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Experimental Analysis on Multi Pass Flat Plate Collector Solar Air Dryer

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Abstract: *In this paper, the designing and testing of a new type of efficient solar dryer, particularly meant for drying fruit, is described. The dryer has two compartments: a solar collector and a drying chamber were the product to be dried is placed. This arrangement was made to absorb maximum solar radiation by the absorber plate. In this dryer, the heat from the sun is stored as sensible heat in granite sheet. A blower is placed at the air inlet to accelerate the drying rate. The absorber plate of the dryer attained a temperature of 77^0C when it was studied under no load conditions. The maximum air temperature in the dryer, under this condition was 41 ^0C. The dryer was loaded with 2kg of grape having an initial moisture content of 80 %, and the final moisture content of 6% was achieved within 36 hr. The collector glazing was inclined at a particular angle, suitable to the location, for absorption of maximum solar radiation. A detailed performance analysis was done on both dryers with granite (thermal storage medium) and without granite then; drying time reduction and moisture loss rate is found out and compared.*

Keywords: *Solar dryer, Drying chamber, solar collector, Absorber, Granite sheet.*

1. INTRODUCTION

Many farmers of the world are faced with the problem of reducing the moisture content of their harvested crops to prevent spoilage during storage. The situation is worse for farmers in the rural areas of developing countries where there is no access to electricity and harvested crops are often stored in heaps. Most of the harvested crops are susceptible to deterioration due to poor preservation. So, inorder to remove moisture drying is done. Drying (dewatering) is a simple process of excess water (moisture) removal from a natural or industrial product in order to reach the standard specification moisture content. It is an energy intensive operation. Especially essential is to reduce the foodstuff moisture content, as these have in general a water content much higher (around 25–80%, but generally for agricultural products around 70%) than the one suitable for long preservation. Drying of fruit and vegetables is one of the oldest methods of food preservation. In addition, drying enhances the storability, transportability, nutritional value retention, flavour and texture of food products Reducing moisture content of foodstuff down to a certain level slows down the action of enzymes, bacteria, yeasts and molds. Thus food can be stored and preserved for long time without spoilage. Another case of drying (or dewatering) is the total removal of moisture until food has no moisture at all.

Dehydrated food, when ready to use, is re-watered and almost regains its initial conditions. The widest among drying methods is convective drying (whereby heating takes place by convection between the hot air and the products surface), i.e. drying by flowing heated air circulating either over the upper side, bottom side or both, or across its mass. Hot air heats up the product and conveys released moisture to atmosphere thus drying psychrometry is of importance because it refers to the properties of air–vapor mixture that controls the function of drying. In direct solar drying called “sun drying” the product is heated directly by the sun’s rays and moisture is removed by natural circulation of air due to density differences. Two basic moisture transfer mechanisms are involved in drying:

1. Migration of moisture from the mass inside to the surface.
2. Transfer of the moisture from the surface to the surrounding air, in the form of water vapor.

Open sun drying is the most conventional form of drying Basically heating is done by using electric heaters which consume high amount of electric energy .the electric heater consist of a heating coil which heats up when electricity is passed through it. As this disadvantage of high current usage it is essential to find a substitute for this so as a renewable source of energy solar heaters are introduced.

1.1. Objective of Present Thesis

Some primary objectives of the present study are:

1. To design a two pass solar dryer with aluminum as absorber plate and granite sheet as thermal storage medium.
2. To experimentally investigate the performance of this new solar dryer.
3. To find out the percentage of moisture removed from the fruit (grape)
4. To compare the drying time for the fruit in the solar dryer with granite sheet and dryer without granite sheet as well as with open sun drying.
5. To find out the variation of temperature of a) aluminium absorber b) Granite sheet c) dryer inlet temperature with time in a day.

2. LITERATURE REVIEW

Both theoretical and experimental studies are reviewed. Numerous studies in the field of solar dryer have been reported. Different Solar dryer models and their study of drying time and moisture removal rate are reviewed.

