Content list available at http://epubs.icar.org.in, www.kiran.nic.in; ISSN: 0970-6429

Indian Journal of Hill Farming

December 2021, Volume 34, Issue 2, Page 70-75

Performance of solid desiccant dehumidifier for low temperature drying applications

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ARTICLE INFO

Article history:
Received: 29 October, 2021
Revision: 21 November, 2021
Accepted: 28 December, 2021

Key words: Dehumidification, solid desiccant dehumidifier, adsorption-desorption and drying.

ABSTRACT

This paper incorporates with the study of performance evaluation of solid desiccant dehumidifier. It was observed that the maximum adsorption capacity in the process air side is 12.79g/m^3 of dry air at 80°C. The adsorption capacity decreased to 3.39g/m^3 of dry air at 50°Ctemperature of the regeneration air. It was also observed that adsorption capacity increases with increase in temperature of regeneration air. The desorption capacity at regeneration side increased as the temperature of regeneration air rose. The regeneration side's minimum desorption capacity was 1.1 g/m^3 of dry air at 50°C temperature of the regeneration air, while the regeneration side's maximum desorption capacity was 9.61 g/m^3 of dry air at 80°C temperature of regeneration air. It was observed that desorption capacity increased with increase in regeneration temperature. It was found that the solid desiccant dehumidifier has the ability to produce low humidity process air at about 29-35% relative humidity and 43 $\pm$ 0.3°C temperature for the dying of products.

1. Introduction

Drying operation is an energy intensive manufacturing process that account for almost 15% of industrial energy consumption (Atuonwu *et al.*, 2011). Low temperature drying of products using low humidity low temperature air has recently become a very important and popular research focus for its features of eco-friendliness and energy efficient (Ge *etal.*, 2013). The air with low humidity has better moisture adsorption capacity, and it increases the drying rate and reduces drying time. Low temperature and low humidity air can be obtained by controlling regeneration temperature of the desiccant and mass flow rate of air. Low temperature drying of agricultural products leads to high retention of texture, color, nutrients and better quality. Therefore, drying using a solid desiccant dehumidifier is the best alternative method for food drying (Attkan *et al.*, 2016).

To remove moisture from humid air, solid desiccant dehumidification technology is an energy efficient alternative to traditional air dryingsystems, especially when solar energy and waste heat is used for regeneration of the desiccants (Goodarzia*et al.*, 2017). Solid desiccant dehumidification system (or desiccant wheel) could be coupled with other drying systems to provide desired air quality. The main component in these systems is desiccant wheel which is a rotary wheel stacked inside with desiccant materials. The overall efficiency of the system depends on the adsorption and desorption capacity of the desiccant materials. In our recent work it was presented about the feasibility of using cellulose rich organic fiber materials like, coconut (*Cocos nucifera*) coir, jute(*Corchoruscapsularis*) fibers and banana (*Musa acuminata*) pseudostem as desiccant was studied. The adsorption characteristic of the jute fibers was found to be superioras compared to other two organic fibers (Baruah*et al.*, 2019).

The present work was undertaken to evaluate the performance of a solid desiccant dehumidifier to reduce the moisture from ambient air, and to assess the use of dehumidified air for the low temperature drying applications.

2. Methodology

The present research was carried out in Silchar, which is situated in the Southern Assam, has tropical warm humid climate (temperature 15-35ºC, relative humidity >75%) with heavy rainfall (>2500 mm) during the period of May-June, 2018. Solid desiccant dehumidifier seems to have a great potential for drying and storage of various food products

