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EVALUATION OF DIFFERENT DESIGNS OF THERMAL STORAGE IN SOLAR DRYING SYSTEM

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تقييم التصميمات المختلفة للخزانات الحرارية فى اجهزة التجفيف الشمسى

ملخص

تم تصميم و تصنيع نظام تجفيف شمسى مبسط يتكو ن من سخا ن هو اء شمسى و حجرة للتجفيف وخزان حرارى. و قد تم تصميم الخزان الحرارى بطريقة جديدة و بسيطة لكى يتم تسخينه بواسطة أشعة الشمس المباشرة بجانب الهواء الساخن القادم من السخانات الشمسية.

تمت دراسة اداء النظام فى عدة اوضاع بالنسبة لحجرة التجفيف على مدى ٢٤ ساعة لتحديد افضلها فى الاستخدام. كذلك تمت دراسة اداء افضل هذه الاوضاع تحت تأثير سرعات الهواء المختلفة لتحديد انسبها من حيث درجة حرارة الهواء الداخل لحجرة التجفيف على مدى ٢٤ ساعة.

ABSTRACT

* A simple ,easy built forced convection solar drying system consisting of a solar air heater, drying chamber and thermal storage has been constructed and tested.

A new simple pebble bed storage , with special and easy form was designed to be heated with direct solar energy or hot air from the heater or both.

The drying system performance was studied under different locations of the storage box with respect to the drying chamber during 24 hours of operation.The performance of the drying system with the best location was studied under different flow rates.

INTRODUCTION

Two of the characteristic problems regarding the applicability of solar energy as an alternative to conventional energy sources, are its intermittancy and low density. Specifically for solar food dryers, these factors make it difficult to obtain a reliable system, i.e capable of operating at reasonably consistent temperatures.

One possible way to minimize this problem is through the storage of solar energy for later use during times of reduced solar radiation. Storage of energy may be accomplished through numerous methods which can be classified into latent heat and sensible heat techniques.

Rock or pebble bed storage which belong to the latter technique have been shown to be desirable, simple and inexpensive thermal storage for solar energy (1-3). It appears to be a more suitable way in solar drying system since the heat carrying agent is usually hot air. The hot air flow used for drying can be used to transfer the collected heat to the bed and to retrive the stored heat when needed. For these reasons many drying systems with layers of pebble placed at the bottom of the drying chamber have been built (4-5).

Although this method is simple to stabilize the temperature in the drying chamber and raise the average chamber temperature during night ,yet it decreases the heat flux to the drying air temperature during the day.

So the input energy to the system must be increased to account for the more added thermal inertia of the storage bed. This could be achieved by increasing the area of the air heaters or developing a more efficient design of the storage bed which is the subject of the present work.

CONSTRUCTION OF THE DRYING SYSTEM

The investigated drying system is shown in Fig (1). It consists of :

1-A solar air heater of $3m^2$ area , made of black painted corrugated absorber. It is covered with one layer of window glass ,3 mm thick and insulated with 5 cm hard foam at the bottom and sides.

2-Drying chamber of 1.5 m^3 volume made of double wall galvanized iron steel with 5 cm insulation. Two suction fans, are located at the top of the drying chamber.

3-A storage bed with walls having the same width as the drying chamber made of double walls of galvanized steel sandwitching with 5 cm insulation from sides and bottom. Its internal sides are covered aluminum foil sticker. The box is filled with black painted pebbles and covered with window glass, 3 mm thick. As shown in Fig (2) ,this bed has another insulated cover to be used during night to reduce thermal losses and its internal face acts as a reflector during sun hours by covering it with aluminum foil.. The storage bed with this design has the advantage of being heated with hot air as well as solar radiation , which is also enhanced by using a reflecting surface . Three locations of this bed with respect to the drying chamber were studied.

