International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 849

EXPERIMENTAL INVESTIGATIONS ON DESICCANT COATED FIN-TUBE HEAT EXCHANGERS RETROFITTED TO A CONVENTIONAL HVAC SYSTEM

M. Jagirdar[1], W.L. Ong [1], G.W. Ho[1], P.S. Lee[2*],

[1]Multi-Disciplinary Laboratory Blk E3, #03-01, 2 Engineering Drive 3, National University of Singapore, Singapore 117581

[2]Department of Mechanical Engineering, National University of Singapore, Singapore 117575

ABSTRACT

Experiments are conducted under typical humid ambient conditions of Singapore on an advanced air-conditioning system wherein desiccant coated fin-tube heat exchangers (DCFTHX) are retro-fitted within the ducting of a conventional HVAC system with a water-cooled condenser. The desiccant is regenerated using room-return air (specific humidity of 0.0109 kg/kg d.a.) and the low-grade heat (warm water at 35.5°C) from the condenser unit. During dehumidification, water from the cooling tower helps in maintaining low air temperature, thereby improving the adsorption performance of the DCFTHX. It is found that DCFTHX managed 39% of the cooling load thereby reducing the compressor load by the same percentage. The experiments prove the efficacy of such internally cooled/heated desiccant systems for practical applications.

Keywords: desiccant dehumidification; heat exchanger; desiccant coated heat exchanger; air conditioning; HVAC

1. INTRODUCTION

Maintaining indoor thermal-comfort of occupants using HVAC (heating, ventilation and air-conditioning) equipment is a multi-billion-dollar industry worldwide. Apart from maintaining comfortable indoor temperature, indoor humidity level is also regulated to ensure good health and comfort of occupants. In fact, for humid environments (such as that of Singapore), latent heat load (pertaining to the moisture removal) can be more than half of the total air-conditioning load for the fresh-air part. Thus, making moisture removal more efficient can lead to a very significant reduction in energy consumption.

NONMENCLATURE

Abbreviations	
DCFTHX	desiccant coated fin-tube heat exchanger
HVAC	heating, ventilation and air-conditioning
Symbols	
d_i	inner tube diameter (m)
d_o	outer tube diameter (m)
H_f	fin thickness (m)
L_x	length of the fin (along direction of air flow) (m)
L_y	width of the fin (m)
L_z	tube length (height of HX) (m)
m_d	coated desiccant mass (kg)
$m_{w,cool}$	mass flow-rate of cool water (kg/s)
$m_{w,hot}$	mass flow-rate of hot water (kg/s)
P_f	fin pitch (m)
T	Temperature (°C)
V_a	volumetric flow-rate of air (m^3/s)
X_l	longitudinal tube pitch (m)
X_t	transverse tube pitch (m)
Y	specific-humidity (kg/kg d.a.)
ρ_d	desiccant density (kg/m$_3$)
W	sorbate uptake (kg water/kg desiccant)
RH	relative humidity

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

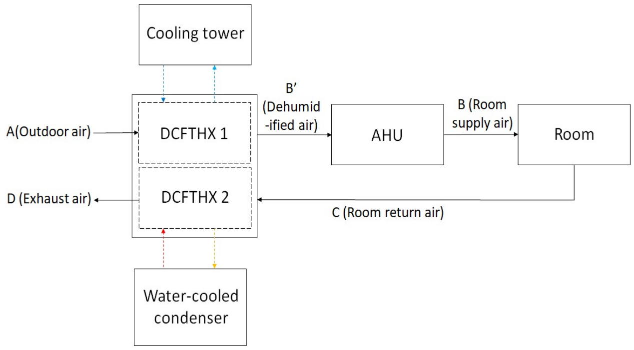

Fig 1 Schematic of the HVAC system with water-cooled condenser retrofitted by DCFTHX

The most commonly used vapor compression refrigeration systems over-cool the air to below the dew-point temperature (of supply air to air-conditioned space) to remove moisture. In contrast, desiccant systems can adsorb moisture efficiently even when air is not saturated (considerably above the dew point temperature). This makes desiccant based systems attractive since they can potentially save energy by (i) reducing latent heat load on other HVAC equipment (ii) improve the COP by eliminating the need for over-cooling air below the required supply air dew-point temperature. Therefore, desiccant wheels have traditionally been used. However, they require high temperature heat for regeneration (typically >80 °C), moreover, the adsorption process is adiabatic which makes adsorption less effective and more energy intensive. This is among the main challenges for its wide-spread commercial use. The present solution is a dehumidifier that works on (nearly) isothermal dehumidification process to dehumidify air which enables it to be regenerated at a much lower temperature.

