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Performance Evaluation and Parameter Analysis on a Composite Solid Desiccant based Air Conditioning System

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***Abstract*-An experimental investigation in Kasaragod, Kerala is presented to evaluate the performance and energy saving capacity of a solid composite desiccant wheel based air-conditioning system composed of silica gel and calcium chloride. The system also consists of a split type air-conditioner (1.0 ton refrigeration), air ducts and a blower. The effect of different parameters such as process air mass flow rate, regeneration temperature, inlet humidity ratio, inlet temperature etc. on the performance of the system is studied. The performance evaluation of the air conditioning unit is done with and without connecting the dehumidifier. During parameter analysis it is found that factors such as high process inlet velocity, high inlet humidity ratio, low regeneration temperature etc. reduces the moisture removal capability of dehumidifier. During performance analysis it is found that there is an increase of 3.4% in refrigeration effect, 4.2% decrease in the compressor work input and an increase of 30% in the COP of the system when the dehumidifier is connected. But when the energy performance analysis is done it is found that there is a decrease of 15% in energy consumption rate.**

Keywords - Dehumidification, Desiccant, Silica, Vapour compression system, Regenerator.

I. INTRODUCTION

Air conditioning has a very important part in our day to day life. Increase in the comfort demands of the occupants in turn increases the requirement of air conditioning to a large extent. Two major problems that we are facing in air conditioning systems are large energy consumption rate and environmental hazards. The conventional form of air conditioning system that we are using that is vapour compression system is not that economical. The conditioning of the air includes humidification and dehumidification according to the amount of humidity present in the air. Dehumidification consumes a lot of power. Dehumidification is an essential thing in our day to day life because humid atmosphere is not a comfort zone for the occupants. The rate of growth of bacteria and fungi is directly proportional to humidity. So when the humidity is very high the materials, occupants etc. are not safe. So the humidity has to be reduced. Many methods are introduced for dehumidifying the air.

Dry air plays a special role in improving processes or products in many of the industries including food production, pharmaceutical production and chemical industries. Dry air prevents corrosion and deterioration of the products. It also optimizes seed moisture level and minimise microbial deterioration in seeds. So dehumidification is an essential factor in these areas.

There are mainly three types of dehumidification processes that are cooling based dehumidification, compression based dehumidification and chemical based dehumidification. In cooling based dehumidification air is cooled below its dew point temperature and thus the water vapour is condensed and removed. In compression based dehumidification system air is compressed to a larger pressure at which it dehumidifies the air. But both these processes consume a lot of power. Chemical based dehumidification is an economical method to dehumidify the air. Here we use some chemical called desiccants to dehumidify the air. Desiccants are the materials having a great affinity towards water vapour. It adsorbs or absorbs the water vapour in the air flowing over it. So by keeping desiccants in the flow path we can attain dehumidification.

Desiccant dehumidification is mainly classified into two types, solid desiccant dehumidification and liquid desiccant dehumidification. Among this the most economical method is solid desiccant dehumidification in which solid material are used as desiccants. In conventional form of air conditioning system the moisture is removed when it is passed over the evaporator coil. But this process consumes a lot of power. Therefore we use a desiccant dehumidification system so that moisture can be removed far before the air actually enters into the air conditioning system and thereby we can save a lot of power. To make the dehumidification a continuous process it is good to use rotary wheel type dehumidifiers. In this type desiccant is kept inside a wheel which is rotated using a motor and pulley. The whole wheel is divided into two sections namely regeneration section and process section. Dehumidification occurs at the process section and in the regeneration section the moisture adsorbed by the desiccant is removed from it by passing heated air.

The best desiccant is found to be silica gel which has a great affinity towards the water vapour. The principle of adsorption is very simple by which the water molecules binds to the surface of the desiccant. The adsorption capacity is a function of both temperature and vapour pressure. During adsorption two distinct processes occurs, chemical sorption and physical sorption. Chemical sorption occurs due to

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binding of water molecules to the hydroxyl group on the surface of desiccant material and this process is an irreversible process. Physical sorption occurs due to the weak van-der-waals force which binds water molecules on the pores and this process is a reversible process. Silica gel is found to be the best solid adsorbant.

