An introduction of independent humidity control system using liquid desiccant air conditioner

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ABSTRACT

Liquid desiccant air conditioning (LDAC) system presented in this paper realizes independent humidity control, avoids energy loss in the condensing dehumidification process. It can be driven by low-grade heat source (90–60°C) with high efficiency. This paper gives a description of the independent humidity control (IHC) air conditioning system. Such a system is composed of LDAC as the dehumidifying method and chiller as the cooling method. The results of a comparison of the operating cost between the IHC air conditioning system and the conventional system shows that the IHC system has higher efficiency.

INDEX TERMS

Desiccant cooling; Dehumidification; Fresh air treatment; Lithium bromide

INTRODUCTION

In air conditioning systems, latent load covers 20–40% of the total air conditioning load. In conventional air conditioning systems, the air is dehumidified through condensation. The condensing dehumidification method may lead to huge energy consumption. For comfort air conditioning, dry bulb temperature is 24°C, and the dew point is 14°C. In order to dehumidify the air, the temperature of the cold water should be 7°C, and the evaporating temperature of chiller is below 4°C. If only sensible load is concerned, the temperature of the cold water should be set higher. Another problem caused by condensation is IAQ problem. Bacteria and fungi grow on the drain pan of the coil.

Therefore, a kind of independent humidity control method will be required to separate the dehumidifying process from cooling process. The liquid desiccant air conditioner can works as a humidity control method (ASHRAE, 2000; Lowenstein *et al*., 1995; Gommed *et al*., 2002). The LDAC system can be divided into two parts: the regenerator and the air-handling module. The centralized regenerator can have high regeneration efficiency. The air-handling module can be designed in stage type in order to acquire counter flow and lower the irreversible loss of the heat and mass transfer. It can be driven by low grade heat source (90°C), and there seems to be no satisfactory method among other existing technologies to use such low temperature heat source. This method can be applied in CHP systems (Fu Lin *et al*., 2001), and it is an effective mode to optimize urban energy supply system.

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DESCRIPTION OF LIQUID DESICCANT AIR CONDITIONER

Liquid desiccant air conditioning has become more and more attractive for a wide range of air conditioning applications. Some obstacles prevented the development of LDAC, such as low energy efficiency, carry over of the desiccant and corruption caused by the liquid desiccant. These obstacles no longer exist with the development of new technologies. The carry over problem can be settled by adjusting the liquid desiccant spray and distribution method. The corruption can be avoided by using new materials like plastic, which have good qualities and are very cheap.

There are two ways to increase the energy efficiency of LDAC. The first is to optimize the process of the heat and mass transfer. Albers *et al.* (1991) and Yuan Yijun (2000) give a very good method to optimize the heat and mass transfer process. The second way to improve the efficiency of the system is heat recovery. This not only recovers the energy from the room exhaust air, but also from the ambient environment.

The liquid desiccant includes lithium bromide, lithium chloride, lithium calcium and many other kind of brine or their mixture (Younus *et al.*, 1998). Different desiccant have different characteristics that can greatly influence the system performance. The flow rate of liquid desiccant is a very important parameter of the whole system. If it is too high, the concentration difference of the system will be very small, and the concentration of desiccant in regenerator will be high, which will decrease the efficiency of regeneration. If it is too low, the desiccant flow rate in the contactor will not meet the demand of heat and mass transfer. According to mass balance analysis of water during the dehumidifying process, the flow rate should be much smaller than the demand to meet heat and mass transfer demands. And different desiccant should have different flow rates. The liquid desiccant air conditioning system can be divided into two parts: the dehumidifier part and the regeneration part.

