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RESEARCH ARTICLE

Adsorption and regeneration characteristics of composite desiccants

Dharmender[1], Tapan Kumar Khura[2]* (LM-10477), Indra Mani[3], Roaf Ahmad Parray[4], T. V. Arun Kumar[4]

[1]*Ph.D Scholar;* [2]*Principal Scientist;* [3]*Head;* [4]*Scientist, Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi, India..*

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ABSTRACT: Solar dryers are economical for crop drying and are environmental friendly. However, in tropical region due to highhumidity of ambient air the efficiency of solar dryer gets reduced. Desiccants can be used for reducing the humidity of ambient air. In the present study, three desiccants *viz.* silica gel, bentonite clay and activated carbon were selected and tested for their use to improve efficiency of solar dryer. The composite desiccant mixture was prepared by mixing three selected desiccants in different ratios and was evaluated for adsorption and regeneration characteristics. The adsorption rate of different composite desiccants was calculated at 2 h interval. The regeneration rate of composite desiccants was studied at a temperature of 50°C and 55°C and the data were recorded at 1 h interval. The evaluation was done at three weightage levels of adsorption rate: regenerate: unit cost *i.e.* 50:30:20, 60:20:20 and 40:40:20. The maximum value of performance index at three weightage levels based on highest adsorption rate and regenerate rate and lowest unit cost was observed as 1.66, 1.5 and 1.81. The treatment T_1 (Silica gel 100%) was found as better desiccant among the selected composite desiccant with average adsorption rate 1.49 %moisture per h followed by T_5 (Silica gel 80%, Activated 20%) with 1.46% moisture per h, respectively. The statistical analysis showed that the performance efficiencies of silica gel were observed highest 84.33%, 77.33%, and 91.7% at different weightages of adsorption rate, regeneration rate and cost of composite desiccant.

1. INTRODUCTION

Drying is an important unit operation in agricultural processing. In tropical regions, high humidity of air influences the drying process and reduces the drying rate. The drying rate can be controlled by regulating the humidity of air in the drying process.Dry air can be obtained either by compressing air to high pressure or lowering the temperature of air. Both of these processes involves energy and cost. Whereas, dry air can also be obtained by using absorbent/desiccant materials like silica gel, activated carbon, bentonite clay and *etc*. The desiccant has natural affinity for adsorption, it is able to take up additional moisture given up by the air. These desiccants can be effectively used in desiccant drying process. Desiccant dehumidification system has received much consideration in the recent years as a substitute to the physical dehumidification. The advantage of usingdesiccant in a drying system include continuousdrying even during off-sunshine hours, increased drying rate due to hot dry air, more uniform drying and increase in the product quality especially for heat sensitive product. Desiccant material can be broadly classified as liquid and solid desiccant. Handling of solid desiccant in dryer is easier than liquid desiccant. The solid desiccants such as silica gel, bentonite clay, activated charcoal, zeolite, some salts like calcium sulphate, calcium chloride, sodium chloride and activated alumina have been used for removing the humidity from the air in dryer. The dehumidification process through desiccant is continued till the desiccant reaches to its saturation. Regeneration process of saturated desiccants is required in order to reuse desiccant. The desiccant can be regenerated by heating. Temperature required for regeneration of desiccant should be in the range of 40°C to 70°C (Singh and Singh, 1998). The average solar radiation incident over India is 4-7 kWh.m^{-2}day^{-1} with an annual radiation about 1200 kWh.m^{-2} and 250-300 clear

Corresponding Author: Tapan Kumar Khura
**E-mail:* tapankhura2020@gmail.com

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sunny days with around 1500–2000 daylight hours per year depending upon location, which is significantly more than current total energy utilization (MNRE, 2013). The solar dryer appears to be most appropriate and commercial proposition (Mekhilefa *et al.,* 2011, Dubey *et al.,* 2019).

Most of the earlier studies emphasized ona desiccant and few work on the composite desiccant prepared of silica gel, calcium chloride and zeolite, no specific efforts has been made towards the composite desiccant from silica gel, bentonite clay and activated carbon. Therefore, the present study was under taken for evaluating adsorption and regeneration characteristics of different composite desiccant use for solar dryer.