Bukola O. Bolaji et al. [1] studied a rotary wind ventilator incorporated into the dryer, to increase the rate of air circulation through the dryer. Dryer consists of an absorber back plate insulated with foam material. Graph was plotted between time and temperature and time of drying and weight loss. The results obtained show that the temperatures inside the dryer and the air-heater were higher than the ambient temperature during most hours of the daylight. The drying of food items in the dryer was compared with open air-drying of similar items. Comparatively, drying with the solar cabinet dryer showed better results than open air-drying. The results also revealed the dependence of the dryer performance on the proper air circulation through the system. The system efficiency increased as the air velocity through the system increased and 80% and 55% weight losses were obtained in the drying of pepper and yam chips, respectively, in the dryer. The average daylight efficiency of the system was 46.7%.Abdul Jabbar N et al. [2] investigated the benefit over natural drying by using solar drying with and without auxiliary heat for drying beans and peas under different airflow rates .The solar heat may be supplemented by auxiliary heat of different types to reduce further drying time. It is often desirable to vary airflow rate through the system during the different stages of drying .An experimental study is conducted to investigate the performance of a solar drying system and a system equipped with an auxiliary heater as a supplement to the solar heat. The performances of both are compared to that of natural drying. Beans and peas are dehydrated in a system that consists of two flat plate collectors, a blower, and a drying chamber. Tests with four different airflow rates, namely, 0.0383, 0.05104, 0.0638, and 0.07655m^3/s are conducted. It was found that the drying time was reduced from 56 hours for natural drying to 12–14 hours for solar drying and to 8-9 hours for mixed (solar and auxiliary) drying. The efficiency of the mixed drying system was found to increase by 25% to 40% compared to the solely solar drying. A weak relation was observed between the variation of airflow rate and the decreasing rate of the moisture content of the dried material, especially for the mixed drying.BANOUT J et al.[3] designed a direct natural-circulation solar dryer,and compare its performance with the traditional open-to-sun drying. The design of the dryer was made to suit the local farmer needs, as a small-scale home drying unit with a capacity from 3 kg to 8 kg in relations to the product being dried. The purpose of this research was to study the performance of an integral-type natural-circulation solar-energy dryer for the drying of different crops under tropical conditions. It consist of a chimney for getting buoyancy. A K-type thermo-couple complete with digital relative humidity meter was used to measure the drying air temperature and drying air relative humidity inside the dryer. A pyranometer was used to measure the global solar radiation. The velocity of drying air was measured by an anemometer. The moisture contents of dried crops were measured at the starting and the end of each run of experiments.To evaluate drying performance of the solar dryer, the system drying efficiency was calculated. The performance of the integral natural circulation solar dryer is compared with that used in Pucallpa traditional open-to-sun drying. The mean solar radiation values over all the tests varied between 260 W/ m^2 and 390 W/m^2. Drying air temperatures were approximately over 39–70% higher than ambient air temperatures. The drying time required to reach 15% product moisture content in the integral natural circulation solar dryer varied between 7 and 24 hours. To achieve the same 15% product moisture by the traditional open-to-sun drying, from 25% to 85% longer drying time is required. In accordance with results of this research it is possible to conclude that using the integral natural-circulation solar dryer is a more appropriate technology to preserve agricultural products. Drying time is considerably reduced and the final product is acceptable in appearance and quality, because the dried crops are completely protected from rain, insects and dust. The solar dryer reported in this study was designed as a smallscale home drying unit adaptable to local farmers.A.O. Adelaja et al. [4]designed, constructed a forced convection solar dryer and tested for the purpose of drying yam in order to study the moisture removal pattern. In this paper the dryer comprises three main components namely the solar collector, the drying chamber and the pv-extractor assembly. Yam fillets weighing 0.52kg were dried in the dryer while an equal mass was dried in the open sun and the profiles obtained in both cases were compared. Quantity of heat used in evaporating moisture is found out. Efficiency of dryer and average drying rate is also found. The load test involved cutting 1.04kg of yam into slices of about 3mm, washed and weighed. This was divided into two parts, 0.52kg each. One part was spread into the first tray of the chamber which had earlier been checked for air tightness so as to avoid heat and moisture losses. The second part was spread in the open sun. An hourly measurement of the temperatures at specific locations and mass of the specimen was carried out between 10.00 and 17.00 hours each day for three days.Design parameters are Reynolds number,Nussult number, Coefficient of heat transfer,Heat removal factor, Total heat loss coefficient, Useful energy collected, mass flow rate, Collector efficiency. Evaluating the performance of the dryer; the collector and system efficiencies of 65.6% and 54.8% were obtained respectively. The moisture content removal of 75.0% was achieved as against 61.5% (control), indicating 13.5% difference, average drying rate of 0.0481kg/hr were recorded during solar drying of yam .The photovoltaic powered solar dryer designed, constructed and tested here can function on a continuous basis, that is, both during high intense sunshine and non insolation hours especially during cloudy weather.

3. EXPERIMENTAL INVESTIGATIONS

The materials used for the construction of this new type of solar dryer were inexpensive and easily obtainable in the market. The solar dryer consist of a solar collector, a drying chamber inclusive of drying trays.

