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FEASIBILITY OF USING AGRICULTURAL WASTE AS A DESICCANT FOR AIR CONDITIONING SYSTEMS

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ABSTRACT

The present work aims at investigating the feasibility of using agricultural waste as a desiccant for an open cycle air conditioning system. The natural fibers are, therefore, intended to replace chemical desiccants such as silica gel, zeolites, molecular sieves, etc. The study is carried out on coconut coir, palm tree fiber, rice straw, baggase, and silica gel. It was found out that agricultural waste (namely palm tree fiber, rice straw) presents a good performance as compared to silica gel. Also, it is found out that the temperature of the air leaving agricultural waste bed is lower than that of silica gel bed, resulting in lower cooling energy requirements for air conditioning systems. In addition, using agricultural waste offers additional value of preserving our environment and promoting natural products. In the present work, the effect of the different operating parameters on performance of the desiccant beds has been investigated. The performance is generally characterized by the exit air relative humidity, water vapor adsorption capability, adsorption time, desorption time, performance factor, and pressure drop for different types of desiccants (namely silica gel, coconut coir, palm tree fiber, rice straw, and baggase).

KEYWORDS: Agricultural waste – Desiccant air conditioning systems

1 INTRODUCTION

Among Egypt agricultural waste, rice straw, palm tree fiber, and baggase represent a considerable fraction. This agricultural waste is disposed off by burning, which causes significant environmental problems. Located in the hot climatic zone, Egypt relies on air conditioners to ensure residential thermal comfort. Today, the energy consumed by air conditioners represents 50-70% of the total energy consumption in the commercial and residential sectors.

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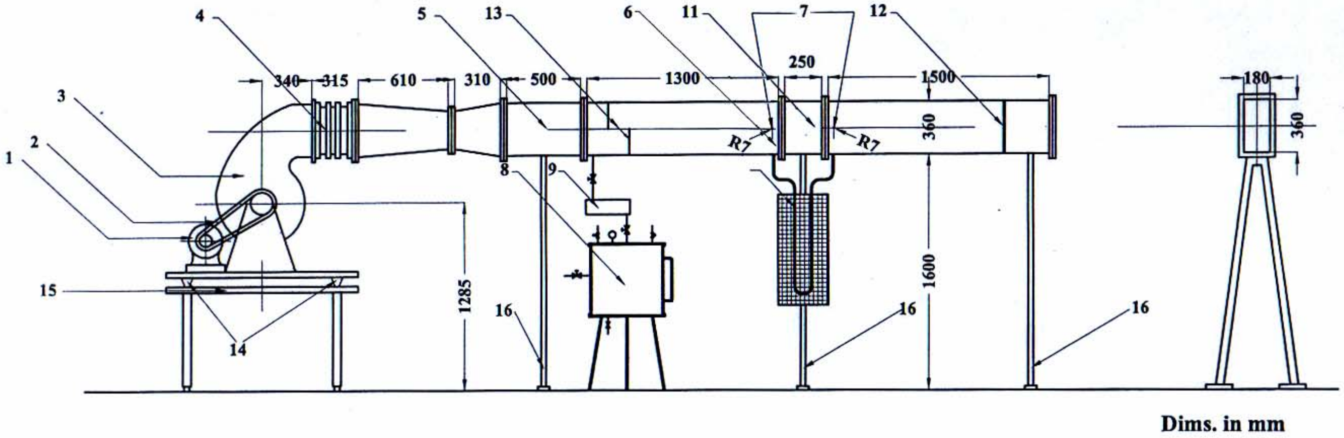
In addition, due to the release of CFCs or HCFCs, from HVAC equipment, steady depletion of the ozone layer is caused. To overcome these issues, various research efforts were devoted to air conditioning systems using desiccants in order to reduce energy consumption. The process of air conditioning by air dehumidification through direct contact with an hygroscopic agent is known and reported by different investigators [1-5].

Desiccant cooling systems are particularly useful when the latent load is large in comparison to the sensible load. Desiccants can also be used to remove contaminants from airstreams to improve indoor air quality [6]. In general, liquid and solid chemical moisture adsorbents such as silica gel and zeolite are often used. These investigations demonstrated the good potential of these materials in this regard (moisture adsorption). However, the temperature of the outlet air from the desiccant system was relatively high, thus requiring more energy for cooling it by the air conditioning system. The basic constituent of the desiccant cooling system is the desiccant bed. The heat and mass transfer characteristics of the bed have significant effects on the performance of the cooling system, and should therefore be adequately considered. The present work presents an investigation on the feasibility of using agricultural waste for moisture absorption as applied to opened-cycle air conditioning systems.

2 EXPERIMENTAL WORK

2.1 Test Rig

A test rig is designed and constructed for testing desiccants and includes humidification and dehumidification sections. A schematic diagram representing the experimental set-up is shown in Figure (1). A vertical, electrically heated steam generator equipped with a superheater was designed and constructed. The heating energy for the steam generator is supplied by means of four electric heaters. The test rig also contains a centrifugal air blower fitted with a variable opening gate, a heating section, a desiccant bed, and measuring devices. The used wind tunnel is a horizontal rectangular duct having the same cross-section as that of the blower outlet [180x360 mm^2]. The duct consists of six sections connected to each other by means of flanges with rubber gaskets to avoid air leakage between sections as shown in Figure (1).



