International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Experimental Study of Heat Absorbing Packed Bed Regenerator for Space Heating for Industrial Purpose

Shivasheesh Kaushik[1], Dr. Anirudh Gupta[2]

[1]M.Tech 4th semester student of ME Thermal, BTKIT Dwarahat, Uttarakhand, India

[2]Assocaite Professor, Mechanical BTKIT Dwarahat, Uttarakhand, India

[3]Assisitant Professor, Mechanical BTKIT Dwarahat, Uttarakhand, India

Abstract: ***Solar radiation is available for limited hours only in a single day. As a result it is often necessary to use a storage system to store this limited hour's available solar radiation, so that it can be used for various applications. Space heating is one of the most important demands of people in winters. Therefore there is a need of a storage system which provides heating in off shine hours during winter. Present work deals with the experimental study of various vital thermal energy storage system parameters such as packed bed size, heat absorbing material particle diameter and number of beds. Besides this, mass velocity of air in charging and discharging of heat absorbing packed bed, pressure drop across bed, cycle time of charging and discharging the packed bed are also studied through experimental setup and validation is carried out through theoretically numerical based equations. Based on the optimization, rock bed length 1.5 m, diameter of rock bed 0.1 m, rock particle diameter 0.03 m, number of beds 2 and mass velocity of working fluid in charging and discharging 0.0125kg/m²-s, 0.00796 kg/m²-s respectively, has been proposed.***

Keywords: Concentratedsolarpower, Thermal storage, Packed Bed, Porous media, Sensible heat

Symbol	Description	Unit
A_c	Cross sectional area of heat absorbing bed	m^2
A_h	Heat transfer area	m^2
C_{pg}	Specific heat of air	J/kg-K
C_{ps}	Specific heat of solid	J/kg-K
D_b	Diameter of heat absorbing bed	m
d_p	Particle diameter	m
G	Mass velocity	kg/m^2-s
$\dot{m}$	Mass flow rate	kg/s
H_c	Average heat transfer coefficient	W/m°C
k_{eff}	Effective thermal conductivity of air	W/m°C
L_b	Length of bed	m
P	Pressure drop across rock bed	Pa
t_{av}	Average temperature	°C
ΔT	Mean air temperature	°C
T_{amb}	Air initial temperature	°C
t_s	Supply air temperature	°C
V_b	Velocity of air in rock bed	m/s
V_o	Velocity of air at orifice	m/s
A_b	Area of air in heat absorbing bed	m
A_o	Area of air at orifice	m
Q_u	Heat flux	W/m^2
μ	Dynamic viscosity of air	kg/m-s
D	Effective particle diameter	m
ρ_g	Density of air	kg/m^3
ρ_s	Density of solid	kg/m^3
ϵ	Porosity of rock bed	-

1. Introduction

As the demand for energy increases in the commercial industry, as well as the household applications, the demand for more efficient energy system and less expensive processes is increasing along with it. Energy sources are vital and essential ingredients for all human transactions. On one hand, the energy sources are limited and on the other hand, the population is increasing continuously and inserts extra pressure on additional energy demands. The continuous increase in the level of greenhouse gas emissions and hike in the fuel prices are the main reasons behind efforts to more effectively utilize various sources of renewable energy. A study on energy efficiency in buildings (EEB) shows that the global building sector needs to cut energy consumption in buildings 60 percent by 2050 to help meet global climate change targets. According to the World Business Council for Sustainable Development (WBCSD), buildings account for 40 percent of the world's energy use with the resulting carbon emissions. Renewable sources as solar energy provide the potential for sustainability. The sun is the powerful source of energy, it provides much more energy in some hour than used by the people in one year, but then limitations of the source turn up. The amount of sunlight that arrives at the earth surface is not so constant. It varies depending upon the condition of the weather, location of the place, and time of year and day. A system that relies heavily on an intermittent source of power needs efficient thermal energy storage. Thermal energy storage is efficient to domestic hot water and space heating demands but still need auxiliary energy to cover the demands.One of the options is to develop more efficient energy storage devices, which are as important as developing new sources of energy. Space heating is one of the most important fields that offer simple, direct utilization of solar energy since only a relative small increase in temperature is needed.

1) To determine the optimum mass flow rate for hot air which is maintained at three different temperature i.e. 40° C, 45° C and 50°C.

2) To determine the Optimum supply air temperature and mass flow rate throughout the night for comfort inside the room.
3) Optimization of heating bed parameters such as:
- Length of the Bed.
- Diameter of the Bed.
- Porosity.
- Rubber Particle Diameter.
- Number of Beds.
- Charging and Discharging Characteristics of Bed.