In this paper parameter analysis is done on a rotary wheel desiccant dehumidifier to study the performance of the dehumidifier. Rotary wheel dehumidifier is designed and the performance analysis of an air conditioning unit is done by connecting the designed dehumidifier to the air conditioning unit.

II. EXPERIMENTAL SETUP AND PROCEDURE

The first and foremost step is to design a dehumidifier. For this a wheel has to be designed. It is in this wheel we keep the composite desiccant material (mixture of silica gel and calcium chloride). Both side of the wheel is covered using wire mesh. Desiccant is kept throughout the thickness of the wheel. The wheel is 30cm in diameter and 2.5cm thickness. When the desiccant gets saturated with water vapour we have to remove the water vapour to increase the adsorption rate. For this a regenerator (here a heating coil) is used. The wheel has to be divided into two sections, one for regeneration and the other for dehumidification. Here the wheel is divided into two equal halves. General outline of the system is shown in Fig.1.

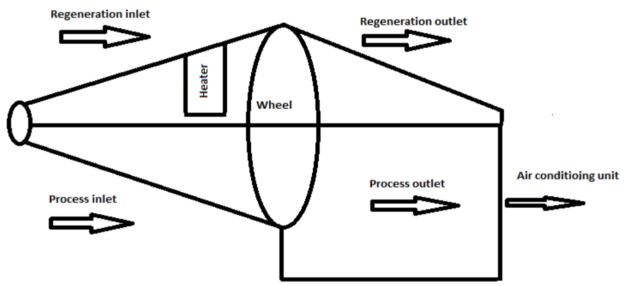

Fig.1. Outline of the dehumidification system

To rotate the wheel a geared ac motor is used with pulley and belt mechanism so that the wheel rotates at a speed of 30rph. To regulate the temperature of coil, a thermostat with rotating knob is connected to the heating coil. After the wheel has been designed, there should be a container which can hold the wheel as a whole so that there will be no air leakage which helps us to do the parameter analysis accurately. The design of the container depends on many factors including the diameter of blower outlet, inlet dimensions of the air conditioning unit, the diameter of the wheel etc.therefore a conical shape is given to the container at the inlet of dehumidifier. A 50 Hz blower having 130000rpm speed is used to blow the air to the dehumidifier. A controlling valve is used to control the flow rate of air during the parameter analysis.

The parameters which are varied during the parameter analysis are process inlet velocity, process inlet humidity, regeneration temperature, process air moisture and reactivation inlet velocity. The instruments used for measuring the varying parameters are wall mounted hygrometer and digital vane anemometer. The inlet of air conditioning system is in a square shape with side 15cm. Therefore the outlet portion of process side is made in square shape to make it fit to the air conditioning unit for doing the performance analysis. Designed dehumidifier is shown in the Fig. 2 and the dehumidifier connected to the air conditioning unit is shown in the Fig. 3.

Some performance indices are used during the parameter analysis such as moisture removal capacity (MRC), dehumidification efficiency (η_{deh}), coefficient of performance (COP) and power consumption rate. Moisture removal capacity is the difference between the inlet and outlet humidity ratio. Dehumidification efficiency is the ratio of moisture removal capacity to inlet humidity ratio. The equations used to find different performance indices are given below where ω_1 and ω_2 are inlet and outlet humidity ratio's respectively.