2. MATERIALS AND METHODS

2.1. Selection of Desiccants

The selection of composite desiccant was based on regeneration characteristics, absorption characteristics and overall cost of the composite desiccants. The study was carried out in processing lab of the division of Agricultural Engineering, ICAR-IARI, New Delhi.The solid desiccants are more compact and most effective compared to liquid desiccants.Three different desiccants were selected and used in different proportions for development of composite desiccants.

Among all solid desiccants generally silica gel, activated alumina, activated carbon are used due to their higher moisture carrying capacity (Anonymous, 1978).Bentonite clay, a low cost solid desiccant is preferred because of expensiveness of most commercial desiccants (Thoruwa *et al.*, 1996). Thus, silica gel, bentonite clay and activated carbon (Fig. 1) were selected for the study.

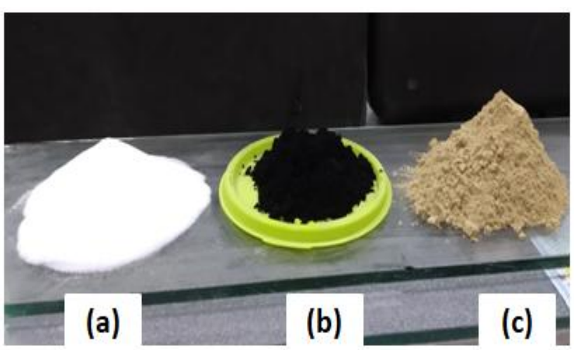

Fig. 1. Selected desiccants (a-silica gel; b-activated carbon; c-bentonite clay) for preparation of composite desiccant

2.2. Preparation of Composite Desiccants

Eleven composite desiccants were prepared by mixing the selected desiccants in different proportions (Table 1). Silica gel, because of its better absorption characteristics, was taken as a base desiccant. The activated charcoal and bentonite clay were used in different proportions to replace 10 to 40% of silica gel in the composite mixture.

Table 1.
Selected composite desiccants with varying proportion of selected desiccants

Treatment	Silica gel (%)	Bentonite clay (%)	Activated carbon (%)
T_1(Silica gel 100%)	100	0	0
T_2 (Bentonite clay 100%)	0	100	0
T_3 (Activated carbon100%)	0	0	100
T_4 (Silica gel 80%, Bentonite clay 20%)	80	20	0
T_5 (Silica gel 80%, Activated carbon 20%)	80	0	20
T_6 (Silica gel 80%, Bentonite clay 10% Activated carbon10%)	80	10	10
T_7 (Silica gel 60%, Bentonite clay 40%)	60	40	0
T_8 (Silica gel 60%, Activated carbon 40%)	60	0	40
T_9 (Silica gel 60%, Bentonite clay 30% Activated carbon10%)	60	30	10
T_{10} (Silica gel 60%, Bentonite clay 10% Activated carbon 30%)	60	10	30
T_{11} (Silica gel 60%, Bentonite clay 20% Activated carbon 20%)	60	20	20

2.3. Experimental Layout

The adsorption rate of each composite desiccant was monitored in a dryer at a set temperature of 40°C. The regeneration characteristics of composite desiccants were studied at a temperature of 50°C and 55°C (Table 2).

Table 2.
Plan of experiment for studyingthecharacteristic properties of selected composite desiccants

Variables	Levels	Parameters studied
Composite desiccant	11	Adsorption rate
Regeneration temperature	2 (50°C, 55°C)	Regeneration rate
Replications	3	Overall cost of desiccant
Total treatments	11 x 2 x 3 = 66	

2.4. Adsorption Characteristics of Composite Desiccants

A sample of 100 g seed at 20±0.5% moisture content (w.b) was kept over a 100 g composite desiccant inside a desiccator with a thin layer perforated paper in between the two. This desiccator is placed inside an oven set at a temperature of 40°C (Fig. 2). After every 2 hours the sample was removed from the oven and weight of seed sample was recorded by use of weighing balance least count 1mg. The reduction in moisture content (% w.b) due to desiccant was taken as absorption rate (% basis) of composite desiccant.The process was continued till the seed sample reached moisture content of 8±0.3% or for a minimum time of 16 hours which ever was attained first.