3.1. Experimental Set Up

The layout of the experiment setup is given below,

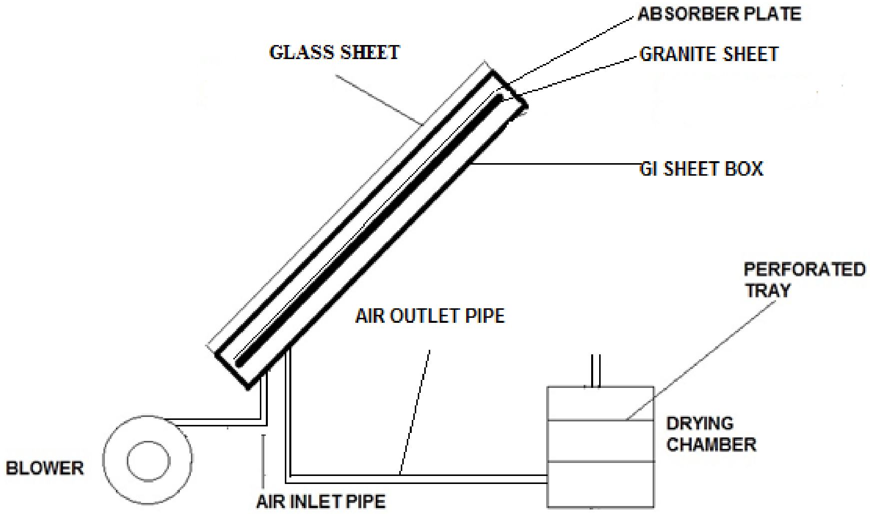


Fig1. *Experimental layout of experimental setup*

The experiment set up consists of a solar collector consisting of aluminium sheet as absorber plate, granite sheet as thermal storage medium,G.I casing and glass sheet.A drying chamber consisting of a perforated tray inside containerand a blower is used . While building a solar collector at first insulation casing is made of insulating material thermocole stacked in between two GI sheet

Box is about 4inch in all sides .the length and width of box is given as to accomodate 1mx0.8m aluminium sheet.The inside length of the GI box is 0.1m more than the absorber sheet so that air passes from lower section of box to the upper section (two pass system). The absorber is placed inside the box ,here aluminium sheet painted black is used as absorber.the dimension of the absorber is as per design 1x0.8m. Below absorber plate granite sheet of same length and width of that of absorber sheet is placed for storing the sensible heat,the thickness of granite sheet is about 4cm. At the top of the absorber, glass sheet is placed which transmits maximum solar radiation falling on it. Drying cabinet consist of a small cylindrical chamber build of GI material and inside which material of high insulation properties are placed or coated so that it does not allow heat to escape out. A blower is used for continously blow air from outside to the solar collector and the air is heated and the heated air is taken to drying chamber,

3.2. Experimental Procedure

The air temperatures at collector inlet, collector outlet, drying chamber, and ambient were measured by laboratory type digital thermometer at regular interval of 1 h between the hours of 0900 and 1800 localtime. The solar intensity was measured by means of a portable pyranometer placed horizontally and facing south. The dryer was loaded with grapes and the weight was measured at the start . The initial weight and the final weight of grapes up to the stage when no further weight loss occurred were known. At the same time same quantity of grapes is dryed in open sun for the same time and we could observe the amount of moisture removed in each case in a given fixed time and also the time taken for drying the grape can also be compared.The grape will be first dried in solar dryer having granite sheet as heat storage medium and we find the drying time for the grape. Secondly the grape is dried in solar dryer which does not have granite sheet as heat storage medium.and also the same amount is dried in open sun.

Table1.

Location- Kasaragod	12.5^{0}N, 75^{0}E
Crop	Grapes
Drying period	May 2014
Drying material quantity	2 kg
Loading rate	2 kg/tray
Initial moisture content	Mi 80% wb
Final moisture content	M_f 6% wb
Ambient air temperature, T_{amb}	32°C (average for May)
Ambient relative humidity, RH_{amb}	15% (average for May)
Max allowable temperature, Tmax	77°C
Drying time (sunshine hours)	9h (average for May)
Flat plate type	Aluminium flate plate collector
Heat storage medium	Granite sheet
Test collector size	1m length and 0.8 m wide

3.3. Theoretical Analysis

Theoretically we are finding the quantity of heat needed to evaporate the water, quantity of heat needed to evaporate the water, average drying rate, mass of air needed for drying, quantity of heat added to the air, area of the collector etc.

