The Experimentation System Design and Experimental Study of the Air-Conditioning by Desiccant Type Using Solar Energy

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Abstract: Using a special solar air heater to gain heat power for regenerating an adsorption desiccant wheel made by composite silica gel, a desiccant air-conditioning experimentation system was designed and manufactured. Combining the advantage of measure and control by "PLC" and the software of "Kingview", the whole year's operating results of this system was tested and analysed. The results indicate this system can keep the indoor air temperature range at 26±2°C and the relative humidity range being 50-70% under the low electricity cost on the whole year in the south of China region when the special solar air heater can offer flux air heating up to 60°C. In this paper some ideas are offered in order to facilitate the availability for air-conditioning using low grade energy, for example, solar energy and surplus or waste heat energy in the industrial process.

Key words: solar energy; desiccant air-conditioning; system designing; study on performance

1. FORWARD

The people will not change the demand on comfort and healthy air quality in the air conditioning circumstance although the energy crisis is more and more serious. So the researchers[1] all over the world pay much more attention on the study of this kind of air-conditioning system which can not only save the high grade non-regenerative energy and protect environment, but also satisfy the demand on the healthy and comfortable circumstance.

In 1955, Penington[2] invented the first refrigerating and air-conditioning system of adsorption dehumidification with the zeolite-water as adsorbent. Later, the refrigerating cycle of adsorption dehumidification in which the adsorbent included lithium chloride-water, silica gal-water, zeolite-water and so on, was widely researched. Then many researchers made their prototype. For example, the I.G.T. institution of American made the air-conditioning prototype with solid adsorption wheel in 1977; the Aireserch institution of American manufactured adsorption air-conditioning prototype in 1980; the Sharp Company of Japan developed the solid adsorption air-conditioning prototype by solar energy in the late 80's of the 20th century; Taipei Electric Power Company manufactured solar air-conditioning prototype. In China, from the mid-90's of the 20th century Dr. Dingjing[3] specially took the overall experimental and theoretical study on enhancing the characteristic of adsorption desiccant wheel which is the kernel component of desiccant air-conditioning system. And also she invented the new type composite adsorbing material as the core of the wheel on which this paper based.

Analyzed in theory, the heat energy had to be cost in the regenerative course of desiccant cooling air-conditioning system no matter fluid or solid was as adsorbent. At present the researchers paid much attention on looking for low grade heat energy, natural energy and regenerative energy as desiccant regenerative energy within the limit of the high grade energy source so that this kind of system have some obvious advantage[4]~[6] in the way of saving high grade energy, green energy source and improving the air quality efficiently. In this paper combining the "PLC " with the advantage of measure and control and software of "Kingview", desiccant solar air-conditioning experimentation system was designed and tested. Looking forward to accelerating the course of the solar air-conditioning applied, the experiments was done in order to analyze and optimize system, improve synthetical characteristics, look for the method of matching components, choose the calculation method of every functional equipment and so on.

2. THE APPARATUS FOR EXPERIMENTAL SYSTEM

2.1 Constitution and design programming of the experimental system

This experimental system was constituted of desiccant unit, air cooling unit, water evaporation unit, heated air solar collector, control and measure unit, air conditioning room structure, and conduits and valves for connecting above units.

