Analysis on the Operating Characteristics of a Household Dehumidifier

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ANALYSIS ON THE OPERATING CHARACTERISTICS OF A HOUSEHOLD DEHUMIDIFIER

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ABSTRACT

Aiming at the energy saving and the improvement of dehumidifying effects, the working process of a household dehumidifier is analyzed, including the changes of evaporating temperatures and condensing temperatures, compression ratio, the state parameters of the air, the heat transfer during the working cycle, etc. The influences of these factors on the operating characteristics are also presented, which give a theory basis to exploit the fuzzy controlled dehumidifier.

1. INTRODUCTION

Humidity is one of the most important factors of comfort, especially in the southern China where the relative humidity of air is usually greater than 80%. High humidity greatly influences the life and the work of people. A dehumidifier can reduce the room humidity to a proper range so that the food and the clothing can be kept in a relative long time, the household electric appliances will have long life and peoples are able to stay in a comfortable area. Therefore, humidifiers are more and more used in modern families as air-conditioning tools to reduce the room humidity.

With the development of technologies and the improvement of people's living standard, fuzzy controlled technology that is completed by singlechip is more and more widely used in domestic electric appliances. Whether in performance, function and economizing on energy or other aspects, they all show powerful competition ability in market. In comparison, the household dehumidifier, which is still controlled by traditional on-off mode, not only goes against energy saving, but also the compressor has to startup continually and the room humidity waves greatly. In order to achieve satisfying dehumidification effect, it's necessary to adopt proper intelligent controlling method to make the dehumidifier has better performance and create more comfortable indoor environment.

It is said that in the overall market of air-conditioner in Japan, the frequency conversion machines using fuzzy control has reached a level of 56.1% in 1994, 81.80% in 1997, 90.00% in 1999. The development foreground of fuzzy controlled air-conditioner shows that it has very important application value to study fuzzy control technology in dehumidifiers. Therefore, a fuzzy control system of a household dehumidifier was fully analyzed in theory and researched in experiment. The working process and the characteristic of a dehumidifier were analyzed. The results will provide some references to the design of its fuzzy controller.

2. THE PROCESS OF DEHUMIDIFICATION

Dehumidification is a process of reducing moisture content of air. At present, there are four dehumidifying methods. They are aeration dehumidifying, absorbing dehumidifying, adsorption dehumidifying, and cooling dehumidifying. Household dehumidifier belongs to the region of cooling dehumidifying. It utilizes refrigeration principle to make wet air cool to below the dew temperature point, then heat it after removing the condensate water, finally it becomes dry air as requested. This kind of dehumidifying process can be realized by refrigeration system and fan unit (Figure

1). The wet air goes through the fan, enter the dehumidifier, and then exchange heat with the evaporator. Because the surface temperature of the evaporator is lower than the dew point of air, when the air is cooled, water in the air would be condensed. The air whose temperature has dropped discharges from the dehumidifier via temperature increasing in the condenser.

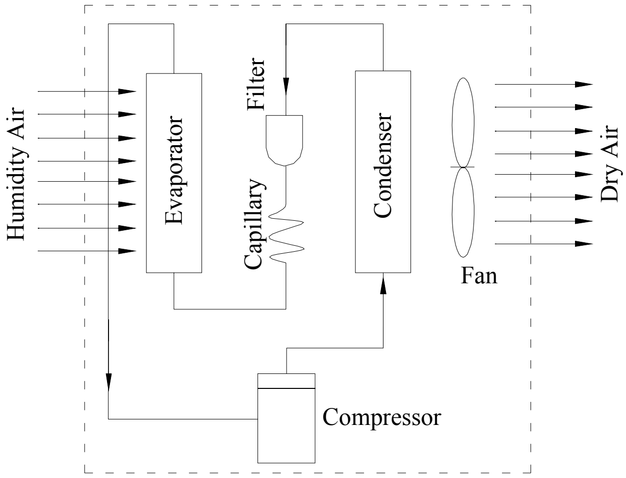

Figure 1 The working system of a dehumidifier

During the working process of the dehumidifier, the state parameters of air would be changed. When wet air goes through the evaporator coil, because the coil temperature is lower than the dew point of the wet air, the dehumidification begins. Here the air temperature drops, water in the air coagulates out, and the moisture content declines, while the relative humidity increases. With a fan, the cooled air in evaporator goes through the condenser, which makes the air temperature increase to a little higher than that it gets into the evaporator, here the moisture content in air is not change, but the relative humidity declines. when the air is discharged from the dehumidifier, its temperature and humidity reach a needed condition. The change of state parameters in each phase is shown in Figure 2. In this figure, Point 1 is the unsettled air condition before the evaporator, point x is the air condition before the condenser. Line 1-x shows the heat and wet exchange when the air goes through the evaporator, point 2 is the air condition when it leaves the condenser. The intersection point of the extended line 1-x and the saturated line is the condition of saturated wet air corresponding to the average out-surface temperature, t_{w0},of the evaporator.

