International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA), Issue. 2, Vol. 5, June 2018
e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 24-35
DOI: 10.26706/IJAEFEA.2.5.20180501

Performance evaluation of forced convection desiccant bed solar dryer integrated with sensible heat storage material

Pramod V. Walke[1*,]
pramod.walke@raisoni.net

Pranav C. Phadke[2]

Kishor S. Rambhad[3]
kishorsrambhad@gmail.com

[1*]Professor, Department of Mechanical Engineering, G. H. Raisoni College of Engineering, Nagpur, India

[2]Energy Unit, Centre for Science and Environment, New Delhi, India

[3]Assistant Professor, Department of Mechanical Engineering, G. H. Raisoni College of Engineering, Nagpur, India

***Abstract*— This paper reports a new type of forced convection indirect type solar dryer setup fabricated in Nagpur, India and its performance was studied. The main objective of the present study was to incorporate new drying technology and develop a solar dryer that could function effectively for few more extra hours even after the sunset. Thus a forced convection indirect type solar dryer integrated with heat storage material (Gravel) & desiccant beds (Silica Gel) was developed.**

In forced convection solar dryer with heat storage material, the grapes were dried from an initial moisture content of 80% to the final moisture content of 20% in about 78 hours, while it took only about 57 hours in the forced convection solar dryer with heat storage and desiccant beds to reach the required moisture content. Due to the use of heat storage material, the temperatures inside the solar dryer remains 3-5°C higher than the ambient temperature even during off sunshine hours. Also, the heat storage regulates the temperature of the collector outlet during uneven climatic conditions. The maximum temperature attainedby air inside the dryer cabinet was 78°C. The desiccant beds can be regenerated in about 5 hours during a normal day and removes the moisture from the products even during the night. The air flow rate in both the cases was maintained at 0.026 kg/s. The quality of the grapes obtained from the solar dryer was excellent with proper coloring and taste as compared to those dried directly under the sun.

***Index Terms*—** Desiccant bed, forced circulation, indirect type, heat storage material, solar dryers, silica gel

I. INTRODUCTION

In developing countries, the majority of the population is engaged in farming activities. Almost 80% of the total food products are cultivated by small farmers. These farmers use conventional means of drying (open air sun drying) for their products. Open air sun drying is still the most common and the oldest method to preserve agricultural products. In the open sun drying, the products are directly placed under the sun and dry from the heat of the sun. However, drying these products directly under the open sun has many drawbacks such as debris, rain, blowing wind, insect infestation, human and animal interference etc. which leads to contamination of the products, uneven type of drying, and uncontrolled moisture content in end products, causing degradation in the quality of the products. Solar dryers have been developed to overcome these problems of open air solar drying. However, there are many barriers to the adoption of solar dryer technology merely the cost. Tara Chandra Kandpal, Atul Kumar and Pallav Purohit [1] analyzed how solar dryers fare economically compared to open sun drying and found that solar drying of agricultural products appears to be financially attractive for cash crops and it may even be possible to justify the use of high cost solar drying systems. However, for drying highly perishable products, it is extremely important to develop low cost systems [2]. Today it is possible to develop low cost solar dryers from local materials. Atul Sharma et al. [2] reviewed some easy-to-fabricate and easy-to-operate low cost dryers that can be suitably employed in small-scale factories or at rural farming villages while A. Fudholi et al. [3] gave examples of several solar driers and their possible prices for local manufacture.

Solar dryers are classified depending upon the mode of air circulation, such as natural circulation and forced circulation dryers and based on type of drying, such as direct solar drying, indirect solar drying and mixed mode solar drying. They are also classified depending upon the construction of the drying section.Ashish D. Chaudhari et. al [4] reviewed different types of solar dryer technologies and concluded that forced circulation solar drying shows better results with reduced drying time than open air sun drying and natural circulation solar drying. Gutti Babagana et al. [5] designed and constructed forced and natural convection solar vegetable dryer with heat storage and compared their performances. They concluded that the forced convection system has higher drying capabilities as compared to natural convection system but requires a source of motive power for the operation which is an added cost.

Use of solar dryers largely depends on the availability of the sun which reduces their functionality. To overcome this barrier, new technologies are being developed using desiccant units and thermal storage systems to make them functional even during off sunshine hours. By usingthese technologies and efficient designs, continuous solar dryers can be operated. Lalit M. Bal et al. [6] reviewed solar dryers with latent heat storage systems thus facilitating continuous use of dryers. M. Mohanraj et al. [7] developed an indirect forced convection solar dryer incorporated with sensible heat storage material for drying chilies. They concluded that the dryer integrated with sensible heat storage material (gravel) enables it to maintain a consistent air temperature inside the dryer and increased the drying time by about 4 hours per day. Riyad Hodali et al. [8] studied the integration of the adsorption unit of silica gel for apricot drying which gave improved quality and reduced drying time from 52 to 44 hours and justified that the integration of desiccant unit is economical. V. Shanmugam et al. [9] incorporated a $CaCl_2$ based regenerative solid desiccant bed into the dryer for drying green peas. The results of their tests have shown that the integration of desiccant unit with solar dryer continues the drying of products in the off sunshine hours and improves the quality of drying and that more uniform drying of products is achieved during desiccant drying. They modified the design further and incorporated a reflective mirror to improve the regeneration of the desiccant and tested it to dry green peas and pineapple [10]. The test results were then conducted with & without the inclusion of the reflective mirror. They concluded that, with the inclusion of a reflective mirror on the desiccant bed the drying potential increases considerably. Sirinuch Jindaruksab et al. [11] performed evaluation of a silica gel based desiccant bed solar dryer. They used three silica gel beds (SGBs) on top, east and west. They analyzed how the system fared compared to non-dehumidification system and found that the drying time of with dehumidification system was up to 20.83 % shorter than without dehumidification system.