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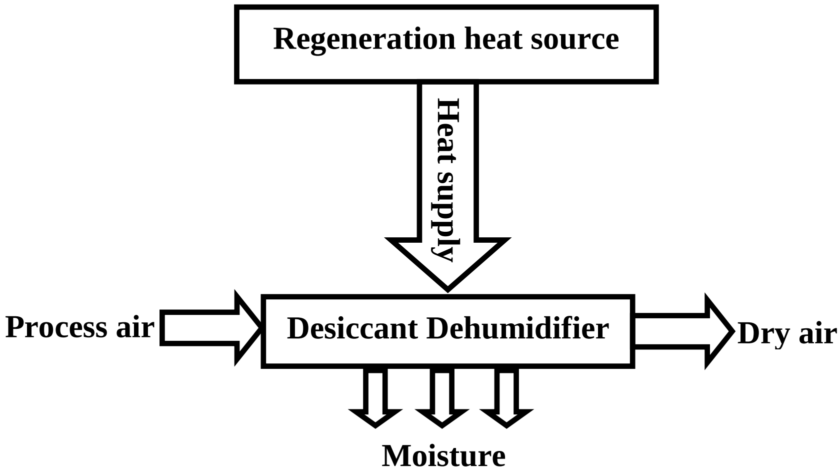

Figure 1. Working principle of solid desiccant dehumidifier

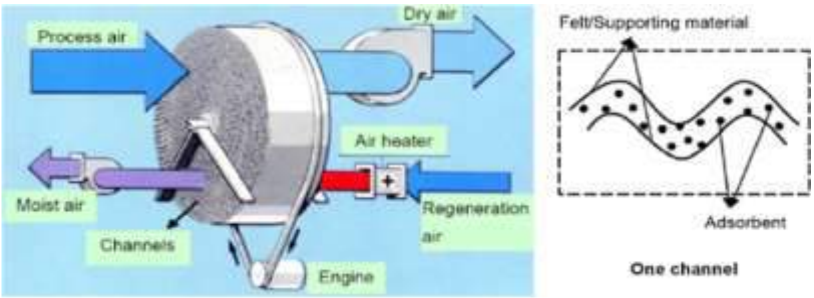

Figure 2. Solid desiccant dehumidifier (Source: La *et al.,* 2010)

in the region, particularly leafy greens and green leafy vegetables. The potential and performance of desiccant wheel under ambient conditions of Silchar, Assam is not available in literature. In the present study, an attempt was made to evaluate the performance of a solid desiccant dehumidifier to reduce moisture from ambient air, and to use the low temperature dehumidified air to dry potatoes and neem leaves. The low temperature dehumidified air can be used to produce potato flakes, powder, animal feed, and chips (which can be preserved for longer time) and the dried neem leaves can be used to produce powder which is an excellent insect repellant.

2.1 Details of solid desiccant dehumidifier

A rotary wheel type solid desiccant dehumidifier manufactured by M/s Chemietron Clean Tech Pvt. Ltd., Ahmedabad (model, Chemietron 150) was used in the present study. An overall view of the desiccant dehumidifier is shown in Figure 3. The technical specifications of the desiccant dehumidifier are given in Table 1.

The dehumidifier had the desiccant wheel made of silica gel in the honeycomb design and it was regenerated using a pair of electric heater. The desiccant wheel had the adsorption zone in the 3/4th of the circular sector and regeneration zone in the rest ¼ of the circular sector. A controller is provided that allowed the setting of the required relative humidity for the processed air and temperature for the heater.

A constant flow of ambient air was drawn by the dehumidifier at the rate of 255 m^3/h. As the air passed through the rotary desiccant wheel made of silica gel, the moisture in the air gets adsorbed, and the low relative humidity air (process air) passes out. The processed air could be given to a storage space or drying chamber. The ambient air for the regeneration of the desiccant wheel enters from the opposite end at the constant rate of 68 m^3/h. It is heated by the electric heater to the set temperature. As the hot air passes through the regeneration zone of the desiccant wheel, it dries the desiccant material.