1) To find the amount of moisture in kilogram to be removed from the product was calculated using the following equation:

$$M_w = \frac{m_p(Mi - Mf)}{(100 - Mf)}$$

2) To find the Quantity of heat needed to evaporate the water,Q $= (M_w \times h_{fg})$
3) To find the Latent heat of vapourization is found out from the general equation ,

$$h_{fg} = 4.186 \times 10^3 \times (597 - 0.56T_{pr})$$

4) To find thequantity of heat needed for vapourization =mass *latent heat of vapourization

   Total heat energy, $E = m \times (h_f - h_i) \times t_d$
5) To find the Average drying rate, $m_{dv} = \frac{m_w}{t_d}$
6) To find the Mass of air needed for drying , $m_a = \frac{m_{dv}}{(w_f - w_i)}$
7) To find volumetric flow rate ,Va =mass flowrate /density
8) To find the Quantity of heat added to the air , $E = m_a \times (h_f - h_i) \times t_d$
9) To find the Area of the collector, $E = A_c \times I \times \text{collector efficiency}$

   Area of the collector, $A_c = \frac{E}{(I \times \text{collector efficiency})}$
10) To find theArea of air vent,

In solar collector and in drying chamber there may be heat loss in form of conduction, convection and radiation, so it is important to find out the loss coefficient

Finding loss coefficient for the flat plate collector

From radiation heat transfer equation,

- To find the Radiation coefficient from plate to glass cover, $h_{rpc} = \frac{\sigma \times (T_p^2 + T_c^2) \times (T_p + T_c)}{\left(\left(\frac{1}{\varepsilon_p}\right) + \left(\frac{1}{\varepsilon_c}\right) - 1\right)}$

- To find Radiation coefficient from cover to surface,

$$h_{rcs} = \varepsilon_c \times \sigma \times (T_c^2 + T_s^2)(T_c + T_s)$$

- To find the Convection coefficient between plate and cover ,

$$h_{rpc} = 1 - 0.0018 \times (T - 10) \times \left(1.14 \times \frac{\Delta T^{0.31}}{l^{0.07}}\right)$$

- Convective heat transfer coefficient for wind blowing over the cover,

$$h_w = 5.7 + 3.8 \times v$$

- Toploss coefficient, $U_t = 1 \Big/ \left[\frac{1}{h_{rpc} + h_{pc}} + \frac{1}{h_w + h_{rcs}}\right]$

- To find the cover temperature, $T_c = T_p - \frac{U_t(T_p - T_c)}{h_{pc} + h_{rpc}}$

- To find the Bottom loss coefficient, $U_b = \frac{k_i}{x_i}$

k_i =insulation thermal conductivity

x_i= insulation thermal thickness

- To find the toploss coefficient for an inclination of 27.5o the equation used is ,

$$U_{t(s)} \Big/ U_{t(45)} = 1 - [(s - 45)(0.00259 - 0.00144 \times \varepsilon_p)]$$

- To find the loss coefficient at the edge,

$$U_{edge} \times A_{edge} = \frac{k_i}{x_i} \times (collector\ thickness \times perimeter)$$

11) To find the Total loss, $U_{total} = U_t + U_b + U_e$

$$A_r = \frac{V_a}{V_w}$$

4. RESULTS AND DISCUSSIONS

Experimental analysis on two phase solar dryer with aluminium as absorber and granite sheet as heat storage medium is done and is compared with the same two phase solar dryer without granite sheet and the following results are obtained.

