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Hybrid liquid desiccant air-conditioning system with a direct expansion evaporative cooler

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Abstract: There is a need to control air temperature and humidity in humid regions, especially when fresh air is demanded. This study investigates the performance of a hybrid liquid desiccant (LD) air-conditioning system with a direct expansion (DX) evaporative cooler. Temperature, relative humidity, and power consumption were measured and reported using a wireless data-logging system at the air conditioning unit's key locations. The results showed that the hybrid unit reached a 34 % saving in the cooling load. In addition, the air hybrid liquid desiccant air-conditioning system with the direct expansion evaporative cooler saved about 32% in power consumption, compared to an uncooled desiccant air conditioning system that saved 23%.

Keywords: *Liquid desiccant dehumidification, Desiccant cooling, Hybrid desiccant cooling system, Air conditioning.*

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1. INTRODUCTION

Air dehumidification can be accomplished in two ways: (1) by chilling the air below its dew point and removing moisture by condensation, or (2) by sorption using a desiccant substance. Desiccants, whether solid or liquid, have a natural tendency in eliminating moisture [1]. Broadly, desiccant dehumidification cooling systems have shown excellent potential in reducing energy consumption over conventional cooling systems. The technology can overcome several outdoor and greenhouse cooling challenges in hot, humid climates [2].

The use of desiccant air conditioning systems as an alternative to traditional cooling systems such as vapour compression systems for temperature and humidity control has increased researchers' interest [3]. Many have studied and addressed various aspects of desiccant use, including the selection of desiccants [4]; utilisation of low-temperature heat for regeneration [5]; heat and mass transfer processes [6]; energy, environment and economic performance [7] control strategies for liquid desiccant air conditioning [8]; and dehumidification and corrosion resistance [9].

Other researchers have considered the use of desiccants in hybrid air conditioning systems. For instance, Li and Jeong [10] evaluated the use of a liquid desiccant in an evaporative cooling assisted 100% outdoor air system under various climatic conditions. They concluded that the proposed system yielded significant energy-saving benefits in hot and humid regions. They identified future work required to verify the actual operating energy consumption of the proposed system and estimated the system performance based on hourly weather conditions. Researchers [11] explored a novel desiccant vapor compression hybrid air conditioning system and established a mathematical model to analyse the effect of the concentration solution on the cooling capacity in their work on liquid desiccant air conditioning equipment and systems. Abdel-salam and Simonson [12] concluded that the desiccant droplet carryover problem is a significant concern. Energy recovery techniques such as air-to-air and liquid-to-liquid resulted in significant improvement in the performance of liquid desiccant air conditioning systems. Their suggested list of topics for future research included investigations to address crystallisation and its influence on determining the effectiveness of regeneration, performance of different types of dehumidifier/regenerators and comparison between direct and indirect solar regeneration. Further, Abdel-Salam and Simonson [12] proposed designing guidelines and operation strategies for liquid desiccant air conditioning systems.

For both outdoor cooling and greenhouse applications, which require 100% fresh air, air quality, temperature and humidity of ambient air are critical factors that determine the acceptability of the microclimate in the given environment in hot regions, it is preferable to lower the ambient air temperature (cooling) to enhance comfort levels; but, in hot and humid climates (such as several Gulf nations), removing moisture from the air (dehumidification) is almost extremely effective as cooling [13].

Desiccant cooling with dehumidification has been a known technology for some time, but it is now just a beginning to realise its potential [14]. Desiccant cooling units do not require ozone-depleting refrigerants, and they can use solar thermal energy or waste heat, thus lowering peak electrical demand [15]. Although the concept of solar liquid desiccant air conditioning systems was proposed as far back as 1955 [16], there has been a lack of progress to commercially take advantage of these low-energy systems.

Different research methods were developed, whether analytical, experimental, or simulation for various designs by using liquid desiccants as dehumidifiers combined by cooling devices operated by different mechanisms.

Ahmed et al. [17] studied an exergy analysis of a liquid-desiccant-based hybrid air-conditioning system and found an optimum desiccant mass-flow rate for minimum irreversibility. Yabase et al. [18] developed a system between a hybrid liquid desiccant and R718 centrifugal heat pump, in which they reduced CO_2 emissions by more than 40% compared to traditional systems. Mucke et al. [19] studied hybrid liquid desiccant air-conditioning systems compared to traditional air conditioning systems for a different climate. Their results showed a reduction in electric energy consumption of around 30-60% when using hybrid liquid desiccant air-conditioning systems. Wang et al. [20] developed a dynamic model to design a liquid desiccant hybrid air conditioning system. Chen et al. [21] proposed hybrid liquid desiccant dehumidification and evaporative cooling system. The energy-saving ratio increases significantly compared to conventional vapour compression.

