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EXPERIMENTAL INVESTIGATION OF THE PERFORMANCE OF HYBRID DESICCANT AIR CONDITIONING SYSTEMS

دراسه عمليه لأداء أنظمة تكييف الهواء الثنائية التى تستخدم ماده مازه للرطوبة

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خلاصة:

يستعرض البحث دراسة عملية لتقييم أداء أنظمة تكييف الهواء الثنائية لنوعين مختلفين هما النظام البعدى والنظام القبلى ، وكذلك مقارنتهما بنظام التكييف التقليدى الذى يستخدم دورة انضغاط البخار. ويتكون النظام محل الدراسة من عجلة تجفيف هواء دوارة مدمجه مع دورة انضغاط البخار التقليدية. فى هذه الدراسة إستخدم محلول كلوريد الليثيوم كمادة مازه للرطوبه . تم دراسة تأثير بعض العوامل المختلفة على أداء النظام منها: سرعة ودرجة حرارة هواء التنشيط ، سرعة هواء الإمداد ، سرعة دوران عجلة التجفيف. وجد من الدراسة أن نظام تكييف الهواء الثنائى البعدى يوفر قدرا مناسبا فى سعة ملف التبريد يقدر بحوالى 23% مقارنة بالنظام التقليدى ويصل معامل أداء هذا النظام الى ضعف قيمة معامل أداء النظام التقليدى باستخدام سخان طرفى . أما في نظام تكييف الهواء القبلى فقد وجد أنه يحقق أقل درجة حرارة ندى لهواء الإمداد مع وجود زيادة فى معامل أداء هذا النظام تقدر بحوالى 70% مقارنة بالنظام التقليدى باستخدام سخان طرفى. كما وجد أن استخدام سرعة دوران مقدارها (1 لفه/ الساعة) لعجلة التجفيف يحقق الأداء الأمثل لهذا النظام.

Abstract

In this study, an experimental evaluation of a hybrid desiccant air conditioning in post and pre-cooling arrangements is studied and compared versus the traditional vapor compression system (VCS). The system is mainly consisted of a rotary dehumidification unit integrated with a VCS. The dehumidification unit comprises a rotating liquid desiccant wheel. Lithium chloride is used as the working desiccant material in this investigation. The effect of regeneration air velocity, temperature and rotational speed of the wheel on the performance of the system is studied. The post cooling hybrid system is found to be an energy efficient system, it saves nearly 23% of cooling coil capacity compared to VCS. The COP of the post cooling arrangement is nearly twice that of VCS with reheat. The pre cooling arrangement ensures low dew point temperature with an increase of COP of about 70% compared to VCS with reheat. A rotational speed of 1 rph is recommended for optimum performance. The results of the numerical model of another work is used for comparison with the experimental results of this study.

Keywords: hybrid desiccant system; vapor compression system; rotary desiccant wheel.

Nomenclature

C_p	Specific heat at constant pressure, J/kg.K.
d	diameter, m
L	Wheel thickness, m
M	Mass per unit volume, kg/m^3
q	Heat of absorption, kJ/kg$_{water}$
Q	Heat transfer rate, kW
T	Air temperature, °C
V	Air velocity, m/s
Y	Air humidity ratio kg$_{vapor}$/kg$_{air}$

Greek

ε	Void fraction area (-)

Abbreviations

Abs	Absorption
AH	Auxiliary heater
COP	Coefficient of performance
ECOP	Hybrid coefficient of performance
SHF	Sensible heat factor
SMRR	Specific moisture removal rate, g/kg.s
VCS	vapor compression system
IAQ	Indoor air quality

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Subscripts

a	Air
cc	Cooling coil
D	Desiccant
L	Liquid
S	Supporting structure
reg	regeneration
V	Vapor

