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Development of low cost solar dryer for Oman conditions

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Abstract: Solar dryer is one of the technologies which are used in many countries to dry the agricultural products. In the present work, development of low cost pebble bed solar dryer was made to suit for Oman weather conditions. The system consists of solar collector with pebbles for heat storage and cost effective food drying chamber. Initially, dryer performance was studied with banana and study results revealed that maximum dryer room temperature of 68°C and the moisture loss content of 52%. In addition, dryer chamber efficiency of 34% was achieved in the study. Overall, the study results indicated that late evening drying up to 7PM was noticed and the developed dryer system gave better results than dryers available in the market.

Keywords: Solar dryer, Pebbles, Collector efficiency, Dryer efficiency

1. INTRODUCTION

Renewable energy is the best source of energy in the world and it can be used in many countries that don’t have the petroleum or oil energy sources. Energy coming from the sun, wind, and geothermal heat sources are usually used in many areas. However, solar energy is the largely used renewable energy in Oman because of high sky clearness ratio.

In the past, people using different methods of drying from solar energy. They are using open air sun dryers to dry the foods for a long time. But this method of drying have many disadvantages on the quality of dried foods such as insect damages, decay effect and rodent attacks. The performance of this system is calculated on the basis of time taken to dry the agricultural foods and the final products quality and energy collected from the sun. Over the years, people tried to solve the problems of the solar dryer system and have faced many problems such as can’t use dryers in the night and also dry the foods in a short time. Fuller R.J. (2011) presented review article for solar dryer. In his study indicated that agricultural foods should be dried with temperature less than 100°C. Overall, study highlighted solar dryer design methods, absorber, glazing materials and control systems to improve the performance of solar dryer. Okonkwo and Okoye (2005) studied the performance evaluation of pebble bed solar dryer. The test performance indicated that maximum absorber temperature of 72oC and chamber temperature of 57oC when ambient air temperature was 34oC. The study with cassava showed a moisture reduction of 10.2% in 3-days of drying process as against open air sun drying value of 22.2%. In addition, study results revealed that products dried under passive solar crop dryer were of high quality while there was fungus build-up on the open air sun dried products. Santos, Queiroz and Borges (2005) studied the...
performance of solar dryer with different design collectors suitable to Brazilian climatic conditions. The study results indicated that solar energy storage with pebble bed solar drying systems were storing very high heated energy in order to dry the agricultural foods in the best way and enhanced the energy storage with selecting good materials and proper dimensions for the collector. Similarly, Feyza (2007) did comparison study between different types of solar drying systems. The study results indicated that pebble bed solar dryer is the best one for drying agricultural products. Chandrakumar and Jiwanlal (2013) carried out experimental study on pebble bed solar drying system. The study results highlighted that collector surface geometry, temperature of the air entering to the chamber and the product nature signifies the overall performance of dryer. The performance results indicated that temperature needed to dry the foods in the day is 75°C; in the night, chamber temperature drops to 50-55°C with pebble bed dryer. Anuradha A and Rachel Oommen (2013) carried out experimental study on pebble bed solar dryer with cauliflower and ladies finger. Different quantities of storage material were employed to study their performance. The study results indicated that efficiency of the dryer was 32-41% for cauliflower and 30-39% for ladies finger. The moisture content of cauliflower was reduced from 74% to 7.1% and 82% to 6.8% for ladies finger and also observed faster drying rate when compared to open sun drying. Fagunwa, Koya and Faborode (2009) developed an intermittent solar dryer for cocoa beans. In their study, drying mechanism was based on combination of convective heating and direct radiation, with a provision for controlling the rate of airflow through the beans. The experimental study indicated that dehydration of cocoa beans from 53.4% to 3.6% in 72 hours drying process for an ambient temperature of 25-30°C and quality of the dried beans is good.

In this context, in the current work, developed a low cost pebble bed passive solar energy storage dryer for Oman conditions and the performance is studied for different quantities of banana. Later, the study could be extended for dates drying in rural parts of Oman.