Thus, the main objective of the present study was to incorporate different technologies and develop a solar dryer that could function effectively even during off sunshine hours. A fabricated setup of forced convection desiccant based solar drier integrated with heat storage material was created for drying of grapes and to compare the effects of desiccant beds on the drying time to that of forced convection solar dryer and with open sun drying.

II. Nomenclature

- T_1 located at blower outlet, °C
- T_2 inlet to the flat plate collector, °C
- T_3 temperature of gravel stone- heat storage material, °C
- T_4 temperature of copper tubes, °C
- T_5 outlet to the flat plate collector, °C
- T_6 inlet to the dryer cabinet, °C
- T_7 top Tray in the Drying Cabinet, °C
- T_8 second tray in the drying cabinet, °C
- T_9 third tray in the drying cabinet, °C
- T_{10} bottom tray in the drying cabinet, °C
- T_{amb} ambient temperature, °C
- RH relative humidity inside dryer cabinet, %
- RH_{amb} ambient relative humidity, %
- M_o moisture content on dry basis, %
- M_w moisture content on wet basis, %
- M_a mass flow rate of air, kg/s
- I global solar radiation on tiled surface, W/m^2

III. Experimental Set-Up

The schematic diagram of the experimental setup is as shown in the fig.1. The forced convection solar dryer consists of mainly 3 parts: blower, flat plate collector and the drying cabinet. The measuring instruments and control panel mainly consists of: thermocouples, hygrometer and weighing machine.

The drier cabinet is the main part which holds the products that are to be dried. The cabinet is constructed from double walled wood between them pop liquid are filled as insulation. Due to the pop liquid, cabinet retains more heat and consistent temperatures can be achieved inside. The cabinet is painted black to absorb more solar radiation, thereby increasing the temperatures inside the cabinet. The cabinet is constructed with the dimensions of 0.8m x 0.8m x 0.8m as its length, breadth and height. At the top of the drier cabinet, a tapered structure of 0.5m is provided to take out the moisture removed from the products. A small fan is provided at the top which helps in recirculation of air inside the drier during night time.

The flat plate collector consists of a rectangular box with copper tubes inside through which air is made to flow. Generally, the area of the collector must be twice the cross-sectional area of the drier cabinet, and thus, the collector is designed with dimensions of 1m x 1.4m as its breadth and length respectively.

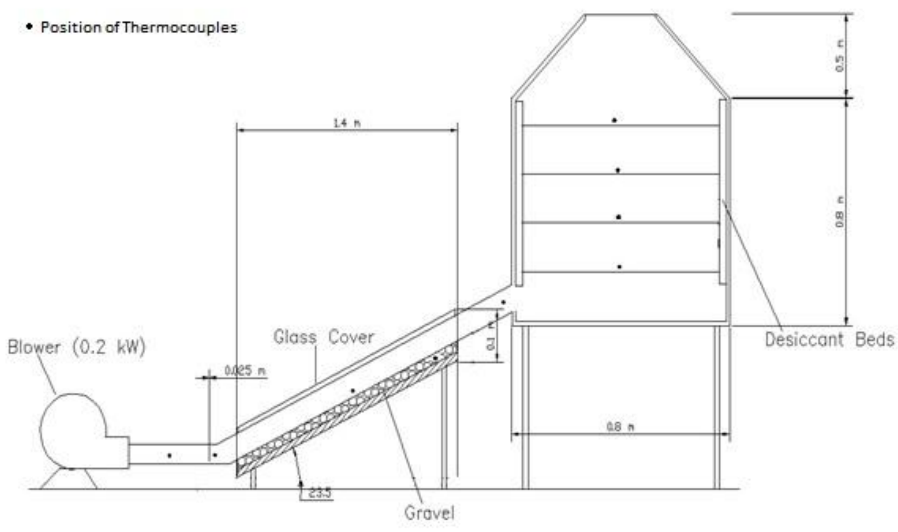

Fig 1: Schematic diagram of the experimental setup

There are total 9 copper tubes inside the flat plate collector which are attached to copper plates. All these copper tubes and plates are painted black to absorb maximum solar radiation. Below the copper tubes there is a highly reflective aluminum sheet which reflects the sun rays on copper tubes. A transparent glass is provided at the top to increase the heat inside the collector through green-house effect. This entire assembly is covered with an insulated glass wool at the bottom and on its sides. To absorb maximum solar radiation, the collector is faced southwards and inclined at an angle of 23.5° with respect to horizontal. An industrial blower is connected to the flat plate collector which forces the air through the collector and into the dryer cabinet. The entire assembly is made air tight so that maximum air can be reached into the drier cabinet. It has been successfully proved through experimentation that, for practical applications, the air flow rate through flat plate collector should be between 0.01-0.03 kg/m^2s [10, 12]. Based on this, the blower is selected with following specifications:

TABLE I

SPECIFICATION OF BLOWER

HP of the Blower: 0.28HP	Phase: Single Phase
Current: 1 AMP	Watts: 210 Watts
Voltage: 230 V	Speed: 2800 R.P.M

The maximum velocity obtained from this blower is 9.6 m/s. The readings were taken at this constant velocity and flow rate of 0.026 kg/s.

Fan is situated at the top of the dryer cabinet. This fan is used to circulate the air within the dryer cabinet at night to allow the desiccant beds to absorb the moisture from the products. The fan used for air flow rate of 0.035 kg/s.

Below the copper tubes of the flat plate collector, the gravel stones are placed which acts as a sensible heat storage material and absorbs and stores the heat within them. As the temperature of air and copper tubes reduces, during off sunshine hours, the heat can be recovered from these stones, and the air can thus be heated. Due to this, the dryer can even function during off sunshine hours. A.A. El-Sebaii et al. [13] performed a study on double pass solar air heater with different packed beds and found that gravel stones as the heat storage material gave the best performance. Thus gravel stones were selected for this solar dryer. Also, by the use of heat storage material, the temperatures inside the dryer cabinet became regulated and uniform.

