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The Packed Bed Rock - Air

Zaki Haddad (Author)[1],
Dr Radwan Al-Masri (Supervision)[2]
Al-Baath University, Qusair - Homs - Syria
[1]haddad.zaki@yahoo.co.uk
[2]ralmasri@albaath-univ.edu.sy

Abstract

The packed bed Rock-Air has been performed by Al-Baath University. It contains Basalt rock, the approximate diameter of each rock is estimated at 0.0275 meter.

The packed bed is used for cooling in summer, there is one fan for charging the packed bed performed by cool air from the ambient air when the temperature is at the lowest level (during the night in summer). The same fan will be used for supplying the cool air processed by the packed bed for cooling the office.

This research is an estimation of the thermal quantity which will be stored in the packed bed Rock-Air.

For this purpose, a set of assumptions must be taken into consideration: the temperature of rock in the packed bed is 24°C, the ambient air is 15°C, the rock is like a ball with a diameter of 0.0275 meter. The packed bed is divided into sections (the number of sections depends on the size of the ball) and each section consists of 146 columns and the losses for these (vertical thermal -grade, air temperature, charging-…) were neglected.

The research aims at finding the thermal quantity, temperature of the rock, temperature of the air in the packed bed and the time needed to get effective full charging.

Keywords: *Air-Rock, Cooling air, Temperature, Thermal storage*

1. Introduction

Energy is very important in our lives; the consumption of fossil fuel has largely increased recently, so researchers start thinking of finding new sources. Renewable energy like (solar - wind - …) start to be taken as an important energy and nowadays researchers are exerting huge efforts to invest in the sources of renewable energy effectively. But there are some time constrain due to the availability of the Sun that needs to be taken into consideration. Another factor that needs to be considered is the use of renewable energy when there is no agreement between the time of consumption and that of generating. Therefore, energy has to be stored.

There are several types of storing energy, but this research deals with thermal storage. The thermal storage can be divided into sensible, latent and chemical technologies. The Rock Storage is particularly chosen for this research.

Several researchers have studied the packed bed rock - air. To name a few: Prof. Dr. Ibrahim Sezai [1] explained some methods of thermal storage, and one of them was packed bed rock - air. Also, Turkish researchers [2] were interested in using packed bed rock - air and took the packed bed especially for agricultural purpose. Moreover, some Japanese researchers, Hiroaki Kitano and Kazunobu Sagara [3] studied heating in winter by storing the solar heat by means of packed bed rock - air.

2. The Packed Bed Rock-Air:

The packed bed rock-air is used for thermal storage. The objective of this research is to predict and estimate the behavior of thermal energy in packed bed. For this purpose, some necessary assumptions were made.

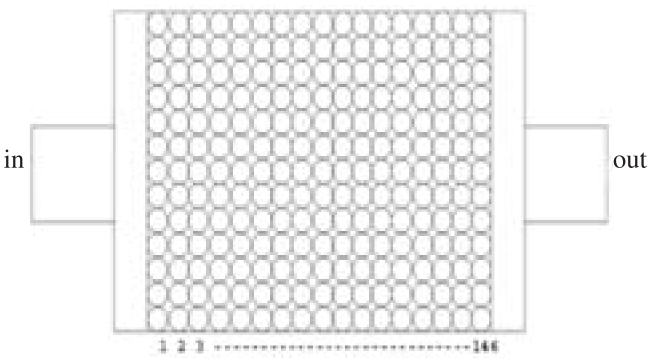

Figure 1. Theatrical packed bed

The elements of storage are assumed to be ball-shaped with a diameter of 0.0275 for each rock (the estimations depend on experimental results). The material of the ball is made of Basalt rock, and the dimensions of packed bed are H (2 m) (73 ball), W (3 m) (109 balls), and l (4 m) (146 balls). The adiabatic condition, initial temperature of the elements is 24°C, and that of the ambient air is 15°C. Moreover, the losses for these (vertical thermal -grad, the charging temperatures - heat transfer among elements in the contact points …) are neglected, and the packed bed is charged by a fan (5000 m^3/h).