$$MRC = \omega_1 - \omega_2 \qquad (1)$$

$$\eta_{deh} = \frac{\omega_1 - \omega_2}{\omega_1} \qquad (2)$$

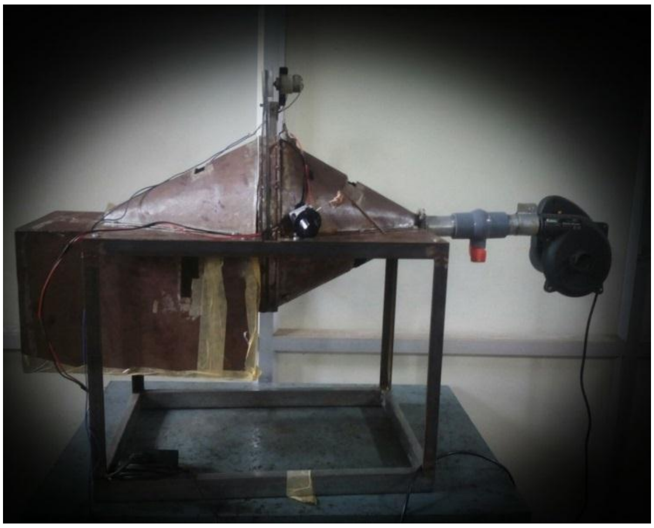

Fig.2. Designed composite solid desiccant wheel dehumidifier

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Fig.3. Dehumidifier connected to the air conditioning unit

III. EXPERIMENTAL RESULTS

Experimental tests have been carried out with different parameters to evaluate the performance of the designed dehumidifier. Parameters such as process inlet velocity, process inlet moisture, reactivation temperature, process inlet temperature and reactivation inlet velocity are varied and its effect on the proposed system is studied. Also tests were conducted on the air conditioning unit by connecting it to the dehumidifier to study the effect of dehumidifier on the proposed air conditioning unit. For this COP and power consumption rate of air conditioning unit with and without connecting the dehumidifier is found. Both values are compared and percentage difference in COP and power consumption rate is found.

A. Parameter Analysis

The parameter analysis is done by varying the inlet parameters. At first process inlet velocity is varied and its effect on outlet humidity is studied. The result obtained is shown graphically in Fig. 4. The result shows that when process inlet velocity increases the amount of moisture removed will get reduced. This is because when velocity increases the residence time in which desiccant and air come in contact reduces which in turn reduces the adsorption rate.

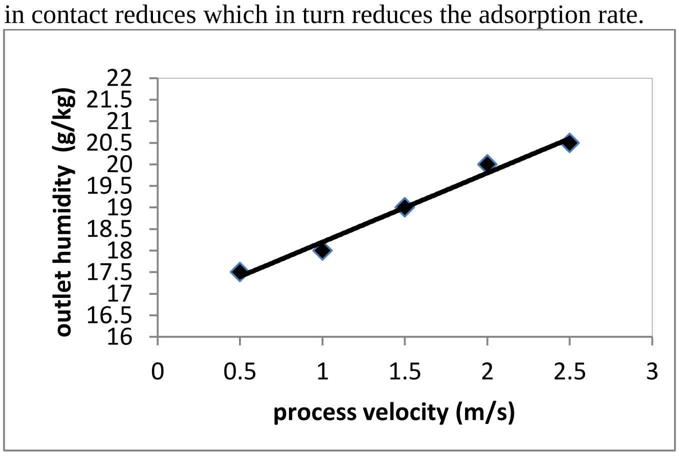

Fig.4. Variation of outlet humidity ratio with process inlet velocity

When the effect of process velocity on process outlet humidity is studied it is seen that the process outlet humidity reduces with increase in velocity. This occurs because dehumidification is an exothermic reaction. When velocity reduces more dehumidification occurs and thus outlet temperature will be high at low process velocity as it is shown in Fig. 5.

The study shows the effect of inlet humidity on outlet humidity is in such a way that the outlet humidity increases with increase in inlet humidity. Inlet humidity is varied by keeping different layers of wet cloth in the flow path. The variation is shown graphically in Fig. 6.It shows that if the inlet humidity is very high we have to keep a regulating mechanism or double layer of desiccant to keep the inlet atmosphere in a humidity as expected.