To make the solar dryer continuously operational even during the nights, desiccant beds were used. Indicative silica gel was selected to observe its absorption and regeneration cycles. The silica gel, as it adsorbed moisture turned pink and as it was heated, it turned to its blue color.Silica gels are attached on three sides of the dryer cabinet with the help of an industrial adhesive. As the temperature inside the dryer increases during the sunshine hours, these silica gel beds release the moisture along with the drying products. During off-sunshine hours, the cabinet is made air tight and the silica gel absorbs moisture from the products, thereby making the solar dryer continuously operational.

Thermocouples are used to sense the temperature. In this project eleven k-type thermocouples (chromel–alumel) having range of −200 °C to +1350 °C are used. One end of the thermocouple is attached at various locations in experimental setup and the other end is connected to temperature indicator to record all readings at one place. To measure the ambient relative humidity as well as the relative humidity inside the dryer cabinet, hygrometer is used. It has a dial gauge which shows relative humidity in percentage from 0% to 100%. Weight balance is used to weight the initial and final weight of the products. By weighing the initial and final weight of the products, the moisture removal rate can be determined.

III. WORKING

Air is forced through blower into the flat plate collector where it is heated. The flow rate of the blower is set to optimally heat the air in the collector. Below the copper pipes of the collector gravel stones are used to absorbs the heat from the air and stores it. These stones then supply the heat to the flowing air during the off sunshine hours.

The air from the collector then flows into the drying chamber. The drying chamber has four racks fitted inside for loading of the products. The racks have wire mesh structure which lets the air flow through them in order to evenly dry the products. On the sides of the drying cabinet, silica gel desiccant beds are fitted. During the day time, as the air flows into the cabinet, these desiccant beds gets heated up and they lose their moisture along with the drying products and thus get regenerated. During the off sunshine hours, when the blower is switched off, the silica gel desiccants adsorb the remaining moisture from the products and thus keep them dry even during the night.

A two way fan is provided at the top of the drying chamber which acts as an exhaust during the day. During the off sunshine hours, this fan recirculates the air within the dryer at the set flow rate so that the silica gel desiccant beds can adsorb the moisture from the products. Fig. 2 shows air flow diagram.

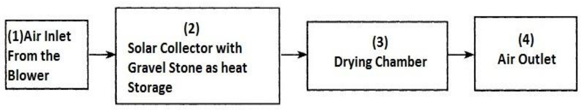

Fig 2: Air Flow Diagram

IV. EXPERIMENTATION AND CALCULATION

The experimentation and observations were taken on the setup initially without the use of desiccant beds i.e. for forced convection indirect type solar dryer integrated with heat storage material (test 1), then tests were conducted by incorporating silica gel as desiccant material along with heat storage material (test 2) and finally tests were done by drying grapes directly under the sun i.e. open air sun drying (test 3). Mainly, temperature, relative humidity and ambient conditions were observed. Also, the drying capacity of the solar dryer during varying climatic conditions was observed. Based on the observations, parameters such as total drying time, condition of the products, initial and final moisture content and collector efficiency were calculated. The observations were taken on an hourly basis starting from 10.00 AM onwards until temperatures inside the dryer was equal to the ambient temperature.

The experiments were performed at an optimum, constant air flow rate of 0.026 kg/s [10, 12] and velocity of 9.6 m/s. Grapes (1.2 kg) were loaded on the 4 trays and were dried to turn them into resins. The experiments were conducted daily until the batch of grapes was turned into resins of required moisture content. Grapes were selected for the experimentation with initial moisture content of about 80 % wet basis.

Initial weight of the grapes = 1.200 kg

Initial moisture content of the grapes = 80 % wet basis

Air flow rate = 0.026 kg/s

Blower velocity = 9.6 m/s

Based on the observations, following parameters were calculated:

Moisture content on dry basis, $M_o = (W_o - W_d)/W_d$

Moisture content on wet basis, $M_w = (W_o - W_d)/W_o$

Collector Efficiency is given as: $ή_c = M_a * C_p(T_5 - T_2)/ I * A_c$

The results were then compared for all three types of tests based on the above parameters.

V. RESULTS AND DISCUSSION

Based on the observations, graphs were plotted for all three tests and finally results were tabulated for test 1 & 2.

A. Test1: Forced convection solar dryer without desiccant beds:

It took about 4 days for grapes to turn into raisins in test 1, during which, ambient temperature, cabinet temperatures, collector inlet, outlet temperatures were collected and graphs for which are plotted. Fig. 3 shows variation of collector inlet temperature (T_2), temperature of gravel stones (T_3), temperature of copper tubes (T_4) and collector outlet temperature (T_5) for day 1.