1. Introduction

In any air-conditioning system, two types of loads have to be met, sensible and latent loads. Conventional systems use vapor compression unit to meet both these loads. To meet the latent load, air must be dehumidified by cooling it below its dew point. The higher latent heat load, lower is the evaporator temperature required. But there is a limitation on the evaporator temperature too since it must not go below 0°C, the freezing point, and a very low supply temperature of air can create situations of cold drafts in the air-conditioned space. Therefore, in conventional systems reheat is often required in high latent heat load application, which implies very poor COP, in addition to a lot of waste energy. In addition, large mass flow rates are maintained because moisture removal per unit mass of air is limited. Simple desiccant systems are well suited to meet latent heat loads. Here the process air is brought in contact with a material possesses high affinity for water. Moisture is absorbed/adsorbed by this desiccant material and the heat of absorption/adsorption released in the process heats the air up. The air is thereafter cooled by passing over the cooling coil of the VCS.

Ali et al [1] proposed a compact energy efficient solid desiccant air conditioning system. The system consists of a conventional vapor compression unit combined with a rotary desiccant dehumidifier. The drying matrix is regenerated entirely using the heat rejected from the condenser of the vapor compression unit through a heat pump whose discharge conditions are adjusted to suit the dehumidifier regeneration conditions. It has been found that the overall COP of the new system improved significantly. Burns et al. [2] studied three hybrid system configurations for supermarket applications (high latent load) and a comparison of their performance with conventional air-conditioning system was made. The cycles termed as ventilation-condenser cycle, recirculation-condenser cycle and ventilation-heat exchanger cycle. they reported that these cycles would give energy savings, in comparison to the conventional air-conditioning systems, ranging from 56.5 to 66% at moderate ambient conditions of 30°C, 0.016 kg_{vapor}/kg_{air}, SHF of 0.35 and space conditions of 24°C, 0.0104 kg_{vapor}/kg_{air}. These calculations were based on the concept of weighted energy consumption, with one unit of electrical energy weighted twice that of thermal energy. Singh et al. [3] have analyzed the afore-mentioned three hybrid cycles, introduced in [2], for Indian climatic conditions. Modeling of the dehumidifier operating at a fixed regeneration temperature of 135°C, and regeneration to process air area ratio of 0.33, is done using the performance data from a manufacturer. It is reported that energy savings ranging from 30% to 50% can be easily achieved at lower SHF.

Investigation by Yadav [4] showed that the hybrid vapor compression system was more promising under high latent heat load or higher ambient humidity conditions, and significant energy saving can be achieved over traditional vapor compression system. Yadav and Kaushik [5] have studied a hybrid solid desiccant system. It was found that the system resulted in 25% energy saving over a VCS. Howell and Peterson [6] reported that a hybrid liquid desiccant system can reduce the areas of evaporator and condenser by about 34%, and economize electricity consumption by about 25%. Due to high latent load ratios in supermarket, the use of vapor compression units is inefficient.

Adnan et al [7] introduced energy efficient system using liquid desiccant to overcome the latent part of the cooling load in an air conditioning system. The proposed system was studied at different operational conditions. It was concluded that the proposed system can be used effectively to reduce electric energy consumption in air conditioning. As an example at ambient temperature of 40°C, air humidity ratio of 0.015 $kg_{vapor}/kg_{d\,air}$ and a SHF of 0.9, the proposed system consumes about 0.3 of the energy consumed by a conventional air conditioning system.

Mohan et. al [8] studied the performance of absorption and regeneration columns for a liquid desiccant-vapor compression hybrid system. The liquid desiccant is used only for dehumidification of supply air in the absorber which can be subsequently regenerated in the regenerator using condenser heat. They reported that higher the specific humidity and lower the temperature of the inlet air, higher will be the dehumidification in the absorber. Similarly, the regeneration can be increased by increasing the temperature and decreasing the specific humidity of the inlet air to the regenerator. Further, the solution temperature has negligible effect on the performance of air dehumidification or solution regeneration owing to low flow rate of the solution.

Research on the hybrid desiccant air-conditioning is also reported in references [9-13]. Although the desiccant air conditioning is so promising, the detailed theoretical analysis and experimental results pertaining to the hybrid desiccant air-conditioning are few.

In this paper, some experiment results on a post and pre-cooling arrangements of hybrid desiccant air conditioning system are reported and the effects of the relevant operating parameters on the performance of the whole system are analyzed.