First location :Fig (3-a):

The storage bed is placed between the air heater and drying chamber. In this case, the bed is heated with both direct solar radition and hot air from the collector during sun hours and then discharged during night.In this case energy balance for the bed during heating is :

$$(M\ Cp)_s\ (\Delta T_s / \Delta\theta) = [(m\ Cp)_a\ (T_c - T_r) + I_1\ (\tau\alpha)_s\ A_s - Q_L] \quad (1)$$

Second location Fig(3-b)

The storage bed is isolated from the system during sun hours . The direct solar energy is stored in the pebble bed during sun hours and then discharged through gates opened during night,the energy balance of the bed will be:

$$(M\ Cp)_s\ (\Delta T_s / \Delta\theta) = [I_1(\tau\alpha)_s\ A_s - Q_L] \quad (2)$$

Third location Fig(3-c)

The same pebble volume is placed at the bottom of the drying chamber and enhancing the input energy to the heater by using the south face of the dryer as a reflecting surface ,energy balance for the bed is then

$$(M\ Cp)_s\ (\Delta T_s / \Delta\theta) = (m\ Cp)_a\ (T_c - T_r) - Q_L \quad (3)$$

Where T_s , T_c and T_r are the average storage bed temperature, outlet air temperature from the air heater and inlet air temperature to the drying chamber respectively.

PERFORMANCE EVALUATION

1-Analysis

Useful energy gained from the system over 24 hours of operation starting from 9 a.m is:

$$Qu = \Sigma\ m \,.\, Cp_a \,.(T_r - T_a)\,.\, \Delta\theta \quad (4)$$

and total solar enrgy reaching the system during sun hours in

Case 1 and case 2 is :

$$Q_S = \Sigma\,(I_1 A_s + I_2 A_c).\, \Delta\theta \quad (5)$$

and Case 3

$$Q_S = \Sigma\,(I_2 A_c).\, \Delta\theta \quad (6)$$

Where I_1 and I_2 are the total solar radiation reached bed surface and collector surface respectievely.

Then the overall system efficiency will be

$$\eta = Q_u / Q_S \quad (7)$$

Experimentation

The system performance is evaluated for the three previously mentioned locations over 24 hours of operation. The system was heated from 9 am to 3 pm then covered and discharged

The following values are measured every half an hour

1- Ambient temperature , outlet air temperature from the air heater and inlet air temperature to the drying chamber

2- Storage pebble temperatures

3- Solar intensity

4- Air flow velocity

Thermocouples of the J type (iron-conestantan) together with digital millivoltmeter were used to measure temperatures and a pyronometer was used to measure solar intensity and a hot wire anemometer was used to measure air velocity.

RESULTS AND DISCUSSION

1-The average storage bed temperature T_s during sun hours for the three locations were measured . The temperature rise $T_s - T_a$ was drawn in Fig (4). From this figure, $T_s - T_a$ for the second location is the highest one since solar energy is captured during heating.

2- The temperature ratio $R = T_r/T_c$ during heating is drawn in Fig(5).R_1, R_2 and R_3 are referred to the three different storage locations. As expected $R_2=1$ has the highest value ,since air is entered directly from the air heater to the drying chamber while in the other cases pebble bed absorbs some of the energy available before the drying chamber.

3-The useful energy gained from the system for each case over 24 hours of operation are shown in Fig(6). As seen from this figure, second location has the highest energy gained.

4-The overall efficiency of the system for the three storage bed locations was found to be 42.5%, 51% and 34.5%.

5-Heating and discharging the system with location 2 was studied under the effect of one and two fans (flow rates .06 and .12 kg/s respectively) and drawn in Fig (7). Using one suction fan (low flow rate) gives higher temperature during heating and discharging. This may give the option to use high flow rate during heating and low flow during night to obtain relatively hot air temperature. .

