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# Analysis on Hydrophobic Membrane-Based Air Pre-Dehumidification and Capillary Radiation Air Conditioning System

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## ABSTRACT

Temperature and humidity are two important factors for human thermal comfort and air conditioning system. Traditional air conditioning system adjust temperature and humidity simultaneously in evaporator, and the evaporation temperature is generally lower than the dew point temperature of air, accordingly, the thermal comfort is not easy satisfied and the whole energy efficiency is relative low. Temperature and humidity independent control of air conditioning system is an effective mode that can supply the needed indoor parameters with high energy efficiency. Capillary network radiation system is a comfortable and energy-saving terminal energy supplements mode with no blowing feeling; however, it only adjust temperature and the condensation water often occurs in the capillary tube surface. Therefore, air pre-dehumidification process can help to raise the air dew point temperature to ensure the higher temperature working fluid in capillary tube. In this study, a hydrophobic membrane-based air pre-dehumidification and capillary radiation air conditioning system is built. The hollow fiber membrane is acted as the dehumidifier when the concentrated lithium bromide solution with low temperature flows into the membrane while the wet air pass through the outside of membrane. The water vapor will pass across the membrane pores from wet air to lithium bromide solution and absorbed, and then the diluted lithium bromide solution is regenerated by other heat energy independently, furthermore, the air temperature is controlled by capillary network radiation system. Finally, the influence factors of indoor parameters and the whole energy efficiency are analyzed.

## 1. INTRODUCTION

In air conditioning system in summer, especially in hot and humid area, the thermal comfort in building and energy saving performance are two important factors, the thermal comfort are currently affected by temperature, humidity, air velocity, radiation, air quality and personality feeling. Traditional air conditioning system adjust and control the temperature and humidity simultaneously which called condensation dehumidification mode[1], the evaporation temperature is generally lower than the air dew point temperature while the temperature of air supply should be heated again, as a result, the whole energy efficiency is relative low, moreover, in condensation dehumidification mode, the condensation water discharged disorderly and the circulating air supply mode is in poor body sensitivity which can cause headache of people. Temperature and humidity independent control of air conditioning system is an effective mode to satisfy temperature and humidity demand, separately[2]. The liquid desiccant system is an effective temperature and humidity independent control of air conditioning system with energy saving performance[3], However, in traditional liquid desiccant system, the liquid desiccant solution such as lithium bromide solution, lithium chloride solution, and calcium chloride solution absorb or desorb water vapor with air in direct contact mode, the liquid droplet entrainment and air pollution often happens between wet air and the liquid desiccant solution, and it can cause corrosion for ventilating pipe and air pollution[4]. In recent years, membrane-based air dehumidification is proposed as a new type of dehumidification technology[5,6], the membrane material generally used are polythene, polypropylene, polytetrafluoroethylene and polyvinylidene fluoride (PVDF) [7], etc. They were often made into plate and frame module, spiral wound module, tubular module, capillary module, and hollow fiber module. The membrane pores is so small that the mean pore diameter is around equal to the mean free path of water vapor[8], and only water vapor can diffuse across the pores while liquid feed and ions cannot penetrate the due to the property of hydrophobicity. The driven force of water vapor transfer across the membrane pore is the water vapor pressure difference between membrane's two sides called feed side and permeate side. Accordingly, in the membrane-based

liquid desiccant dehumidification system, the liquid desiccant flows in closed circulation, the heat and mass transfer in membrane pores in indirect contact mode and the liquid droplet entrainment and air pollution will never happen.