2. The Hybrid System

A schematic diagram of hybrid desiccant air conditioning system in both arrangements is shown in Fig.1. The proposed system is mainly consisted of a dehumidification unit (mainly a rotating liquid desiccant wheel) integrated with a vapor compression system (VCS). In the post cooling hybrid desiccant system shown in Fig.1 (a), air is dehumidified in the desiccant wheel (A) before it enters the cooling coil (B) of the DX unit. The dehumidified air is then cooled to the desired conditions by the cooling coil (B). The desiccant wheel is regenerated using the condenser (G) heat of the VCS and further heated by using an auxiliary heater (F). The psychometric chart of this system is shown in Fig.2 (a). In the pre-cooling hybrid desiccant system shown in Fig.1(b), air is speed decreases. This is because that the lower the rotational speed the higher the contact time between air and desiccant material. As the contact time between the desiccant material and air increases the absorption and regeneration processes are enhanced. When the wheel turns faster between the dehumidification and regeneration parts, there is no enough contact time between air and desiccant material. Eventually, it is recommended to lower the wheel speed to obtain higher dehumidification performance and hence higher ECOP and SMRR. The ECOP increasing with the process air mass flow rate increase due to the increase of total cooling capacity. But it is observed that with higher values of process air mass flow rate, the enhancement in ECOP is decreased.

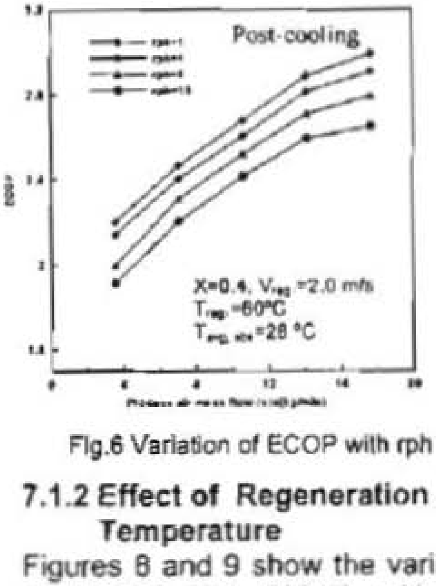

Fig.6 Variation of ECOP with rph

7.1.2 Effect of Regeneration Air Temperature

Figures 8 and 9 show the variation of ECOP and SMRR with the regeneration air temperature respectively. The ECOP of post-cooling decreases with the increase of regeneration temperature, see Fig.8. As the desiccant wheel serves the latent load in the post-cooling arrangement, high regeneration temperature means high energy input to regenerate the desiccant material and so low ECOP. The SMRR increases with the regeneration temperature increase as shown in Fig.9. As the regeneration temperature increases the dehumidification efficiency also increases and so the humidity drop is large.