2.2 Methods for evaluation of performance of the solid desiccant dehumidifier

Adsorption study of desiccant dehumidifier was carried out throughout the day for 15 days under ambient conditions. Process airflow rate was maintained at 255 m^3/h. The rotary speed of desiccant wheel was set at 100 rph. The regeneration

Figure 3. The rotary wheel type solid desiccant dehumidification system

Table 1. Specifications of solid desiccant dehumidifier

1.	Nominal air flow rate of process air, m^3/h	255
2.	Fan motor power, kW	0.25
3.	Diameter of dehumidifier wheel, mm	500
4.	Thickness of dehumidifier wheel, mm	50
5.	Desiccant material	Silica gel, honey comb design
6.	Rotational speed of dehumidifier wheel, rph	9
7.	Drive motor to dehumidifier wheel, kW	0.04
8.	Type of regeneration	Electric heater
9.	Regeneration temperature, ºC	80–130
10.	Heater power, kW	3.5
11.	Nominal air flow rate of reactivation air, m^3/h	68
12.	Fan motor power, kW	0.10

air temperature was varied from 50ºC to 80ºC. The regeneration air flow rate was maintained at 68 m^3/h. The variation in temperature and relative humidity of process air and regeneration were measured at every 30 minutes interval from 10.00 a.m. to 5.00 p.m. The variation in temperature and relative humidity of process air entering the dehumidifier and process air leaving the dehumidifier was plotted against time on each day.

Adsorption capacity is the capacity of the desiccant wheel to adsorb moisture from the ambient air entering the dehumidifier on the surface. It is the difference between the absolute humidity (kg/m^3 of dry air) of process air in and process air out of the dehumidifier.

Adsorption capacity of the dehumidifier = (Absolute humidity of process air in – Absolute humidity of process air out)

Desorption capacity (moisture removal capacity at regeneration side) is the capacity of the desiccant wheel to desorb moisture from the desiccant bed surface. It is the difference between the absolute humidity (kg/m3 of dry air) of regeneration air out and regeneration air in.

Desorption capacity of the dehumidifier= (Absolute humidity of regeneration air out – Absolute humidity of regeneration air in)

Adsorption capacity and desorption capacity of the dehumidifier was plotted against various regeneration air temperature.

3. Results and Discussion

3.1 Study of Variation in relative humidity and temperature of the process air in and process air out of the dehumidifier

Adsorption and desorption characteristics of the desiccant dehumidifier was studied throughout the day. The variation in relative humidity (R.H.) and temperature of the process air in and process air out of the dehumidifier throughout the day is shown in Figure 4 and data are presented in Table A-1 of Annexure-A. The experiment was conducted at a regeneration temperature of 80ºC. The temperature of the process air in varied from 31ºC at 10:00 hours to 35°C at 13:30 hours, and then decreased to 32°C at 17:00 hours. The relative humidity of the process air in decreased from 82% at 10:00 hours to 69% at 13:30 hours, and then increased to 85% at 17:00 hours. The average values of temperature and relative humidity of process air in were 32.73°C and 78.07%, respectively. The temperature of the process air out was increased from 42.3°C at 10:00 hours to 43.9°C at 13:30 hours, and then decreased to 42.4°C at 17:00 hours. The relative humidity of the process air out decreased from 34% at 10:00 hours to 29% at 13:00 hours, and then increased to 31% at 17:00 hours. The average values of temperature and relative humidity of the process air out were 31.53°C and 42.7%, respectively.

The experimental results indicate that temperature and relative humidity of process air out of the dehumidifier depends on the conditions of the process air in to the dehumidifier. Initially, the temperature was low at both sides, and then started increasing. It decreased again in the evening hours. The temperature of the process air out of the dehumidifier increased with increase in temperature of the process air in to the dehumidifier, and decreased with decrease in temperature of the process air in to the dehumidifier. Initially, relative humidity was higher at both process air in and process air out, and then it started decreasing at both sides. There was increase in the relative humidity again in the evening at the end of experiment.