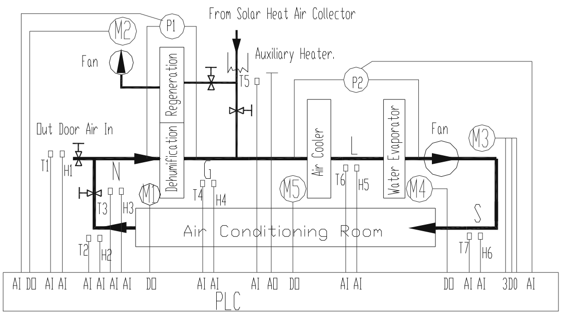


Fig.1 The design programming for experimental system

Fig.1 showed the programming of the solar adsorption desiccant air-conditioning experimental system. The kernel component of desiccant unit was the efficient adsorption desiccant wheel made by composite silica gel, of which the regenerative temperature was not high. There were regenerative section and disposal section in the desiccant wheel. The core of air cooling unit was air fin cooler where the high temperature drying air was isothermally cooled out of the desiccant unit. The kernel part of cooling system by water vaporized was the water direct-evaporator made by wet curtain. The evaporator mainly consisted of water spray system, paper corrugated packing with high specific surface area and centrifugal fan pumping air. The dried and cooled air was humidified and cooled approximately in the isenthalpic course in the evaporator. Air conditioning room, which could simulate the walls, standard doors and windows in ordinary air-conditioning room, mainly consisted of insulated board with knowable thermal conductivity. The purpose was that the thermal leakage in air conditioning room's structure could be easily calculated so as to measure and calculate refrigerating effect. The air heated solar collector was set in order that the adsorption desiccant wheel offered the regenerative heat. The shortage heat was supported by auxiliary electric heater which situated in the top of the air-conditioning room consisting of air conditioning room's structure.

Control unit included PLC, operation screen and computer monitoring system. There were 15 simulation signals enter points including 7 temperature monitoring transmitting points, 6 humidity monitoring transmitting points and 2 differential pressure transmitting points. Simulation signals output(0~100%)(1 point), could be adjusted by PID(controlled by T5 simulation signal input) in order to control auxiliary heater. There were 7 points for digital signal output and input. M1~M5 showed in Fig.1 was low-power machine, of which M_3 was in frequency control with max power 0.32kw.

2.2 Definition parameters in design and calculation

The parameters in design and calculation included target parameters and parameters in procedure state points showed in Fig.2.

In Fig.2 it was showed that point O was the outdoor state point, N-C indicated the adsorption desiccant course, C-L showed the iso-humidity cooling course, L-S was the evaporation cooling course, S-H showed the heat-exchange course indoor and N indicated the point where fresh air outdoor and return air were mingled.

The target parameters were standard atmosphere pressure, outdoor dry-bulb temperature of 33.5°C, relative humidity of 80%, average dry-bulb temperature of 26±1°C and relative humidity of 65±10% in simulating air-conditioning room. The external size of simulating air-conditioning room was 7×4×3 (m). The heat load could be approximately calculated. It was about 3kw. The max experimental heat load indoor was 7kw. The set value of target refrigerating output was 10kw. The supply-air temperature in the simulating air-conditioning room was no more than 23°C. The relative humidity was about 85%. The return-air temperature could be calculated with the relation between enthalpy and supply-air flux.

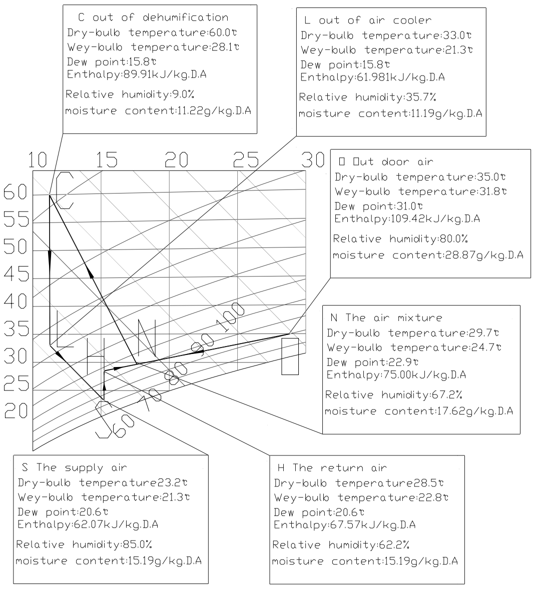


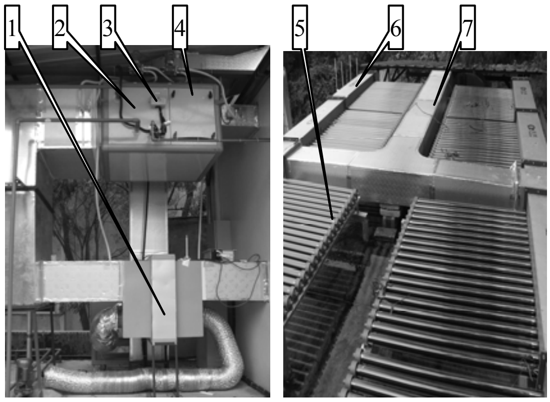
Fig.2 The parameters about the condition of cooling course