1-A.C. electric motor
2-V-belt
3-Air blower
4-Flexible textile connection
5-Heating section
6-Thermocouple location
7-Digital hygrometer location
8-Steam generator
9-Superheater
10-U-tube manometer
11-Desiccant bed
12-Hot wire anemometer
13-Baffles
14-Rubber seat
15-Table
16-Supports

Fig. 1: A schematic diagram representing the experimental set-up

The third section is the heating section whereas the fourth section is equipped with two baffles to ensure good mixing of air and steam. At the end of the fourth section, upstream of the desiccant bed, a small glass pipe (7 mm in diameter) is fitted for digital hygrometer probe for measuring inlet air relative humidity. Also, a hole (2 mm diameter) is provided in for fitting a copper-constantan thermocouple measuring the inlet air temperature. The fifth section is the desiccant bed section. At the entrance of the sixth section, downstream the desiccant bed, a small (glass pipe 7 mm in diameter) is fitted for digital hygrometer probe measuring the exit air relative humidity and temperature.

2.2 Experimental Procedure

The following parameters were measured: inlet air relative humidity, inlet air temperature, exit air relative humidity and temperature at different time intervals, and air velocity. The parameters derived from the measurements are: water vapor adsorbed, adsorption and desorption time, pressure drop across, and the performance factor for different types of desiccants. The effects of the following parameters were studied in all cases: inlet air relative humidity, air velocity, inlet regeneration temperature, and desiccant bed material. Water vapor adsorbed is calculated from the following equation:

$$W_{ad} = \frac{\dot{m}_a(\omega_1 - \omega_2)\tau}{m_d} \tag{1}$$

, the pressure drop across the desiccant bed is calculated from:

$$\Delta P = \rho_w g \Delta \mathrm{H} \tag{2}$$

and the performance factor for the desiccant material is defined as:

$$P_f = \frac{\dot{m}_a(h_1 - h_a)}{\dot{m}_a(h_2 - h_a)} \tag{3}$$

3 RESULTS AND DISCUSSIONS

3.1 Adsorption mode

The value of the inlet relative humidity considered is 92%. The velocity is 0.3 m/s for the silica gel and 5 m/s for other desiccants. The velocity for the silica gel is lower than the other desiccants due to the silica gel blocks the air flow and increases the pressure drop across the bed.

3.1.1 Effect of Desiccant Material on Exit Relative Humidity

The results in Figure (2) show that exit air relative humidities as a function of adsorption time for coconut coir, palm tree fiber, rice straw, and baggase beds are higher than that of silica gel bed. Results show that the exit air relative humidity for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 91%, 88%, 90%, 89%, and 16% respectively after 5 minutes of adsorption process. Also, it was observed that the adsorption time for coconut coir, palm tree fiber, rice straw, and baggase beds is low compared to that of the silica gel bed. Results show that the adsorption time for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 6, 8, 7, 7, and 220 minutes respectively, showing that the water vapor adsorption capacity for silica gel bed is higher than other desiccants.

3.1.2 Effect of Desiccant Material on Air Temperature Rise

The results in Figure (3) show that the air temperature rise along the adsorption time for coconut coir, palm tree fiber, rice straw, and baggase beds are less than that of silica gel bed. Results show that the air temperature rise for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 0.1, 0.6, 0.4, 0.3, and 18 ^{o}C respectively after 5 minutes of adsorption process.

3.1.3 Effect of Desiccant Material on Water Vapor Adsorbed

The results in Figure (4) show that the water vapor adsorbed along the adsorption time for coconut coir, palm tree fiber, rice straw, and baggase beds are less than that of silica gel bed. Results show that the water vapor adsorbed in coconut coir bed, palm tree fiber bed, rice straw bed, baggase bed, and silica gel bed are 0.062, 0.241, 0.223, 0.191, 0.255 $kg_{w.v}/kg_d$ respectively at the end of adsorption process. The silica gel bed offers the highest adsorption capacity followed by palm tree fiber, rice straw, baggase, and the coconut coir the (lowest).

3.2 Desorption mode

During the desorption mode, the regeneration temperature is 65 ^{o}C, while the air velocity is 0.3 m/s for the silica gel bed and 5 m/s for other desiccants.

3.2.1 Effect of Desiccant Material on Exit Relative Humidity

The results in Figure (5) show that the exit air relative humidity along the desorption time for coconut coir, palm tree fiber, rice straw, and baggase beds are less than that of silica gel bed. Results also show that the exit air relative humidity for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 19.7 %, 18 %, 16%, 19%, and 68% respectively after 5 minutes of the desorption process. Also, the desorption time for coconut coir, palm tree fiber, rice straw, and baggase beds is low compared to the silica gel bed. Results show that the desorption time for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 10, 12, 5, 9, 45 minutes respectively. This is due to the fact that the silica gel bed requires higher temperatures than that of other desiccants.