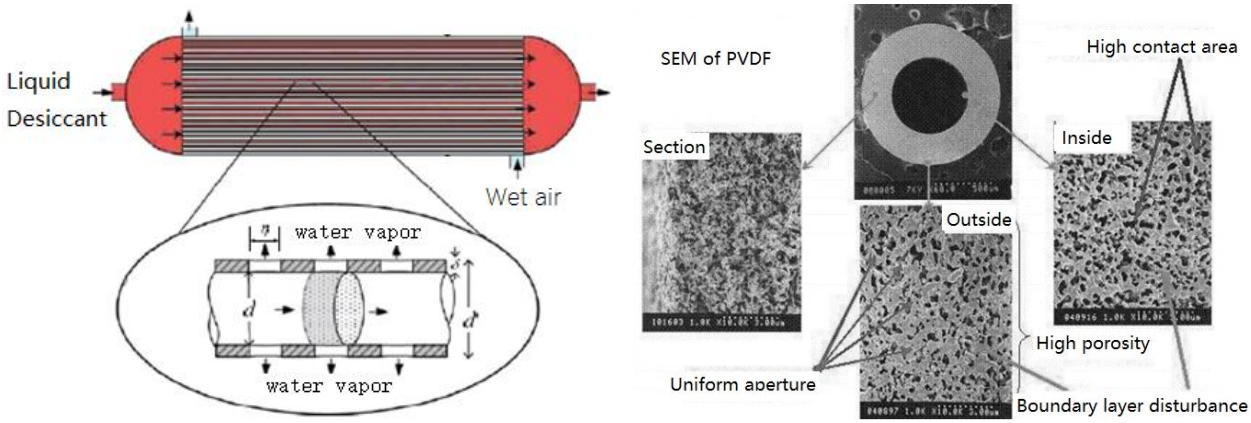
On the other hand, capillary radiant heat transfer is a great potential energy-saving technology for terminal energy supply in building [9,10], it has remarkable merits of large heat transfer area, higher temperature cooling source, and what's more, it has no blowing feeling in human body. However, in traditional capillary radiant cooling system without dehumidification process, the water vapor often condense on the capillary surface. Therefore, the capillary radiant cooling system should combined with dehumidification process.

As mentioned above, in this study, a hydrophobic membrane-based air pre-dehumidification and capillary radiation air conditioning system is presented, firstly, the humidity is pre-dehumidified by hydrophobic membrane-based liquid desiccant system, and the temperature is adjust and controlled by capillary radiation system, these two key factors in the building are controlled independently, moreover, closed circulation of liquid desiccant can avoid liquid droplet entrainment and air pollution. When the humidity is pre-dehumidification, the temperature of cooling water in capillary radiation system can be higher leading to higher energy efficiency of the whole system.

## 2. MEMBRANE-BASED DEHUMIDIFICATION

### 2.1 Heat and mass transfer in hydrophobic membrane

Figure 1 (a) shows the hollow fiber membrane module, there are hundreds of membranes filled in the module uniformly, the liquid desiccant solution flows into the lumen side, and wet air flows away the outside of membrane. The water vapor will transfer across the membrane pores due to the water vapor pressure difference between the two sides of the membrane. Accordingly, in membrane dehumidification process, the water vapor pressure in wet air is higher than that in liquid desiccant solution, and in membrane regeneration process, the water vapor pressure in wet air is lower than that in liquid desiccant solution. More importantly, the mean diameter of membrane pores is around equal to the mean free path of water vapor, the liquid molecules or ions cannot transfer across the membrane pores because of the hydrophobicity of membrane and the micro aperture properties.




(a) Hollow fiber membrane module (b) SEM of mono-membrane

**Figure 1:** Hollow fiber membrane module and the SEM of mono-membrane

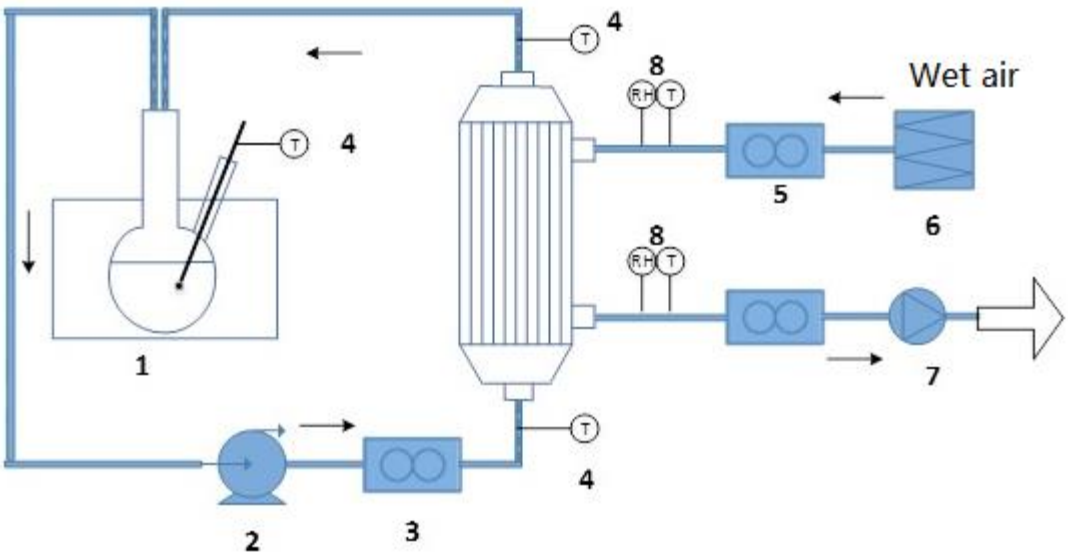
Figure 1 (b) shows the SEM photo of mono-membrane pipe of polyvinylidene fluoride material. The membrane usually has high porosity more than 80%, as a result, the membrane contact area of both liquid desiccant solution and wet air is high enough either in a single membrane pipe or in the membrane module (hundreds of membrane pipes). Moreover, the micro aperture with high porosity can disturb the micro flow in the boundary layer to enhance the heat and mass transfer process. And what's more is that the liquid desiccant solution and the wet air is divided by membrane, the noncontact mode between the liquid desiccant and the wet air can avoid potential liquid droplet entrainment and air pollution.