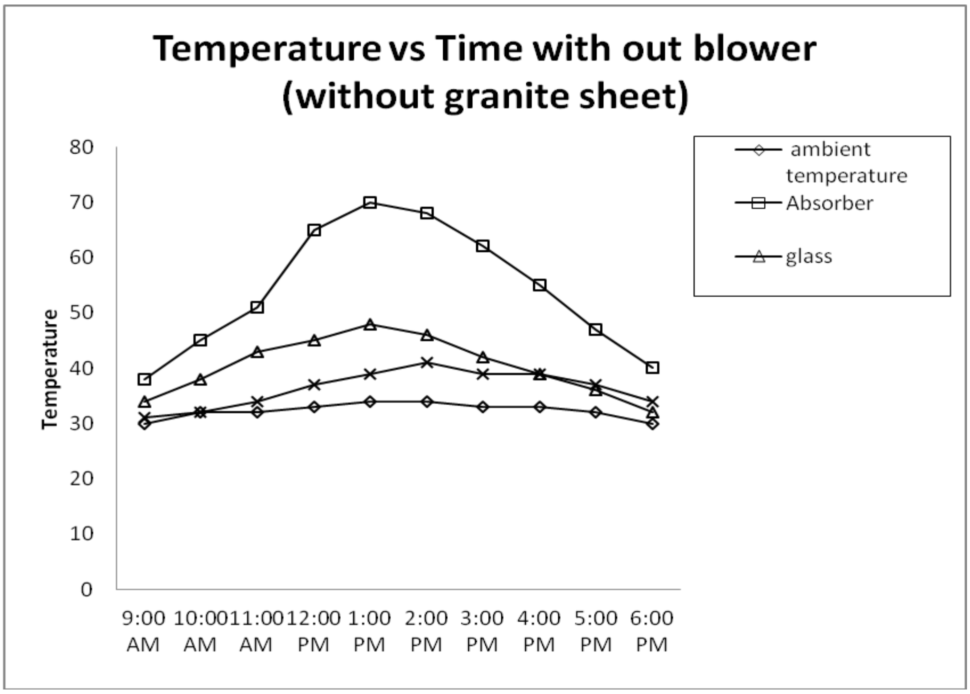


Fig2. *Temperature Vs Time graph without blower (without granite sheet)*

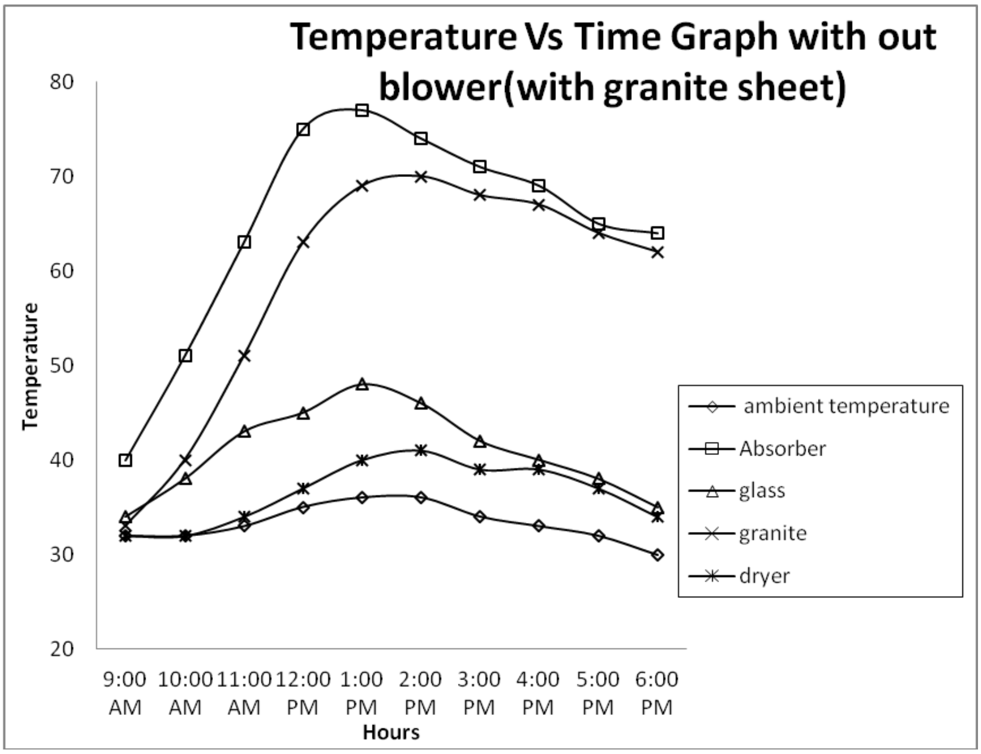


Fig3. *Temperature Vs Time graph without blower (with granite sheet)*

From the graph it is seen that without using blower the temperature of absorber increases from 40°C at 9AM and attained a maximum temperature of 77°C at 1PM and gradually decreases to 64 °C at 6PM.But in the case of granite sheet it it attains a temperature of 33°C at 9AM and slowly increases to

73°C at 2PM and then it maintains the temperature and at 6PM a temperature of 67°C is reached .this temperature is maintained by the sensible heat stored in granite sheet. The glass temperature gradually rises from morning and reaches close to fifty at 1PM and then decreases gradually to ambient temperature .As there is no blower the hot air near absorber does not reaches the drying chamber and so the temperature inside drying chamber is very low compared to absorber and granite it only reaches temperature close to fourty.