2. Experimental Details

Packed beds generally represent the most suitable storage units for air-based solar heating systems. Storage in Packed bed is accomplished by heating the heat absorbing material with hot air with the help of solar air heater when solar insolation is available (day) and then utilizing it as a source of heating when solar insolation is absent (night). Packed bed acts as a regenerator in charging and discharging processes. A schematic diagram of packed bed sensible heat storage technique is as shown in Fig.3.1. The cylindrical heater is made up of 1m long Iron pipe and nichrome wire and screws. The cylindrical hollow heater have 10.6cm outer diameter with heavy insulation and 7.6cm inner diameter of iron pipe which hold heavy insulation above the surface of the iron pipe about 3cm in thickness which is insulated by using coconut rope and Paris of plaster material . Nichrome wires are mounted circularly on the cylindrical rod made of Paris of plaster as shown in above figure. The cylindrical heater gave heat to the packed bed with help of blower.Cylindrical heater is placed 2.7m away the packed bed to supply heat to the absorbing material placed in the packed bed.

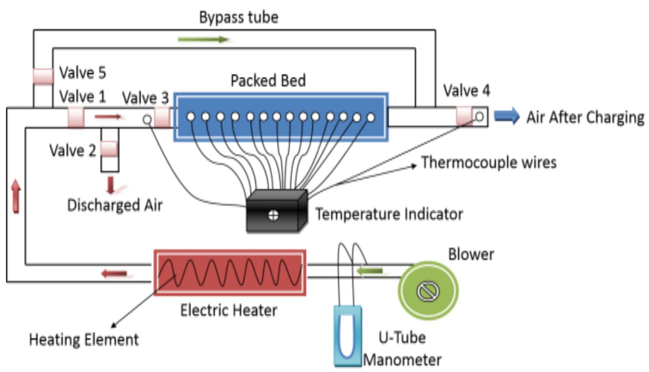

Figure 1: Schematic Diagram of Experimental Setup

Figure 2: Photographic view of Inner heating coil of heater mounted circular on P.O.P insulating material rod

Figure 3: Photographic view of Outer section of heater insulated with P.O.P and Coconut Rope

3. Design of Circular DUCT/Packed (Heat Absorbing) Bed

Length of the packed bed $L_b = 1.5$m

Diameter of the packed bed $D_b = 0.10$m

Figure 4: Photographic view of packed bed with insulation

Fig.5. Photographic view of packed bed without insulation

Figure 6: Photographic view of preparing for packing/rapping the Glass Wool (insulation) over the 1.6m long pipe for proper insulation

After assembling the whole experimental setup, the measuring instruments were installed in proper position and electric connections of the following namely variac; temperature indicator and cylindrical heater were made. Air is sucked through the blower, driven by motor to the duct/packed (heat absorbing) bed. Before heating the duct/packed (heat absorbing) bed all thermocouples were checked by adjusting the corresponding selector switch position. Before starting the experiment all the joints are sealed with the help rapid fast araldite and m-seal, so that no leakage occurs from the duct/ packed (heat absorbing) bed. After that Variac should be adjusted to the proper voltage and this voltage is supplied to the strip heater. The steady state condition occurs after 1.5-2 hours after starting the heater and blower. When steady state condition occur the temperature of different thermocouples should be noted. Then the mass flow rate can be changed with the help of gate valve attached to the blower and thus by changing the different decided temperature and mass flow rate the process should be repeated until all the readings are achieved for the material placed in the packed (heat absorbing) bed.

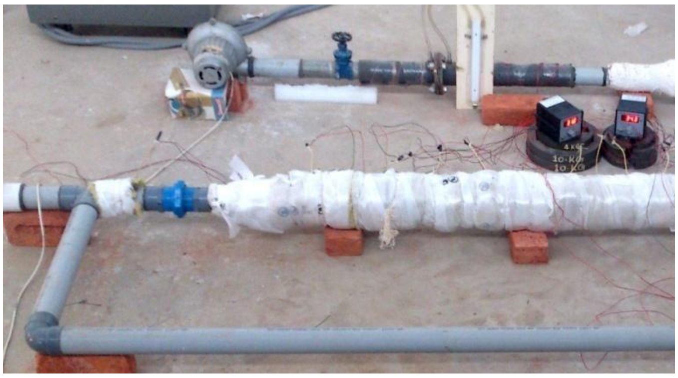

Figure 7: Photographic view of experimental setup (duct side)

4. Analytical Formulation

The Nusselt number determined from the experimental data for heat absorbing Packed Bed have been compared with the values obtained from Dittus -Boelter equation for Nusselt number respectively.

