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EFFECT OF VARIOUS PARAMETERS ON THERMAL ENERGY STORED IN THE PACKED BED SOLAR AIR HEATING SYSTEM

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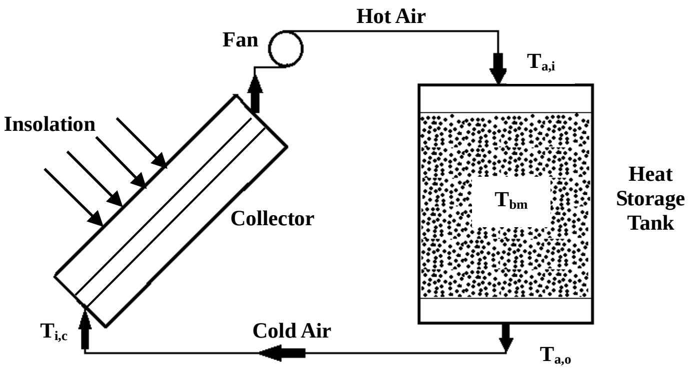
ABSTRACT

Solar energy is a dominating source over other energy resources. It has capability of being used for any energy application. However its intermittent nature requires an energy storages system along with the solar collector to make it more dependable. Solar air heaters utilize the packed bed as their storage system. This stored energy in the packed bed can be used for providing the continuous supply of thermal energy in the absence of sun and it can also be used in addition to the current supply. The present paper is aimed at investigating the effect of various parameters on thermal energy stored in the packed bed solar air heating system.

KEYWORDS: *Solar Air Heater, Renewable energy, Heat storage, Packed Bed.*

I. INTRODUCTION

Energy storage provides a mean for improving the efficiency of a wide range of energy systems. Typically energy storage is used when there is time or rate mismatch between energy supply and energy demand or where intermittent energy sources are accessible, similar to that of solar energy. The storage system stores energy when the collected amount is in excess of the requisite of the application and discharges energy when the accumulated amount is inadequate [1]. Figure1 shows the schematic of a solar energy cum storage system considered in the study.



$T_{a,i}$ = air temperature supplied to bed.
$T_{a,o}$= air temperature leaving the bed.
$T_{i,c}$= air temperature supplied to collector.
T_{bm}= mean bed temperature.

Figure 1. Schematic of the solar energy cum storage system.

In solar air heating systems the low density of air makes it impractical to store the heated air itself. It is therefore necessary to transfer the thermal energy from air to a denser medium. During charging mode, solar heated air is constrained into the top of the container i.e. upper plenum and it then passes evenly down through the bed heating the storage and goes out through the lower plenum. Air is drawn off at the base and came back to the collectors [2]. At the point when energy is needed from storage, the airflow is turned around. Room air enters from bottom and flows to the top of the bed and is delivered into the building. After losing heat in the room again, room air comes to the bottom of the bed and the cycle is repeated.

Solar air heating collector is used to charge the packed bed energy storage system. The air coming out of the storage system returns to the collector for recirculation through the collectors. The temperature of the air affects the performance of the collector. Consequently, there is an interaction between performance of solar collector and stratification of storage system.

In the present work, the effect of system and operating parameters on the thermal energy storage of the solar collector system has been proposed to be investigated. This paper is organized as follows: Section II provides the details of the parameters for the system in the current study. In Section III performance of the system is predicted. Section IV gives results and a discussion. Conclusion has been presented in Section V.

II. PARAMETERS FOR THE SYSTEM

In order to investigate the performance of the solar collector for a given set of system and operating parameters, it is important to alter the suitable values or range of values of all relevant parameters for the storage system. These parameters can be categorized into fixed and variables parameters as follows:

2.1. Fixed Parameters of Bed

These parameters comprise of collector dimensions, storage dimensions and their related parameters, thermo-physical properties, ambient temperature and inlet temperature. The list of fixed parameters is given in Table 1.