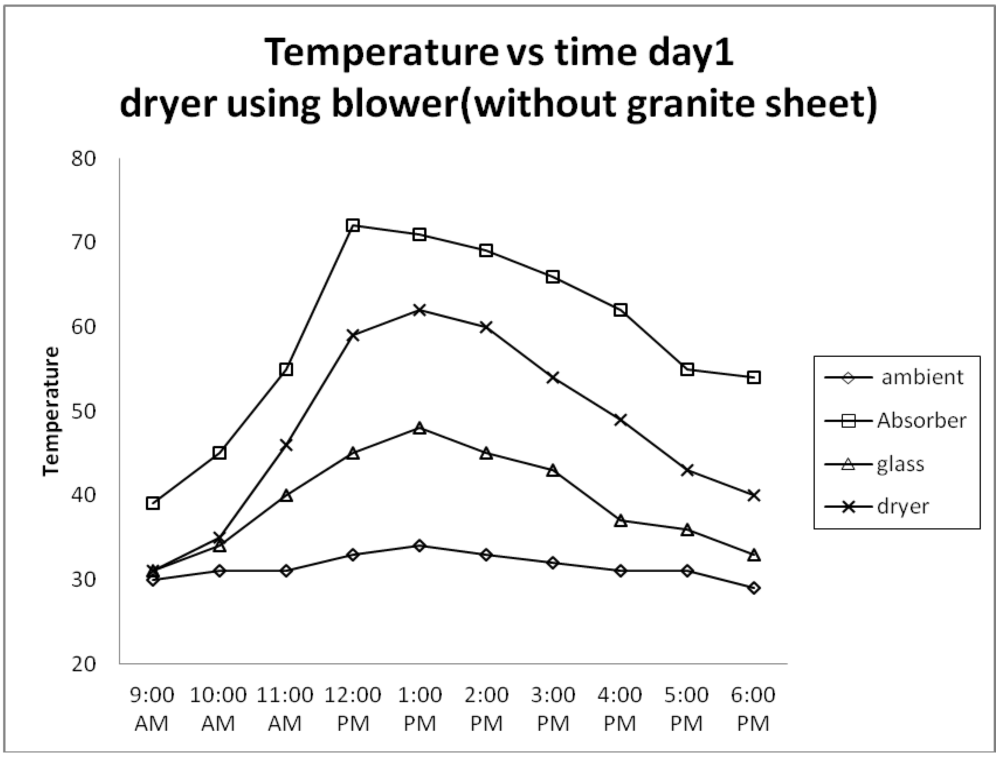


Fig4. *Temperature Vs Time graph with blower (without granite sheet) day 1*

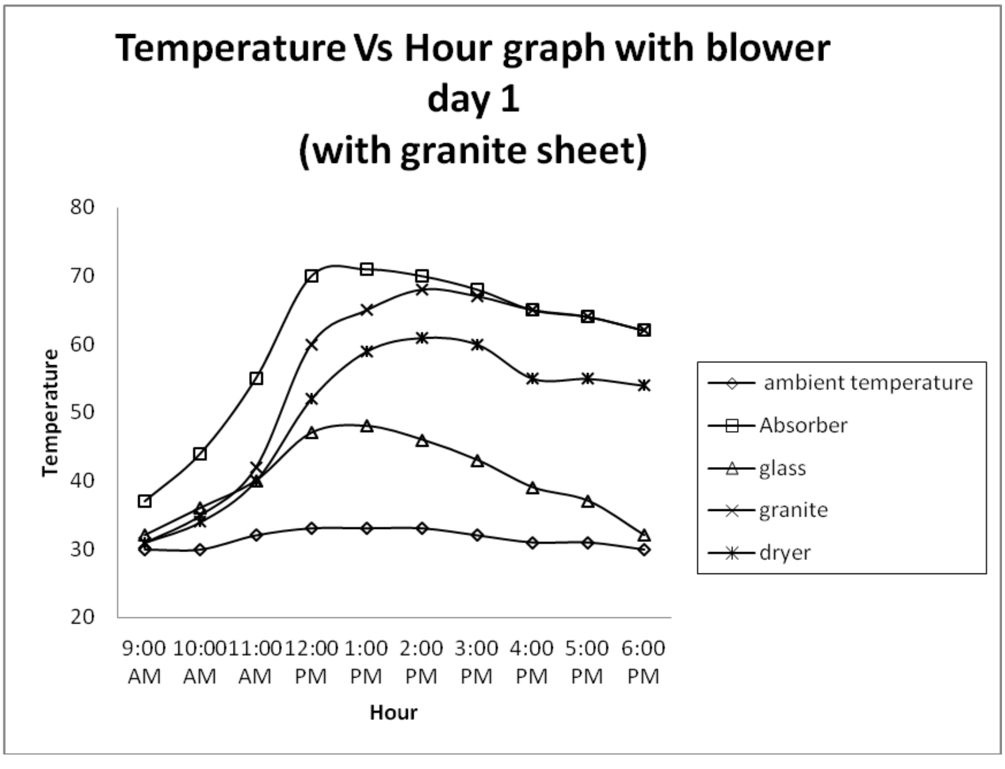


Fig5.*Temperature Vs Time graph with blower (with granite sheet) day 1*

From the graph it is seen observed that the max absorber temperature attained is 72°C in the case of both dryer without granite sheet and with granite sheet. The maximum Granite temperature attained is 68°C and is maintained at 55°C until 6PM.The max dryer temperature attained is 61°C in the case of solar dryer with granite sheet. By comparing the two graphs 6.1 and 6.2 it is observed that in the case of solar dryer without granite sheet the dryer temperature drops gradually after 3pm, but in the case of solar dryer with granite sheet the dryer temperature line is having a slight slope only after 3pm ,that is even though there is decrease in temperature it is in very slow rate .