2.3 Function apparatus of experimental system

Fig.3 showed the function apparatus photos of experimental system. In Fig.3, the suspension deck wind cabinet was assembled with the cooling unit, water evaporating unit and centrifugal fan when the final drawing was designed. For centrifugal fan, the rated input air was 2500m^3/h, after pressure was 280Pa, the three-phase electromotor was external-roto moto of which the rated frequency 50Hz corresponding to 0.32kw. The air outlet horizontally butt blast pipe directly in order to reduce the loss of the blow refrigerating output cooled by evaporation. The air inlet jointed to air outlet of desiccant unit with U wind pipe which didn't require thermal insulation.

According to the experimental experience of earlier stage, the main parameters and characteristics of every unit in the function apparatus of experimental system were planned around the target parameter and experimental system. They were showed as follows:

(1) The basic parameters of desiccant adsorption wheel were showed as follows. The processed air volume was 2000m^3/h. The diameter of wheel was Ø800mm. The thickness of wheel, of which the stuff was composite silica gel, was 100. The front face area ratio of disposal and regenerative section was 1/1. The approach wind velocity was about 1.1m/s. Corresponding to the requirement, the regenerative air need 1000m3/h and the approach wind velocity was about 0.55m/s. Temperature of the regenerative air was not lower than 65°C.



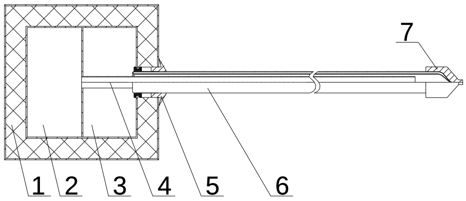
1—desiccant wheel, 2—cooling unit,3—port of water evaporator,4—centrifugal fan, 5—solar air heat collector,6—branching pipe of air heat collector, 7—main line of air heat collector

Fig.3 The function apparatus photos of experimental system

(2) The solar air heat collector, which situated in the top of experimental room, mainly consisted of the row of solar air heat collector tubes, branching pipe of air heat collector and main line of air heat collector. The air inlet of heat collector was distributed in four corners. The downward bent pipe was used considering water proof. In order to reduce heat loss, branching pipe of air heat collector and main line of air heat collector were customized high pressure

stainless steel tube with hard polyurethane foam inside and outside. The heat collector was made of vacuum glass tube. The diameter was Ø47 and the length was 1250mm for every vacuum glass tube of which the section configuration was showed in Fig4. According to the summer outdoor climate in Guangzhou, when it was calculated on the condition of the dry-bulb temperature of 33.5°C, the wet-bulb temperature of 27.7°C in air inlet, the total radiant intensity of 550w/m^2, the efficiency of heat collector of 40% and the target dry-bulb temperature of 65°C in air outlet, the endothermic area of solar air collector could be estimated as 40m^2, from which it could be calculated that vacuum glass tube should be 240.

(3) The water-evaporating air fin cooler was chosen as cooling unit. The state parameters of air inlet were the dry-bulb temperature of 57°C and the relative humidity less than 10%. The state parameters were dry-bulb temperature of 33°C and relative humidity of 35%. The heat load required to be cooled was about 18.6kw. It could be calculated that the area of heat exchange was 30.6m^2 according that the log mean temperature difference of cross flow was 11.8℃. The dimension of red copper was chosen as ф10mm×0.7mm. The pipe bundle of aluminum casing fin tube with the size of δ＝0.2mm, fin spacing of 2.2mm and distance between tube centers of 25mm, was arranged with the shape of regular triangle. Then it was known that the total length of heat-transfer tube required by heat exchanger was $L \approx 68.93m$. When the row of tubes was taken as 6 in the direction of air flow and there were tubes of 18 in every row, the total number of tubes was 108. So the length of every tube was 640mm.