- **Dittus -Boelter Equation** :

$$Nu_s = 0.023\, Re^{0.8} Pr^{0.4} \qquad (1)$$

Porosity of Matrix, P

Calculation of Porosity of the bed has been based on the number of layers of wire screen and its geometric specifications.

$$P = \frac{V_t - V_s}{V_s} = \frac{P_t^2 D - [\pi/2 (d_w)^2 p_t]\, N}{P_t^2 D} \qquad (2)$$

Mass Flow Rate, m

Calculation of mass flow rate, using the following equation:

$$m = C_d A_2 [\frac{2\rho \Delta P_o}{1-\beta^4}]^{0.5} \qquad (3)$$

Where C_d = coefficient of discharge

A_2=area of orifice

β=ratio of orifice diameter to pipe diameter

ρ = the density of air

Its value is obtained after calibration of orifice plate against a standard pitot tube is found to be 0.62.

Area of orifice, A_2

$$A_2 = \frac{\pi}{4} (D_2)^2 \qquad (4)$$

Reynolds Number, Re

Calculation of Reynolds number for packed bed has been Based on the following equation:

$$Re = \frac{\rho v D}{\mu} \qquad (5)$$

Where:

- D is a characteristic linear dimension, (m)
- μ i v is the mean velocity of the object relative to the fluid (m/s).
- s the dynamic viscosity of the fluid (N·s/m² or kg/(m*s))
- $\rho$is the density of the fluid (kg/m³)

Nusselt Number (Nu)

In heat transfer at a boundary (surface) within a fluid, the Nusselt number is the ratio of convective to conductive heat transfer across (normal to) the boundary. Named after Wilhelm Nusselt, it is a dimensionless number. The conductive component is measured under the same conditions as the heat convection but with a (hypothetically) stagnant (or motionless) fluid.

Mathematically

$$Nu = \frac{hL}{K_f} = \frac{\text{Convective heat transfer coefficient}}{\text{Conductive heat transfer coefficient}} \qquad (6)$$

Where, L= Characteristic length

K_f = Thermal conductivity of fluid

h= Convective heat transfer coefficient

Average Bed Temperature t_{av}

The average temperature of packed bed has been evaluated based on the assumption that thermocouples located at a particular position indicate average temperature of the volume of the bed covered by this thermocouple. The average temperature has been calculated as follows:

$t_{av} = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + t_8 + t_9 + t_{10} + t_{11} + t_{12} + t_{13} + t_{14}/14$

Mean Air Temperature ΔT

$$\Delta T = t_{\text{surface temperature}} - t_{\text{fluid temperature}} \qquad (7)$$

Air Properties in Charging and Discharging

The air properties are density (ρ_g), dynamic viscosity (μ) and specific heat (C_{pg}) are taken at the bulk mean temperature at any instant of operation. The bulk temperature, T_b is defined as the mean of air and solid temperature at any instant.

$$\mathbf{T_b} = \frac{\mathbf{Tsolid+Tair}}{\mathbf{2}} \qquad (8)$$

Heat Flux, Q_u

$Q_u$is a product of V,I

$$Q_u = V.I / A_h \qquad (9)$$

Average Heat Transfer Coefficient

Determination of average heat transfer coefficient, $h_c$between Packed Bed and air was based on following equation:

$$H_c = Q_u / \Delta T \qquad (10)$$

$\Delta T = t_{\text{surface temperature}} - t_{\text{fluid temperature}}$

ΔT is the average Packed Bed temperature based on the average of the temperature measurement made along the length and depth of the packed bed. The heat transfer area, A_h has been determine on the basis of the following relation

$$A_h = \pi.d.L \qquad (11)$$

Air Velocity, v

The air velocity in bed is calculated as:

$A_o V_o = A_b V_b$ (12)

5. Results and Discussion

The execution of packed bed heat storage system relies on different parameters, for example, selection of the material utilized inside the bed for sensible heat storage, mass stream rate of the air, temperature of air, porosity and measurements of the packed bed. These parameters have their own essentialness in the execution of packed bed heat stockpiling framework. In present study, two parameters were viewed as, for example, inlet air temperature, mass stream rate of air which were examined tentatively. The impact of three distinctive air channel temperatures i.e. 40°C, 45°C and 50°C and the three mass flow rates of air i.e. 0.00796 kg/s, 0.00985 kg/s, and 0.0125 kg/s on charging and releasing profile of packed bed were studied. The measurements of the bed were 1.5 m in length and 0.1 m diameter with uniform porosity of 0.39 and material of 0.04 m in diameter.This part incorporates the approval of present work with Transient investigation utilizing numerical method, charging and discharging profile of plastic material inside the bed for three distinctive mass stream rates of air with diverse air inlet temperatures.

Results for Air Inlet Temperature of 40°c During Charging

At first air inlet temperature was situated to be 40°C utilizing electric heater and blower and the mass flow rate was set to be 0.00985 kg/s utilizing electric Variac.