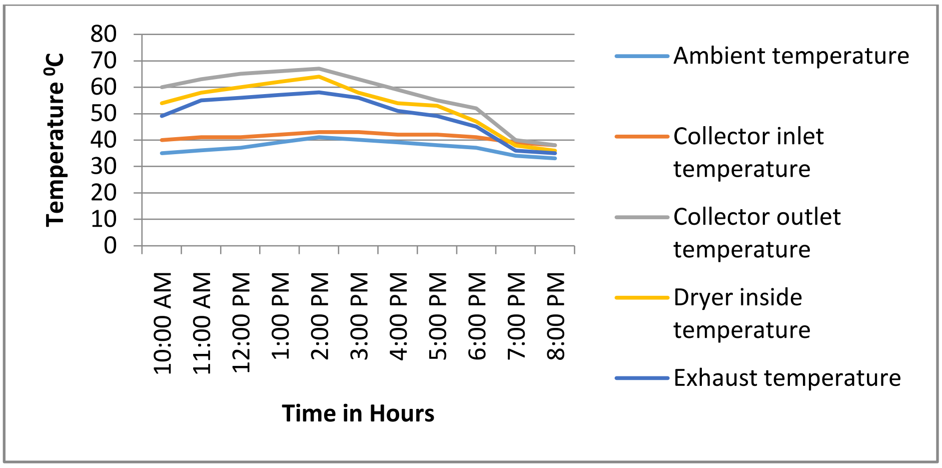

Fig. 3: Variation of temperature at various locations during Test –2 of day-1

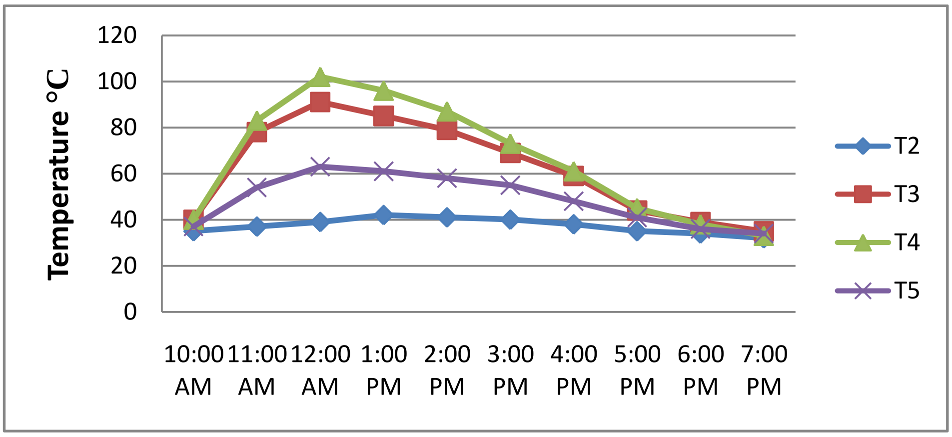

Fig 4: Variation of collector temperatures and gravel stones vs. time for day 1

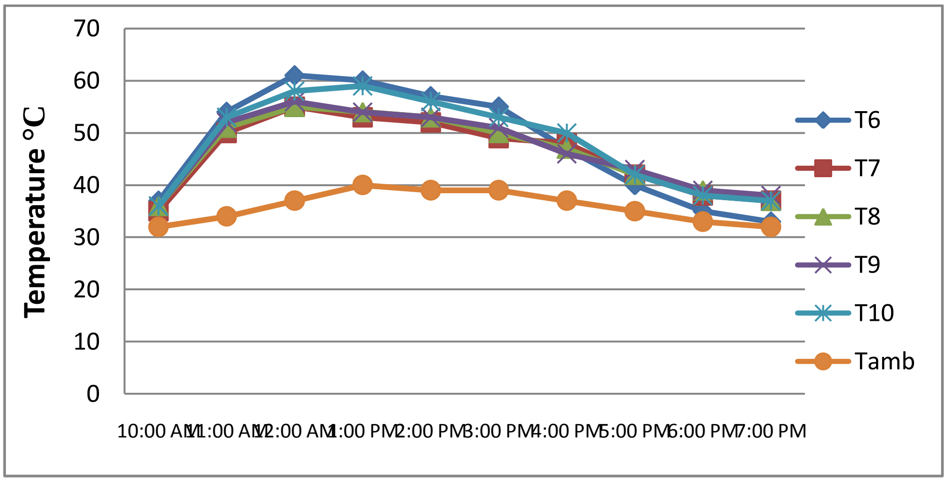

Fig 5: Variation of cabinet temperatures and ambient temperature vs. time for day 1