To a limited extent, such dehumidifiers have been tested experimentally on a laboratory-scale as well as mathematical models have been developed to predict their performance (see [1–13]). There is however, a dearth of experiments that show their performance on a practical scale in an operational environment, especially when such units are retrofitted to existing vapor compression refrigeration system-based HVAC systems. The presented work discloses the performance of DCFTHX under ambient conditions of Singapore to cool an indoor space requiring an air-flow rate of 2100 m^3/hr.

2. EXPERIMENT METHODOLOGY AND RESULTS

2.1 DCFTHX

Figure 1 shows the schematic of a HVAC system with water-cooled condenser, retrofitted with desiccant coated fin-tube heat-exchangers (DCFTHX). The desiccant mixture consists of 83.3% silica with 16.7% Calcium chloride by weight. This desiccant mixture is mixed with an additional 10% (by weight) of hydroxyethyl cellulose as a binder for coating. The sorbate uptake was found to be a function of *RH* as $W = -61.0329RH^3 + 143.0182\,RH^2 - 77.1117RH + 22.6522$.

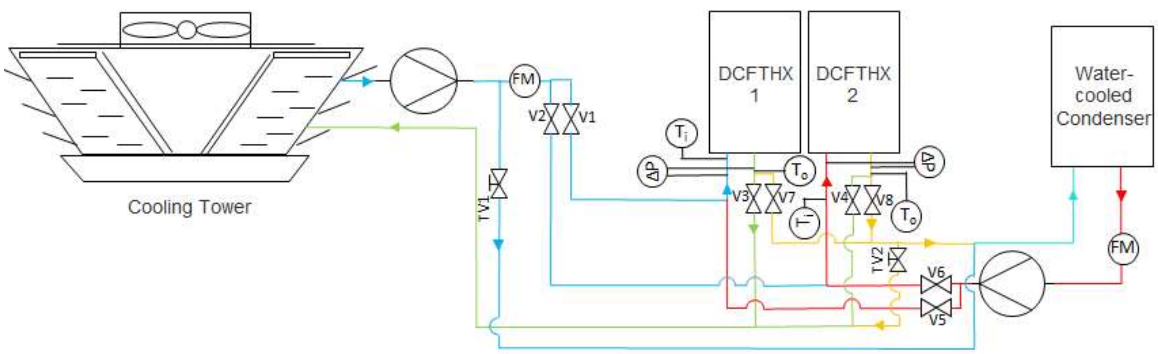

Fig 2 Schematic of the water-circuit

Outdoor air at state A passes through one of the DCFTHXs, gets partly dehumidified to state B', then as it passes through the cooling coil (AHU), air gets cooled and further dehumidified and is then sent to the room at state B. The room-return air, before being exhausted is utilized for regeneration of the second DCFTHX. The DCFTHX dehumidifying air is supplied with cool-water from the cooling tower while the DCFTHX being regenerated is supplied with warm water from the water-cooled condenser. The detailed diagram of the water-circuit is shown in figure 2. Water temperatures, flow-rates as well as pressure-drop are measured in water-loops of both the DCFTHX units. The 2-way valves V1 to V8 are used to periodically switch on/off cool/hot water supplies to the two DCFTHX units so that while one is dehumidifying supply air, the other gets regenerated. After a specific time-period, the two units switch their operation. The DCFTHXs may be installed in supply and exhaust air ducts as shown in Figure 3. The dampers D1 to D8 are used to switch the operations of the two units periodically. Working of the dampers is as follows: when dampers D1 and D4 are open and dampers D2 and D3 are closed, exhaust (regeneration) air would be diverted to DCFTHX1 and outside (supply) air would be diverted to DCFTHX2; while when dampers D2 and D3 are open and dampers D1 and D4 are closed, regeneration air would pass through DCFTHX2 and supply air would pass through DCFTHX1.

Difference between desiccant wheels and DCFTHX may be noted as follows: (i) DCFTHX facilitates simultaneous cooling/heating. This greatly improves dehumidification performance, since the reduction in adsorption caused due to rise in temperature of air, in case of desiccant-wheels, is not experienced in these units. (ii) DCFTHX is akin to a fixed desiccant-bed. Thus, no moving parts offers the advantage of lower maintenance/leakage issues.