Many components design also need to be explored. The two essential components of a desiccant cooling system are: (i) the regenerator – used to maintain the strength of the desiccant through the action of solar or other thermal energy sources, and (ii) the dehumidifier – used to bring the desiccant into contact with air. In addition, a system will typically contain heat exchangers (either separated from or integrated with the above), evaporators, pumps and fans for moving the liquid and air in the system.

2. System description

Fig. 1 shows a photograph of the hybrid vapor compression refrigeration and liquid desiccant dehumidification. The system includes a regenerator, a dehumidifier, a vapor compression refrigerator, a cooling tower and three heat exchangers (HX). Table 1 shows a self-explanatory list of the unit's components in a simplified format.

2.1. Dehumidification process

As shown in fig.2, the ambient air is precooled by the cooler until state B, then meets the strong desiccant sprayed above the desiccant pads. Then it flows through the eliminator to remove moisture C. Dehumidified outdoor air then flows across the evaporator to state D' and finally over the evaporative cooling pads to achieve space cooling to state D.

2.2. Regeneration process

To recover the diluted desiccant back to strong affiliation to moisture. As shown in fig.2, ambient air is heated to state F by the heater/condenser before the air is blown into the regenerator. It meets diluted desiccant sprayed from above the desiccant pads and then through the eliminator before being exhausted as humid and hot air G.

Fig .1. Photograph of the hybrid DX liquid desiccant air handling unit

(Fig.2) shows a schematic diagram of a hybrid vapor compression refrigeration, liquid desiccant dehumidification, and all air process, liquid desiccant, and water paths.

The equipments used for the various components of the desiccant system (dehumidifier, regenerator, and evaporative cooler) are essentially air contacting equipment for liquid-air interactions, designed to enhance heat and mass transfer, for handling low liquid flow and large process air flow rates; with minimal air pressure drop; while providing the desired large contact surface area.

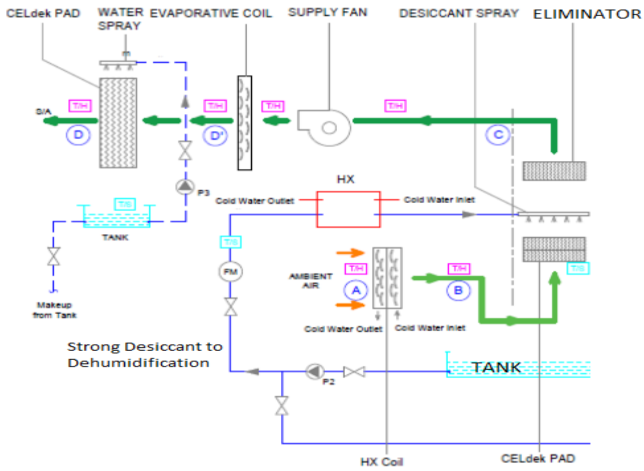

Fig.2. Schematic diagram of the hybrid DX liquid desiccant air handling unit

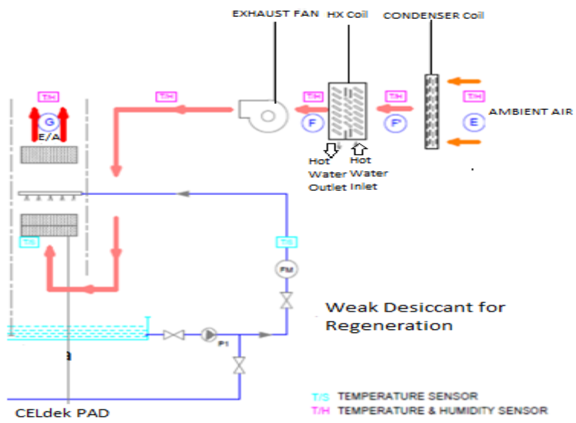

Fig.3. Schematic diagram of the hybrid DX regeneration part

Table 1. Schedule of main parameters of experimental test rig.

Supply / Exhaust air fan	**2400 CFM**
Condenser Coil	56*41*6 cm; 8mm*4 Aluminium fins
Evaporator Coil	40*37*5 cm; 8mm*2 Aluminium fins
Desiccant Pump (Regenerator, Dehumidifier)	16 m^3/h
Compressor Capacity	2.2 Ton

3. Experimental methodology

The experiment is conducted with a fixed volumetric flow rate of 650 CFM for supply and 1900 CFM for exhaust airflows. The desiccant shower is 3.76 kg/s. The setpoint temperature and relative humidity of supply air were set at 25° C and 50%, respectively. Values of temperature, relative humidity and desiccant flow rate and airflow rate were measured by devices mentioned in table 2.

Table 2. Specifications of measuring devices.