1—thermal insulating pipe，2—exhaust chamber，3—air intake chamber，4—core of stainless steel tube，5—seal gland，6—glass vacuum collector ，7—cushion

Fig.4 The all-grass evacuated tube section configuration for solar energy collector by air flowing

(4) The cooling unit of water-evaporator was made of heat and humid exchanger with special paper. The state parameter of air inlet was 33°C, 36%RH, the corresponding moisture content of 7.37g/kg. If water was directly evaporated, the humidified and cooled air could be in the state of the dry-bulb temperature of 23.2°C and relative humidity of 85%RH. The air cooled efficiency with direct evaporation could reach $\eta = \frac{t_1 - t_2}{t_1 - t_d} = 83.8\%$. The model of CELdek@5090 was chosen as paper heat and humid exchanger of which the thickness was δ=100mm, the approach wind velocity was 3.3m/s and the according humidifying efficiency was more than 85%. So it could be estimated that the front face area of paper heat and humid exchanger was about 0.168m^2. The paper heat and humid exchanger have the windward size with the width of W=640mm and the height of H=265mm. The water circulating pump was correspondingly chosen with water flow of 0.5m^3/h and delivery lift more than 1.5m.

(5) The exterior-protected construction of air-conditioning room for experimentation was showed in Fig5. The indoor flow was blasted from the ceiling and partial return air reflowed by side in order to make the temperature and humidity inside the experimental air-conditioning room homogeneous.

Fig.5 The photos of air-conditioning room for experimentation

(6) The control and measure unit consisted of temperature and humidity transducer, pressure difference transducer, PLC integrated cabinet with hemicontinuous electricity in FX2N series and man-machine interface monitored by MT508S touch screen and flat of "Kingview" with combined communication. The local regulation was achieved by manipulating the touch screen. It was carried out through the flat of "Kingview" in computer that the experimental data was memorized and disposed.

3 EXPERIMENTAL CONTENT,RESULT AND ANALYSIS

3.1 $Q_0 - E$ experiment

The $Q_0 - E$ experiment meant the relation of blowing-in volume in summer, refrigerating output and COP in this article. The outdoor parameter was representative in this experiment. Method of thermal equilibration was used for measuring refrigerating output. The method of thermal equilibration meant that electric heating circulating fan was placed inside the exterior-protected construction, of which the voltage of electric heating winding was adjusted so as to make the indoor temperature and humidity in balance in the range of target parameter (dry-bulb temperature of 26±1 ℃ and relative humidity of 65±10％). At the same time, the real power of electric heating circulating fan and the real power W consumed by all device in experimental system were calculated. It was the refrigerating output Q_0 in experimental system that real power of electric heating circulating fan added to thermal leakage of exterior-protected construction. The synthesis energy efficiency in system was defined as $E_0 = \frac{Q_0}{W + Q_j}$, if the Q_j collected by solar collector was added to the consumption. The refrigerating energy efficiency on power consumption in experimental system was defined as $E_e = \frac{Q_0}{W}$, if the Q_j collected by solar collector was not added to the consumption. Because the blowing-in related to the function effect in every unit all of the experimental apparatus, the converter plant, adjusting rotational speed of fan, was assembled in the control unit of experimental apparatus so as to lay the hardware foundation on this experiment.

Because it was found in preliminary experiment that air temperature in the outlet of solar collector waved strongly, high building blocked and the weather was cloudy and rainy, the solar collector had biggish effect only in the noon. In order to cover the shortage, auxiliary finned electric heater was stringed in the outlet of solar heat collector. It is better to make regenerative air temperature reach the set regenerative temperature, when the additional heating was achieved by closed-loop self-controlled operation-stop frequency. The consumed power was calculated in the mean time.