3.2.2 Effect of Desiccant Material on Exit Air Temperature

The results in Figure (6) show that the exit air temperature along the desorption process for coconut coir, palm tree fiber, rice straw, and baggase beds are less than that of silica gel bed. Results also show that the exit air temperature for coconut coir, palm tree fiber, rice straw, baggase, and silica gel beds are 64.5, 55, 65, 60.7, and 42 ^{o}C respectively after 5 minutes of the desorption process.

3.3 PRESSURE DROP ACROSS DESICCANT BED

The inlet air relative humidity during the experiments is adjusted to 72%. The results in Figure (7) show that the pressure drop across coconut coir, palm tree fiber, rice straw, and baggase beds are less than that of silica gel bed. The pressure drop across the bed varies from 68.67 Pa to 137.34 Pa for coconut coir, 68.67 Pa to 147.15 Pa for palm tree fiber, 53.95 Pa to 117.72 Pa for rice straw, 58.86 Pa to 132.435 Pa for baggase, 206.01 Pa to 264.87 Pa for silica gel.

3.4 INVESTIGATION OF THE OPTIMUM DESICCANT MATERIAL

3.4.1 Adsorption process

The values of the parameters considered to study the effect of desiccant material are inlet air relative humidity which has a value of 92%, and air velocity which has a value of 0.3 m/s for the silica gel bed, whereas the air velocity for other desiccants is 5 m/s.

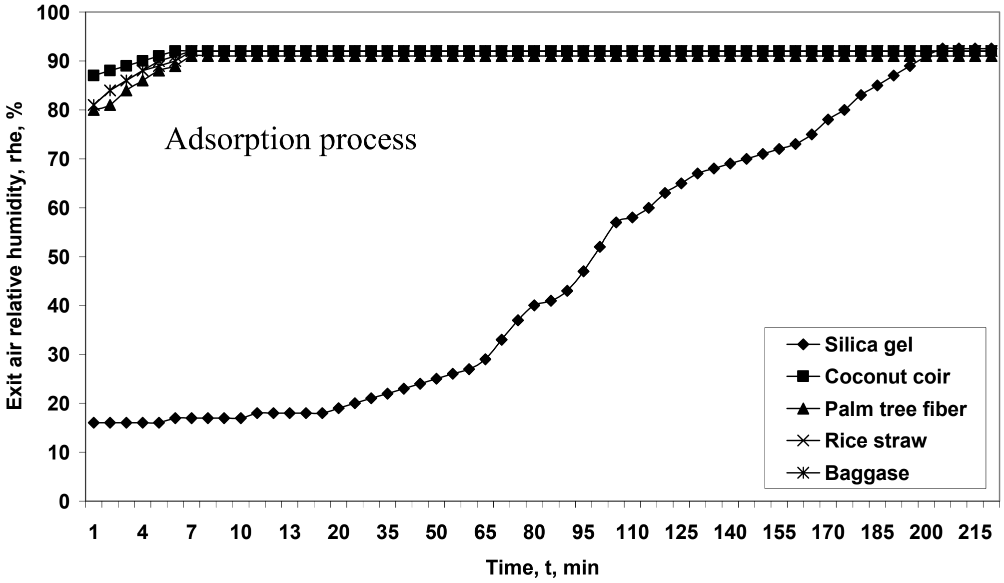


Fig. 2: Variation of exit air relative humidity with time for different types of desiccants

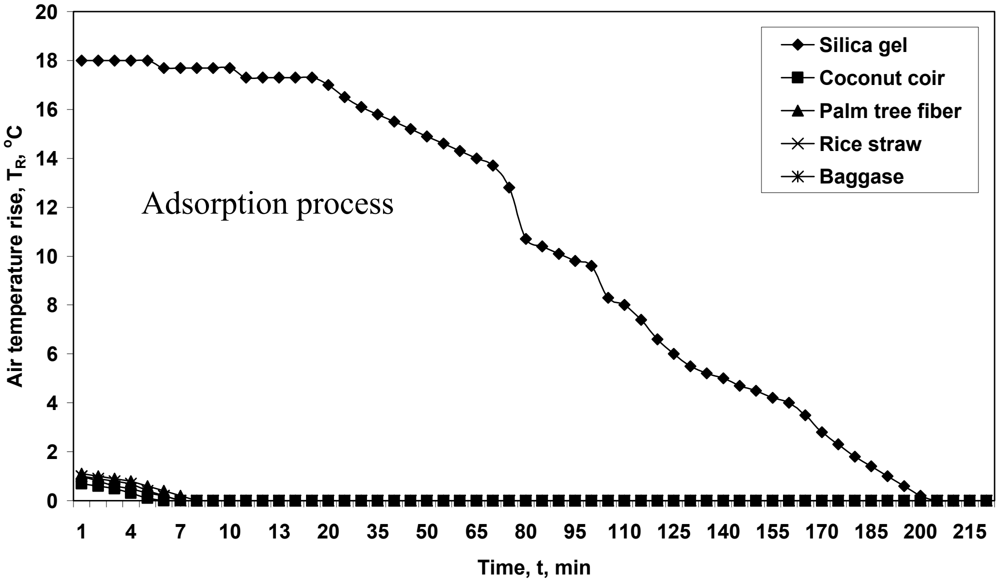


Fig. 3: Variation of temperature rise with time for different types of desiccants