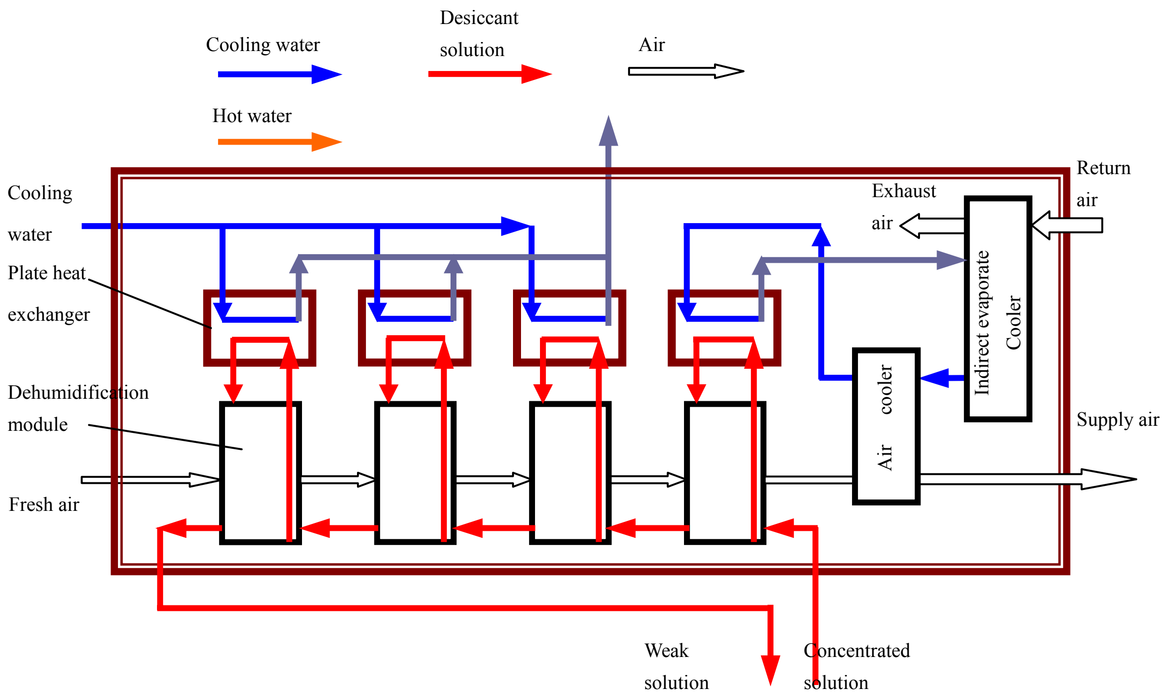

Figure 1 The dehumidifier.

The Dehumidifier

Figure 1 shows the schematic diagram of the dehumidifier. There are two airflows through the dehumidifier, the supply air and the exhaust air. The supply air is dehumidified by the desiccant solution and is cooled by the exhaust air and cooling water. The heat rejected from absorption process can be absorbed and the process occurs at a constant temperature. Otherwise during the process, the temperature will increase after the liquid desiccant absorbs the water vapour in the air. This will lead to a large decrease in the ability of moisture absorption. ‘Cooling while dehumidification’ can greatly increase the system performance.

What is more important is multi-stage dehumidifier. In the stages, the flow rate of desiccant can be high enough to meet the demand of heat and mass transfer. Between the stages, the flow rate of desiccant can be small. So the concentration difference of the desiccant solution between the inlet and outlet of the dehumidifier can much higher than that of one stage. This low flow rate operation method can improve the efficiency of the regenerator.

The dehumidifier can realize energy recovery by the indirect evaporative cooler and air cooler. It can not only recover the sensible heat but also the latent heat. The return air can also cool one or two stages of the dehumidifier.

The Regenerator

Figure 2 give a schematic diagram of regenerator driven by hot water. The regenerator has similar construction of the dehumidifier, and is also multi-stage. The plate heat exchangers work in series to heat the desiccant solution. An air-to-air heat exchanger is used to recover the exhaust heat in the air.

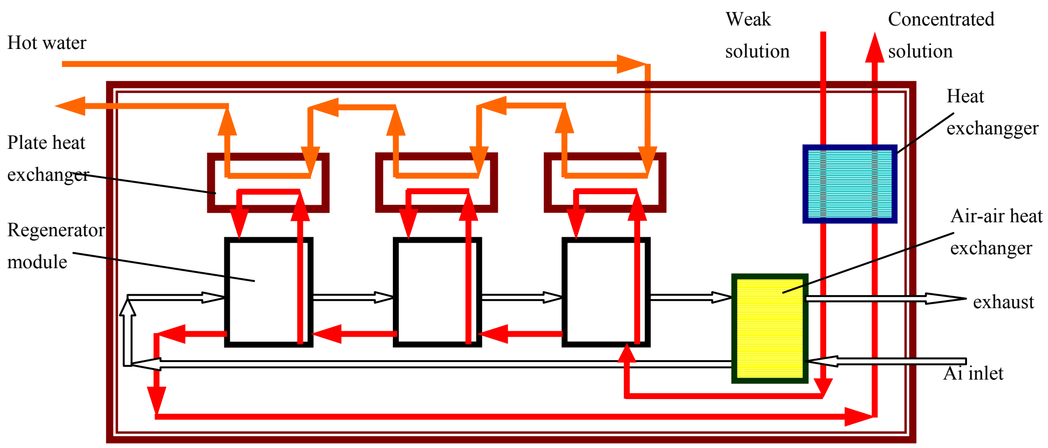

Figure 2 The regenerator.