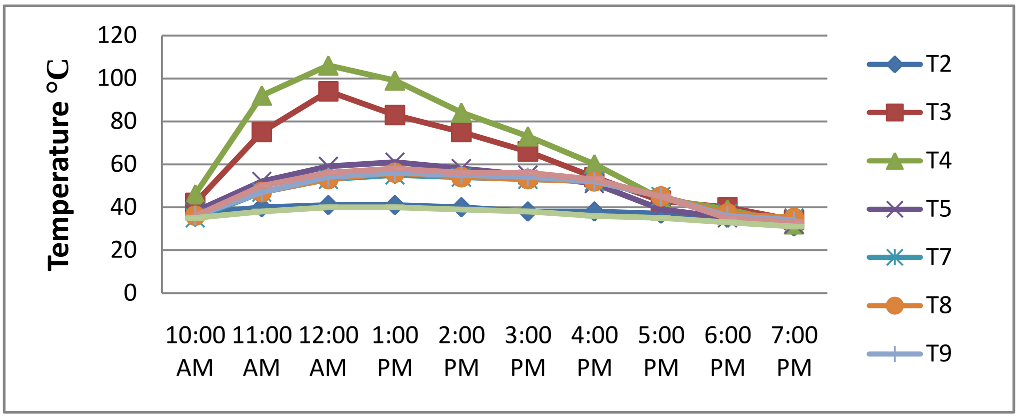

Fig 6: Variation of temperature vs. time of the day for day 2

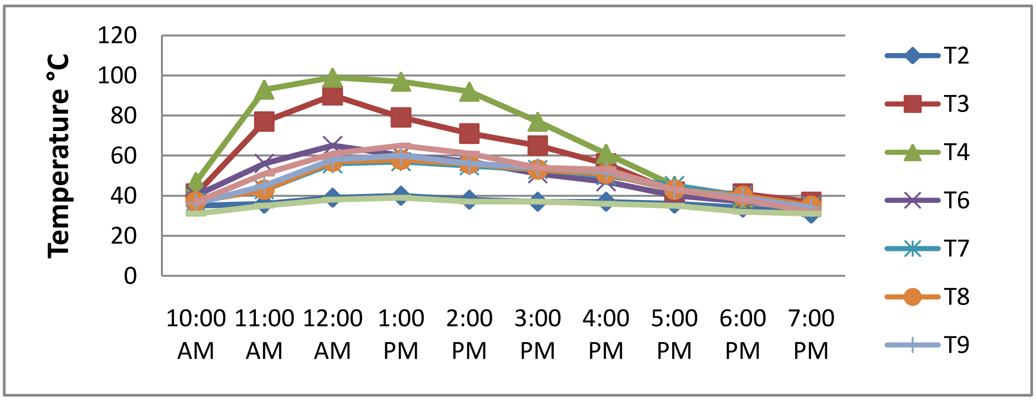

Fig 7: Variation of temperature vs. time of the day for day 3

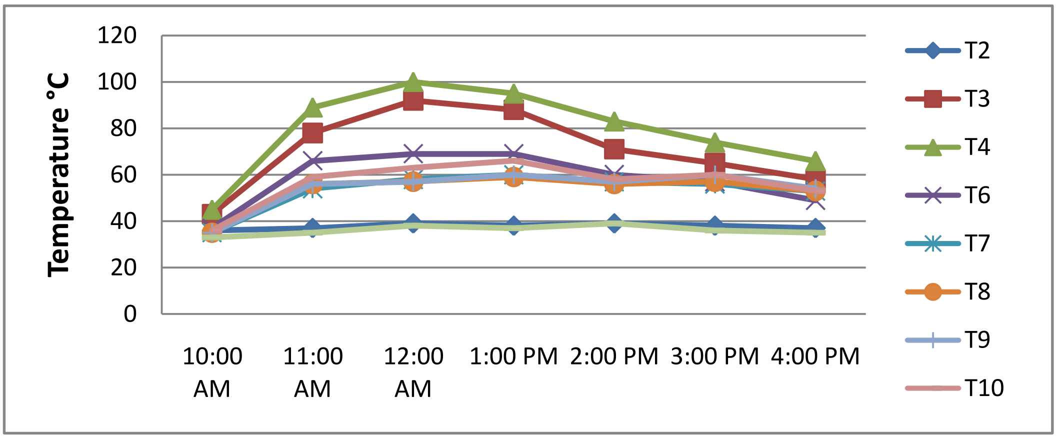

Fig 8: Variation of temperature vs. time of the day for day 4

From Fig 4, it is seen that, overall temperatures keeps on increasing until sun is at the highest position, 12 Noon. After 5.00 PM, as the temperature of the copper tubes in the collector decreases, heat storage material-gravel stones, provides heat to the copper tubes and thereby, keeps the temperature of collector outlet, a few degrees higher than the ambient. It is seen that due to the use of gravel stones, solar dryer can be kept on working for up to 2-3 hours until collector outlet temperature becomes equal to the ambient temperature.

Fig. 5 indicates variation of cabinet temperatures (T_7, T_8, T_9 and T_{10}), ambient temperature (T_{amb}) and dryer inlet temperature (T_6) for day 1.

From Fig 5, it is seen that the temperature of bottom tray of the cabinet (T_{10}) is higher as compared to the top most tray of the cabinet (T_7). This is because the heated air flows from lower trays to the upper trays. The temperatures inside the cabinet keep increasing as cabinet inlet temperature increases. However, after 3 PM, the cabinet temperatures remain higher than the cabinet inlet temperature (T_6). This is because; the 4 trays in the cabinet are perforated mild steel trays, which remains heated up for a longer time, thereby increasing the cabinet temperatures. Thus, the grapes are dried through conduction effect as well.

Fig 6, 7 and 8 shows variation of collector inlet temperature (T_2), temperature of gravel stones (T_3), temperature of copper tubes (T_4) and collector outlet temperature (T_5) as well as cabinet temperatures (T_7, T_8, T_9 and T_{10}) and ambient temperature (T_{amb}) for day 2, day 3 & day 4. Similar trends as that of day 1 can be observed.

B. Test 2: Forced convection solar dryer with desiccant beds:

For test 2, heat storage materials as well as desiccant beds were used together to carrying out drying of grapes in the solar dryer. The grapes were loaded at 10.00 AM and the drying process continued for about 3 days, throughout the nights, until required moisture content was reached in the grapes. It took about 3 days for grapes to turn into raisins in test 2,during which, ambient temperature, cabinet temperatures, air inlet temperature, air outlet temperatures and relative humidity were collected and graphs for which are plotted.

Fig 9 shows variation of collector inlet temperature (T_2), temperature of gravel stones (T_3), temperature of copper tubes (T_4) and collector outlet temperature (T_5) for day 1.

From the graph, it is seen that temperatures of copper tubes (T_4), gravel stones (T_3) and collector outlet temperature (T_5) keeps on increasing as solar radiation increases throughout the day. During cloudy hours, the temperatures of copper tubes dips down, however, the heat storage material- gravel stones, provides heat to the copper tubes, thereby regulating the temperatures. Also, due to the presence of gravel stones, the temperature at collector outlet remains 3-5°C higher than the ambient temperature even during evenings. Here, the blower is switched off at about 7.30 PM when temperatures inside the dryer becomes equal to ambient temperatures and the fan inside the cabinet is switched on which circulates the air within for desiccant beds to absorb moisture.

Fig. 10 indicates variation of cabinet temperatures (T_7, T_8, T_9 and T_{10}), ambient temperature (T_{amb}) and dryer inlet temperature (T_6) for day 1.