CONCLUSION

Pebble bed storage is a simple technique to store solar energy.The proposed storage design helps to raise inlet air temperature to the drying chamber during night without decreasing this temperature during sun hours. Among the three suggested locations, second location can supply the system with the heighest temperatures during 24 hours. Although the rise in temperature during night is not high (just to prevent rewetting of the products) ,yet more higher temperature could be obtained by lowering the flow rate during discharging. A need for more studies are required to size the pebble bed volume with the drying requrements (drying air temperature ,flow rate, etc.)

NOMENCLATURE

A_c Collector area, m^2

A_s Projected area of the storage bed ,m^2

Cp_a Specific heat of air,J/Kg.C

Cp_s Specific heat of pebble bed,J/Kg.C

I_1 Solar radiation reaced bed surface , W/m^2

I_2 Solar radiation reached collector surface, W/m^2

m Air mass flow rate ,kg/sec

M Mass of the pebble bed, Kg

R Temperature ratio

T_a Ambient temperature, C

T_c Outlet air temperature from the collector,C

T_s Inlet air temperature to the drying chamber,C

T Average temperature of the storage bed.,C

Q_L Heat loss,W

Q_s Total solar energy input to the system ,J

Q_u Useful energy gained from the system,J

Greek letters

η Overall efficiency of the system.

$(\tau\,\alpha)_s$ Effective transmissivity absorbtivity of the pebbles

θ Time,s

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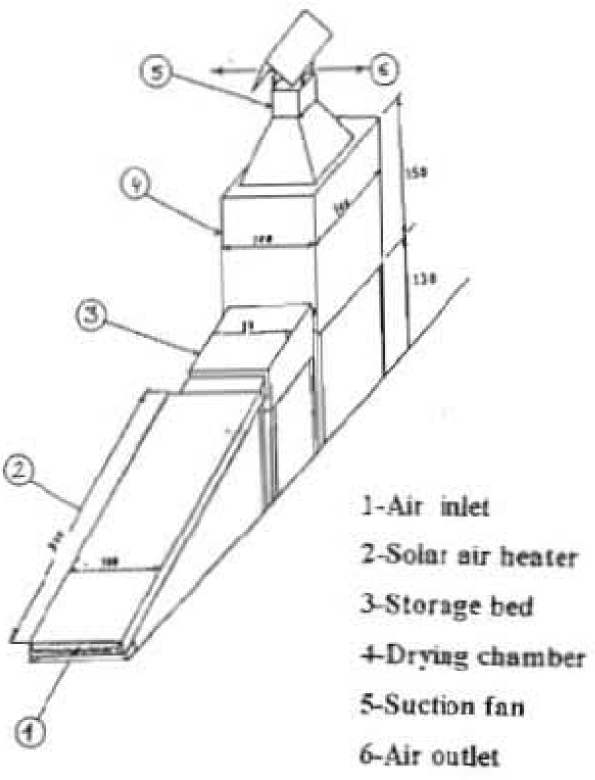