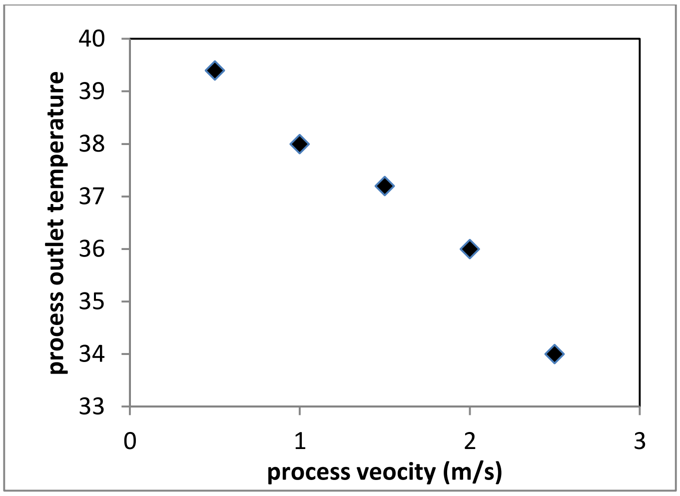

Fig.5. Effect of process velocity on process outlet temperature

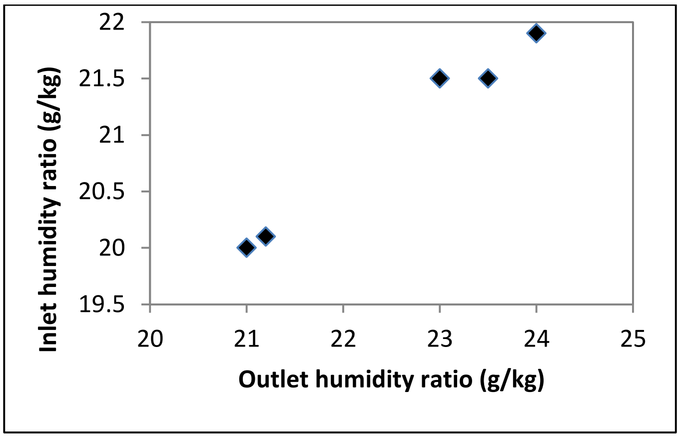

Fig.6. Effect of inlet humidity ratio on outlet humidity ratio

Regeneration temperature is also an important parameter which plays an important role in the working performance of the dehumidifier. The effect of regeneration temperature on outlet humidity ratio is studied. It shows that when regeneration temperature increases the amount of humidity removed also increases. That is the outlet humidity reduces with increase in regeneration temperature and the effect is shown graphically in the Fig. 7.

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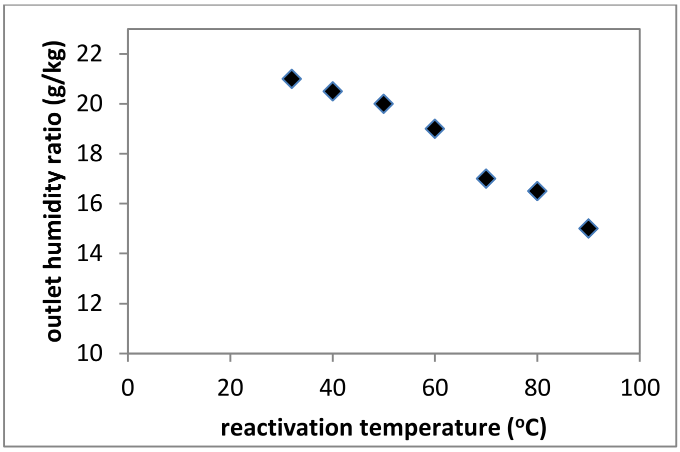

Fig.7. Effect of reactivation temperature on outlet humidity ratio

Then the effect of process inlet velocity on moisture removal capacity is studied. From the study it is seen that when the process inlet velocity increases moisture removal capacity reduces. The reduction occurs due to the reduction in the residence time which reduces the amound of humidity removed with increase in process inlet velocity. The variation is shown graphically in the Fig. 8. Moisture removal capacity is found out using equation 1.