Adsorption and desorption characteristics of the dehumidifier

Adsorption capacity is the capacity of the desiccant wheel to adsorb moisture on the surface. It is the difference between the relative humidity of process air in and process air out of the dehumidifier. The adsorption capacity of the dehumidifier at different temperatures of the regeneration air are shown in Figure 5, and the data are presented in Table A-2 of Annexure-A. It was observed that the maximum adsorption capacity in process side is 12.79g/m^3 of dry air at 80°C. The adsorption capacity decreased to 3.39g/m^3 of dry air at 50°Ctemperature of the regeneration air. It was also observed that adsorption capacity increases with increase in temperature of regeneration air.

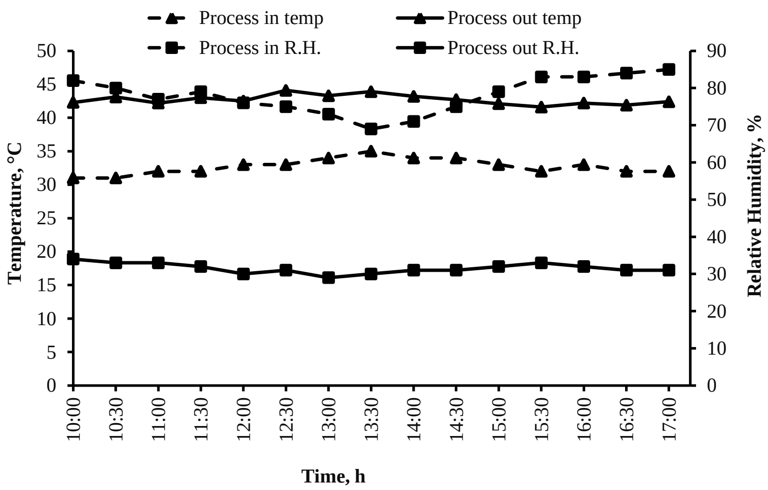

Figure 4. Variation in relative humidity (R.H.) and temperature of the process air in and process air out of the dehumidifier throughout the day

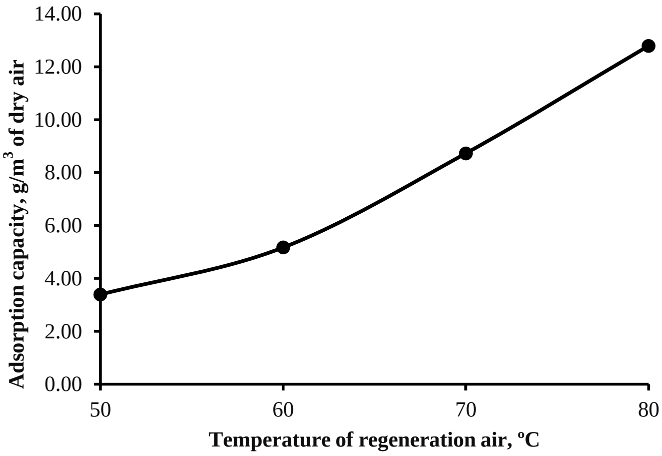

Figure 5. Variation in adsorption capacity of the dehumidifier with temperature of the regeneration air

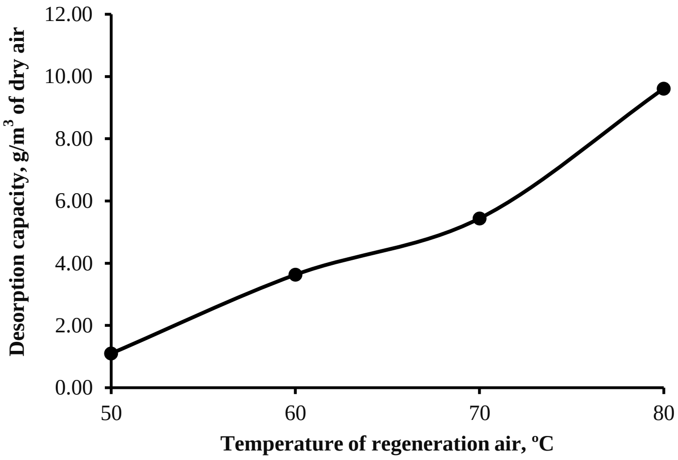

Figure 6. Variation in desorption capacity of the dehumidifier with temperature of the regeneration air