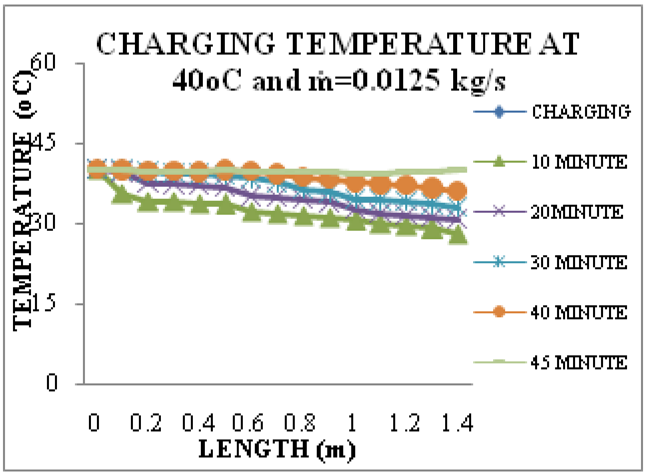

Figure 8: Temperature profile of charging packed bed with ṁ=0.0677 kg/s and inlet air temperature at 40°C.

Presently the warmed air was gone through the packed bed. As the warmed air goes through the packed bed, the temperature of the packed bed will increment because of heat exchange from high temperature air to shakes. The temperature profile inside the packed bed at the time interim of 10 minutes was plotted in graph. The temperature from inside the packed bed diminishes with length of bed and this profile moved upwards with the compass of time. It is seen from the graph that packed bed achieve an estimated uniform temperature of 40°C after 80 minutes.The charging time of bed with inlet air temperature of 40°C and mass flow rate of air as 0.00796 kg/s decreases to about 20 minutes, as compared to mass flow rate of 0.00985 kg/s and same inlet temperature. It also decreases to 15 minutes when mass flow rate is 0.0125 kg/s. The optimum result for charging bedinlet air temperature at 40°Cwhen mass flow rate is 0.0125 kg/s is 45 minutes as shown in Fig.8.

Results for Air Inlet Temperature of 40°c During Discharging

In the wake of discharging cycle, the climatic air is gone through the heated packed bed, during which the heat exchange happens from warmed bed to air and the temperature of air will increment with the lessening in temperature of material utilized inside the bed i.e. Waste Hard Rubber.

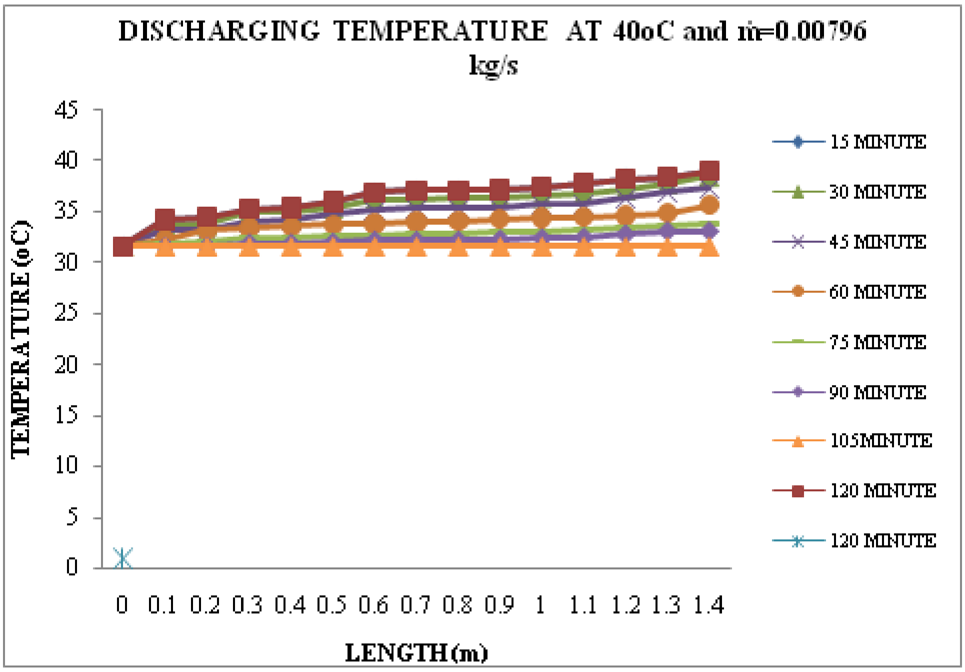

Figure 9: Temperature profile of discharging bed with ṁ=0.00796 kg/s and ambient temperature of air as 27.5°C