A group of representative experimental results in $Q_0 - E$ experiment were shown in Fig6. From 45 past 11 to half past 15 in the middle time of August in 2005, the outdoor mean dry-bulb temperature was 34.2°C, the wet-bulb temperature was about 28.1°C and the mean radiant intensity was 760w/m^2. The set indoor parameters were dry-bulb temperature of 26°C and relative humidity of 65%. The outlet temperature of solar collector waved from 44.2°C to 67.8°C. The regenerative auxiliary electric heater winding automatically heated up in compensation so as to maintain air temperature in the range of 65±1°C.

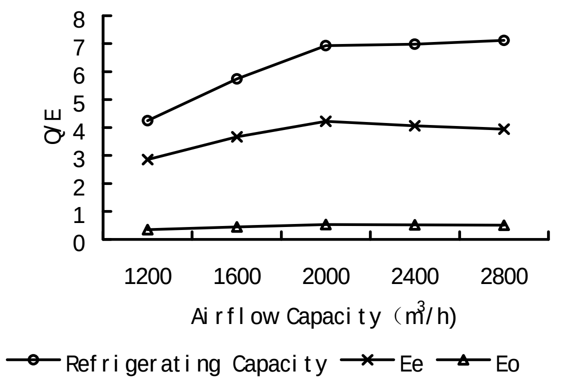


Fig.6 The relation between airflow capacity and Refrigerating capacity and EER during the summer

It was known in Fig6 that cooling capacity almost scaled up firstly with the increase of airflow capacity, the cooling capacity would not increase obviously when airflow capacity exceed a certain value (cooling capacity was about 7.2kw when airflow capacity was about 2100m^3/h in the system). On the one hand it meant that airflow capacity was one of the important matching parameters in this kind of system. It was basically reasonable that airflow capacity of 2000m^3/h was matched as key parameter in design on every unit. On the other hand it showed that cooling capacity could be adjusted with changing airflow capacity in the certain scope.

The ERR shown in Fig6 was very low with the max value of 0.52, but the refrigerating ERR of power consumption could reach to 4.22. Although experimental definition needed improving, it could illustrate that desiccant air-conditioning cooled by evaporated water was of strong practical value. In use of regenerative and low grade energy like solar energy, it had prosperous applied future in the field of architecture, energy-saving and environmental protection with further optimization of system, especially improving the characteristics of desiccant wheel in desiccant air-conditioning cooled by evaporated water.

3.2 ITH Experiment

ITH Experiment, which was the abbreviation of Indoor temperature and humidity adaptive regulating, referred to the self-adaption synthesis characteristics of indoor temperature and humidity in different condition. Because PLC integrated cabinet with hemicontinuous electricity was assembled in experimental apparatus, the process characteristics in system could be continuously measured, such as import, export and so on. Considering the process parameters, it could self-regulate towards the set target according to control decision. It meant that in the course of regulating temperature and humidity, PLC autonomous system could automatically select function mode according to contrast on indoor ant outdoor environmental parameters. Temperature was regulated firstly and then humidity was adjusted on the whole. There were two modes of regulating temperature including drop and rise in temperature. Drop in temperature was achieved by water in desiccant air evaporated. Rise in temperature was realized by switching from solar air collector to the string auxiliary electric heater. Hot air capacity was regulated according to proportion between fresh air and air flow capacity adjusted by frequency forced draught blower. The desiccant wheel was adapted in order to regulating humidity when desiccation was required. The wet-curtain humidifying water pump, shown in Fig1, started up when humidification was required.

In the flat of “Kingview” the history data could be memorized and the characteristics of regulating indoor temperature and humidity could be monitored in the whole year. Because of too much detection data, it was adopted in this paper which could be preventative in summer outdoor environment and reflect self-adaption characteristics on practical indoor temperature and humidity.