2.5. Regeneration Characteristics of Composite Desiccants

The regeneration of a desiccant is essential because after adsorption of moisture from the seed the surface of desiccant becomes saturated. This, in turn, results in decreasing its moisture carrying capacity. The regeneration characteristics of the composite desiccants after adsorption was studied at a temperature 55°C as the maximum attainable temperature withina solar dryer ranged from 50 to 60°C (Pachpinde *et al*., 2018). The sample of composite desiccant after adsorption was kept in desiccator inside the oven set at the temperature under consideration. After every one hour the sample was removed and the weight was recorded. The loss in weight (g) per hour was taken as regeneration rate ($g.h^{-1}$) of composite desiccant.

2.6. Selection of Efficient Composite Desiccant

The criteria for selection of efficient composite desiccant were high regeneration rate and absorption rate and low overall cost of the composite desiccant. For this an index was developed named as 'desiccant performance index' as following

Desiccant performance index (DPI) =

$$W_1x_1 + W_2x_2 + W_3\frac{1}{x_3} \quad ...(1)$$

Where,

W_1, W_2, and W_3 are the weightage factors for adsorption rate, regeneration rateand cost, respectively, and X_1, X_2 and X_3 are the observed values for adsorption rate (% $m.c.h^{-1}$), regeneration rate ($g.h^{-1}$) and overall cost (INR) of composite desiccant, respectively. The cost (x_3) of composite desiccant was calculated based on the individual costs of three selected desiccants and their proportion in the composite desiccant.

3. RESULTS AND DISCUSSION

3.1. Adsorption Rate of the Composite Desiccant

The adsorption rate of treatment T_1 (Silica gel 100%) was observed highest 1.49% $m.c.h^{-1}$ followed by T_5 (Silica gel 80% Bentonite clay 20%) with adsorption rate of 1.46% $m.c.h^{-1}$ among the composite desiccants (Fig. 2). This was because of highly porous with a larger surface area (800 $m^2.g^{-1}$) of silica gel desiccant. The silica gel desiccant does not undergo any chemical reaction during adsorption and does not form any by product. Similar trend were reported by Yadav and Bajpai (2012) and Kumar *et al*. (2014) in their studies where the adsorption rate of silica gel was found higher compared to activated charcoal and activated alumina. The lower adsorption rate of 0.73 % $m.c.h^{-1}$ was observed for desiccant of pure bentonite clay. The result also showed that the adsorption rate during initial 8h was higher in all the treatments due to higher vapour pressure gradient (Fig. 2).