The ambient air temperature coming directly from the blower during the discharging cycle was around 31.6°C, so, when the temperature of the bed goes down the ambient temperature of the air during the discharging cycle, the bed was assumed to be discharged completely. The temperature profile of waste hard rubber material inside the packed bed for mass flow rate of 0.00796 kg/s, in the wake of charging time of same mass flow rate with 40°C air inlet temperature is plotted in Fig.8. It is seen from the figure that the packed bed releases totally following 120 minutes. It is clearly shown from the results that the discharging period also decreases with increase mass flow rate. The discharging time for the mass flow rate of 0.00985 kg/s and inlet air temperature 40 °C decreases to 20 minutes when compared with the mass rate of 0.00796 kg/s. Fig.9.shows that the discharging time further decreases to 40 minutes when mass flow rate was 0.0125 kg/s for the same inlet charging temperature of 40°C. The discharging time reduces to 60 minutes and 20 minutes for the mass flow rate of 0.0125 kg/s when compared to the discharging time for the mass flow rates of 0.00796 kg/s and 0.00985 kg/s respectively for same inlet bed charging temperature of 40°C. The optimum result for discharging bed for maintained temperature at 40°C when mass flow rate is 0.00796 kg/s is 120 minutes as shown in Fig.9.

Results For Air Inlet Temperature of 45^0 C During Charging

Here, the air inlet temperature is situated to be 45°C and the charging profile of material inside the bed is to be concentrated on for mass flow rate of 0.00796 kg/s of air. Results demonstrates the temperature profile of bed during the charging for mass stream of 0.00796 kg/s and 45°C inlet air temperature. It is observed from the results that the charging time after the bed gets completely charged is nearly 85 minutes. It is also observed from the results that the maximum temperature reached to about 45°C very slowly as compared to inlet temperature of 40°C and after that it reaches to uniform temperature of 45°C.As the mass stream rate of air expands, the charging time of the bed diminishes.

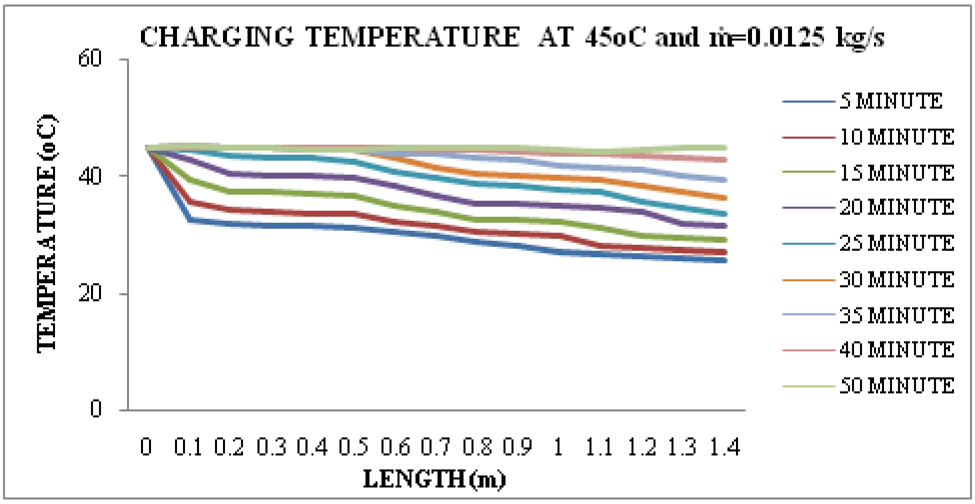

Figure 10: Temperature profile of charging packed bed with ṁ=0.0125 kg/s and inlet air temperature at 45°C.

This impact is plainly seen from the results, in which the mass flow rates were taken as 0.00985kg/s and 0.0125 kg/s separately. The charging time from the figure watched were 65 minutes and 50 minutes for two diverse mass flow rates as specified previously. The optimum result for charging bed inlet air temperature at 45°Cwhen mass flow rate is 0.0125 kg/s is 50 minutes as shown in Fig.10.

Results for Air Inlet Temperature of 45°c During Discharging

Releasing cycle of the bed was considered for distinctive mass flow rates when the charging was done at temperature 45°C. Results demonstrates the temperature profile of bed for diverse mass flow rates during the discharging period and the time variation is indicated for mass stream rates considered here during the charging and discharging period. Results demonstrates the temperature profile of bed for the mass stream rate of 0.00796 kg/s and 45°C air inlet temperature. During discharging period the air at ambient temperature of 31.6°C was flowing through the bed with a mass flow rate of 0.00796 kg/s, 0.00985 kg/s, and 0.0125 kg/s respectively and 45°C air inlet temperature. The bed gets discharged completely when the temperature of the charged air after taking away the heat from the bed goes below that temperature i.e. 31.5°C. The bed get discharged after 125 minutes with mass flow rate of 0.00796 kg/s and air inlet temperature of 45°C while the ambient air temperature was 31.6°C.The discharging time of the bed decreases with increase in mass flow rate of air. The bed get completely discharged in 120 minutes with a mass flow rate of 0.00796 kg/s. Result for mass flow rate 0.0125 kg/sand result for mass flow rate 0.00985 kg/s as compared to theresult for mass flow rate 0.00796 kg/s, shows decrease in discharging time with 100 minutes and 70 minutes for mass flow rate of 0.00985 kg/s and 0.0125 kg/s respectively for same inlet air temperature of 45°C.The optimum result for discharging bed for maintained temperature at 45°C when mass flow rate is 0.00796 kg/s is 125 minutes as shown in Fig.11.