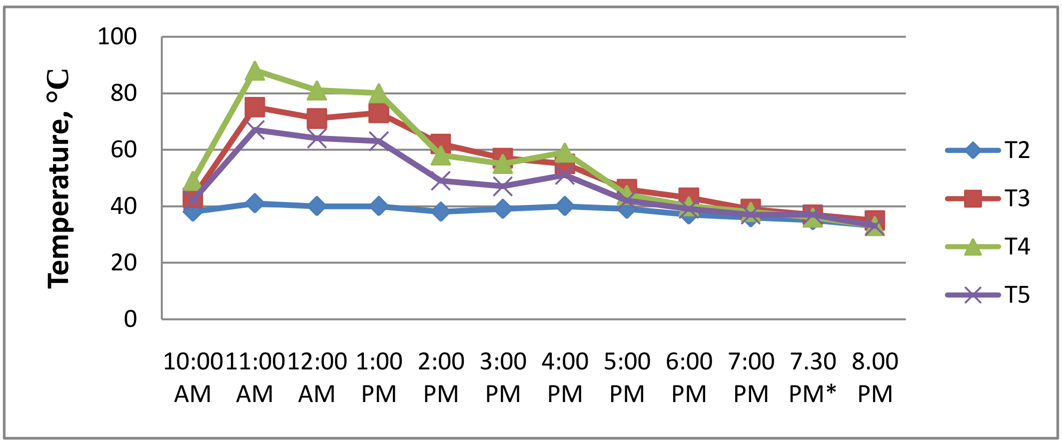

Fig 9: Variation of collector temperatures and gravel stones vs. time for day 1

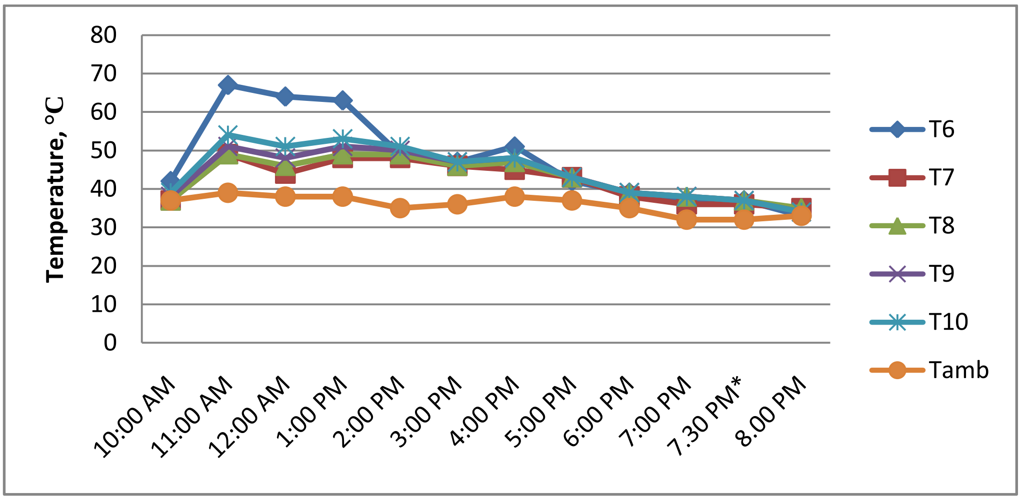

Fig 10: Variation of cabinet temperatures and ambient temperature vs. time for day 1

Fig 11 shows photographic view of variation of desiccant beds, their moisture absorption and desorption times. At 10 AM in the morning, the desiccant beds have absorbed all the moisture from the products throughout the night and are turned into pink. As the blower is turned on at 10.00 AM, the cabinet gets heated up. The moisture from the products as well as the desiccant beds is then removed and then the desiccant beds get regenerated.

As the temperature inside the dryer cabinet increases, the desiccant beds starts regenerating. Here the bed on the middle rack is considered which takes the longest time for regeneration. Thus, it takes about 4-5 hours on a normal average day for the desiccant beds to be regenerated.

Fig 12 and 13 shows variation of collector inlet temperature (T_2), temperature of gravel stones (T_3), temperature of copper tubes (T_4) and collector outlet temperature (T_5) as well as cabinet temperatures (T_7, T_8, T_9 and T_{10}) and ambient temperature (T_{amb}) for day 2 and day 3. Similar trends as that of day 1 can be observed.

Fig 14 shows variation of relative humidity inside the dryer cabinet for three consecutive days.