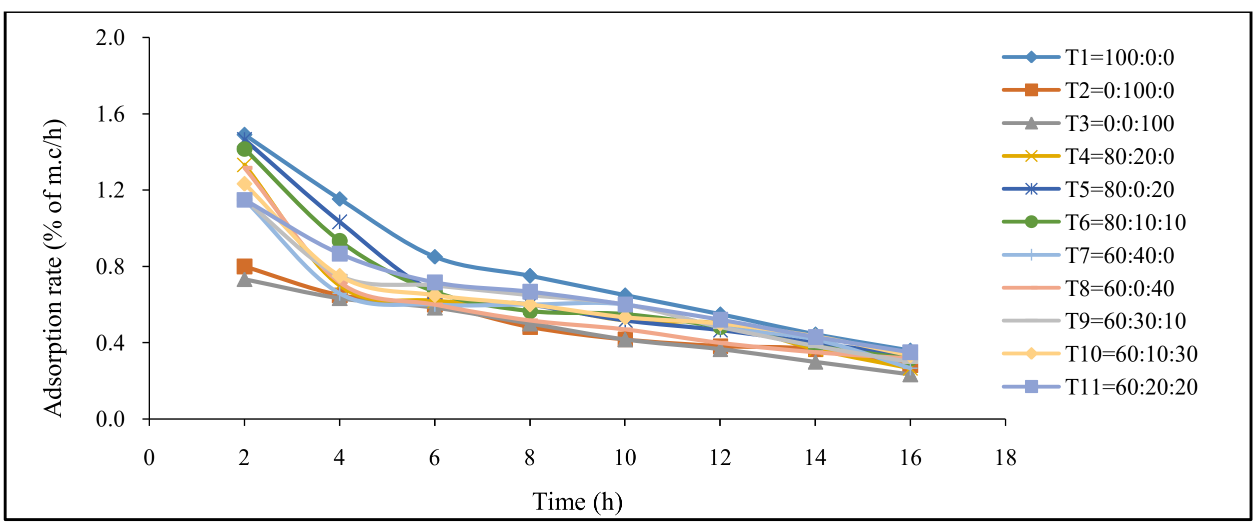

Fig. 2. Adsorption characteristics of different composite desiccants

3.2. Regeneration Rate of the Composite Desiccant

The average regeneration rate of composite desiccant during initial 2-h at 55°C was observed as T_1 (4.33g.h^{-1}), T_2 (2.84g.h^{-1}), T_3 (2.89g.h^{-1}), T_4(3.63 g.h^{-1}), T_5 (3.92g.h^{-1}), T_6 (3.73g.h^{-1}), T_7 (3.32g.h^{-1}), T_8 (3.61g.h^{-1}), T_9 (3.4g.h^{-1}), T_{10} (3.48g.h^{-1}) and T_{11} (3.39g.h^{-1}), respectively (Fig. 3). The average regeneration rate was found highest of treatment T_1 (silica gel 100%) with (3.05 g.h^{-1}) and followed by the T_5 (silica gel 80 %, activated carbon 20%) (2.67g.h^{-1}). Silica gel (T_1) was found to have the highest value of regeneration rate and hence accounting for its faster re usability during drying process.Similar trends were observed by Chua and Islam (2015) and Kumar *et al.* (2014). Dupont *et al.* (1994) studied and compared the performance of silica gel and activated alumina. The lowest average regeneration rate of 2.04 g.h^{-1} rate was observed for bentonite clay (100%) and forall other treatments *i.e.* T_3, T_4, T_6, T_7, T_8, T_9, T_{10} and T_{11}, the average values were 2.05, 2.46, 2.54, 2.28, 2.45, 2.30 and 2.34 g.h^{-1}, respectively (Fig.3).

3.3. Cost Analysis of Different Composite Desiccants

The market rate of 100 g of silica gel, activated carbon, and bentonite clay was Rs. 168, Rs. 75 and Rs. 70, respectively. Based upon the individual cost of three selected desiccants and their proportion in the composite desiccant, the cost of composite desiccants was calculated and presented in Table 3.

3.4. Performance Index of Selected Composite Desiccants

The composite desiccants were evaluated for performance based on adsorption characteristics, regeneration characteristics, and unit cost. The evaluation was done at three weightage levels of adsorption rate: regenerate: unit cost *i.e.* 50:30:20, 60:20:20, 40:40:20. The maximum value of performance index at three weightage levels based on highest adsorption rate and regenerate rate and lowest unit cost was observed as 1.66, 1.5 and 1.81 for a weightage level of 50:30:20, 60:20:20 and 40:40:20, respectively. It was observed that desiccant performance index based at all three weightage levels was highest for Silica gel (100%). The respective values at weightage level of 50:30:20, 60:20:20 and 40:40:20 were 1.4, 1.17 and 1.6. For all other composite desiccants, the performance index was lower than the mentioned values at respective weightage levels. Based on desiccant performance index, silica gel was selected for solar dryer. Significant difference in desiccant performance index was observed for composite desiccants at all the three weightage levels (Table 4 to 6).