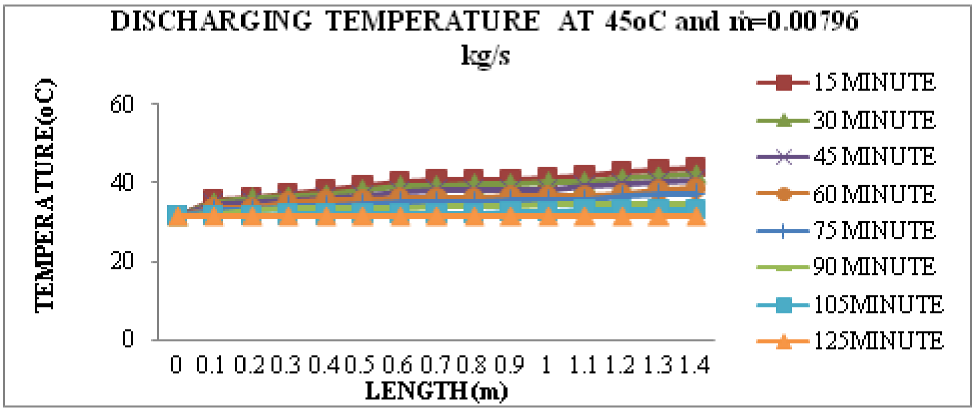

Figure 11: Temperature profile of discharging bed with ṁ=0.00796 kg/s and ambient temperature of air as 27.5°C

Results for Air Inlet Temperature of 50^0 C During Charging

Here, the air inlet temperature is situated to be 50°C and the charging profile of material inside the bed is to be concentrated on for mass flow rate of 0.00796 kg/s of air.

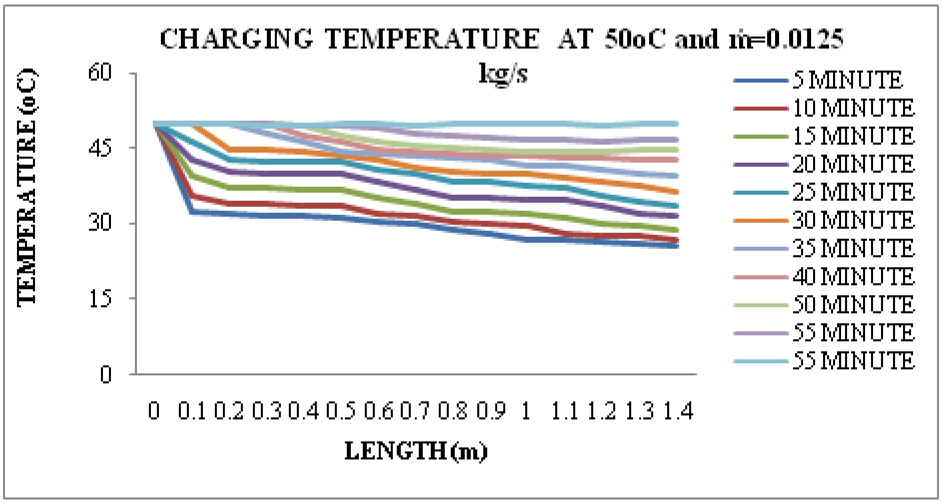

Figure 12: Temperature profile of charging packed bed with ṁ=0.0125 kg/s and inlet air temperature at 50°C.

Results demonstrates the temperature profile of bed during the charging for mass stream of 0.00796 kg/s and 50°C inlet air temperature. It is observed from the figure that the charging time after the bed gets completely charged is nearly 90 minutes. It is also observed from the result that the maximum temperature reached to about 50°C very slowly as compared to inlet temperature of 40°C and after that it reaches to uniform temperature of 50°C. As the mass stream rate of air expands, the charging time of the bed diminishes. This impact is plainly seen from the result, in which the mass flow rates were taken as 0.00985kg/s and 0.0125 kg/s separately. The charging time from the figure watched were 70 minutes and 55 minutes for two diverse mass flow rates as specified previously. The optimum result for charging bed inlet air temperature at 50°Cwhen mass flow rate is 0.0125 kg/s is 55 minutes as shown in Fig.10.

Results for Air Inlet Temperature of 50°c During Discharging

Releasing cycle of the bed was considered for distinctive mass flow rates when the charging was done at temperature 50°C. Results demonstrates the temperature profile of bed for diverse mass flow rates during the discharging period and the time variation is indicated for mass stream rates considered here during the charging and discharging period.