Table1. Fixed Parameters of Bed

Description	Parameter	Value
Volume of packed bed (m^3)	V_b	15
Length of packed bed (m)	L	6
Number of bed element	N	60
Initial bed temperature (°C)	T_{bi}	25
Density of air (kg/m^3)	ρ_a	1.1
Dynamic viscosity of air (kg/s-m)	μ_a	1.865×10^{-5}
Inlet air temperature to bed (°C)	T_{ai} or T_{bi}	40
Ambient temperature (°C)	T_∞	25
Density of storage material (kg/m^3)	ρ_s	1920
Specific heat of air (J/kg°C)	C_{pa}	1008
Specific heat of storage material (J/kg°C)	C_{ps}	835
Collector area (m^2)	A_c	20
(for collector)	$F_R(\tau\alpha)_e$	0.62
(for collector)	$F_R U_l$	3.38
Time interval (minutes)	Δt	1

2.2. Variable parameters of Bed

The variable parameters comprise of sphericity of material, void fraction, equivalent diameter, inlet temperature of air to bed, temperature rise parameter ($\Delta T/I$) and solar radiation intensity (I). The range of variable parameters representing packing material geometry has been chosen on the basis of available correlation while the range of design parameters (temperature rise parameter and insolation) has been decided on the basis of range of application of air heater. These are listed in Table 2.

Table 2. Variable parameters of Bed

Description	Parameter	Value
Equivalent diameter of packing material (m)	D_e	Corresponding to the material element under consideration. (0.05-0.2)
Sphericity of material element	Ψ	Corresponding to the material element under consideration. (0.5-1)
Void fraction	ε	Corresponding to the material element under consideration. (0.30-0.50)
Inlet to bed temperature (^{0}C)	T_i	35°C to 75 °C
Insolation (W/m^2)	I	500, 750, 1000
Temperature difference	ΔT	10°C to 55°C
Temperature rise parameter (^{0}C m^2 /W)	ΔT/I	0.05 to 0.1

III. PERFORMANCE OF THE SYSTEM

The performance can be predicted on the basis of detailed consideration of heat transfer processes in the system. It may be noted that the results need to be presented as function of two design parameters namely Temperature rise parameter (ΔT/I) and Insolation (I).

The calculation commences with fixed value of design parameters (ΔT/I and I) and proceeds with the calculation of other parameters for system incorporating storage and collector. For this purpose a step by step procedure has to be followed which is given below:

- A set of the values of the parameters namely void fraction (ε), sphericity (Ψ) and equivalent diameter (D_e) as per the geometry used is selected for which the calculation is to be performed.
- A set of values of design parameters specifically Temperature rise parameter, (ΔT/I) and solar insolation, (I) is selected.
- Useful heat gain by collector is calculated by using energy balance equation [3],

$$Q_u = A_c \times [\,(F_R(\tau\alpha)_e \times I) - F_R U_l (T_{ic} - T_{amb})] \quad (1)$$

where A_c is collector area, I is insolation, T_{amb} is ambient temperature. The term $(\tau\alpha)_e$ represents effective transmittance-absorptance product, U_l is overall heat loss coefficient (W/m^2 ^{0}C) and F_R is the heat removal factor defined as ratio of actual useful energy gain to the maximum possible energy gain.

Here T_{ic} is the outlet temperature of the air from the packed bed and is equal to T_{a60} (temperature of the air leaving 60th element of the bed).

A straightforward simulation method [4] is used for the thermal behavior of packed bed storage systems. The simulation is based on a one-dimensional transient analysis of energy exchange between the air stream and the material particles, using a finite difference method.

The following relation is used to find the final temperature of the air '$T_{a,m+1}$' at the exit of each element.

$$T_{a,m+1} = T_{b,m} + \left(T_{a,m} - T_{b,m}\right)\ exp\,(-\Phi_1) \quad (2)$$

where $\Phi_1 = \frac{\text{NTU}}{\text{N}}$ and NTU (number of transfer unit)$= \frac{h_v A_b L}{(\dot{m}C_p)_a}$

where A_b is cross sectional area of packed bed, L is length of packed bed and N is number of bed elements.

Volumetric heat transfer coefficient, 'h_v' is calculated by using the expression [5] for Nusselt number in the modified form as:

$$Nu = \frac{h_v D_g^2}{k_a} \quad (3)$$

where k_a is thermal conductivity of air.