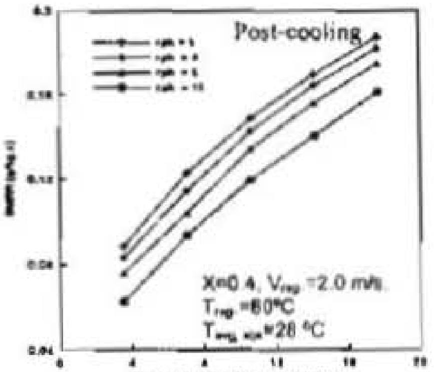

Fig.7 Variation of SMRR with rph

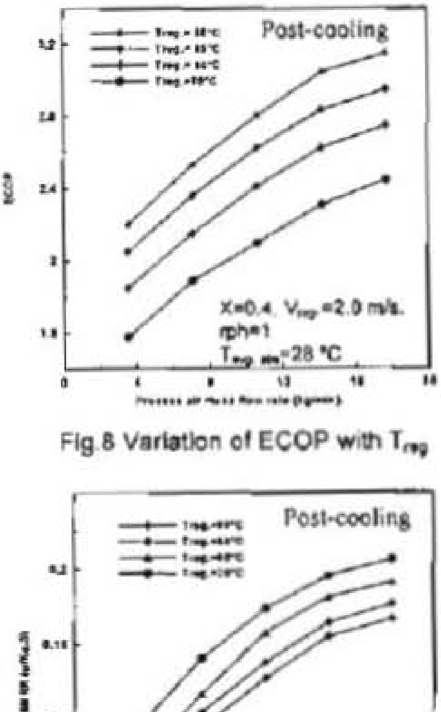

Fig.8 Variation of ECOP with T_{reg}

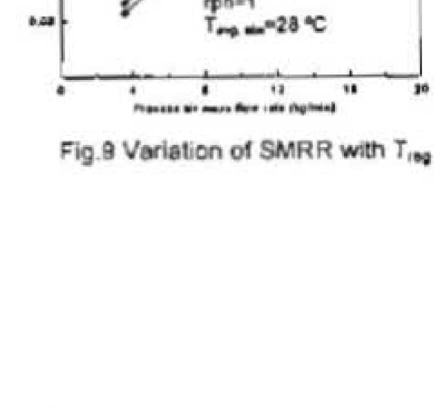

Fig.9 Variation of SMRR with T_{reg}

7.1.3 Effect of Regeneration Air Velocity

Figures 10 and 11 show the variation of ECOP and SMRR with the regeneration air velocity respectively. The regeneration temperature and the regeneration velocity have an observed effect on the ECOP and SMRR. This is because that the amount of regeneration heat is controlled by both regeneration temperature and regeneration air velocity. As the regeneration air velocity increases the ECOP of the post-cooling decreases. But the SMRR is enhanced with the increase of regeneration air velocity. Also, the comparison between measured data and calculated results obtained from [14] for the ECOP and SMRR at different regeneration velocities shows a reasonable agreement between the measured data and calculated results. The difference is in order of 2.5 to 8 percent; this may emphasize the validity of the model introduced in [14] to predict the performance of the hybrid system. The difference may be due to the assumptions of the theoretical model and also, the accuracy of the measurements.

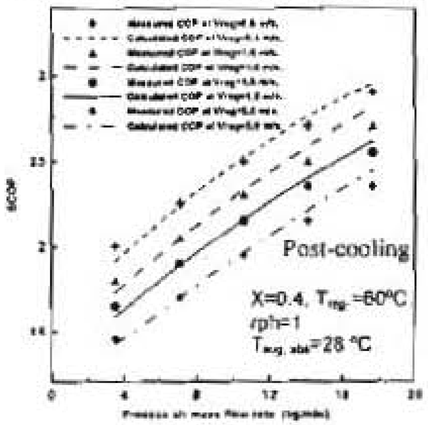

Fig.10 Variation of ECOP with V_{reg}

7.2 Pre-Cooling Arrangement

The effect of the same parameters described in the post-cooling

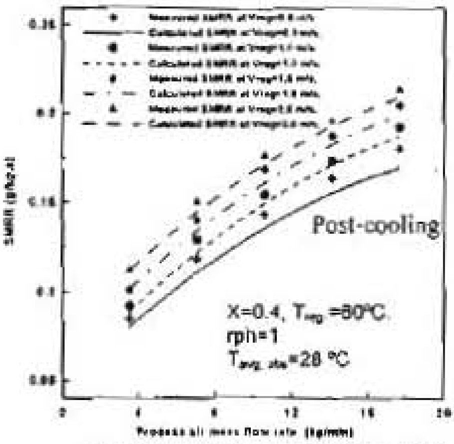

Fig.11 Variation of SMRR with V_{reg}

arrangement are used in the pre-cooling arrangement. But due to the difficulty in controlling the regeneration temperature exiting from the condenser, the auxiliary heater is used here to control and adjust the regeneration heat.

7.2.1 Effect of Wheel Rotational Speed

Figures 12 and 13 show the variation of ECOP and SMRR with the rotational speed respectively. For the same causes mentioned before in the post-cooling, the ECOP and SMRR for the pre-cooling arrangement is also increasing as the rotational speed decreases. Eventually, it is recommended to lower the wheel speed to obtain higher dehumidification performance and hence higher ECOP and SMRR.