PERFORMANCE OF LDAC IN DIFFERENT CLIMATES

In order to describe the performance of LDAC, the efficiency can be defined as:

$$\mathrm{EER}_{\mathrm{liquid}} = \frac{Q_c}{Q_h} \qquad (1)$$

$\mathrm{EER}_{\mathrm{liquid}}$ is the energy ratio of LDAC, Q_c is the net cooling capacity of the equipment in kW; and Q_h is the heat consumption of the regenerator in kW.

As for the dehumidifier, because of the cooling water and the energy recovery, the dehumidification process occurs at a constant temperature. The heat recovery can cool the air to supply temperature after the air passes the dehumidifiers. The net cooling capacity of the process is:

$$Q_c = \Delta i = i_{in} - i_s \tag{2}$$

i_{in} is the enthalpy of the fresh air (kJ/kg air); i_s is the enthalpy of the supply air (kJ/kg air).

In Figure 2, the temperature of the hot water is 90°C. Hot water heat desiccant solution in the plate heat exchanger. The air of regenerator come from outdoor air, the water evaporates into the regenerator air which exhausts into the ambient air after heat recovery heat exchanger. The heat needed by regenerator for evaporating 1 g water is q (kJ/g), which can be calculated as:

$$q = \frac{i_{st} - i_{out}}{d_{in} - d_{out}} \tag{3}$$

where i_{in} is the enthalpy of the fresh air (kJ/kg air); i_{out} is the enthalpy of the exhaust air of the regenerator (kJ/kg air); d_{in} is the humidity ratio of the fresh air (g/kg air); d_{out} is the humidity ratio of the exhaust air of regenerator (g/kg air).
According to Eqn (1)

$$EER_{liquid} = \frac{Q_c}{Q_h} = \frac{Q_c}{\Delta d * q} \tag{4}$$

According to Eqns (1)–(4), the efficiency of the LDAC can be acquired. The simulation result of the LDAC performance in different climates is listed in Table 1. In Table 1, the temperature of hot water is set to be 90°C. The result shows that the LDAC equipment has very high energy efficiency. The efficiency is more than 1 most of the time.

Table 1 The performance of LDAC in different climates

Day clock	Outdoor air temperature (°C)	Outdoor air humidity ratio (g/kg dry air)	Supply air temperature (°C)	Supply air humidity ratio (g/kg dry air)	Efficiency of LDAC	Efficiency of regenerator
6_16_17	37.7	14.9	21.1	9.83	2.05	0.86
6_21_8	26.5	12.1	19.8	9.83	1.86	0.83
6_22_15	38.8	18.0	21.7	9.83	1.64	0.87
6_25_13	22.2	12.3	19.5	9.83	1.21	0.82
6_30_21	26.4	14.3	20.2	9.83	1.35	0.85
7_7_20	30.3	20.2	21.5	9.83	1.19	0.87
7_9_17	31.8	30.2	23.2	9.83	1.03	0.86
7_14_16	39.0	12.1	20.7	9.83	3.70	0.84
7_18_11	30.5	16.1	20.9	9.83	1.43	0.86
7_29_10	26.6	17.4	20.8	9.83	1.15	0.87
8_3_11	32.5	25.0	22.4	9.83	1.13	0.87
8_4_15	34.9	16.3	21.2	9.83	1.64	0.87
8_5_19	30.5	24.7	22.3	9.83	1.09	0.87
8_15_15	35.1	20.7	21.9	9.83	1.33	0.87

8_17_12	30.2	12.0	20.1	9.83	2.41	0.83
8_24_20	26.2	21.6	21.5	9.83	1.03	0.87
9_8_21	21.6	14.3	19.9	9.83	0.99	0.85
9_18_12	22.0	16.6	20.3	9.83	0.96	0.86

PROPOSED INDEPENDENT COOLING AND DEHUMIDIFYING AIR CONDITIONING SYSTEM

The LDAC can work as a humidity control method. Air conditioning system can be put up by the concept of independent humidity control based on the LDAC, as shown in Figure 3. The cold water needed for handling the sensible load of the building can be at a temperature of 18°C. So the terminal in the building, such as fan coil or radiant cooling unit, works at dry condition. The chiller would have higher efficiency because the evaporation temperature is higher.

The latent load comes from human and fresh air. The number of humans decides the flow rate of the fresh air. So it is possible to handle the latent load as well as fresh air demand by fresh air supply if the fresh air is dried. The dehumidifier and the regenerator of the LDAC are separated. The regenerator can be centralized. The strong desiccant solution from the regenerator is distributed by pipes to different dehumidifiers. The weak solution from the dehumidifiers flows back to the regenerator. A receiver is introduced to store the solution. It can realize energy storage as well as act as a buffer of desiccant solution when the density changes. This is very important in open cycles.