Fig (1) Solar drying system

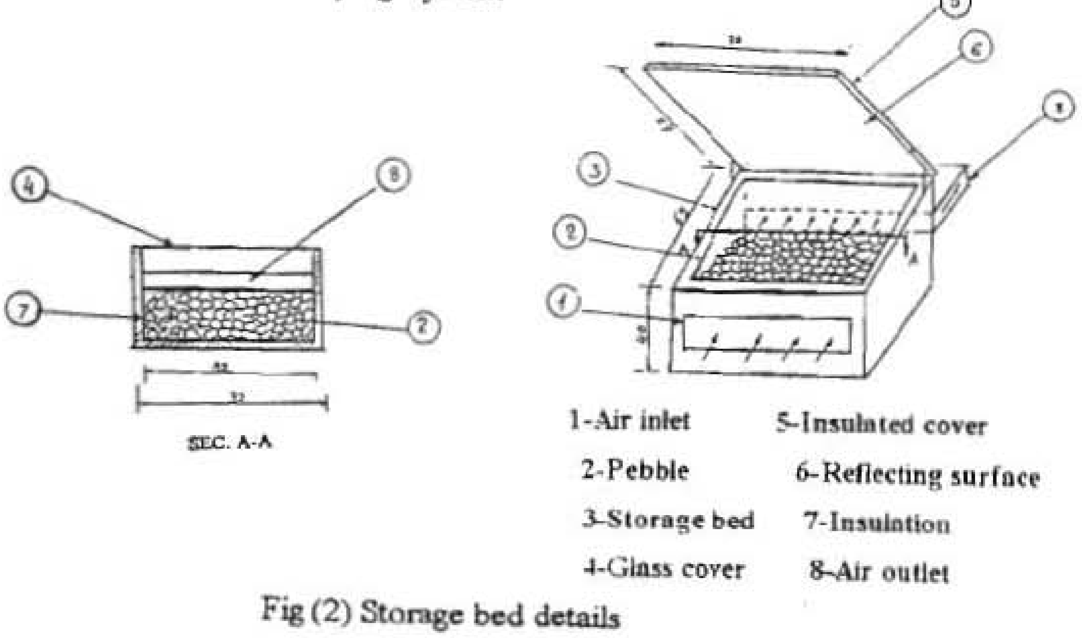

Fig (2) Storage bed details

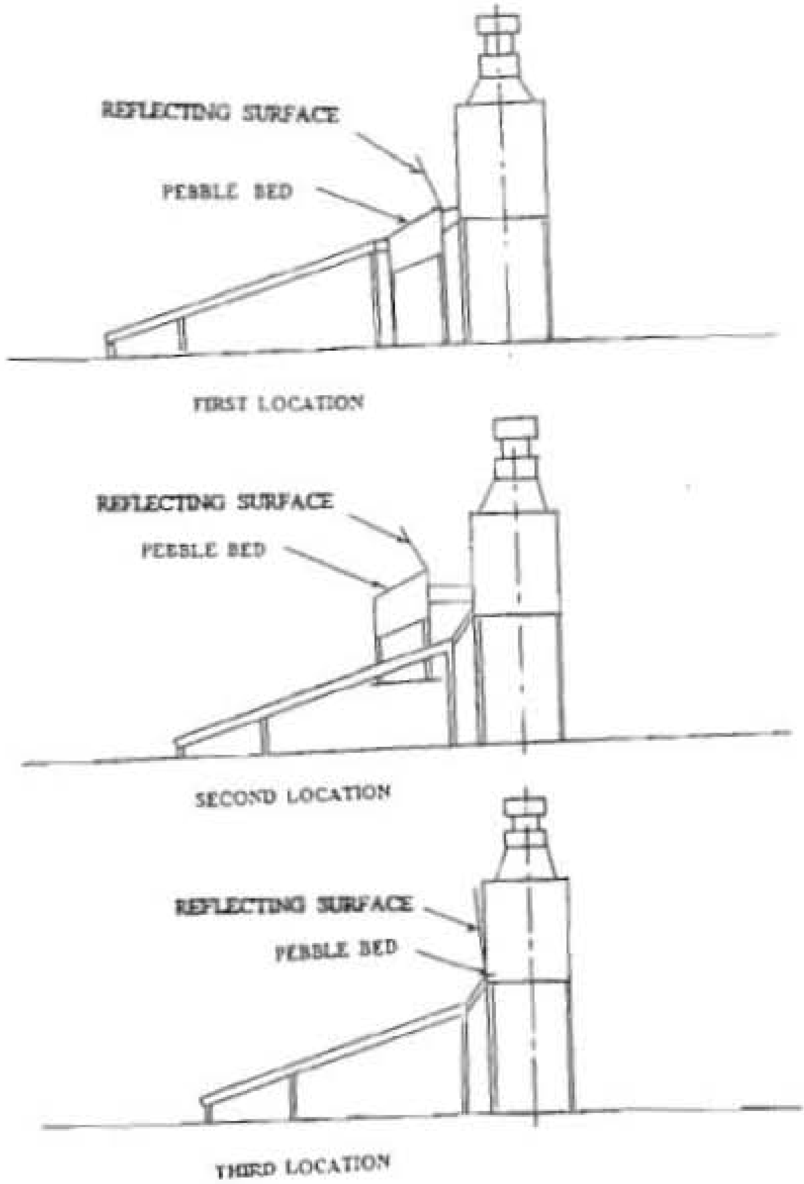

Fig (3) Pebble bed location

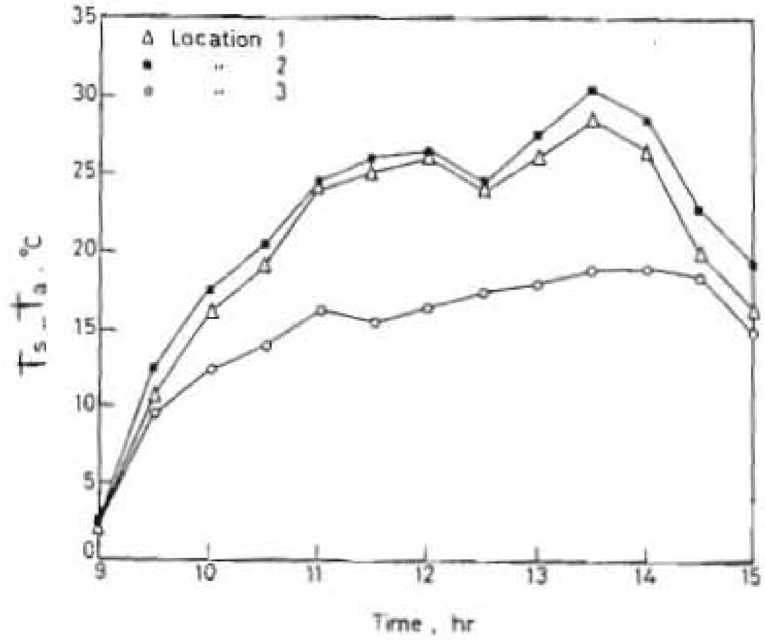