The correlation for Nusselt number in terms is given by [6]

$$Nu=0.437\times R_e^{0.75}\times\psi^{3.35}\times\varepsilon^{-1.62}\{exp(29.03\times log10(\psi)^2))/D_e^2] \quad (4)$$

Thus the expression for volumetric heat transfer coefficient is:

$$h_v=k_a\times 0.437\times Re^{0.75}\times\psi^{3.35}\times\varepsilon^{-1.62}[exp(29.03(log\ \psi^2))]/D_e^2 \quad (5)$$

Temperature of each bed element and air leaving bed element is calculated as follows:
Following relation is used to find the temperature of the bed element '$T_{b,m(t+\Delta t)}$'.

$$T_{b,m(t+\Delta t)} = T_{b,m(t)+} + \left[\Phi_2\left(T_{a,m} - T_{a,m+1}\right) - \Phi_3\left(T_{b,m} - T_{amb}\right)\right]\Delta t \quad (6)$$

where $\Phi_2 = \frac{(\dot{m}C_p)_a N}{(\rho C_p)_s AL(1-\varepsilon)}$

$$\Phi_3 = \frac{(U\Delta A)_m}{(\dot{m}C_p)_a}\Phi_2$$

and Δt is time increment.

Mass flow rate of air is calculated as,

$$m_a=Q_u / C_{pa}(T_{ib}-T_{ic}) \quad (7)$$

where T_{ib} is inlet to bed temperature.
T_{ic} is the inlet to collector temperature (T_{a60}) and Q_u is useful heat gain by collector.

Reynolds number is calculated by:

$$Re=G\times D_e/\mu_a \quad (8)$$

where D_e is equivalent diameter.
G is mass velocity calculated by; $G = m_a/A_c$

IV. Result And Discussion

The results obtained from the mathematical simulation of the packed bed solar energy storage system have been reported and discussed in this section. The effect of system parameters on the performance parameter i.e. thermal energy stored in the bed is being discussed.
The amount of thermal energy stored in the bed using bed elements of different shapes increases with increase in charging time as can be seen from Figure 2. During charging the temperature of air at the exit from the bed remains constant for quite some time and till then the energy stored in the bed also remained same for different shapes of the material elements. Subsequently, the effect of shape begins to appear and it has been found that for sphericity of ψ=1, bed has stored the maximum amount of thermal energy as compared to the elements of non-spherical shapes as can be seen in Figure 3. This is corresponding to the heat transfer coefficient values for different shapes of material elements because the heat transfer coefficient has been seen to be maximum for the elements having sphericity of 1 and the minimum for that of 0.76.
The effect of void fraction on the thermal energy stored in the bed has been shown in Figure 4. It is found that the energy storage decreases as the void fraction is increased for the bed packed with elements of a given shape. This additionally relates to the nature of variation of heat transfer coefficient decreasing with increase in void fraction. Figure 5 shows the change of total thermal energy stored as function of void fraction changes. The result shows that with increase in void fraction the amount of total thermal energy stored decreases. Figure 6 and Figure 7 show the effect of

equivalent diameter on the thermal energy stored in the bed and total thermal energy stored in the bed respectively. It is seen from the plots that for the minimum value of equivalent diameter the thermal energy stored and total thermal energy stored in the bed is maximum.

