulose fibre absorber is disposable. In the case of metal absorbers, fouling of the metal surface reduces performance and necessitates considerable time and effort for cleaning.

During the test by spraying the desiccant, a substantial amount of the moisture was removed from the air and relative humidity was reduced by around

30%. This proves that the desiccant cycle in the system is working effectively. The return air from the room is dehumidified by the spraying desiccant.

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