Fig (4) Average storage bed temperature rise above ambient

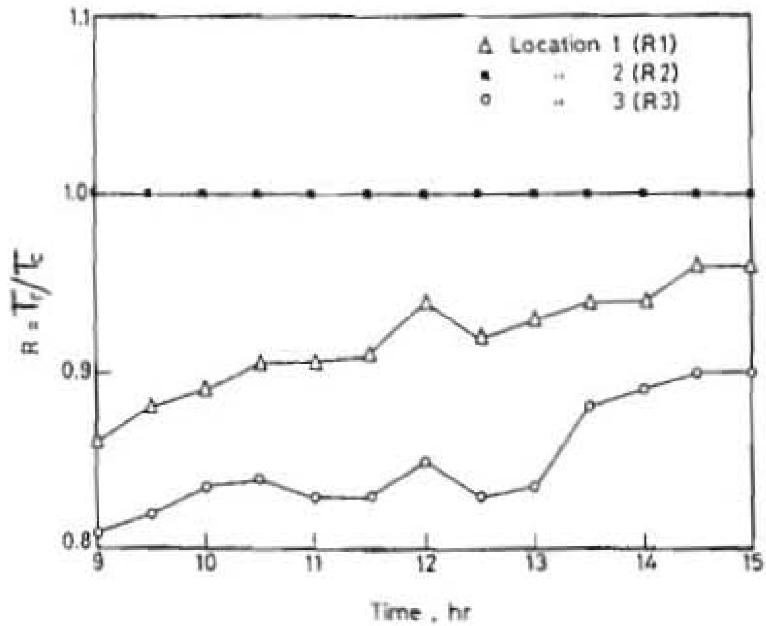

Fig (5) Temperature ratio R versus Time for the three storage designs

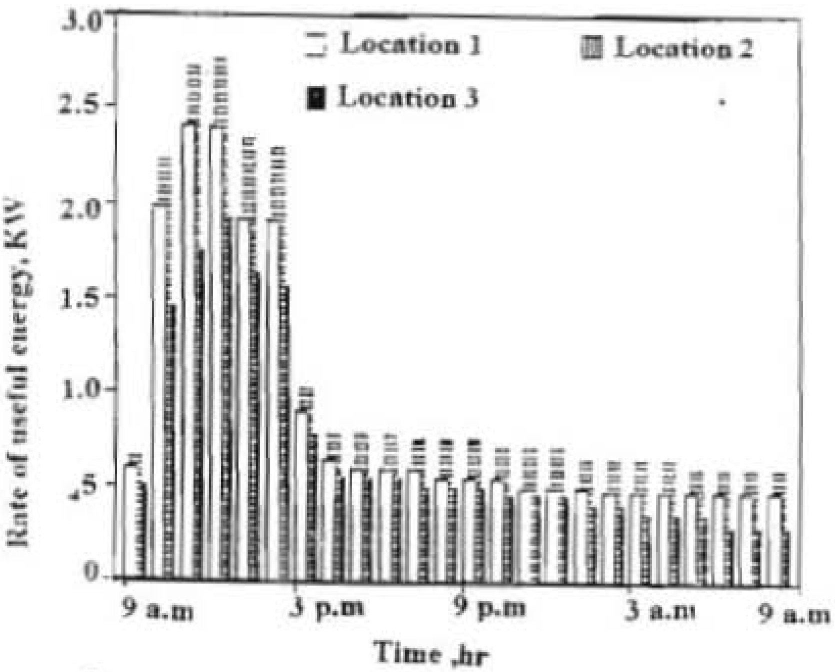