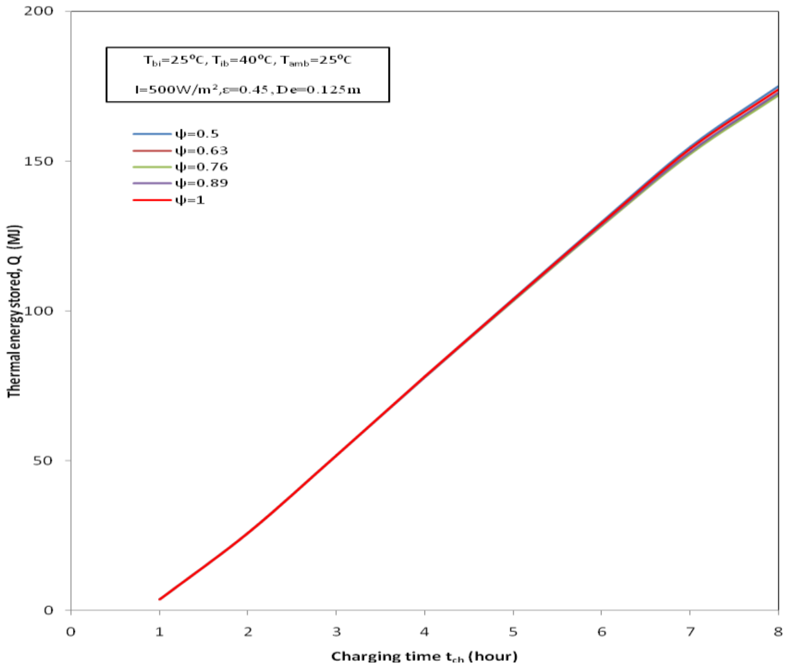


Figure 2. Variation of thermal energy stored in the bed using bed elements of different shapes at the end of charging time.

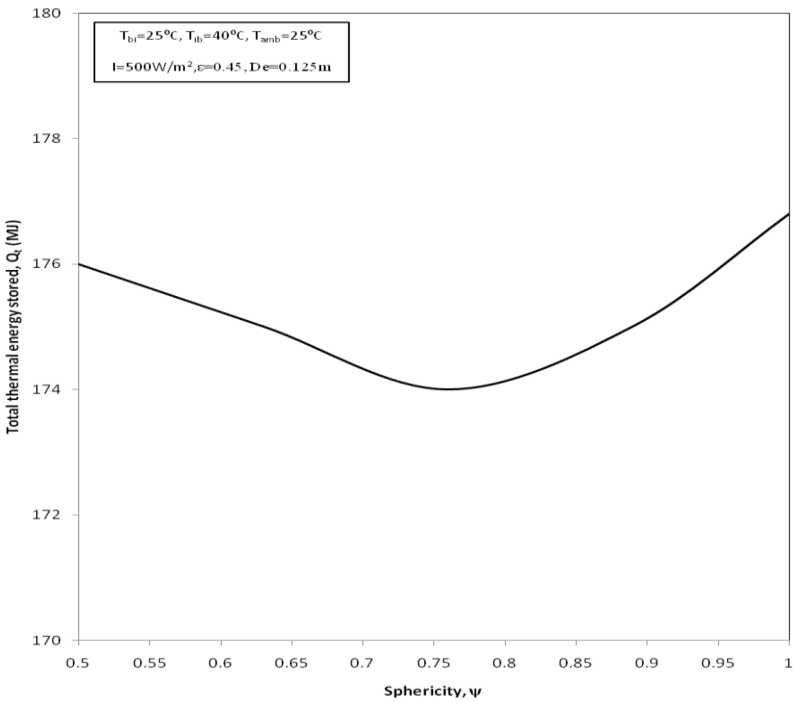


Figure 3. Total thermal energy stored in the bed using bed elements of different shapes at the end of charging time.