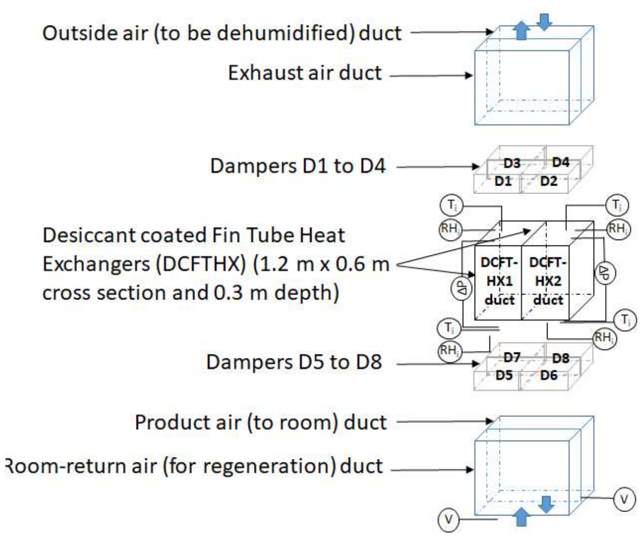

Fig 3 Schematic of the air-ducts

2.2 Experiment procedure

At the start of the experiment, the actuators (pumps and blower-fans) are turned-on along with water-flow control-valves as well as dampers (controlled by a programmable controller). Outlet air temperature and humidity are continuously monitored; after a periodically steady-state is reached, data from sensors is recorded every second through a Lab-view program. It may be noted that each of the processes (dehumidification and regeneration) lasted for two minutes each.

Fig 4 Photograph of the experimental setup

A photograph of the AHU and the upstream ducting housing the DCFTHX as well as the cool/hot water carrying tubes is as shown in Figure 4. Dimensions of the DCFTHX are as described in Table 1.

Table 1: Geometrical parameters of DCFTHX

Variable	Value	Variable	Value
X_l	22 mm	L_y	0.610 m
X_t	25.4 mm	L_z	1.2 m
d_i	8.5 mm	P_f	2.5 mm
d_o	9.5 mm	H_f	0.1 mm
L_x	0.308 m	m_d	11 kg

2.3 Results

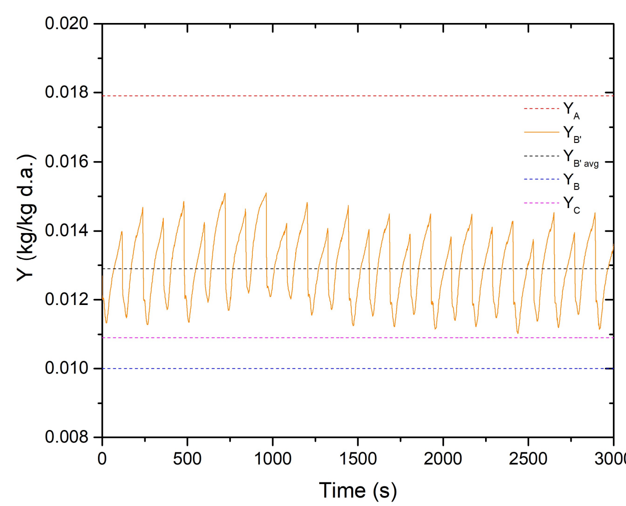

Fig 5 Specific humidity versus time. Note that T_A, $T_{B'}$, T_B, T_C respectively are 29.5, 28.05,14 and 24.3 °C while $T_{w,hot}$ and $T_{w,cool}$ are 35.5 and 27.9 °C respectively

Experiments were conducted over several days, however in the interest of brevity, a single result obtained under typical ambient conditions of Singapore is presented. Figure 5 shows the fluctuations in outlet specific humidity ($Y_{B'}$) with time as well as other specific-humidity values (at state points A,B and C in Figure 1) that are nearly constant. DCFTHX helps in reduction of humidity from Y_A = 0.0179 kg/kg d.a. to $Y_{B'avg}$ = 0.0129 kg/kg d.a. while the cooling coil further reduces it to Y_B = 0.010 kg/kg d.a.. Thus, a large proportion of latent heat load is managed by the DCFTHX units. Given the supply air flow-rate of 2100 cmh and state points A and B, the total cooling load is 24.51 kW out of which 9.57 kW (or 39% of the total cooling load) is managed by DCFTHX. In contrast, the extra hydraulic power required to blow/pump both the air-streams and water streams is respectively 67.4 W and 21.5 W respectively. Thus, cooling capacity generated is two orders of magnitude greater than the total electrical input required.