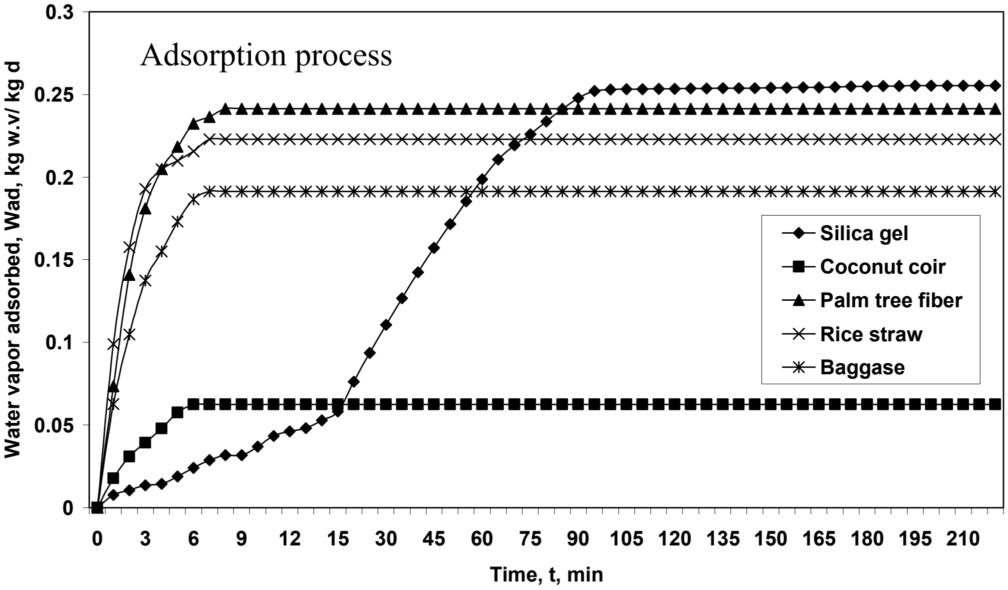


Fig. 4: Variation of water vapor adsorbed with time for different types of desiccants

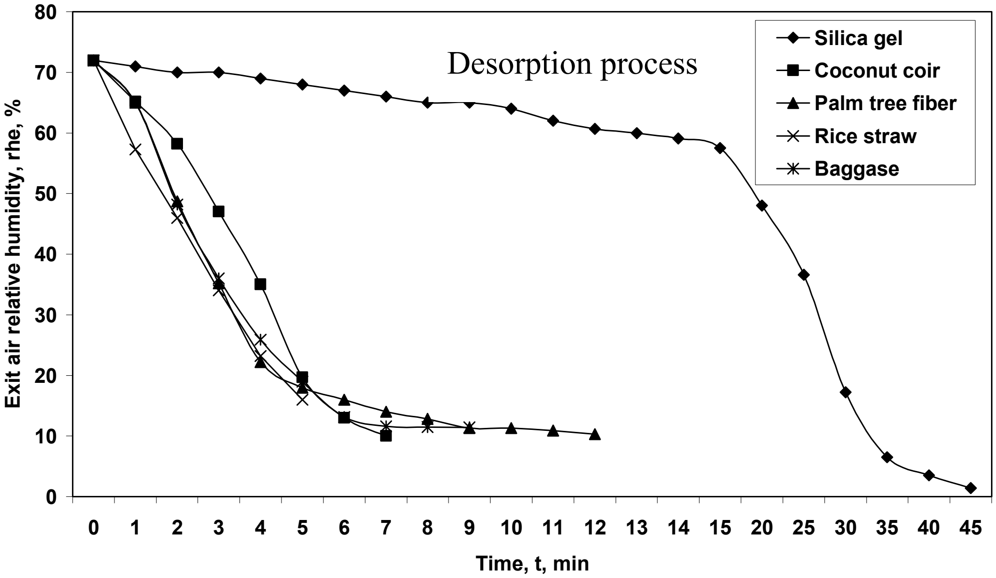


Fig. 5: Variation of exit relative humidity with time for different types of desiccants (Desorption process)

The results in Figure (8) show that the highest water vapor adsorbed is in the silica gel bed of a value of 0.255 $kg_{w.v}/\ kg_{d}$ at the end of adsorption process. It is also shown that the water vapor adsorbed in the coconut coir, palm tree fiber, rice straw, and baggase beds is 0.062, 0.241, 0.223, and 0.191 $kg_{w.v}/\ kg_{d}$ respectively. It is concluded that the highest temperature rise is the silica gel bed of a value of 18 ^{o}C, as compared to 0.6 ^{o}C for palm tree fiber, 0.4 ^{o}C for rice straw, 0.1 ^{o}C for coconut coir, and 0.3 ^{o}C for baggase after 5 minutes of adsorption process. The time required to complete adsorption for the different types of desiccants is shown in Figure (9). The results show that the adsorption time for silica gel, baggase, rice straw, coconut coir, and palm tree fiber beds are 220, 7, 7, 6, and 8 minutes respectively. The highest adsorption time is observed for silica gel bed, followed by palm tree fiber, rice straw, baggase, and at last coconut coir. Experimental results confirmed that agriculture waste (palm tree fiber, rice straw) has a good potential and offer a good performance as compared to the traditional silica gel.