2. THERMAL ANALYSIS ON PEBBLE BED SOLAR DRYER

2.1 Pebbles

A pebble is a clast of rock with a particle size of 2 to 64 mm based on the Krumbein phi scale of sedimentology. Pebbles come in various colors and textures and can have streaks, known as veins, of quartz or other minerals. Normally, sandstones and soapstone are used as pebbles for storing solar energy. In the current work, soapstone pebbles are used and it is a metamorphic rock that is composed primarily of talc, with varying amounts of chlorite, micas, amphiboles, carbonates, and other minerals. Normally, soapstone’s are nonporous, nonabsorbent, low electrical conductivity, heat resistant and high specific heat capacity. The properties of the pebbles are given in table 1.

| Parameter                  | Value            |
|---------------------------|------------------|
| Type of Pebble material   | Soapstone        |
| Density, kg/m³            | 2.5x10³          |
| Specific heat of pebbles, kJ/kg K | 0.84 |

2.2 Analysis of solar dryer

In any solar dryer, useful energy gained by the collector is equivalent to the amount of energy absorbed by the pebbles which is given by equation (1). The drying process is dependent on the energy absorbed by the collector and the maximum capacity of heated air can flow through the solar collector.

\[ Q_u = Q_{st} = V_{pebble} \times \rho_{pebble} \times C_{p,pebble} \times \Delta T \]

Where, \( V_{pebble} \) is volume of the pebbles in m³; \( \rho_{pebble} \) is density of pebbles in kg/m³; \( C_{p,pebble} \) is specific heat of the pebbles in kJ/kg K; \( \Delta T \) is rise in temperature in °C.

In addition, collector plays an important role in dryer performance. The collector efficiency is calculated from equation 2.
\[ \eta_c = \frac{Q_v}{\pi A} \] .......................... (2)

Where, \( Q_v \) is the useful energy gained by the collector in W; \( A \) is Area of the collector in m\(^2\); \( I \) is the intensity of radiation in MW/m\(^2\).

In the solar dryers, there is an equivalent relationship between the energy which is required to dry the crops and the energy which is gained by the air. So, energy required for evaporation is represented as,

\[ E_p = M_w \cdot L_v \] .......................... (3)

\( M_w \) = mass of the foods in kg; \( L_v \) = latent heat of vaporization in kJ/kg.

In addition, drying chamber efficiency is very important to know the effectiveness of the chamber to obtain good results on drying.

The dryer chamber efficiency and time taken to dry the foods is calculated from equations (4) and (5) respectively as,

\[ \eta_{chamber} = \frac{M_w \cdot L_v}{A \cdot I} \] .......................... (4)

And, time taken to dry the foods as

\[ t = \frac{E_p}{\eta_d \cdot \eta_c \cdot A I} \] .......................... (5)

In the solar dryer, energy received by the product is used in vaporization of surface water. The interstitial water migrates from the surface and the product becomes dryer. The moisture removal of the product is calculated from the equation (6), i.e.

\[ M_c = \frac{M_i - M_f}{M_i} \times 100 \] ........................................................... (6)

Where, \( M_i \) is the initial mass of the foods in kg and \( M_f \) is the final mass of the foods in kg.

3. DEVELOPMENT OF LOW COST Solar Dryer

In the present work, low cost pebble bed solar dryer was developed for Oman conditions. The developed pebble bed solar dryer consists of two important parts namely, (1) Pebble solar collector and (2) Dryer chamber.

3.1 Pebble solar collector: This solar collector is a flat plate type collector, which are collecting the energy from sun and storing the energy. The developed solar collector is having the dimensions of 1000mm length, 550mm width and 200mm depth and those dimensions were obtained from thermal calculations, refer figure 1. The wall of the collector is made of wooden materials which serves as insulation material and the plate used in this collector is aluminium plate which is having more absorbing rate. Three quarter of the collector is filled with soapstone pebbles and which were painted with black colour to increase energy absorption rate. In addition, the collector was covered by a glass to provide a good air circulation in the system.

![Figure 1. Pebble solar collector](image)

3.2 Dryer chamber: Drying chamber is an important part of the solar dryer which is having the dimensions of 900mm height, 450mm width and length respectively, refer figure 2. It is made of wooden
materials to store the heated air and is covered by aluminium sheet to increase the drying rate. The developed system consisted of three trays which were required to dry the foods. In between the solar collector and the drying chamber there is a blower which is transferring the heated air through the system from the collector to the drying chamber.

![Dryer chamber](image)

**Figure 2.** Dryer chamber

### 4.0 EXPERIMENTAL SET-UP

![Developed Low cost solar dryer](image)

**Figure 3.** Developed Low cost solar dryer

Figure 3 highlights the developed low cost pebble bed solar dryer system. The dryer collector area was filled with pebbles painted by black colour and sucker type fan was used for transferring the heated air from the collector to the dryer chamber. Most of the experiments were carried out using 2 kg of banana. From the recorded air temperatures, physical properties of pebbles and geometrical details of collector, the performance of the pebble bed dryer system was evaluated. In the current work, experiments were carried out for 4-days to understand the dryer chamber efficiency, moisture content removal percentage etc.

