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Integrating Finned Tube Heat Exchanger and Liquid Desiccant Cooling

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Abstract— Lower electrical power consumption and greenhouse gas emission would help to make the technology of air conditioning more sustainable. In present work, a conventional finned tube cooling water coil for air conditioning application was integrated with a liquid desiccant distribution and collection system to work as an internally cooled liquid Desiccant-Air contacting device. More than two-fold rise in latent cooling could be achieved as compared to only chilled water at 16.5^{o}C temperature. This shows that by use of liquid desiccant, the total cooling provided by a cooling coil can be increased and latent cooling can be significantly enhanced at higher cooling water temperatures.

Index Terms— Air Conditioning, Dehumidification, Finned Tube Heat Exchanger, Liquid Desiccant, Chilled Water, Internally Cooled Contacting Device, Liquid Desiccant Distribution System.

1 INTRODUCTION

Over the last two decades, the world primary energy consumption has increased by 49% and carbon dioxide production has increased by 43% [1]. This high energy consumption worldwide is attributable to continuous growth in population, economic growth in emerging regions craving for better lifestyle [2]. Rapid rise of world energy consumption has created serious concerns about depletion of energy resources and the environmental impact like global climate change. This imbalance between resources and utilizations is not sustainable and there is a need for finding alternate energy savings concepts.

At present, the most broadly utilized air conditioning and cooling system is the vapour compression refrigeration (VCR) system, which is driven by electric power. The ever expanding need for air conditioning in a growing country like India puts stress on electric grid. Alternative technologies for air conditioning are being researched with the end goal to make the technology more environment-friendly.

Ability to use low grade thermal energy, high density energy storage near ambient conditions, possibility of multi-staging, air washing capability and flexibility in laying the components are some of the favourable features of the liquid desiccant based air- conditioning (LDAC) system. The liquid desiccant system can dehumidify the humid air in an absorber by the direct contact between the humid air and concentrated. solution [3]. The exchange of water vapour between air and desiccant depends on the vapour pressure in the surrounding air and on the desiccant surface respectively. Lower temperature of LD is desirable in absorber for higher moisture transfer potential. The moisture absorbed by LD in absorber needs to be rejected to ambient air in regenerator, which works at higher temperature.

2 EXPERIMENTAL SET-UP AND INSTRUMENTATION

The objective of the current work is to integrate a liquid desiccant air conditioning (LDAC) system with a chilled water cooling coil which gets chilled water from a VCR based water chilling plant. Such a combination can be used to reduce enthalpy of outdoor air taken in a central AC system (as a dedicated outdoor air system, DOAS). The LDAC system consists of LD storage, pumping, distribution and collection systems. A complete LDAC system would also need a regenerator, where the moisture absorbed by LD in dehumidifier is rejected to ambient air by heating the LD. In current work, regenerator is absent and fresh LD is supplied to the device all the time from LD storage tank.

The current experimental set-up (Fig. 1) includes finned tube heat exchanger as LD-Air contacting device, LD distribution system, LD supply and collection tank, blower, peristaltic pump and tubing. Overall dimensions of the cooling coil (finned tube heat exchanger) are 410×410×75 mm deep and provides total surface area of around 22 m^2. Fin density is 16 FPI and wavy fins are used. Fin thickness is 0.2 mm while the tube outer diameter is 10 mm. There are four tube rows and chilled water flows through all of them in parallel. There are sixteen passes of water in each row. Tube arrangement is staggered type with longitudinal pitch and diagonal pitch equal to 20 mm.

The chilled water coil itself is used as internally cooled air-LD contacting device where the air is dehumidified as well as cooled sensibly. Such a concept was earlier implemented by Mehta and Badrakia and the need for more effective and uniform wetting of coil was expressed [18]. Current system utilized LD spraying system for better distribution of LD over the chilled water cooling coil (in place of a ¼″ SS tube with 1 mm

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diameter holes in previous work) with higher flow rate of LD. A non-contact type variable speed pump was used to pump LD to the spraying nozzle as the LD is quite corrosive to metals. A plate heat exchanger is also used to cool LD with the chilled water coming out of the coil.

Three side of the test enclosure are made from stainless steel (grade 304) sheet. An openable sliding acrylic sheet cover is provided on fourth side. Required foam insulation was provided to reduce heat ingress into the enclosure. The nozzle provides spray in single plane in triangular shape. The liquid desiccant used is aqueous solution of calcium chloride due to better economy and easy availability. As liquid desiccant is very corrosive, a non-contact variable speed pump was used to pump the liquid desiccant. A centrifugal blower was used in induced draft mode to move air. Measuring instruments details and specifications are given in Table 1.