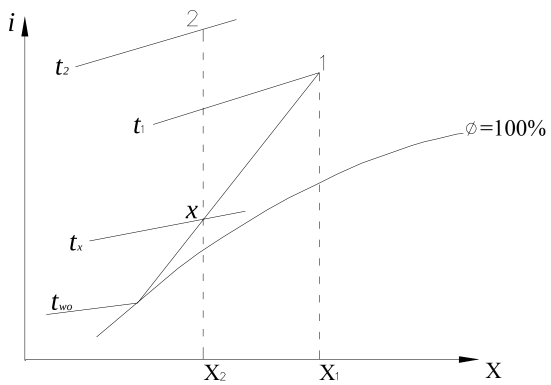

Figure 2 Enthalpy-moisture diagram of dehumidification process

3. WORKING CHARACTERISTIC ANALYSIS OF THE DEHUMIDIFIER

In the real working process of the dehumidifier, when the room temperature and humidity are high, the efficiency of dehumidification is high; while the room temperature and humidity are low, the efficiency of dehumidification is low. This is the characteristic of cooling dehumidification. As shown in Figure 3, when the high temperature air (point 1) is cooled from t1 to t1, the humidity drops from x1 to x1; when low temperature air 2 is cooled from t_2 to t_2', the moisture content drops from x_2 to x_2'. Even if the air enthalpy difference is the same ($\Delta i_1 = \Delta i_2$) with the same cooling effects, the dehumidifying content of 1 is lager than 2. This is because that only when air is cooled below the dew point, the dehumidification is possible. It is more different for 2 to reach the dew point than 1, and it also costumes more cooling capacity when it reaches the dew point. It is known from the hythergraph, if the moisture content is low, the saturation curve is plane, thus the dehumidification efficiency is low. Considering the operation condition of the compressor, the evaporating temperature at point 2 is lower than that in point 1, the compression ratio is also larger at point 2. High-pressure ratio causes low volumetric efficiency and low refrigerating capacity. So the dehumidification capacity decreases, too.

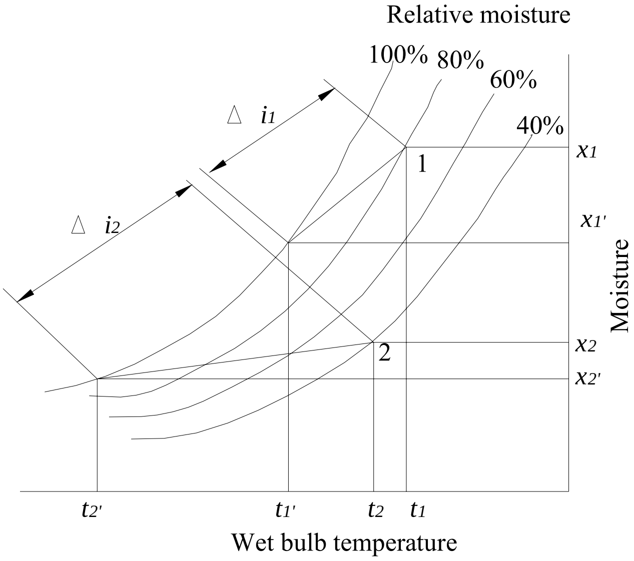

Figure 3 Hythergraph of dehumidification process

The dehumidifier with traditional on/off control has dehumidification capability loss when it turns on or off. Compared with the sensible heat capacity, the latent heat capacity loss is much bigger. When the compressor stops, the fan of the dehumidifier is still on working, the water which originally coagulated from the air to the coil, changes to evaporate from the coil to the air; If the fan motor also stops after the compressor is off, when the compressor starts up again, at the beginning of its operation (60~90 second), the water on the evaporator coil would also evaporate back to the air.

When analyzing the dehumidification performance loss as the compressor on or off respectively, it is assumed that:

(1) The evaporator coil can contain the water whose latent heat capacity is M_0, while the coagulated water quantity on the coil is larger than M_0, the redundant water would drain out from the coil;
(2) On the process of startup, the latent heat capacity and the sensible heat capacity all can be expressed by the first order inertia step response, and the time constant is the same.