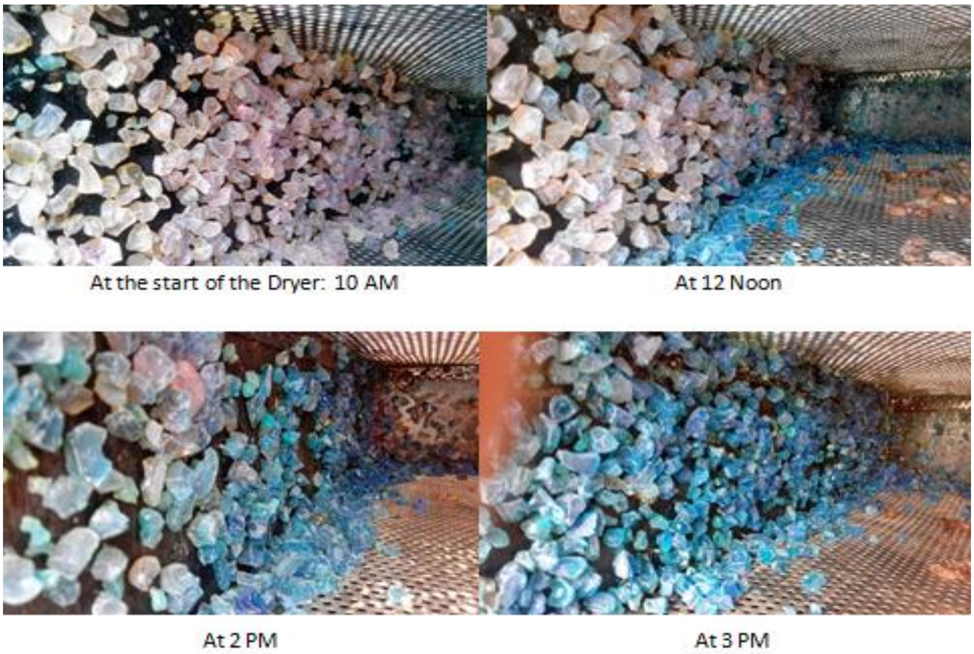

Fig 11: Desiccant beds adsorption and regeneration

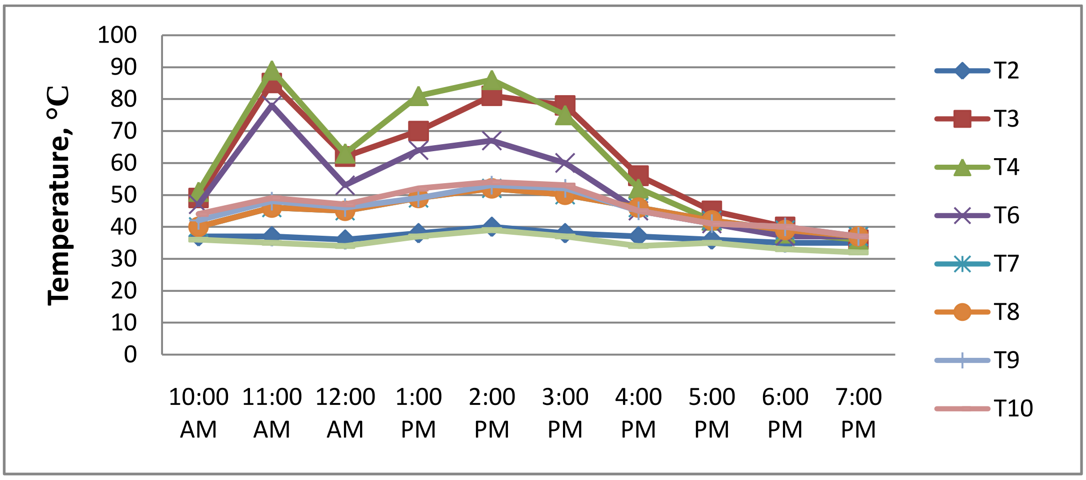

Fig 12: Variation of temperature vs. time of the day for day 2

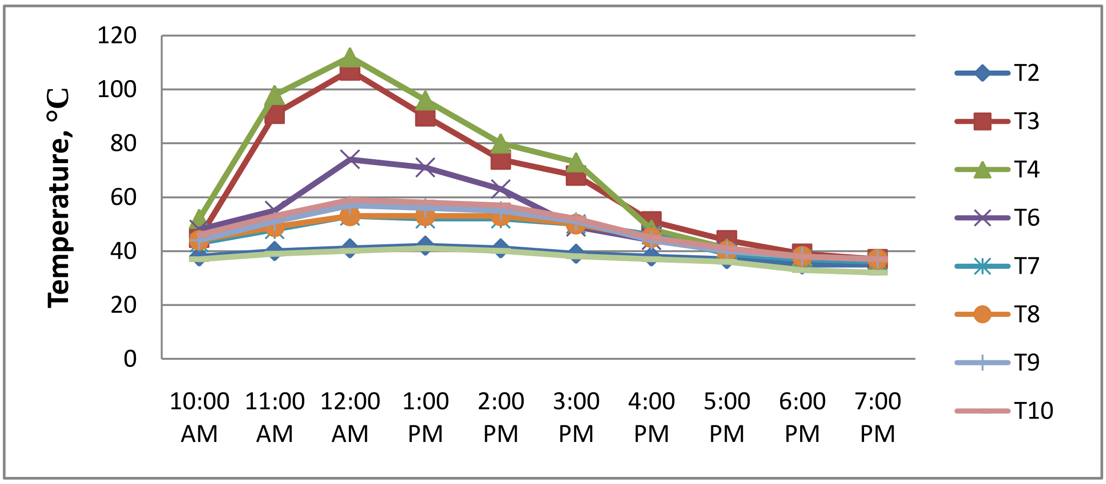

Fig 13: Variation of temperature vs. time of the day for day 3

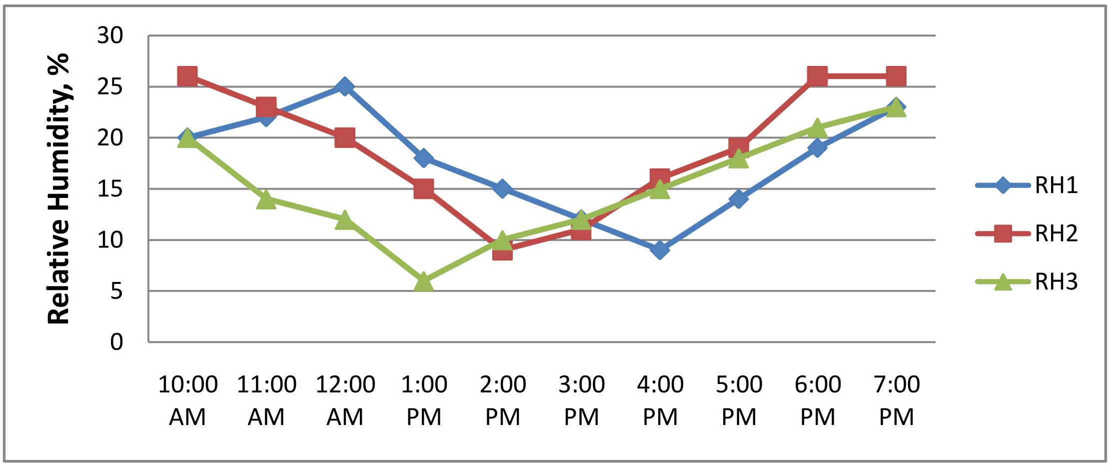

Fig 14: Variation of dryer relative humidity for 3 days

Here, RH_1, RH_2 and RH_3 represent the relative humidity for day 1, day 2 and day 3 respectively. As seen from the graph, the relative humidity for day 1 increases drastically initially. This is due to high moisture removal rate during initial drying periods. As the drying continues, the moisture removal rate is reduced. And it is the least for day 3.