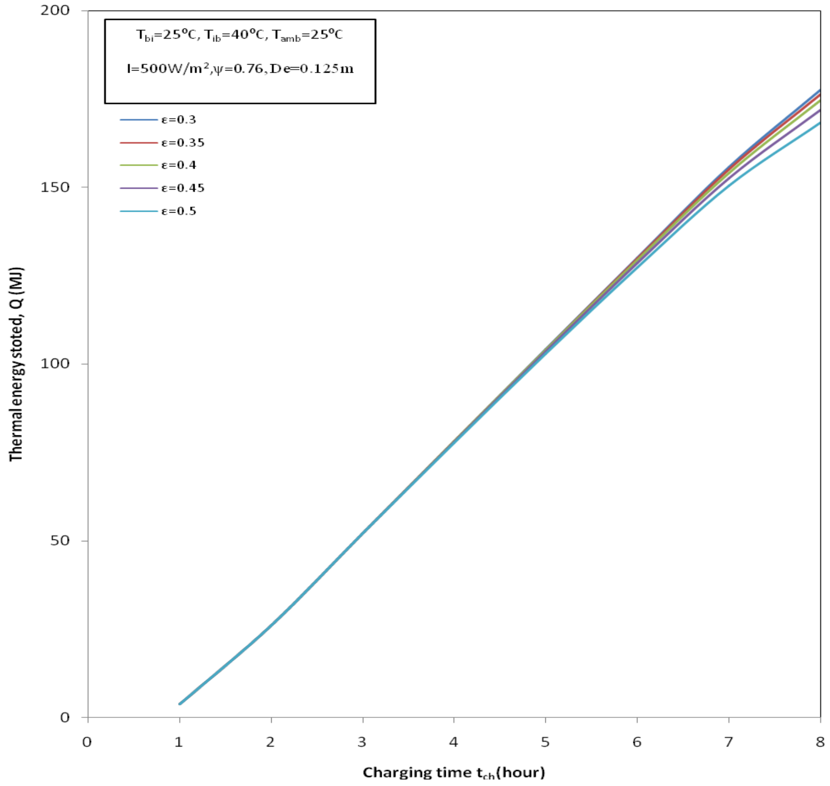


Figure 4. Thermal energy stored in the bed using bed elements of different void fraction during the charging period.

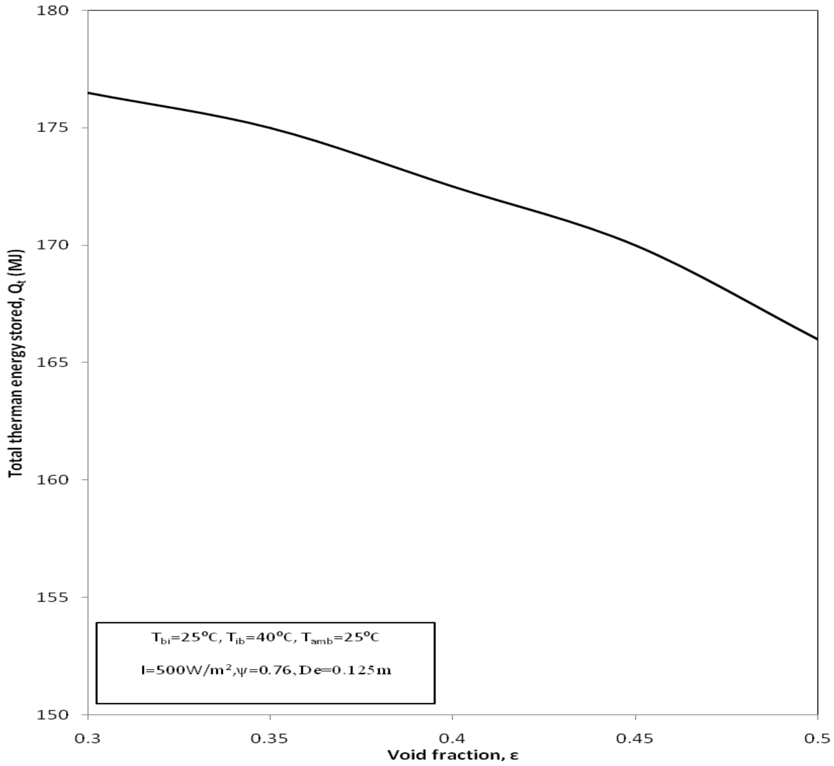


Figure 5. Effects of void fraction of bed on total thermal energy stored in the bed at the end of charging time.