This is called "cell method" to calculate the packed bed. It depends on analytical method to find out the storage energy and temperature in the packed bed, (the Excel program will be used for this purpose).The simulation takes one section. Therefore, the element is one column whose base is one ball and the highest is 73 balls. Moreover, the period of time (t) for every step is 150 sec. In order to find the results, there are three equations:

The thermal quantity lost from the air is:

$$Q = \rho_a \cdot G_a \cdot c_a \cdot t \cdot (T_{f2} - T_{f1}) \quad (1)$$

The thermal quantity which depends on volumetric heat - transfer coefficient is:

$$Q = h_v \cdot t \cdot V_r \cdot (T_{1,1} - T_{f2}) \quad (2)$$

and

$$Q = \rho_r \cdot V_r \cdot c_r \cdot (T_{1,1} - T_{1,2}) \quad (3)$$

Where

$$C_1 = \rho \cdot c_a \cdot G_2 \quad (4)$$

$$C_2 = h_v \cdot V_r \quad (5)$$

$$C_3 = \rho \cdot V \cdot c_r \quad (6)$$

There are Q, T_{f2} and $T_{1,2}$ unknown with three equations so the results can be detected:

$$Q = C_1 \cdot t \cdot (T_{f2} - T_{f1}) \quad (7)$$

$$Q = C_2 \cdot t \cdot (T_1,1 - T_{f2}) \quad (8)$$

$$Q = C_3 \cdot (T_1,1 - T_1,2) \quad (9)$$

$$C_1 \cdot t \cdot (T_{f2} - T_{f1}) = C_3 \cdot (T_1,1 - T_1,2) \quad (10)$$

$$C_2 \cdot t \cdot (T_1,1 - T_{f2}) = C_1 \cdot t \cdot (T_{f2} - T_{f1}) \quad (11)$$

$$C_2 \cdot T_1,1 - C_2 \cdot T_{f2} = C_1 \cdot T_{f2} - C_1 \cdot T_{f1}) \quad (12)$$

$$C_1 \cdot T_{f2} + C_2 \cdot T_{f2} = C_2 \cdot T_1,1 + C_1 \cdot T_{f1}) \quad (13)$$

$$T_{f2} = \frac{C_2 \cdot T_1.1 + C_1 \cdot T_{f1}}{C_1 + C_2} \quad (14)$$

$$C_1 \cdot t \cdot (T_{f2} - T_{f1}) = C_3 \cdot T_1,1 - C_3 \cdot T_1,2 \quad (15)$$

$$C_3 \cdot T_1,2 = C_3 \cdot T_1,1 - C_1 \cdot t \cdot (T_{f2} - T_{f1}) \quad (16)$$

$$T_1,2 = \frac{C_3 \cdot T_1.1 - C_1 \cdot t \cdot (T_{f2} - T_{f1})}{C_1} \quad (17)$$

$$Q = C_3 \cdot (T_1,1 - T_1,2) \quad (18)$$

The Excel program has been used to find the numerical results and diagrams applied on equations (14,17,18) where t=150 sec for each element so the results will be proceeded from element 1 to 146 and will be returned for next period by the same steps and so on.

2.1 Temperature of the air:

Figure (2) shows air temperature in the packed bed in several times. T_a150sec shows rapid changing for the temperature of the air at the beginning of the bed, because there are two factors that will be effective; the wide surface of the elements and the good heat transfer. T_a1500sec shows the same behavior but the changed area is bigger because the first elements don't lose all energy. Therefore, it requires more time; hence, the temperature of air discharged remains without any change till approximately more than half of the packed bed is charged.

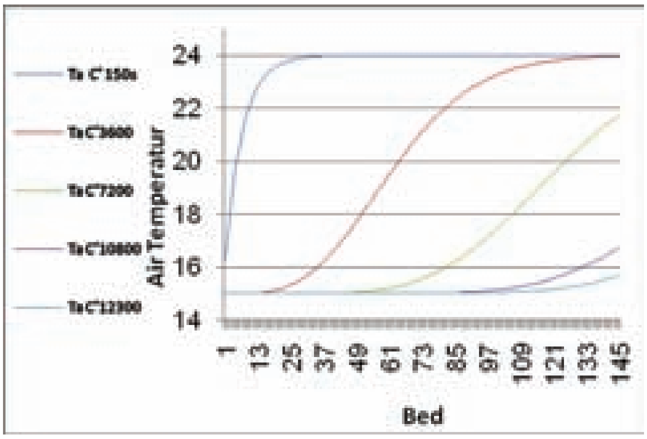

Figure 2. Temperature of the air in relevance to the bed elements

2.2 Temperature of the elements:

Figure (3) shows elements of temperature during several times, The behavior of the temperature of the elements is the same as the temperature of the air, but there is a difference between them just in the time factor and that is typically to reach the thermal impact of elements.