Assuming that during the compressor ceasing, due to the evaporating, the change of latent heat capacity is:

$$q(t) = Q_e e^{-\frac{Q_e}{M_0}t} \tag{1}$$

Where, Q_e is the original evaporating latent heat change ratio.
In time $0 \sim t$,the evaporating latent heat capacity is:

$$M(t) = M_0\left(1 - e^{-\frac{Q_e}{M_0}t}\right) \tag{2}$$

In $0 \sim t_{off}$, of the compressor ceasing time, the evaporating capacity is:

$$M(t_{off}) = M_0\left(1 - e^{-\frac{Q_e}{M_0}t_{off}}\right) \quad (3)$$

During the startup, assuming that the water coagulating latent heat capacity in the heat exchanger can be expressed as:

$$q(t) = Q_1\left(1 - e^{-\frac{t-t_B}{\tau}}\right) \quad (4)$$

where: Q_1 —Steady coagulating latent heat change ratio;
τ—time constant;
t_B —the time when the water begins to coagulate during the startup

In $0 \sim t_{on}$, during the process of start-up, the coagulating capacity is:

$$Q(t_{on}) = \int_0^{t_{on}} q(t)dt = Q_1\left[t_{on} + \tau\left(e^{\frac{t_B}{\tau}} - e^{-\frac{t_{on}-t_B}{\tau}}\right)\right] \quad (5)$$

The time when coagulating water begins to flow out:

$$t_0 = t_{wet}\left(1 - e^{-\frac{r}{t_{wet}}t_{off}}\right) - \tau\left(e^{\frac{t}{\tau}} - e^{-\frac{t_0-t_b}{\tau}}\right) \quad (6)$$

Where,

$$t_{wet} = \frac{M_0}{Q_1}$$

$$r = \frac{Q_e}{Q_1}$$

The dehumidifying content in each cycle is:

$$q_1 = Q_1(t_{on} - t_0) \quad (7)$$

If $t_{on} < t_0$, there is no dehumidification content here. Supposed that LHRss is the latent heat ratio in steady state, then the latent heat ratio in part load is:

$$LHR = \frac{q_1}{q_t} = \frac{Q_l}{Q_l + Q_s} \times \frac{t_{on} - t_0}{t_{on} + \tau\left(e^{-\frac{t_{on}}{\tau}} - 1\right)}$$

$$= LHR_{ss}\frac{t_{on} - t_0}{t_{on} + \tau\left(e^{-\frac{t_{on}}{\tau}} - 1\right)} \quad (8)$$

Where, q_t is sensible heat capacity
Q_s is sensible heat change ratio.

From above equation:

$$\frac{LHR}{LHR_{ss}} = \frac{t_{on} - t_0}{t_{on} + \tau\left(e^{-\frac{t_{on}}{\tau}} - 1\right)} \quad (9)$$

Where, $t_{on} = \frac{3600}{4C_{\max}(1-x)}, t_{off} = \frac{3600}{4C_{\max}x}$

C_{max} is the maximum off-times per unit time x is the moisture content.

It is known from above analysis, after the compressor stops, the amount of heat exchange would decrease gradually, at the same time the temperature of the coil would escalate. When the coil temperature increases to the dew point temperature, the water would not coagulate any more and the dehumidification is ended. With the coil temperature increasing, the coagulated water on the coil begins to evaporate back to the air. If the water on the coil is enough and these is only heat exchange between water and air, the final temperature on the coil surface would be the wet bulb temperature of the air. If the coil temperature keeps increasing, the water on the coil would evaporate unceasingly till all evaporates and the temperature of the coil is same to the air. Khattar,M.K. et al (1988) got the same conclusion, the moisture coagulating content on the coil is shown in Figure 4.

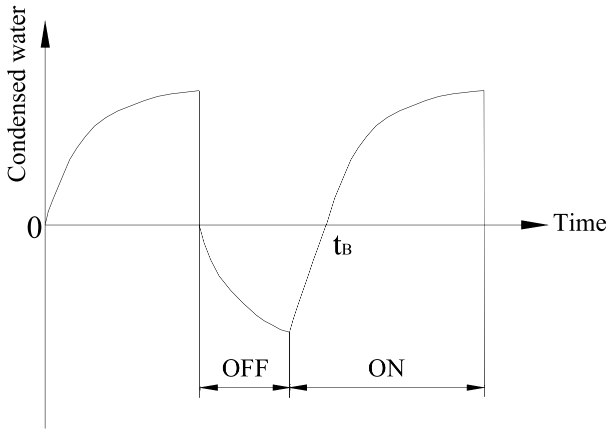

Figure 4 Water coagulating content on the coil

6. CONCLUSIONS

The analysis results show that, the dehumidification efficiency is high at high room temperature and humidity; In the process of dehumidifying, constantly startup or ceasing of the compressor will cause the dehumidification performance loss.

To develop the fuzzy controlled frequency conversion dehumidifier with the compressor operating continuously is the main developing direction. This kind of dehumidifier has some features such as: At the beginning of dehumidifying, fuzzy controlled frequency conversion dehumidifier can operate with high frequency, and drop the room humidity to the set value quickly. In the normal operating period, it can stabilize the room humidity waving with low operating frequency. Thus it not only saves the energy, but also removes the dehumidifying performance loss at the compressor on or off, and improves the dehumidifying effect.

REFERENCES

Khattar, M. K., 1985, Fan cycling effects on air conditioner moisture removal performance in warm humid climates, *Final report*, EPRIEM-4226.