3.4.2 Desorption process

The values of the parameters considered to study the effect of desiccant material are regeneration temperature which has a value of 65 ^{o}C, and air velocity which has a value of 0.3 m/s for the silica gel bed, whereas the air velocity for other desiccants is 5 m/s. The results in Figure (10) show that the highest exit air relative humidity is the silica gel bed of a value of 68% after 5 minutes of desorption process, then coconut coir bed of a value of 19.7%, then baggase bed of a value of 19%, then palm tree fiber bed of a value of 18%, and at last rice straw bed of a value of 16%. Also, it is noticed that the highest exit temperature is the rice straw bed of a value of 65 ^{o}C after 5 minutes of desorption process, followed by coconut coir bed of a value of 64.5 ^{o}C, baggase bed of a value of 60.7 ^{o}C, palm tree fiber bed of a value of 55 ^{o}C and at last silica gel bed of a value of 42 ^{o}C. The results in Figure (11) showed that the highest desorption time is of silica gel bed of a value of 45 minutes, followed by palm tree fiber bed of a value of 12 minutes, the coconut coir bed of a value of 10 minutes, the baggase bed of a value of 9 minutes, and finally the rice straw bed of a value of 5 minutes. Increasing regeneration temperature results in a decrease in the exit air relative humidity for all desiccant beds. It is also concluded that this results in a decrease in the time required for desorption the desiccant beds.

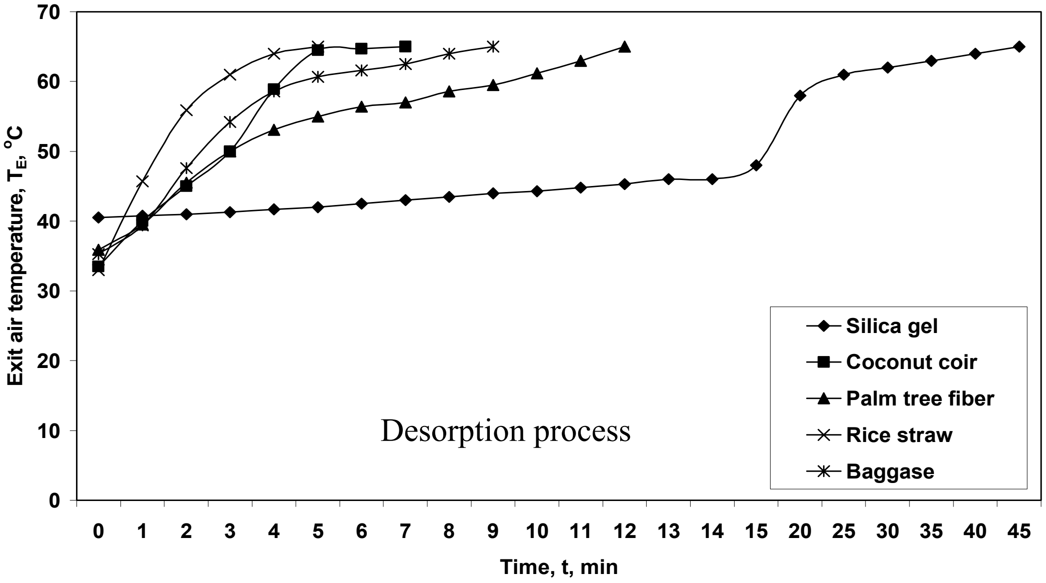


Fig. 6: Variation of exit temperature with time for different types of desiccants (Desorption process)