### 5.0 RESULTS AND DISCUSSION

#### 5.1 Thermal analysis of solar dryer:

At the beginning, from analytical equations the parameters like useful solar energy, collector efficiency and dryer efficiency were calculated and the calculated values are indicated in Table 2. The calculated results showed dryer chamber efficiency of 30% and it gave reasonable thoughts to start the fabrication of solar dryer from chosen dimensions.

| Parameters | Value |
|------------|-------|

![Table 2. Predicted results from thermal analysis](image)
Useful energy, $Q_u$ | 8160 W
--- | ---
Collector efficiency | 40%
Dryer chamber Efficiency | 30%

5.2 Intensity of solar radiation: Experimental study had been carried out for 4-days in the month of May, 2017 to understand the behavior of low cost dryer in Al Seeb area- Muscat, Oman. The typical solar intensity plot is displayed in figure 4. The measured results showed highest solar intensity value of 1001 W/m$^2$ at 12:00 PM noon.

![Solar Intensity Graph](image)

Figure 4. Variation of solar intensity at different time intervals: Al Seeb area – Muscat, Oman

5.3 Experimental Study:

The performance evaluation of low cost pebble bed solar dryer filled with banana was studied for 4-days. During the study, relative humidity of the dryer and ambient conditions were recorded with humidity sensors and thermometers. In addition, moisture loss from the banana was measured by weight loss method.

Initially, dryer chamber temperature with respect to pebbles quantity was studied, figure 5. The study showed with less quantity of pebbles, the dryer room temperature reached to 52°C. However, with large quantity pebbles (three fourth of collector volume i.e., 45 kg) the temperature raised to 65°C and also, late evening drying up to 7PM was noticed. Hence, throughout the experiment large quantity of pebbles were used to understand the dryer performance.

![Temperature Graph](image)

Pebbles quantity: Small, Medium, Larger

Temperature °C: 0, 10, 20, 30, 40, 50, 60, 70
Later part of the experiment, dryer chamber was loaded with different quantities of banana to evaluate the moisture loss percentage. Figure 6 represents the variation of moisture loss content from the banana with different quantities of loading. The study had been performed for 1.5 hours in each loading experiment to get the tentative idea of moisture loss content. From test results, it was confirmed that lower quantity of banana dried faster than the others.

The dryer room temperature along the time is indicated in figure 7 and the results revealed that maximum dryer room temperature of 65 °C was observed at 2PM. With the help of pebbles, the heat content of the system was increased. Also, about 58°C temperature was observed at 7PM and it enabled to dry the banana effectively.

In the later part of the study, 2kg banana loading was placed in the dryer chamber to understand the moisture loss content. The study had been performed on May 10, 2017 from 11AM to 3PM and for each hour the moisture loss content was recorded by weightage difference. At 11AM, the observed moisture content was around 90% and as the time progressed the moisture content dropped to 50%, refer figure 8.
Similarly, efficiency of the solar pebble bed dryer system was evaluated from moisture loss content data and dryer chamber temperatures. The efficiency of the pebble bed solar dryer system with respect to temperature is indicated in Figure 9. An average efficiency of 34% was observed during the study and it also in line with thermal calculations result. From the above study, it was confirmed that the designed low cost pebble bed solar dryer was effective for Oman conditions for the food products drying. In the later part of the work, dryer performance will be studied with Dates.

6. CONCLUSION
In this work, low cost pebble bed passive solar crop dryer was developed and tested for Oman conditions. The following conclusions are drawn from this work:

1. From thermal analyses, the efficiency of dryer system is found to be 30 % as against 34% from experiments. The error could be due to variation in solar intensity values. In addition, a maximum dryer room temperature of 65°C was noticed in the afternoon and the late evening drying was observed with pebble bed storage system.

2. Experimental results revealed that 50% moisture content reduction was noticed for 4-hours of the run. Though the test run was very less, but it gave good thoughts on dryer performance.

3. Overall, the developed low cost pebble bed solar dryer gave satisfactory results for Oman conditions and the same approach could be used to dry the dates and fish. In addition, the system efficiency could be improved with proper insulating material and good air circulation without any loses of heat energy inside the dryer chamber.
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