3 EXPERIMENTATION

The experiments were done for air drawn from a well ventilated room, which nearly represented the outdoor air conditions. This air was induced over the cooling coil by a blower at a rate of 526 kg/h. The velocity of air over the cooling coil was quite low, around 0.76 m/s only due to lower capacity of the blower. First part of each experiment was done with fins of the cooling coil not wetted with LD. Only cool water was passed through the cooling coil. The inlet and outlet temperature and relative humidity of air were measured after achieving steady state. Immediately after this, the liquid desiccant spraying over the coil was started with cooling water supplied at same temperature. The inlet and outlet conditions of air were again measured after achieving steady state. The flow rate of liquid desiccant was 53.73 kg/h. This gives liquid to gas flow rate ratio (L/G) around 0.1, which is again quite low as compared to those reported in literature. A plate type of heat exchanger was used to cool LD before it was sprayed over the coil. This heat exchanger provided cooling rate of around 1.6 kW and dropped the temperature of LD by around 13.5ºC which was otherwise at 34ºC. Keeping the temperature of LD lower would help to keep its water vapour pressure low and provide higher potential for moisture transfer.

Comparison of performance of the coil used only with cooling water in first part and that with LD in contact with air, cooled by water in second part, was done. Thus, effect of presence of LD on the performance of the system was investigated. The air velocity was same in both experiments, while inlet air humidity ratio was also nearly constant at around 14 g_w/kgda. Various performance parameters like change in humidity ratio, humidity effectiveness, moisture removal rate, sensible cooling, latent cooling, total cooling rate were calculated (Table 2).

4 RESULTS AND DISCUSSIONS

Table 2 presents the observation cum results table for two sets of experiments, one set done at 12.5°C and the other at 16.5ºC chilled water temperature.

Table 1
Specifications of Measuring Instruments.

Property	Instrument	Range	Resolution
Water & LD Temperatures	ADI make RTD (PT-100) and scanner	-100 °C to 200 °C	0.1 °C
Air Velocity	Testo® make Anemometer	+0.1 to +15 m/s	0.01 m/s
Air Temperature	HTC Easy Log™ datalogger	-40 to +70 °C	0.1 °C
Air Relative Humidity	HTC® Easy LogTMdatalogger	0 to 100%	0.1% RH
Mass	Weighing machine (Scale-Tec™)	150 kg / 10 kg	10 g / 1 g

Each set contains one experiment without LD followed by the experiment using LD. Properties like specific volume, humidity ratio and enthalpy are calculated using dry bulb temperature and relative humidity of air as prescribed in reference [19].

Following calculations are done to find the cooling rates and effectiveness of the contacting device:

Calculation of volume flow rate:

$$\dot{V}_a = A_C C_a \quad (1)$$

Where A_C and C_a are cross-sectional area of flow and velocity of air respectively.

Calculation of mass flow rate:

$$\dot{m}_{da} = {}^{\dot{V}_a}/_{v_{da}} \quad (2)$$

Where, v_{da} is the specific volume of dry air.

Calculation of total cooling rate:

$$\dot{Q}_t = \dot{m}_{da} \times \Delta h_a \quad (3)$$

Where, Δh_a is the change in enthalpy of air.

Calculation of latent cooling rate:

$$\dot{Q}_l = \dot{m}_{da} \times 2501 \times \Delta W \quad (4)$$

Where, ΔW is the change in humidity ratio of air.

Calculation of sensible cooling rate.