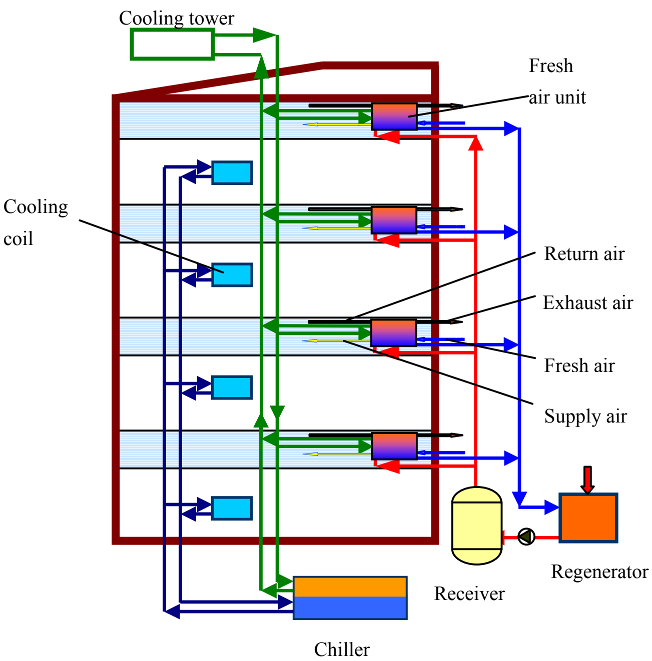

Figure 3 Independent cooling and dehumidifying air conditioning system.

The Operation Cost of Independent Cooling and Dehumidifying System

The conventional air conditioning system is driven by electricity and the temperature of the cold water is 7°C. The proposed independent cooling and dehumidifying air conditioning system is driven by heat and electricity. The chiller used in the latter system should

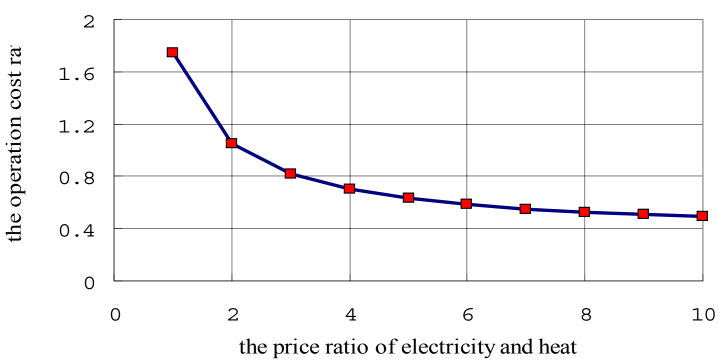

Figure 4 The operation cost ratio of the proposed and conventional systems.

be highly efficient because the temperature of the cold water should be higher that 18°C. In order to compare the operation cost of the two systems, the price ratio of electricity and heat is introduced.

The figure shows if the price of electricity is twice as much as the price of heat, the operation cost ratio will be equal to 1. That means the two systems will have the same operation cost. But if the price of electricity is higher, the operation cost ratio will be less than 1. That means the proposed independent cooling and dehumidifying system will be more cost efficient. Actually, the price of electricity is more than three times the price of heat, for example, in Beijing. So the proposed system should be cost effective most of the time.

CONCLUSIONS

The LDAC has many characteristics such as:

1. Ability to realize independent humidity control, having a high efficiency as well as meeting comfortable demand.
2. Thermally driven by low temperature heat source such as the waste heat produced by cogeneration.
3. Avoid CFC, HCFC or ammonia by using non-toxic salt solution.
4. Can sterilize the air by spraying and improve the indoor air quality.
5. Much cheaper equipment cost than the conventional system.
6. Convenience to match the regeneration heat supply with the latent load by energy storage(Kessling *et al.*, 1998).

Liquid desiccant air conditioning system presented in this paper realizes independent humidity control. The dehumidifier and regenerator can be designed with multiple stages in order to acquire counter flow and lower the irreversible loss of the heat and mass transfer. The independent cooling and dehumidifying air conditioning system avoids energy loss in the freezing dehumidification process and has a higher efficiency than other desiccant cooling systems. It can be driven by low grade heat source (90°C), and there seem to be no satisfactory methods among existing technologies to use such low temperature heat source. This new method can be applied in CHP systems, and it's an effective mode to optimize urban energy supply system.

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