Mass of fruit at the end of day one (with granite sheet) - 1.560kg

Mass of fruit at the end of day one (without granite sheet)-1.670kg

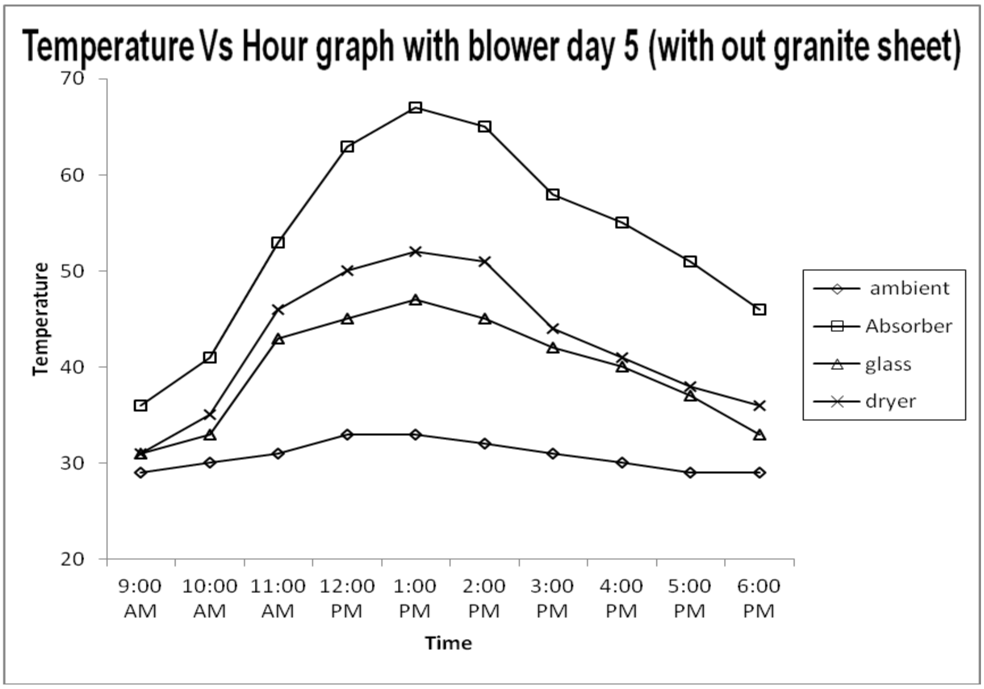
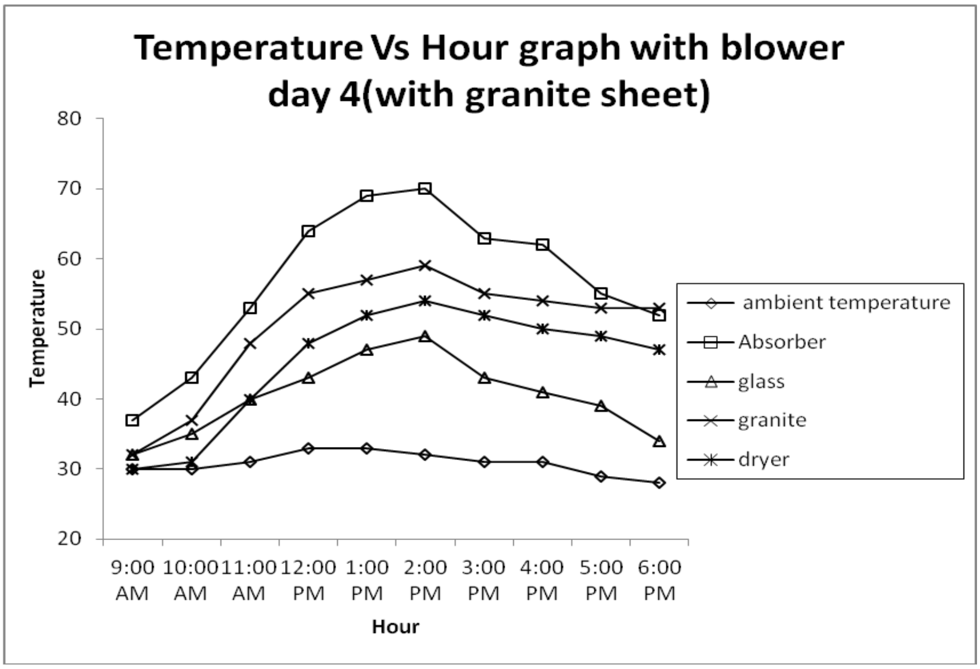
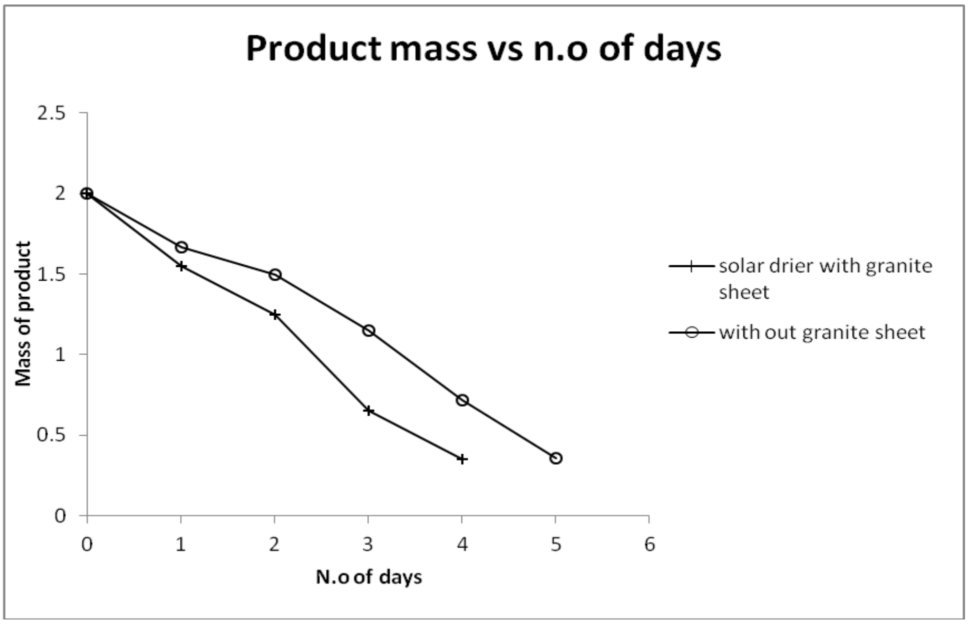


Fig6. *Temperature Vs Time graph with blower (without granite sheet) day 5(last day)*



Temperature Vs Time graph with blower (with granite sheet) day 4(last day)



Graph showing loss of water from the product

Graph shows the decrease in mass of product in each day ie, the reduction in moisture content in each day is shown and the mass of product decrease from 2kg to 0.350kg in 4 days for solar drier with granite sheet but,the solar drier without granite sheet takes 5days to remove the moisture content.

5. CONCLUSION

It is observed that the drying of grapes in the open sun takes 7 to 8 days during clear sunny weather conditions. However, it only takes 4 days in the two pass solar dryer with aluminium absorber plates and granite sheet as heat storage medium but the same two pass solar dryer without granite sheet as heat storage medium takes 5 days to dry the grapes under similar weather conditions. From that we could conclude that the granite sheet acts as good thermal storage medium and gives extra drying time in the evening .Here we get an extra drying time of one hour in the evening and the heat of the granite gets reduced slowly throughout the night and keeps the grapes warm and dry at night.

Also, the quality of dried grapes is remarkably better in two pass solar dryer compared to open sun drying as the product is protected from dust and insects.

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