C. Test 3: Direct sun drying of the products

For test 3, About 1.2 kg of grapes was kept on the roof for drying under the direct sun. However, while drying under direct sun, many problems were faced like blowing wind, insects and bird infestation, dust blown, which deteriorated the quality of the grapes. Also, there were uneven amount of drying observed in the grapes.

The total amount of drying for grapes was about 104 hours (5 Days). The taste, color and quality of grapes were very poor compared to the one dried in solar dryers. Also, due to uneven, uncontrolled rates of drying, some grapes were over dried and turned black while others were not completely dried.

Thus, total results for the two tests of dryer can be summarized in table 1.

TABLE 2

SUMMARY OF THE RESULTS

Parameters	With only heat storage	With heat storage & desiccant
Initial weight of the grapes	1.200 kg	1.200 kg
Initial moisture content of grapes	80 % wet basis	80 % wet basis
Final weight of grapes	0.245 kg	0.241 kg
Total moisture loss	0.955 kg	0.959 kg
Final moisture content (dry basis)	3.89 kg of water/kg of dry matter	3.97 kg of water/kg of dry matter
Final moisture content (wet basis)	20%	20%
Air flow rate	0.026 kg/s	0.026 kg/s
Blower velocity	9.6 m/s	9.6 m/s
Average ambient temperature	35.8 °C	36.11
Collector efficiency	34.3%	39.8%
Daily dryer efficiency per kg grapes	3.88%	5.2%
Total time required for drying	78 hours	57 hours
Time for which blower was on	37 hours	30.5 hours

VI. CONCLUSIONS

The experimental tests were conducted on fabricated setup of forced convection solar dryer. The tests included drying of grapes in forced circulation solar dryer with heat storage material and the second test in forced convection solar dryer with heat storage and desiccant beds. Also, the test was conducted for drying of grapes under direct sunlight. Thus, Grapes with initial moisture content of 80 % were dried to the final moisture content of 20% in 4 days, 78 hours in forced convection solar dryer with heat storage material. Whereas, it took only about 3 days, 57 hours, to dry grapes to the final moisture content of 20% in forced convection desiccant bed solar dryer integrated with sensible heat storage material. Open air sun drying of grapes took about 5 days, 104 hours to reach the required moisture content. However, they were of poor quality with improper color and taste.

Due to the use of heat storage material, gravel stones, the temperatures inside the solar dryer remains 3-5°C higher than ambient temperature even during off sunshine hours. Also, the heat storage material regulates the temperature of the collector outlet during uneven climatic conditions. Desiccant beds continue to remove the moisture from the grapes even during the night, thereby reducing the total drying time required. The desiccant beds can be regenerated in about 5 hours during a normal day. The grape on the lower trays dries at a faster rate compared to the tray which is placed at top. Hence, in case of large scale applications, the trays need to be rotated to ensure uniform drying of the products.The quality of grapes obtained from solar dryer was excellent with proper color and taste as compared to those dried directly under the sun.

References

[1] Pallav Purohit, Atul Kumar, Tara Chandra Kandpal, 2006,"Solar drying vs. open sun drying: A framework for financial evaluation." Solar Energy. 80: 1568-1579.

[2] Atul Sharma, C. R. Chen, Nguyen Vu Lan, 2009, "Solar-energy drying systems: A review." Renewable and Sustainable Energy Reviews, 13: 1185-1210.

[3] A. Fudholi, K. Sopian, M. H. Ruslan, M. A. Alghoul, M.Y. Sulaiman, 2010, "Review of solar dryers for agricultural and marine products." Renewable and Sustainable Energy Reviews. 14: 1-30.

[4] Ashish D. Chaudhari, and Sanjay P. Salve, 2014, "A Review of Solar Dryer Technologies." International Journal of Research in Advent Technology 22: 218-232.

[5] Gutti Babagana, Kiman Silas and B. G. Mustafa, 2012, "Design and Construction of Forced/Natural Convection Solar Vegetable Dryer with Heat Storage." ARPN Journal of Engineering and Applied Sciences 7(10): 105-112.

[6] Lalit M. Bal, Santosh Satya, S.N. Naik, Venkatesh Meda, 2011, "Review of solar dryers with latent heat storage systems for agricultural products. Renewable and Sustainable Energy Reviews," 15: 876-880.

[7] M. Mohanraj, P. Chandrasekar, 2009, "Performance of a forced convection solar drier integrated with gravel as heat storage material for chili drying, Journal of Engineering Science and Technology," 4(3): 305-314.

[8] Hodali, Riyad, and Jacques Bougard, 2001, "Integration of a desiccant unit in crops solar drying installation: optimization by numerical simulation." Energy conversion and management 42(13): 1543-1558.

[9] V. Shanmugam, E. Natarajan, 2006, "Experimental investigation of forced convection and desiccant integrated solar dryer." Renewable Energy 31(8): 1239-1251.

[10] V. Shanmugam, and E. Natarajan, 2007, "Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror." Applied Thermal Engineering 27(8): 1543-1551.

[11] Wisut Chramsa-arda, Sirinuch Jindaruksab, Chatchai Sirisumpunwonga, Sorawit Sonsaree, 2013, "Performance evaluation of the desiccant bed solar dryer." Energy Procedia. 34: 189-197.

[12] A. A. Hegazy, "Optimum channel geometry for solar air heaters of conventional design and constant flow operation, 1999" Energy Conversion and Management 40 757–774.

[13] A.A. El-Sebaii , S. Aboul-Enein, M.R.I. Ramadan, E. El-Bialy, 2007, "Year round performance of double pass solar air heater with packed bed", Energy Conversion and Management 48: 990–1003.