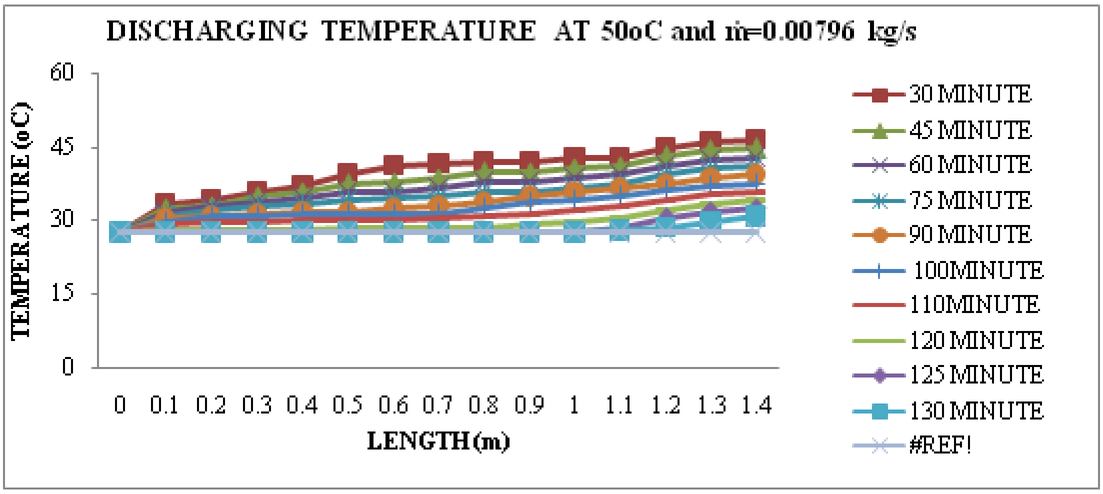

Figure 13: Temperature profile of discharging bed with ṁ=0.00796 kg/s and ambient temperature of air as 33.4°C

Results demonstrate the temperature profile of bed for the mass stream rate of 0.00796 kg/s and 50°C air inlet temperature. During discharging period the air at ambient temperature of 27.5°C was flowing through the bed with a mass flow rate of 0.00796 kg/s, 0.00985 kg/s, and 0.0125 kg/s respectively and 50°C air inlet temperature. The bed gets discharged completely when the temperature of the charged air after taking away the heat from the bed goes below that temperature i.e. 27.4°C. The bed get discharged after 70 minutes with mass flow rate of 0.00796 kg/s and air inlet temperature of 50°C while the ambient air temperature was 27.5°C.The discharging time of the bed decreases with increase in mass flow rate of air. The bed get completely discharged in 125 minutes with a mass flow rate of 0.00796 kg/s. Fig. 4.19, and Fig. 4.20, as compared to Fig. 4.18, shows decrease in discharging time with 110 minutes and 80 minutes for mass flow rate of 0.00985 kg/s and 0.0125 kg/s respectively for same inlet air temperature of 50°C. The optimum result for discharging bed for maintained temperature at 50°C when mass flow rate is 0.00796 kg/s is 130 minutes as shown in Fig.13.

Effect of Mass Flow Rate in Charging Profile of Bed

As the mass flow rate of the air increases, the charging time decreases. This implies that if we charged the bed with higher mass flow rate, it takes less time to charge the bed with uniform temperature of charging air. Fig.14. shows the effect of mass flow rate in charging profile of bed.