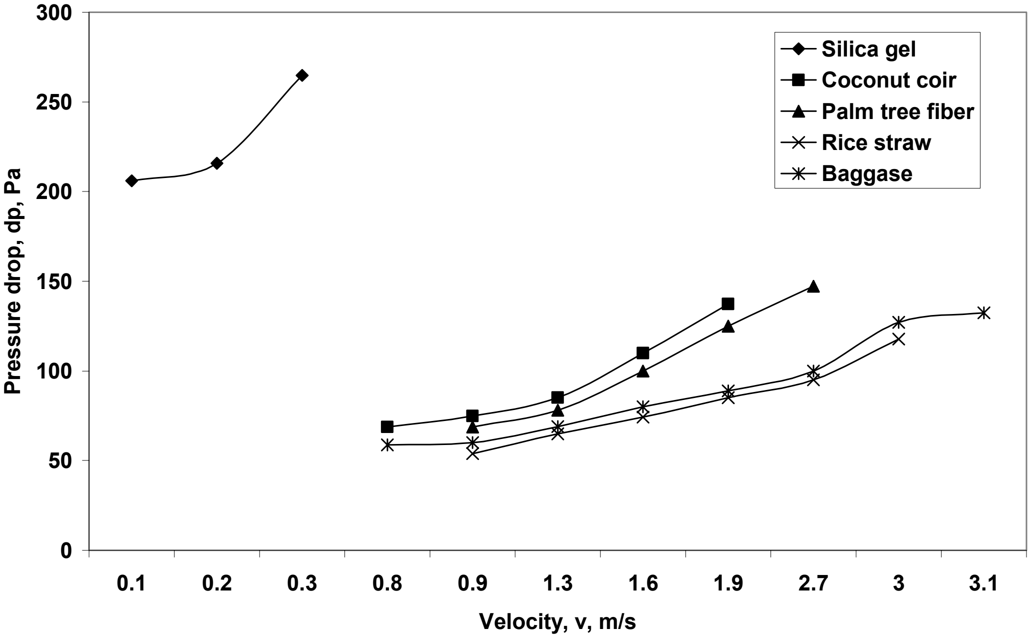


Fig. 7: Pressure drop with velocity for different types of desiccants

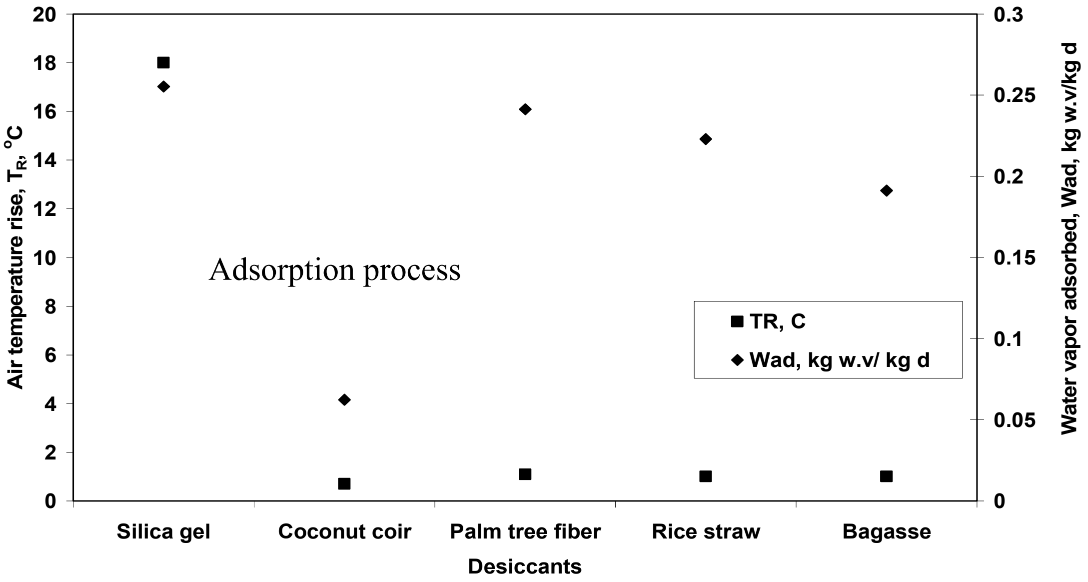


Fig. 8: Temperature rise, and water vapor adsorbed for different types of desiccants

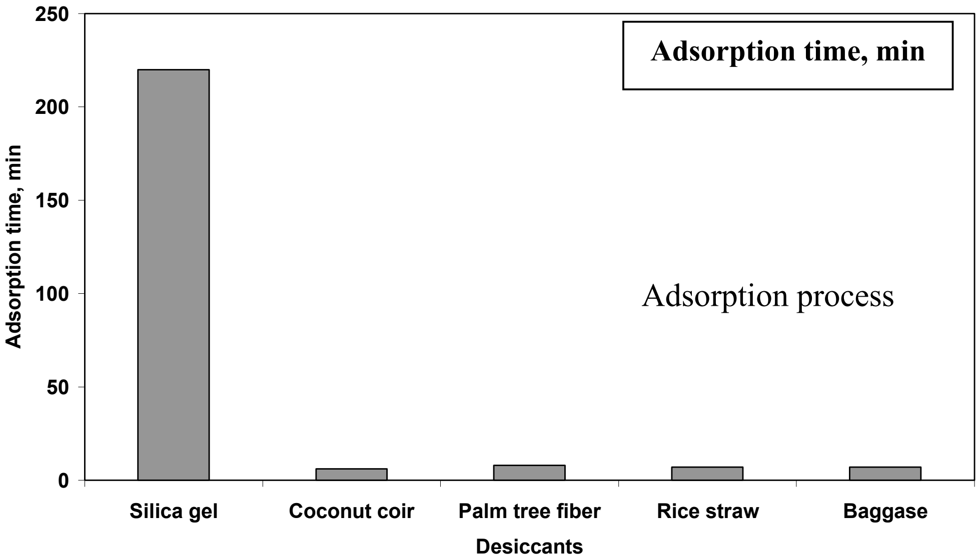


Fig. 9: Adsorption time for different types of desiccants

PERFORMANCE FACTOR OF THE DESICCANT BED

The performance factor of the desiccant bed is defined as the ratio of the latent load extracted in the bed to the sensible load. The values of the parameters considered in the study on different types of desiccant material are inlet air relative humidity (92%), and air velocity (0.3 m/s) for the silica gel bed, whereas the air velocity for other desiccants is (5 m/s). The results in Figure (12) show that highest performance factor is for baggase and rice straw beds of a value of 3.5, followed by palm tree fiber bed of 3.27, and coconut coir bed of 2.67. The lowest performance factor was for the silica gel bed (1.216). In such case less cooling energy (for agricultural waste) is required due to the partial or full elimination of latent load.