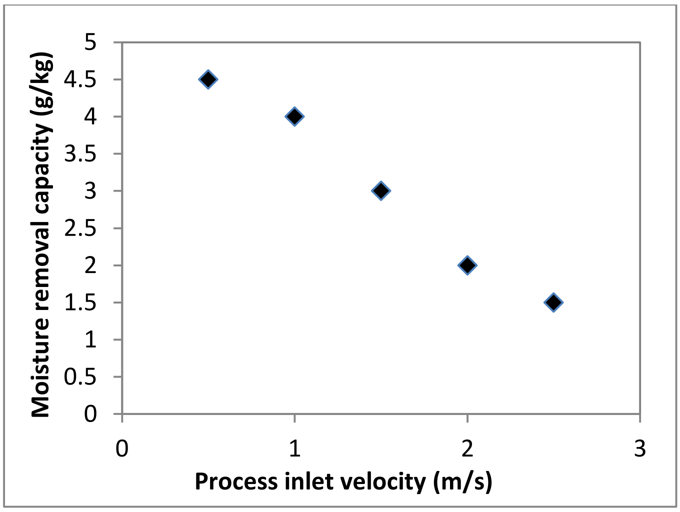

Fig.8. Effect of process inlet velocity on moisture removal capacity

The effect of regeneration temperature and inlet humidity on moisture removal capacity is also studied. When regeneration temperature increases process inlet velocity also increases as shown in Fig. 9.When temperature increases dehumidification capacity increasesdue to the increase in vapour pressure difference. Heated desiccant has a greater adsorption capacity. The study on effect of inlet humidity ratio on moisture removal capacity shows that when inlet humidity ratio increases moisture removal capacity also increases. This variation is shown in the Fig. 10. When inlet humidity increases more amount of moisture will get adsorbed which in turn increases the moisture removal capacity.

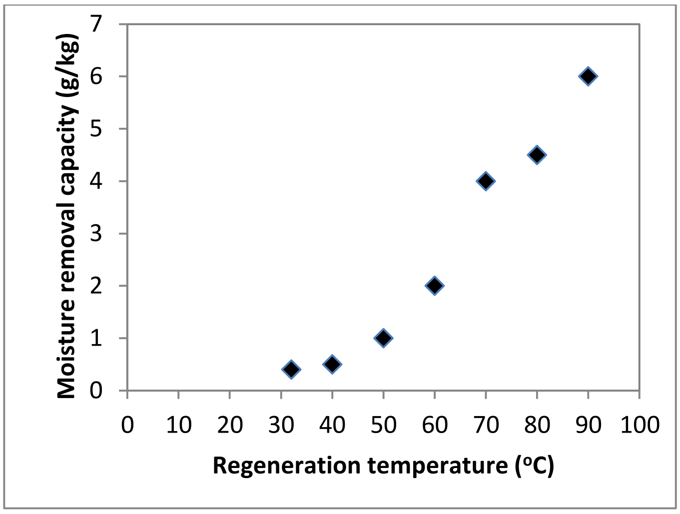

Fig.9. Effect of regeneration temperature on moisture removal capacity

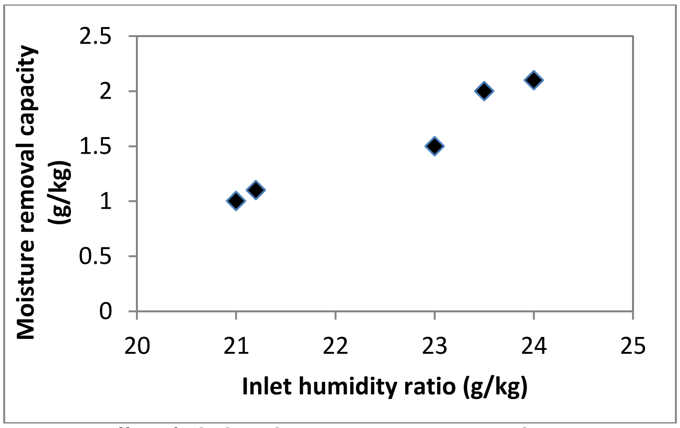

Fig.10. Effect of inlet humidity ratio on moisture removal capacity

The study in variation of dehumidification efficiency with regeneration temperature is done. From the study it is understood that the dehumidification efficiency increases with increase in regeneration temperature. The variation is shown graphically in the Fig. 11. Dehumidification efficiency is found out using equation 2. The effect of inlet humidity on dehumidification efficiency is also studied. It shows that dehumidification efficiency increases with increase in inlet humidity. When inlet humidity increases more moisture will get adsorbed which increases the moisture removal capacity. Increase in moisture removal capacity cause an increase in dehumidification efficiency. This variation is shown in Fig.12.