It should be noted that the water vapor can transfer across the membrane pores bidirectional based on the water

vapor pressure difference between the two sides of membrane, therefore, when the temperature of the liquid desiccant solution is lower or the concentration of the liquid desiccant solution is higher and simultaneously the relative humidity of wet air is higher, the membrane is acted as a membrane dehumidifier. Conversely, the membrane will be acted as a membrane regenerator. Accordingly, the membrane can wholly be used in liquid desiccant system either as a regenerator or as a dehumidifier. In this study, the analysis is focused on membrane-based dehumidification process.

## 2.2 Membrane-based dehumidification tests

Figure 2 shows the experimental tests of membrane-based dehumidification process. Lithium bromide solution of 50% mass concentration is located in the water bath, the temperature is controlled in about 25°C and 28°C,the LiBr solution flow rate is maintained in 1.2 L/min, it is transported by pump to flow into inside of hollow fiber membrane, the flow rate is controlled and measured by liquid flow meter, and the temperature in both import and export of membrane lumen side is measured by temperature sensor; the parameter of wet air is generate and maintain by wet air generator, the air flow rate and the temperature and humidity is measured in both import and export of membrane shell side. The air flow rate is keep in about 1.0 $m^3$/h, the temperature of wet air with relative humidity of 100% is about 26.5°C, 27.5°C, 28.5°C, 29.5°C and 30.5°C, separately. Table 1 show the detailed parameters of PVDF membrane material and the hollow fiber membrane module.




1. Water bath; 2. Liquid desiccant solution pump; 3. Liquid flow meter; 4. Temperature sensor; 5. Air flow meter; 6. Wet air generator; 7. Air pump; 8. Temperature and humidity sensors

**Figure 2:** Hollow fiber membrane module and the SEM of single membrane

**Table 1**: Parameters of PVDF membrane material and hollow fiber membrane module

| **Parameters of Mono-membrane** | | **Parameters of hollow fiber membrane module** | |
|---|---|---|---|
| Average aperture /μm | 0.16 | diameter /mm | 35 |
| Porosity /% | 85 | length of membrane/mm | 220 |
| Inner diameter /mm | 0.8 | Number of membranes | 150 |
| Wall thickness /mm | 0.15 | membrane area/$m^2$ | 0.08 |

### 2.3 Membrane-based dehumidification test result

When the temperature of LiBr solution is maintained in 25.3°C and 28.4°C, the water vapor pressure is about 881 Pa and 1068 Pa, separately. And the water vapor pressure in inlet membrane is controlled as saturated state, as Figure 3 shows. Figure 4 shows the test result of membrane-based dehumidification amount, and Figure 5 shows the moisture content measured in membrane inlet and outlet. It can be seen that the membrane-based dehumidification process is stable and the moisture content in outlet of membrane are maintained about 8 g/kg (air).