Table 3.
Cost of composite desiccants

Treatment	Silica gel (%)	Bentonite clay (%)	Activated carbon (%)	Unit price Rs./100g
T_1	100	0	0	168
T_2	0	100	0	70
T_3	0	0	100	75
T_4	80	20	0	148
T_5	80	0	20	150
T_6	80	10	10	149
T_7	60	40	0	123
T_8	60	0	40	131
T_9	60	30	10	129
T_{10}	60	10	30	130
T_{11}	60	20	20	130

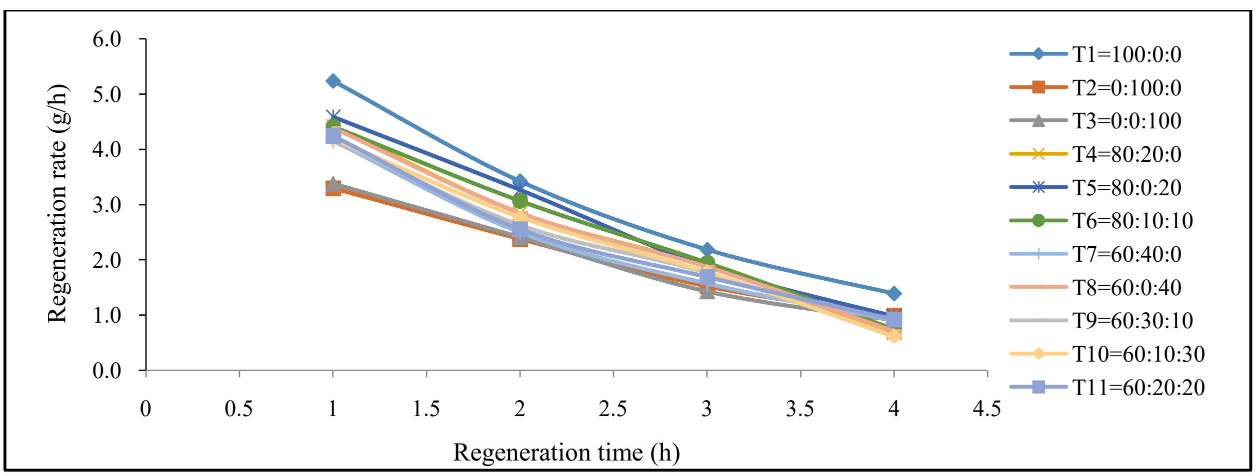

Fig. 3. Regeneration rate of different composite desiccants at 55°C

Table 4.
ANOVA for desiccant performance (index-I) at weightage factor 0.5, 0.3, 0.2 assigned to (adsorption rate, regeneration rate and unit cost)

Source	DF	Sum of square	Mean Square	F Value	Pr > F
Replication	2	0.000	0.0003	0.31	0.735
Treatment	10	0.562	0.056	58.00	<.0001

Table 5.
ANOVA for desiccant performance (index-I) at weightage factor 0.6, 0.2, 0.2 assigned to (adsorption rate, regeneration rate and unit cost)

Source	DF	Sum of square	Mean Square	F Value	Pr > F
Replication	2	0.002	0.001	0.73	0.4935
Treatment	10	0.490	0.049	39.41	<.0001

Table 6.
ANOVA for desiccant performance (index-I) at weightage factor 0.4, 0.4, 0.2 assigned to (adsorption rate, regeneration rate and unit cost)

Source	DF	Sum of square	Mean Square	F Value	Pr > F
Replication	2	0.002	0.001	0.78	0.470
Treatment	10	0.920	0.092	59.53	<.0001

4. CONCLUSIONS

Three desiccants *viz.*, silica gel, bentonite clay and activated carbon were evaluated for use in solar seed dryer. The composite desiccants were prepared by taking different proportions of three selected desiccants (*viz.*, silica gel, activated carbon, bentonite clay). At regeneration temperatures (*i.e.* 50°C and 55°C) the prepared composite desiccants were evaluated for various performance parameters like adsorption capacity, regeneration capacity and cost. Study revealed that 100 per cent silica gel was better desiccant among all the selected composite desiccant with average adsorption rate of 1.49 per cent moisture per h followed by silica gel-activated carbon composite (80:20) having adsorption rate of 1.46 per cent moisture per h. The average regeneration rate of treatment T_1 (Silica gel 100%) was higher among all the composite desiccant at 55°C (3.05 $g.h^{-1}$) followed by carbon T_5 (Silica gel 80%, Activated 20%) having value2.67 $g.h^{-1}$. The statistical analysis showed that the performance efficiencies of silica gel were observed to be highest with 84.33%, 77.33%, and 91.7% at different weightages of adsorption rate, regeneration rate and cost of composite desiccant, respectively.

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