Fig (6) Useful Energy Gained Over 24 hours of operation For the three locations

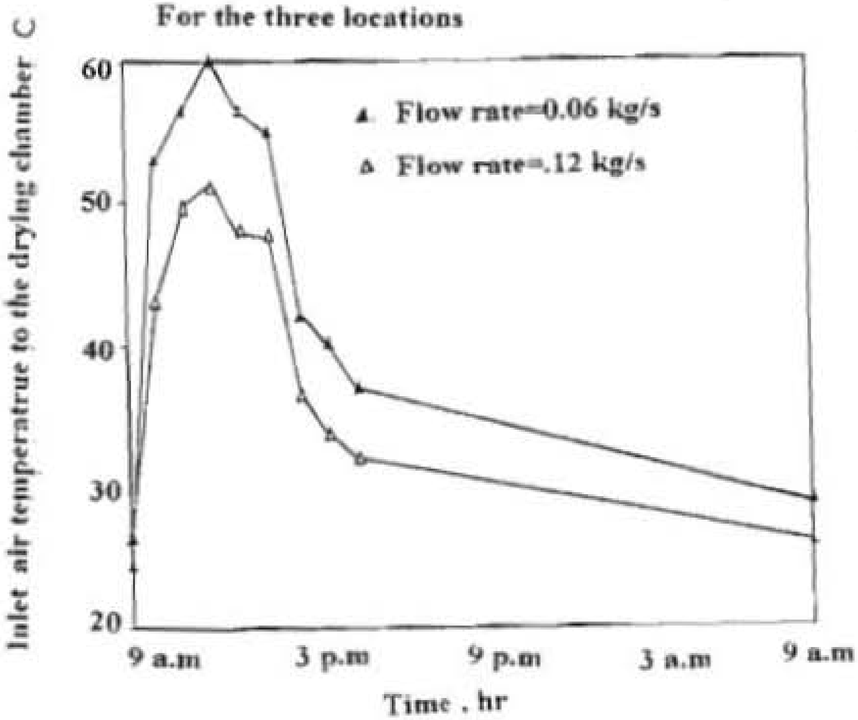

Fig (7) Temperature of the inle air to the drying chamber under differen flow rates