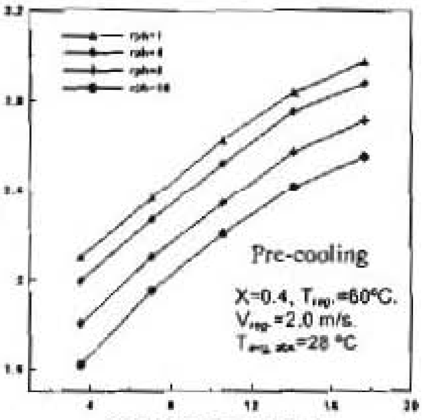

Fig.12 Variation of ECOP with rph

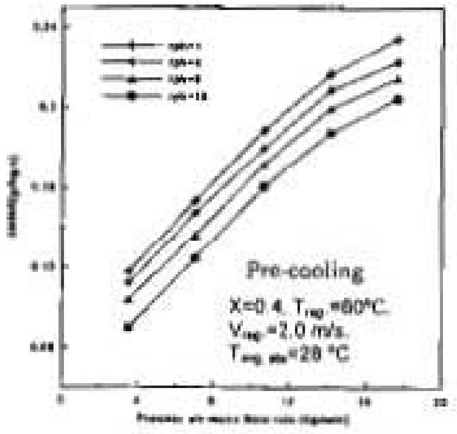

Fig.13 Variation of SMRR with rph

7.2.2 Effect of Regeneration Air Temperature

Figures 14 and 15 show the variation of ECOP and SMRR with the regeneration air temperature respectively. The ECOP of the pre-cooling arrangement increases as the regeneration air temperature increases as shown in Fig.14. This is because the process air temperature is very low before entering to the desiccant wheel so, there is no need to regenerate the desiccant wheel at high temperature. The condenser heat is very sufficient for regeneration process and hence there is no need for auxiliary heating as in post-cooling arrangement. The SMRR is increased with the regeneration temperature increase as shown in Fig.15. As the regeneration temperature increases the dehumidification efficiency also increases and so the humidity drop is large.

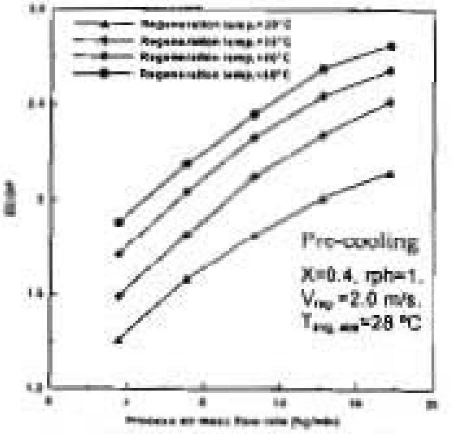

Fig.14 Variation of ECOP with T_{reg}

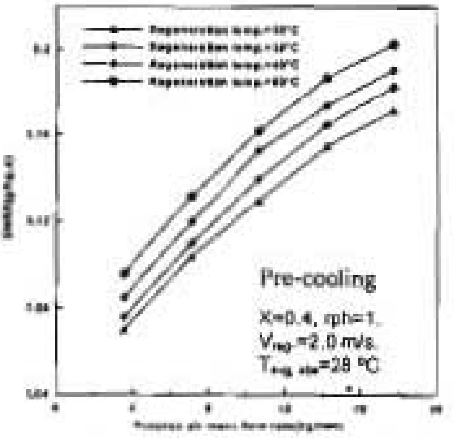

Fig. 15 Variation of SMRR with T_{reg}

7.2.3 Effect of Regeneration Air Velocity

Figures16 and 17 show the variation of ECOP and SMRR with the regeneration air velocity respectively. The regeneration temperature and the regeneration velocity have a similar effect on the ECOP and SMRR. This is because that the amount of regeneration heat is controlled by both regeneration temperature and regeneration air velocity. The increasing of regeneration air velocity increases the ECOP of the pre-cooling arrangement as shown in Fig.16. This because the condenser energy is very sufficient to regenerate the wheel in this arrangement as mentioned in the previous section. Also SMRR is enhanced with the increase of regeneration air velocity.