3. CONCLUSIONS

Desiccant coated fin-tube heat exchanger (DCFTHX) units were successfully retrofitted to existing HVAC system consisting of a water-cooled condenser. Only the water-pipes and the air-duct upstream of the AHU required modifications for installations. Under typical Singapore outdoor conditions of 29.5°C and 0.0179 kg/kg d.a. humidity, the DCFTHX could manage 39% of the total cooling load on the system while utilizing cooling water (from the cooling tower) at 27.9°C. Regeneration was carried out using ultra-low grade waste heat at 35.5°C (condenser-return-water temperature) and room-return (exhaust) air at specific humidity of 0.0109 kg/kg d.a.. The extra hydraulic-power (from pumps and blowers) required due to retrofitting of DCFTHX is negligible compared to the cooling capacity (9.57 kW) delivered.

ACKNOWLEDGEMENT

National Research Foundation (NRF) has supported this research, under Energy Innovation Research Programme (EIRP) R-263-000-B82-279, managed on behalf of Building and Construction Authority (BCA).

REFERENCE

[1] Tu YD, Wang RZ, Ge TS, Zheng X. Comfortable , high-efficiency heat pump with desiccant-coated , water-sorbing heat exchangers. Sci Rep 2017:1–10. doi:10.1038/srep40437.

[2] Oh SJ, Ng KC, Thu K, Kum Ja M, Islam MR, Chun W, et al. Studying the performance of a dehumidifier with adsorbent coated heat exchangers for tropical climate operations. Sci Technol Built Environ 2017;23:127-135.

[3] Ren CQ, Tu M, Wang HH. An analytical model for heat and mass transfer processes in internally cooled or heated liquid desiccant-air contact units. Int J Heat Mass Transf 2007;50:3545–55. doi:10.1016/j.ijheatmasstransfer.2006.12.034.

[4] Kumar A, Yadav A. Experimental investigation of solar driven desiccant air conditioning system based on silica gel coated heat exchanger. Int J Refrig 2016;69:51–63. doi:10.1016/j.ijrefrig.2016.05.008.

[5] Zhao Y, Dai YJ, Ge TS, Wang HH, Wang RZ. A high performance desiccant dehumidification unit using solid desiccant coated heat exchanger with heat recovery. Energy Build 2016;116:583–92. doi:10.1016/j.enbuild.2016.01.021.

[6] Hu LM, Ge TS, Jiang Y, Wang RZ. Performance study on composite desiccant material coated fin-tube heat exchangers. Int J Heat Mass Transf 2015;90:109–20. doi:http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.06.033.

[7] Worek WM, Chung-Ju M. Simulation of an integrated hybrid desiccant vapor-compression cooling system. Energy 1986;11:1005–21. doi:10.1016/0360-5442(86)90031-9.

[8] Li Z, Michiyuki S, Takeshi F. Experimental study on heat and mass transfer characteristics for a desiccant-coated fin-tube heat exchanger. Int J Heat Mass Transf 2015;89:641–51. doi:10.1016/j.ijheatmasstransfer.2015.05.095.

[9] Jagirdar M, Lee PS. Mathematical modeling and performance evaluation of a desiccant coated fin-tube heat exchanger. Appl Energy 2018;212:401–15. doi:10.1016/j.apenergy.2017.12.038.

[10] Zhou X, Goldsworthy M, Sproul A. Performance investigation of an internally cooled desiccant wheel. Appl Energy 2018;224:382–97. doi:10.1016/j.apenergy.2018.05.011.

[11] Erkek TU, Gungor A, Fugmann H, Morgenstern A. Performance Evaluation of a Desiccant Coated Heat Exchanger with Two Different Desiccant Materials. Appl Therm Eng 2018. doi:10.1016/j.applthermaleng.2018.06.012.

[12] Yonggao Y, Xiaosong Z, Geng W, Lei L. Experimental study on a new internally cooled/heated dehumidifier/regenerator of liquid desiccant systems. Int J Refrig 2008;31:857–66. doi:10.1016/j.ijrefrig.2007.10.004.

[13] Yin Y, Zhang X, Peng D, Li X. Model validation and case study on internally cooled/heated dehumidifier/regenerator of liquid desiccant systems. Int J Therm Sci 2009;48:1664–71. doi:10.1016/j.ijthermalsci.2008.12.017.