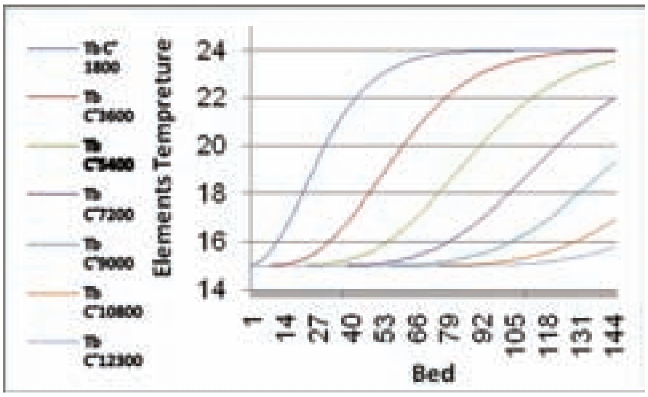

Figure 3. The temperature of the elements in relevance to the elements

2.3 The quantity of stored energy:

Figure (4) shows the energy charged in relevance to time (the temperature of fluid (air) is constant 14 C°). It's possible to see that there isn't any change in the charged thermal quantity for about one and half hour time. So, it is possible to determine the effective time for charging.

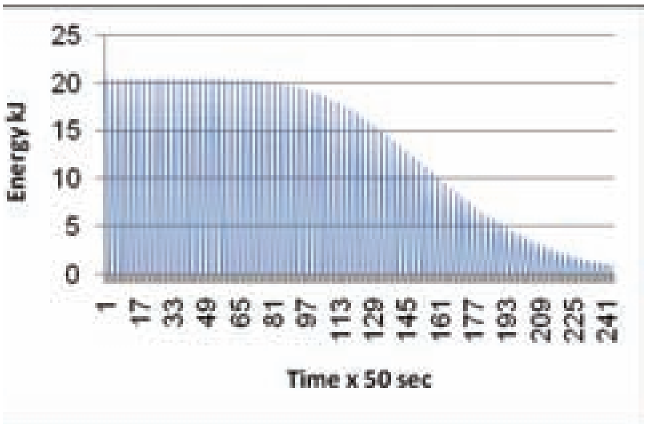

***Figure 4.** the quantity of stored energy in relevance to time*

Nomenclature

ρ_a	Density of air kg/m^3
ρ_r	Density of elements kg/m^3
h_v	Volumetric heat -transfer coefficient, kW/m^3.K (hv was taken from reference [2],[4])
G_a	Flux air m^3/sec
t	Time of charging sec
V_r	Volume rocks m3
c_a	Specific heat of air kJ/kg.K
c_r	Specific heat of elements kJ/kg.K
T_{f1}	Temperature of air before charging C°
T_{f2}	Temperature of air after charging C°
$T_{1,1}$	Temperature of element before charging C°
$T_{1,2}$	Temperature of element after charging C°

Conclusion

This theoretical study deals with temperature in the packed bed and the quantity of stored energy. Concerning the temperature in the packed bed, the elements of thermal storage have a good heat transfer factor and a wide surface; this makes the packed bed a good thermal exchanger. Concerning quantity of stored energy, it will be used for finding the effective period of time for charging (the effective period of time is the period when the charging energy quantity is high). The research which helps us find an economical way of functioning of the system (there is a comparison between this system which is used for cooling and another system which uses compressor for cooling. The results confirm that the packed bed will save 40% of the energy consumption of the compressor. In addition, the comparison was taken between the energy consumption of the compressor and fan (which is used for charging cooling air). Moreover, the same fan will be used for two systems for discharging), then the theoretical study will predict the thermal behavior in the packed bed and help find a good design for it. Therefore, this research can be used for designing cooling system and heating system depending on any thermal source.

It's good to know that the experimental results confirmed the theoretical results with a simple difference because the theoretical study neglects some factors. The instruments which are used to sometimes give wrong results and the storage elements have different sizes.

References

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