$$\dot{Q}_s = \dot{Q}_t - \dot{Q}_l \quad (5)$$

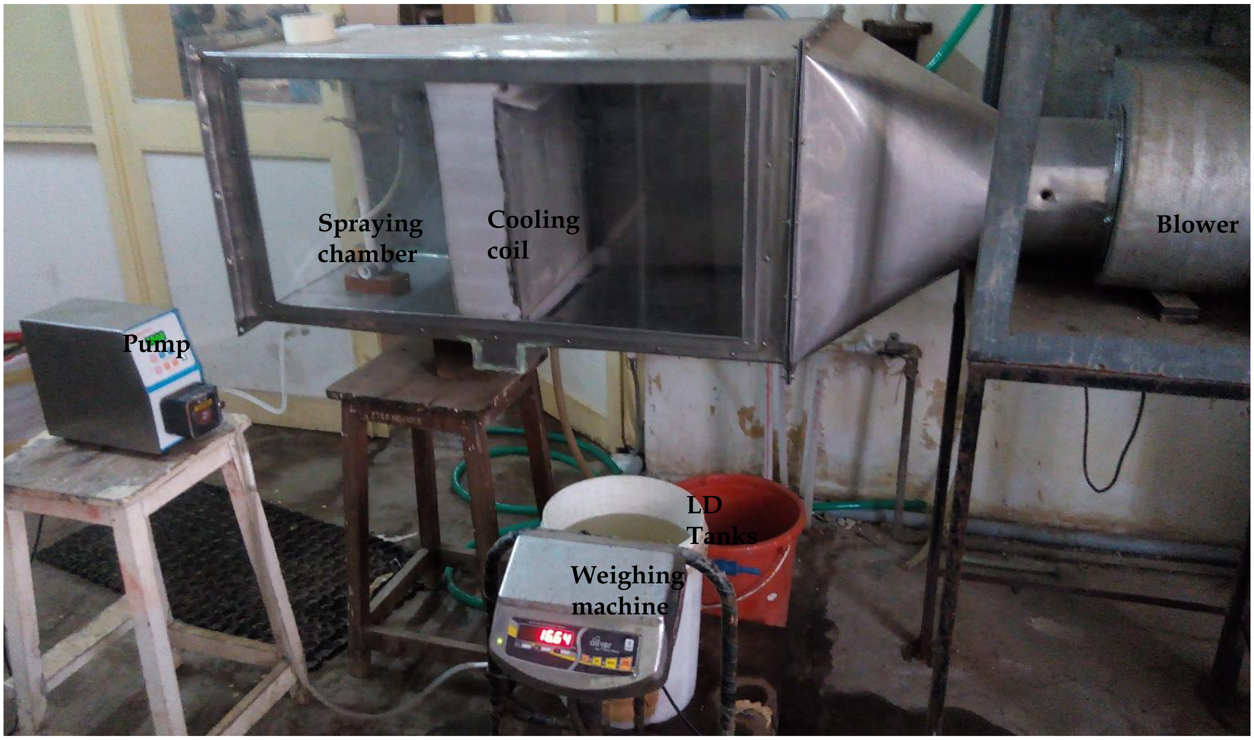

Figure 1 Experimental Set Up

Table 2 Observations cum Results

Parameters	Unit	Chilled water temperature 12.5°C		Chilled water temperature 16.5°C	
		LD + Water	Water only	LD + Water	Water only
Temperature drop of air ΔTa	°C	12.5	13.1	9.4	12.2
Contact factor	%	-	53.0	-	58.5
Inlet humidity ratio, Wi	g_w/kg_{da}	14.0	13.6	14.9	13.9
Outlet humidity ratio, Wo	g_w/kg_{da}	10.1	10.7	11.4	12.8
Change in humidity ratio, ΔWa	g_w/kg_{da}	3.8	3.0	3.5	1.0
Dehumidification effectiveness	%	38.9	-	37.2	-
Enthalpy change, Δhda	kJ/kg_{da}	22.7	21.0	18.6	15.2
Enthalpy effectiveness	%	44.3	62.3	42.8	56.8
Sensible cooling rate, Qs	kW	1.84	1.95	1.38	1.80
Latent cooling rate, Ql	kW	1.48	1.16	1.34	0.43
% rise in Ql	%	27.6	0	211.6	0
Total cooling rate, Qt	kW	3.32	3.11	2.72	2.23
% rise in Qt	%	6.8	0	22.0	0
Moisture removal rate, MRR	kg/h	2.024	1.579	1.839	0.548

The contact factor for cooling coil:

$$CF = \frac{t_i - t_o}{t_i - t_{cw}} \quad (6)$$

The humidity effectiveness is defined

$$\varepsilon_h = \frac{W_i - W_o}{W_i - W_{eq}} \quad (7)$$

The enthalpy effectiveness is defined as:

$$\varepsilon_e = \frac{h_i - h_o}{h_i - h_{eq}} \quad (8)$$

Where Weq and heq are the equivalent humidity ratio and enthalpy respectively. They are calculated using water vapour pressure exerted by LD at average chilled water temperature in the cooling coil.

The coil which provided total cooling rate of 3.11 kW at 12.5^{o}C average chilled water temperature, increased to 3.32 kW when the fins of the heat exchanger were wetted with LD. Thus, the total cooling provided by the coil increased by 6.8% in this case. This increase in total cooling rate was 22.0% at 16.5^{o}C chilled water temperature. The rise in latent cooling rate is more significant. The latent cooling increased by 27.6% and 211.6% respectively in above two cases.

It is seen that the contact factor of the coil is quite low and that needs improvement. The humidity and enthalpy effectiveness of the coil are in the range of 38 and 43%. Enthalpy effectiveness is higher when LD is not used. This shows that real dehumidification potential of LD could not be utilized. The reason could be incomplete wetting of surfaces with LD and thus less effective contact between air and LD.

5 Conclusion and Future Work

Following conclusions may be drawn from the experiments, observations and calculation results:

a. The total cooling capacity of a given finned tube heat exchanger can be significantly increased by making its outer surface wet by Liquid Desiccant.
b. At higher cooling water temperatures, moisture removal rate can be significantly increased by using LD. The cooling water can even come from cooling tower or ground water and still dehumidification can be achieved. If vapour absorption refrigeration is used, higher COP can be achieved by keeping chilled water temperature high.
c. The gain due to LD wetting decreases at lower chilled water temperature. So, if chilled water temperature is produced at low temperature, LD may be used only if high latent loads exist in a given application.
d. The LD distribution system needs to be even more effective to achieve better results.

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