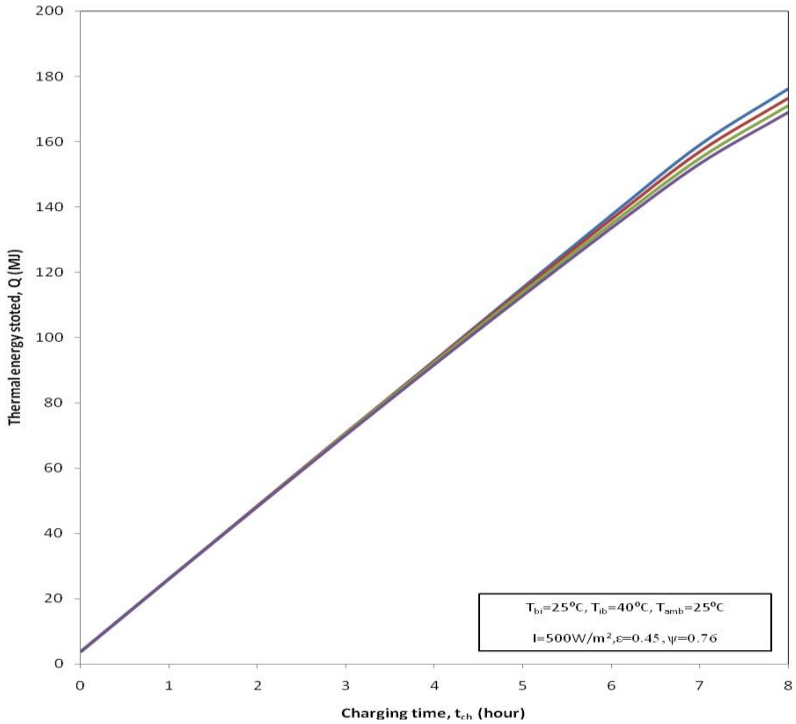


Figure 6. Thermal energy stored in the bed using bed elements of different equivalent diameter during the charging period.

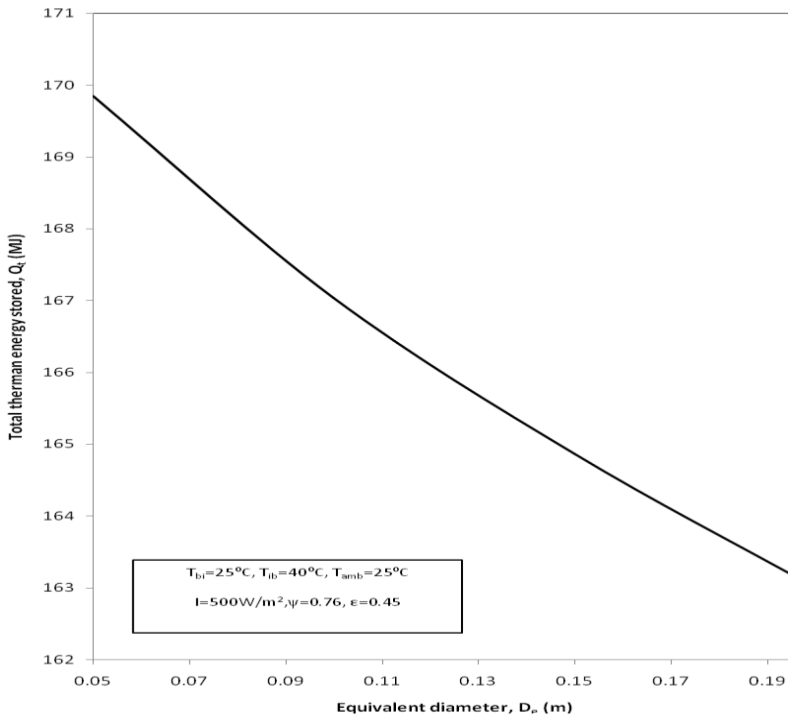


Figure 7. Effects of equivalent diameter of bed elements on total thermal energy stored in the bed at the end of charging time.

V. CONCLUSION

The effects of system and operating parameters on thermal energy stored comprising of collector and bed has been investigated. Based on the work, following major conclusions have been drawn:

1) At the end of charging period of the bed, it has been found that for sphericity of 1.00, bed has stored the maximum amount of thermal energy and for sphericity of 0.76, the minimum amount of thermal energy have been stored.
2) The amount of thermal energy stored at the end of charging time in the bed decreases with increase of void fraction of the bed corresponding to the change in the values of heat transfer coefficient.

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