7.3 The Hybrid Desiccant System and VCS

Figure 18 shows the COP for the hybrid system in post and pre-cooling arrangements; VCS and VCS with reheat. It is clear that the

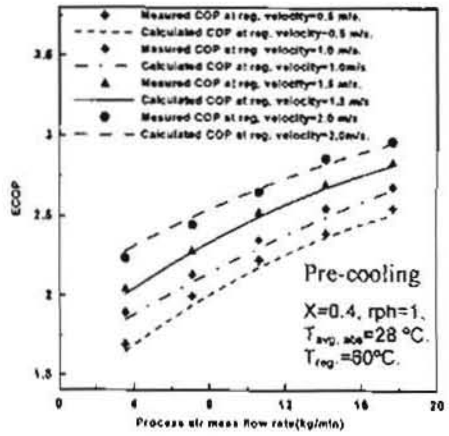

Fig.16 Variation of ECOP with V_{reg}

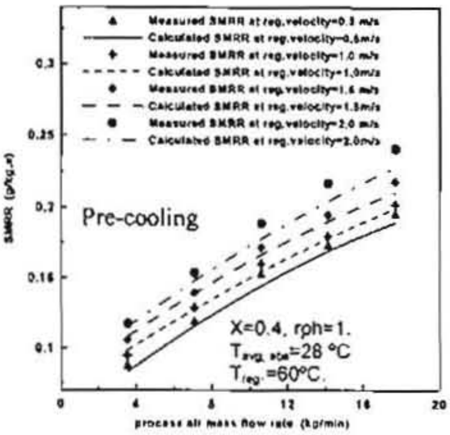

Fig.17 Variation of SMRR with V_{reg}

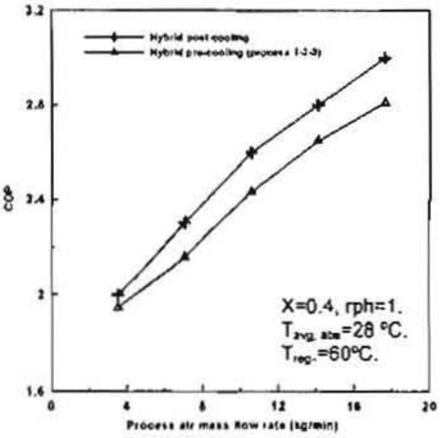

Fig. 18 Variation of COP with air mass flow rate.

COP for each system increases with the mass flow rate because the supply air cooling capacity increases. The COP of the hybrid system in post-cooling mode has always superior COP over the whole modes due to the latent load removed by dehumidification in the desiccant wheel before air cooling. The hybrid system in the pre-cooling mode has a COP lower than that of the VCS because the process air enters to the cooling coil then passes over the desiccant wheel i.e. the total latent and sensible loads are removed by the cooling coil. Also the regeneration heat required for the wheel represents a penalty on the COP. The value of COP of VCS with reheat is nearly 50% of that of post cooling hybrid system.

Figure 19 shows that the SMRR for the pre-cooling hybrid desiccant mode reached higher values than other systems and this explains why this system has the lower dew point temperature. The pre-cooling mode is usually used when the design supply air dew point temperature is very low and it is also used for controlling the relative humidity which is an important measure of maintaining good indoor air quality (IAQ). Fig. 20 shows the variation of dry bulb temperature (DBT) for the different systems, the pre-cooling mode has a DBT higher than the VCS due to the sensible heat gain from the dehumidification of process air after leaving the cooling coil. Also, from Fig. 20 the post-cooling hybrid desiccant based system achieves the same cooling load as the VCS with reheat but with an energy saving of nearly 50%. The sensible heat rise here is significant as it leads to further lowering in DPT and moisture content of the process air which helps in humidity and temperature control. Fig. 21 shows the cooling coil capacity and energy saving percent. The post-cooling mode has less cooling coil capacity than the pre-cooling and