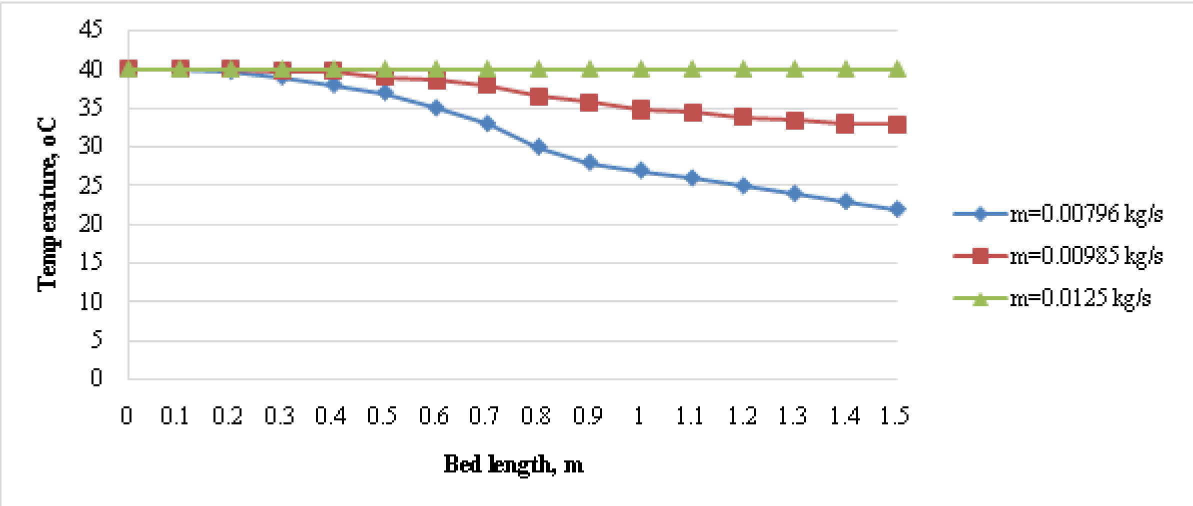

Figure 14: Temperature profile of bed charging at different mass flow rates at 40°C air inlet temperature and 50 minutes

6. Conclusions

The experiment is carried out at three different temperature i.e. 40°C, 45°C and 50°C with three different mass flow rate i.e. 0.00796 kg/s, 0.00985 kg/s and 0.0125 kg/s. It is found that when temperature i.e. 40°C, 45°C and 50°C is maintained with mass flow rate 0.00796 kg/s the charging and discharging time increases and when we supply air at mass flow rate 0.00985 kg/s the charging and discharging time is between 1(for charging)-11/2 (for discharging) hr and finally when we supply hot air at three different temperature i.e. 40°C, 45°C and 50°C with same mass flow rate i.e. 0.0125 kg/s, the charging and discharging time decreases. So for optimum functioning of setup we have taken discharging at 0.00796 kg/s and charging at 0.0125kg/s. The following are the optimum conclusion that we obtained from our experimental setup are as follows:

- Mass flow rate increases the charging time and discharging time decreases in the packed bed.

- During charging Nusselt number decreasing and at the time of discharging the value is increasing in the packed bed.
- As the mass flow rate increasing the pressure drop is decreasing in the packed bed.
- During charging value of Reynolds number decreasing and at the time of discharging the value is increasing in the packed bed.
- Optimum mass flow rate till now for charging is ṁ=0.0125 kg/s.
- Optimum mass flow rate till now for discharging is ṁ=0.00796 kg/s.

References

[1] Littman, H., and E. D. Sliva. 1970. Vol. 7. 4th Int. Heat Transfer Conference, Paris, Versailles.
[2] Hughes. P. J., S. A. Klein, and D. J. Close. 1976. Packed bed thermal storage models for solar air heating and cooling systems. Transactions of the ASME, Journal of Heat Transfer 98, No. 2:336-338.
[3] Riaz, M. 1977. Transient analysis of packed bed thermal storage systems. Solar Energy Journal 21:123-128.
[4] Bejan A. 1978. Two thermodynamic optima in the design of sensible heat units for units of energy storage.Journal of heat transfer.Vol. 100, November.
[5] Balakrishnan, 1979. Heat transfer in packed bed systems - A critical review. IndEngChem (Process Des Dev). 18(1): 30-40.
[6] Garg. H.P., Bandyopadhyay, B. and Sharma, V.K., 1981, Investigation of rock bed solar collector cum storage system, Energy Con. & Mgmt. Vol. 21, pp. 275 - 282,
[7] Saez, A.E. and McCoy, B.J. 1982. Dynamic response of a packed bed thermal storage system-A model for solar air heating. Solar Energy J. 29: 201-6.79-80
[8] Shitzer, A. and Levy, M. 1983. Transient behavior of a rock bed thermal storage system subjected to variable inlet air temperature: analysis and design. Solar Energy Eng (ASME Trans). 105: 200-6.
[9] Adnan M. Waked, 1985, Solar energy storage in rocks, Solar & Wind Technology, Vol. 3, No. 1, pp. 27-31.
[10] Mahmoud, S.A. 1992. Experimental study of a solar space heating model using Jordanian rocks for storage. Energy Convers. Mgmt. 33(9): 833-842.
[11] Choudhary, C. Chauhan, P.M. and Garg, H.P. 1995. Economic design of a rock bed storage device for storing solar thermal energy.Solar Energy. 55(1): 29-37.
[12] Dincer, I. Dost, S. and Li, X. 1997. Performance analysis of sensible heat storage systems for thermal applications.Int J Energy Res. 21: 1257-1171.
[13] Chen Wei and Wei Liu. 2003. Numerical and experimental analysis of convection heat transfer in passive solar heating room with greenhouse and heat storage. Solar Energy 76 (2004) 623–633
[14] Atear, O.E. 2008. Storage of thermal energy.Encyclopedia of Life Support System (EOLSS).
[15] Tatsidjodoung P., Nolwenn, Pierres Le, Luo L. 2012. A review of potential materials for thermal energy storage in building applications. Renewable andSustainableEnergyReviews18 (2013)327–349.