Moisture removal capacity at regeneration side (desorption capacity) is the capacity of the desiccant wheel to desorbs moisture from the desiccant bed surface. It is the difference between the absolute humidity of regeneration air out and regeneration air in to thee dehumidifier. The desorption capacities at different temperatures of regeneration air at constant mass flow rate of 255 m^3/s for process air are shown in Figure 6, and the data are presented in Table A-3 of Annexure-A. It can be observed from the Figure 6 that the desorption capacity at regeneration side increased with increase in temperature of regeneration air. The minimum desorption capacity on the regeneration side was 1.1 g/m^3 of dry air at 50°C temperature of the regeneration air, and the maximum desorption capacity on regeneration side was 9.61 g/m^3 of dry air at 80°C temperature ofregeneration air. It was observed that desorption capacity increased with increase in temperature of regeneration air. Attkan*et* al. carried out a comparative study between dehumidified air drying and tray drying of fenugreek green leavesfrom an initial moisture content of 88.6 % to 5% (wb). (Attkan*et al.*, 2014).

4. Conclusion

From the observations it was found that process airflow rate was about 255 m^3/h. The rotary speed of desiccant wheel was 100 rph. The regeneration air temperature was fixed at 80ºC. The regeneration air flow rate was 68 m^3/h. From the study it can be concluded that the solid desiccant dehumidifier had the ability to give out the low humidity process air at 29-35% relative humidity and 43±0.3°C temperatures which can be used for the low temperature dying of products. Hence, the solid desiccant dehumidifier can be used for the low temperature drying of products.

5. Conflict of Interest

The authors have no conflicting financial or other interests.

6. Acknowledgements

The authors acknowledge Assam University, Silchar for providing the necessary facilities for carried out the research work.

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ANNEXURE-A
ADSORPTION AND DESORPTION CHARACTERISTICS OF THE DESICCANT DEHUMIDIFIER

Table A-1 : Relative humidity (R.H.) and temperature of the process air in and process air out of the dehumidifier throughout the day

Time, h	R.H. of the process air in, %	R.H. of the process air out, %	Temperature of the process air in, °C	Temperature of the process air out, °C
10:00	82	34	31	42.3
10:30	80	33	31	43.1
11:00	77	33	32	42.2
11:30	79	32	32	43
12:00	76	30	33	42.5
12:30	75	31	33	44.1
13:00	73	29	34	43.3
13:30	69	30	35	43.9
14:00	71	31	34	43.2
14:30	75	31	34	42.7
15:00	79	32	33	42.1
15:30	83	33	32	41.6
16:00	83	32	33	42.2
16:30	84	31	32	41.9
17:00	85	31	32	42.4

Table A-2: Adsorption capacity of the dehumidifier at different temperatures of regeneration air
Temperature of process air in = 33ºC
Relative humidity of process air in = 78%

Temperature of regeneration air, ºC	Temperature of process air out, ºC	Relative humidity of process air out, %	Adsorption capacity, g/m^3 of dry air
50	37	60	3.39
60	39	49	5.17
70	42	37	8.73
80	45	27	12.79

Table A-3: Desorption capacity of the dehumidifier at different temperatures of regeneration air
Temperature of process air in = 33ºC
Relative humidity of process air in = 78%

Temperature of regeneration air, ºC	Temperature of process air out, ºC	Relative humidity of process air out, %	Desorption capacity, g/m^3 of dry air
50	35	73	1.10
60	38	67	3.63
70	40	66	5.44
80	44	60	9.61