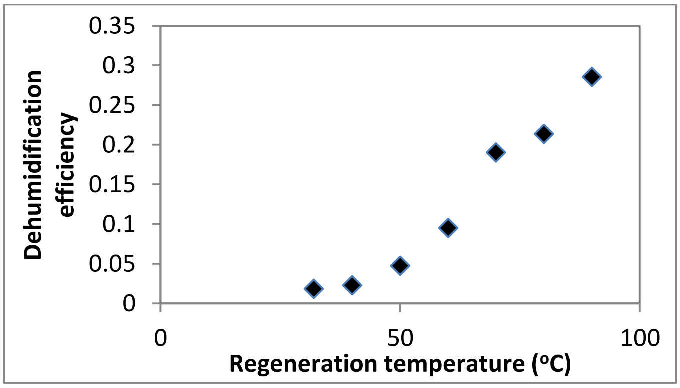

Fig.11. Effect of regeneration temperature on dehumidification efficiency

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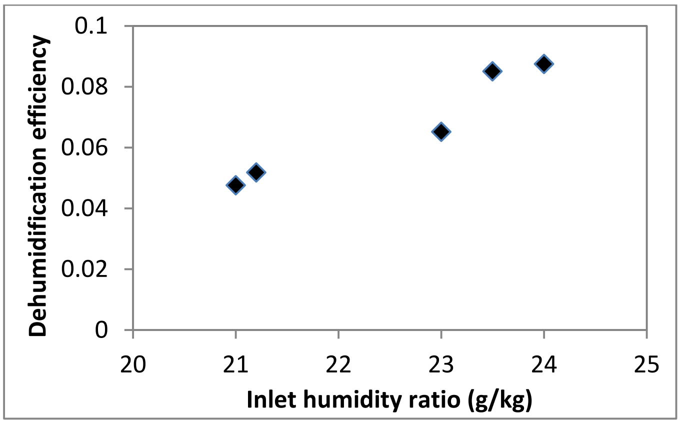

Fig.12. Effect of inlet humidity on dehumidification efficiency

B. Performance analysis

Performance analysis is done on the air conditioning system with and without connecting the dehumidifier. The analysis is mainly done on COP and power consumption rate of the air conditioning system. It is found that refrigeration effect increases from 2.36kJ/s to 2.99kJ/s and the compressor work reduces from 1.69kW to 1.59kW when the dehumidifier is connected to the air conditioning unit. This increase in refrigeration effect and reduction in compressor work give an overall increase of about 30% in COP of the system. The total power consumption reduces about 22% when the dehumidifier is connected.

IV. CONCLUSION

From the analysis of the results the following conclusions can be made:

- When high velocity is given to the process inlet air amound of humidity removed reduces so a speed of 1.5m/s if found to be optimum.
- High regeneration temperature increases the moisture removal rate, dehumidification efficiency and amound of moisture removed. The optimum regeneration temperature is found to be 70°C.
- When inlet humidity increases outlet humidity also increases. So if we need a constant outlet humidity we need to keep some regulators.
- Increase in inlet humidity increeases the moisture removal rateand dehumidification efficiency which shows that when inlet humidity increases more moisture will get adsorbed at the desiccant.
- Optimum regeneration temperature reduces from 80°C to 70°C when composite desiccant is used instead of using silica gel alone.
- When the dehumidifier is connected to the air conditioning unit COP of the system increases by 30% and power consumption rate reduces by 22%.

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