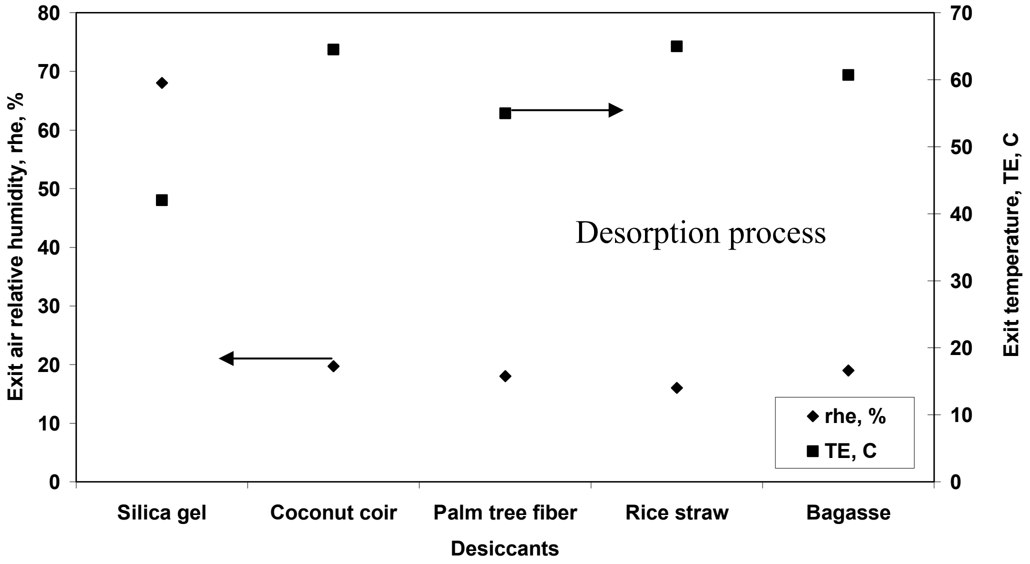


Fig. 10: Variation of exit relative humidity and temperature for different types of desiccants after 5 minutes of desorption process