Sensors	Type	Accuracy	Range
Velocity of air	Anemometer	± (2.0%+50??)	0.8to 30 m/s
Air temperature and humidity sensor	Aranet T/RH	±0.4°C ±4%RH	-40°C to 60°C 0 % to 100 %
Desiccant solution temperature sensor	Aranet T-probe	±0.5°C	-55 to 105°C
Solution and water flow rate	Flowmeter	±0.5%	1 to 10 L/min
Specific gravity	Hydrometer	±0.002	1.400 to 1.600
Energy meter	Schnider	±0.5%	80 to 480 V 50 mA to 6 A

4. Results and Discussion:

The influence of the liquid desiccant is investigated in order to assess the new air conditioning unit's performance. In the following sections, the results of the experimental analysis are presented and discussed.

4.1. Effect of liquid desiccant solution

The total cooling load in the unit is provided by the DX cooling coil. However, the machine's cooling capacity is reduced due to off-setting losses caused by heat accumulation across the supply air fan. Table 3 illustrates the total cooling loads estimated using the Online Interactive Psychrometric Chart for the three modes of operation under the same environmental conditions. In Table 3, the comparison is based on a small sample of selected representative ambient circumstances. Table 3 also shows the actual temperatures and relative humidity measured during the tests used to approximate ambient conditions.

When using the liquid desiccant cycle, the unit's cooling performance in terms of total cooling load improves for the given ambient conditions. For instance, when using only DX, the cooling load on the unit was 16.11 kW compared to 12.9 kW when using LD in the system. This behaviour is expected, as shown in figure 3, the DX starts cooling from (33.5 °C /23.5 g/kg d.a) without using LD, but in the second and third mode the cooling starts at (37 °C /19.7 g/kg d.a), (33 °C /17.3 g/kg d.a) respectively.

Table 3. Total cooling loads at different operations modes

Mode of Operation	Inlet air		After desiccator		T_D(°C)		Cooling Load on DX Coil (kW)	Latent heat (kW)	Power consumption (kW)	Saving in cooling load %
	T_{in} (°C)	ω_{in} (g/kg)	T (°C)	ω (g/kg)	min.	max.				
DX	33.5	23.5	-	-	-	-	16.11	12.71	4.7	0
DX+ Uncooled desiccant	35	23.4	37	19.7	36.9	41	12.9	8.6	3.6	20
DX+ Cooled desiccant	35	23.4	33	17.3	32	35	10.6	7.4	3.2	34

4.2. Effect of precooling for liquid desiccant

Table 3 shows the unit's experimental measured power consumption when operating with only the DX cycle, as well as the power required for the combined uncooled and cooled liquid desiccant at a high level of humidity. Using cooled desiccant achieved 34% savings in cooling load compared to 20 % when using an uncooled desiccant.

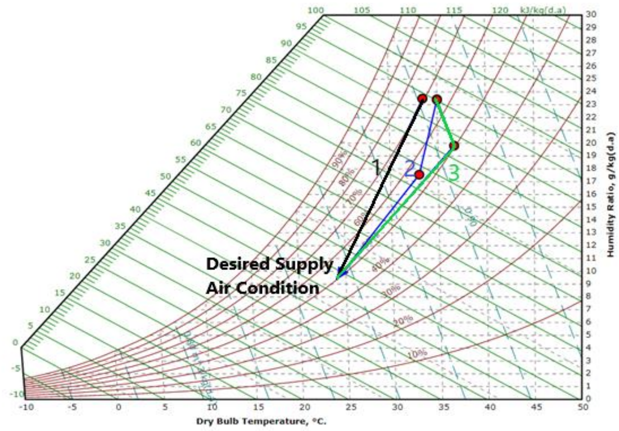

Fig. 3. Experimental results of air for three different modes 1. DX only. 2. DX+ cooled desiccant. 3. DX+ Uncooled desiccant

Conclusions:

This study investigated the effect of using cooled liquid desiccant on the performance of the vapor compression cycle in an open space.

Temperature, relative humidity, and power consumption were measured and reported using a wireless data-gathering device at the air conditioning unit's key locations. The results showed that the hybrid unit was able to achieve a 34 % saving in the cooling load.

In addition, it was found that:

- Using LD could increase the percentage of savings in cooling by 19%; however, sensible heat was found to increase.
- When using cooled desiccant in the experimental rig, the sensible and latent heat were reduced and a 34 % saving in cooling load was achieved.
- Also, it was shown that the air Hybrid liquid desiccant air-conditioning system with DX/evaporative cooler saved 32% in power consumption, compared to that when using an uncooled desiccant which resulted in a 23% saving.

Conflict of interests

The authors declare that there is no conflict of interests.

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