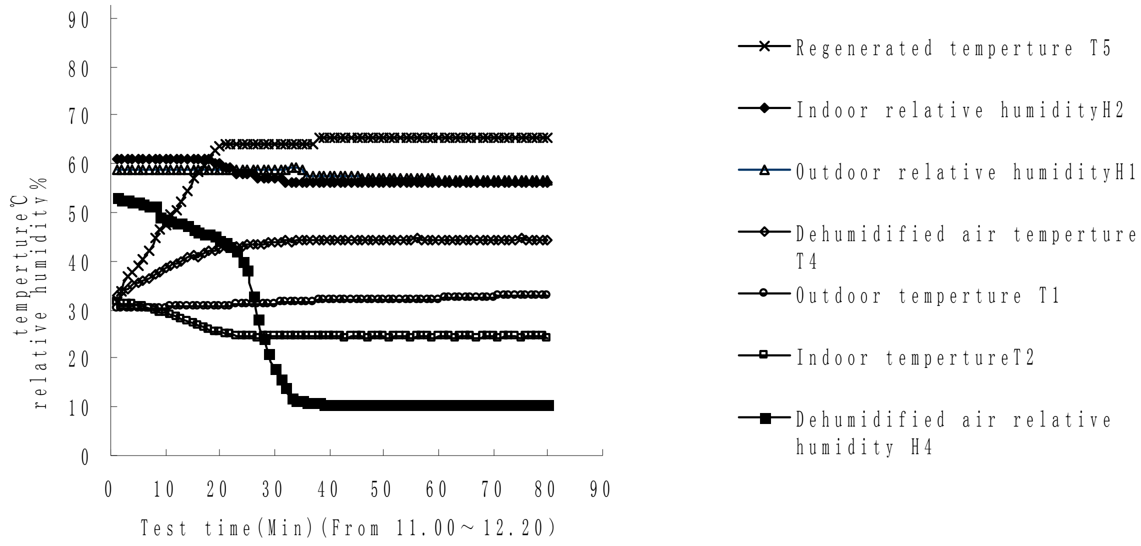


Fig.7 The regulating trend about temperature and relative-humidity control in summer

The representative regulating trend about temperature and relative-humidity control in summer was shown in Fig7 for ITH experiment. The set parameters of indoor temperature and humidity were indoor dry-bulb temperature of 26±1°C and relative humidity of 65±10%. There were only two computers and two strip lamps in the room, so the main disturbance factor was the difference on temperature and humidity inside and outside the room. The regulated air-flow capacity by frequency fan could change the temperature.

In Fig7 the follows was known:

(1) The indoor temperature and humidity could be in the range of set value in 20min after starting up.

(2) The desorption desiccant effect was obvious in this apparatus when the regenerative temperature was about 65°C in the desiccant wheel made by composite silica gel.

4. CONCLUSIONS

(1) The refrigerating ERR of power consumption could reach to 4.22. Although experimental definition needed improving, it could illustrate that desiccant air-conditioning cooled by evaporated water had strong practical value. It provided example of efficiently utilizing the regenerative and low grade energy, such as solar energy and so on.

(2) This system could keep the indoor air temperature range being 26±2°C and the relative humidity range being 50-70% under the low electricity cost on the whole year in the south of China region when the especial solar air heater can offer enough flux air heating up 60°C for desorption.

(3) The matching method between different unit and experiment basis was further researched through design on experiment apparatus and experiment research.

(4) Because the desiccant wheel for dehumidification and wet-curtain apparatus were included in the system, there were all functions of regulation on temperature and humidity in air-conditioning work condition, such as temperature rise and humidification, temperature rise and dehumidification, cooling and humidification, cooling and dehumidification. So the apparatus was hoped to be firstly applied for experiment apparatus for regulating temperature and humidity in the air-conditioning work condition of constant temperature and humidity.

(5) The kernel component of this apparatus was desiccant wheel which was somewhat different from drastic desiccant wheel. With lower regenerative temperature and less resistance, on the one hand different low grade energy could be utilized more efficiently, on the other hand power consumption could be reduced and power efficiency of

refrigerating power consumption could be increased.

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