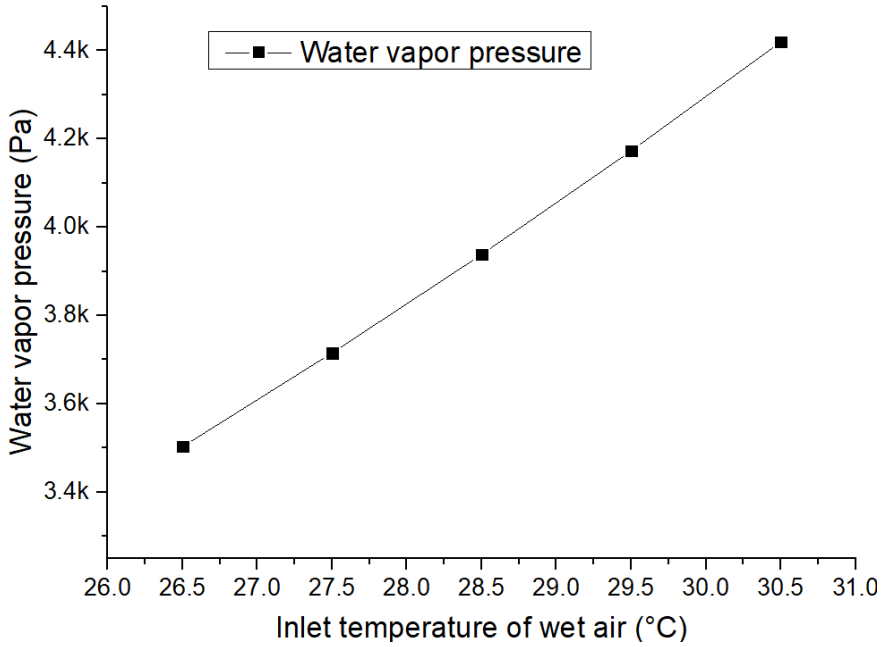



**Figure 3:** Water vapor pressure in inlet of membrane

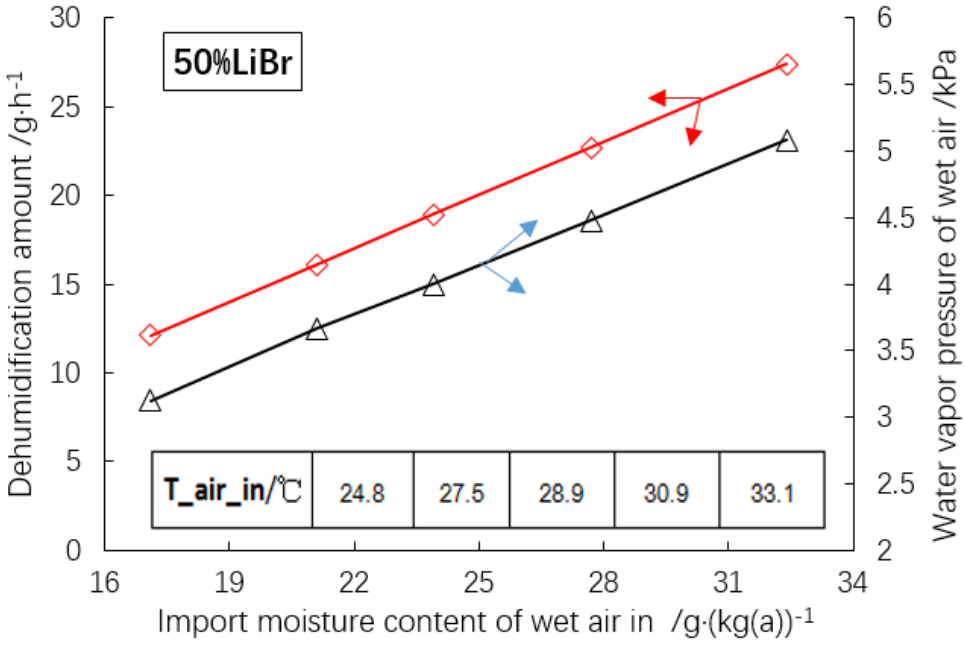



**Figure 4:** Dehumidification amount

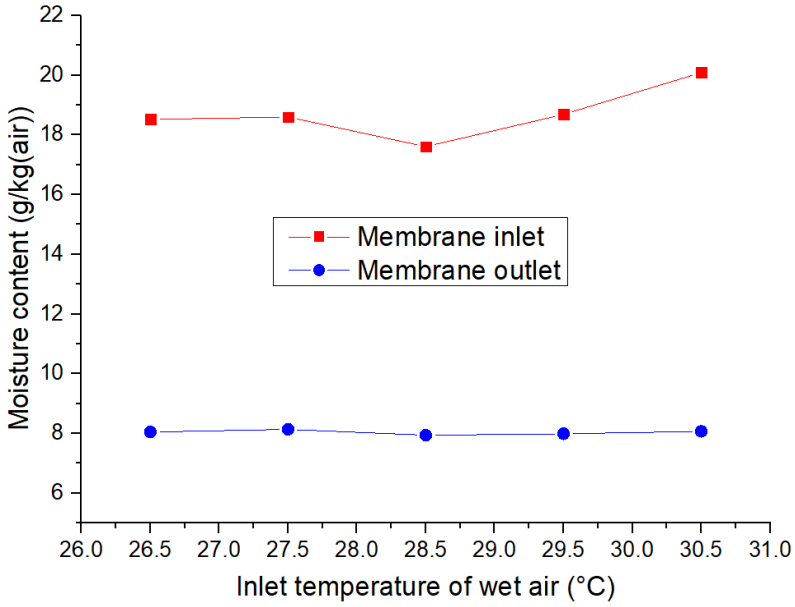



**Figure 5:** The moisture content measured in inlet and outlet of membrane

## 3. MEMBRANE-BASED PRE-DEHUMIDIFICATION AND CAPILLARY RADIATION COOLING SYSTEM

Capillary radiation system is an energy-saving system, it has two remarkable advantages of small temperature difference heat transfer with huge heat transfer area and good thermal comfort with no blowing feeling. Accordingly, the inlet temperature of water can be higher in cooling system and lower in heating system. However, the capillary radiation cooling system always appears dewing phenomenon in the capillary surface. Figure 6 shows the membrane-based pre-dehumidification and capillary radiation cooling system.

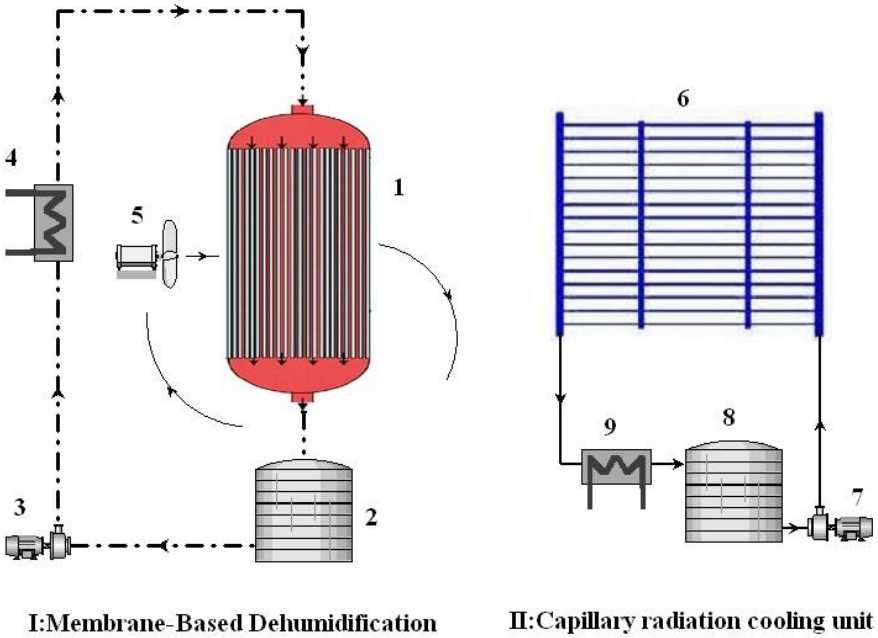



**Figure 6:** Membrane-based pre-dehumidification and capillary radiation cooling system

In membrane-based dehumidification process, the liquid desiccant solution is flowed into the lumen side of membrane cyclically, and the wet air flow away the shell side of membrane cyclically, as a result, the wet air is pre-dehumidified, further, the capillary radiation cooling system can operate, these two system can independent operate, and the temperature and relative humidity is adjust and control independently, furthermore the dehumidification effect can be controlled and adjusted according to the dew point temperature of the air. On the other hand, when the liquid desiccant solution absorb enough water vapor, it can be regenerate by heat source in membrane regeneration mode such as solar energy.

## 4. CONCLUSIONS

In this study, a membrane-based dehumidification process and capillary radiation cooling system is presented. The hollow fiber module with polyvinylidene fluoride material is used as the membrane dehumidifier, the experimental test between lithium bromide and wet air is conducted, the results show that the membrane-based dehumidification process is stable, the moisture content in outlet of membrane are maintained about 8 g/kg(air) along with different moisture content of air in inlet of membrane. Based on this, the membrane-based dehumidification can be combine with capillary cooling system to form the temperature and humidity independent control of air conditioning system completely.

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