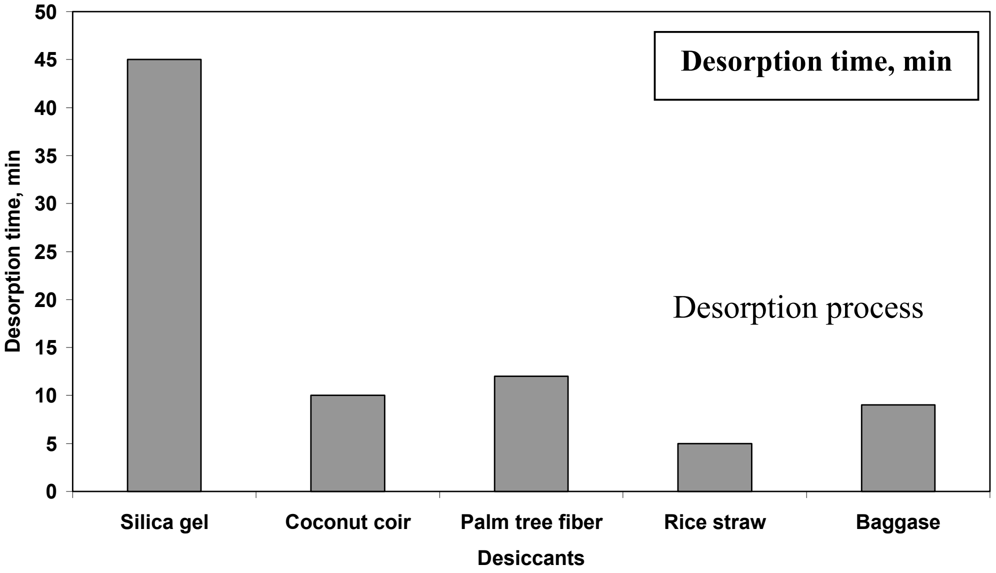


Fig. 11: Desorption time for different types of desiccants

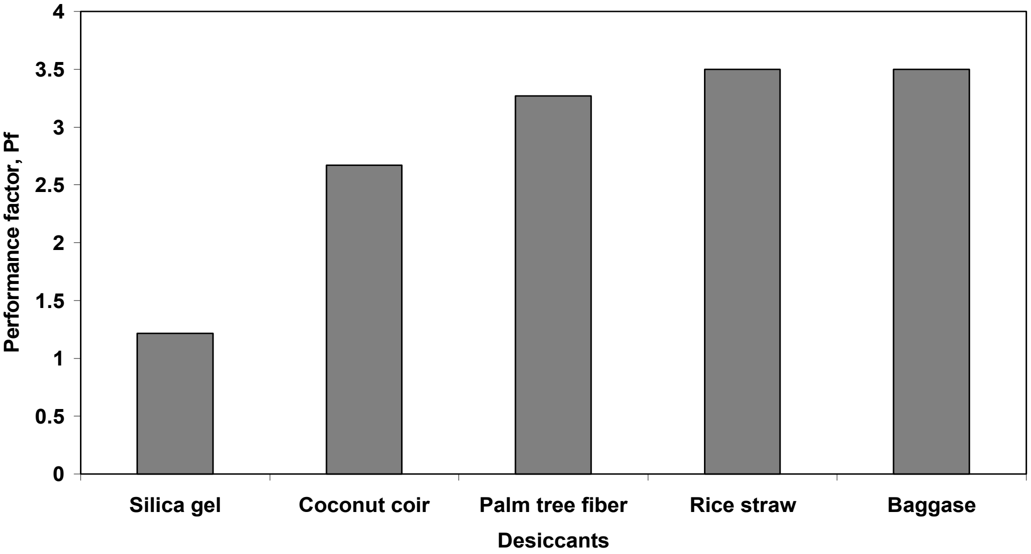


Fig. 12: Performance factor for different types of desiccants

4 CONCLUSIONS

It is concluded from the present work that:

- The silica gel bed offers the highest adsorption capacity followed by palm tree fiber, rice straw, baggase, and the coconut coir the (lowest).
- It is observed that the air temperature rises after 5 minutes for the coconut coir, palm tree fiber, rice straw, and baggase beds are 0.1, 0.6, 0.4, and 0.3 ^{o}C respectively as compared to 18 ^{o}C for silica gel bed in the adsorption process.
- The highest adsorption time is observed for silica gel bed, followed by palm tree fiber, rice straw, baggase, and at last coconut coir.
- It is concluded that the highest pressure drop is observed for silica gel bed, followed by palm tree fiber, coconut coir, baggase, and at last rice straw.
- The highest desorption time is observed for the silica gel bed, followed by palm tree fiber, coconut coir, baggase, and at last the rice straw.
- The highest performance factor is observed for baggase and rice straw followed by palm tree fiber, coconut coir and at last the silica gel.
- Increasing regeneration temperature results in a decrease in the exit air relative humidity for all desiccant beds. It is also concluded that this results in a decrease in the time required for desorption the desiccant beds.
- Experimental results confirmed that agriculture waste (palm tree fiber, rice straw) has a good potential and offer a good performance as compared to the traditional silica gel. Although agricultural waste (namely palm tree fiber and rice straw) has a slightly less water vapor adsorption capability when compared to silica gel, it offers higher performance factor, less pressure drop, and less exit air superheat. In addition, using agricultural waste can give additional advantage of preserving the environment and promoting natural products.

REFERENCES

1. Farooq S, and Ruthven D. M., "Numerical simulation of a desiccant bed for solar air conditioning applications", ASME Trans. 1991; 113: 80-8.
2. Epstien M., Grotmes M., Davidson K., and Kosar D.,"Desiccant cooling system performance: a simple approach", Jr. of Solar Energy Eng.1985;107: 21-8.

3. Dupont M., Celestine B., Nguyen P. H., Merigoux J., and Brandon B., "Desiccant solar air-conditioning in tropical climates: I-dynamic experimental and numerical studies of silica gel and activated alumina", Solar Energy, 1994; 52: 509-517.
4. Dupont M., Celestine B., and Beghin B., "Desiccant solar air conditioning in tropical climates: II-field testing in Guadeloupe", Solar Energy, 1994; 52: 519-524.
5. Ismail M. Z., Angus D. E., and Thorpe G. E., "The performance of a solar-regenerated open-cycle desiccant bed grain cooling system", Solar Energy, 1991; 46: 63-70.
6. Waugaman, D. G., Kini A., and Kettleborough, C. F., "A review of desiccant cooling systems", Journal of energy resources technology, 1993; 115: 1-8.

NOMENCLATURE

W_{ad}	Water vapor adsorbed, $kg_{w.v}/kg_d$
$\dot{m}_a$	Air mass flow rate, kg/s
ω_1	Specific humidity of air entering the desiccant bed, $kg_{w.v}/kg_{d.a}$
ω_2	Specific humidity of air leaving the desiccant bed, $kg_{w.v}/kg_{d \cdot a}$
τ	Time, minute
m_d	Desiccant weight, kg
ΔP	Pressure drop across the desiccant bed, Pa
ρ_w	Density of water, kg/m^3
g	Acceleration gravity, m/sec^2
ΔH	Difference in the water height, m
h_1	Enthalpy of air entering the desiccant bed, kJ/kg
h_2	Enthalpy of air leaving the desiccant bed, kJ/kg
$\dot{m}_a(h_1 - h_a)$	Latent load, kW
$\dot{m}_a(h_2 - h_a)$	Sensible load, kW
P_f	Performance factor