A study of heat transport in unsaturated porous media involving vapor diffusion

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Abstract

This paper presents the experimental analysis of unsaturated flow over flat plate which is embedded in a porous packed bed. In this study, the influences of particle size, supplied fluid flux, particle size and supplied heat flux on flat plate on heat transfer and mass transport during unsaturated flow over flat plate which is embedded in a porous packed bed are systematically investigated. It is found that the optimum control of some parameters results in the highest transport phenomena in a porous packed bed.

The results presented in this study provide more physical understanding of the characteristics of unsaturated flow in a porous packed bed.

Keywords*:* porous media, unsaturated flow, flat plate, heat transfer and mass transport.

1. Introduction

The heat and mass transfer in Porous Media is an interesting topic. There are a variety of engineering applications such as the heat dissipation from an electric power cable installed underground. Another example in agricultural production involves using waste heat source, from power plants, buried underground to warm soil. These applications have been presented in recent books [1 - 4].

Many researches regarding the physical phenomena of heat and mass transfer in porous materials have been proposed with saturated Porous Media [1-2]. Earlier, Darcy developed an equation to describe flow through sands. It has been generalized to a variety of situations. At the same time, a few researches [3-11] about heat and mass transfer in unsaturated porous media have been studied due to the phenomena complexity of the multiphase changes and the effective thermal property included hydrodynamic property and the mass transfer characteristic of liquid and gas in a void.

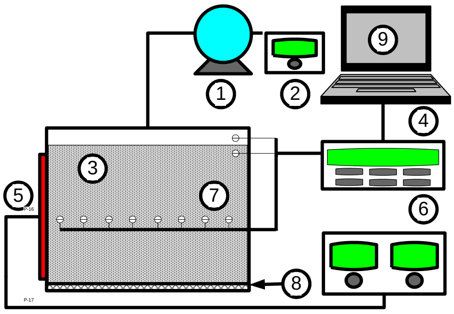
In this research, the characteristics of unsaturated flow over a flat plate embedded in a porous packed bed were studied. The heater was attached on the vertical copper plate embedded in the porous packed bed. The porous media in the packed bed was unsaturated porous media. The air was set to flow through the packed bed. The behavior of the unsaturated flow over the flat plate was investigated. The result presented here provides a basis for fundamental understanding of heat transport and unsaturated flow in porous media.

2. Experimental apparatus

The experimental apparatus can be explained into two sections as shown below.

2.1 Experimental devices

The experimental device formed is an air circulating system. It consists of a particle packed bed with glass beads of grain size 0.15mm and 0.40mm. The sample container made of acrylic, 80×325×420mm, is insulated with the firing styrol. The wire net, 0.1mm mesh, is installed at the container bottom. The stream flow is driven by an air pump. The meter is assigned to control flow. The heating system consists of the heated plate, 250×60×4mm being copper. It is imbedded on the sample container side. The power source of the heated plate can be adjusted.



Equipment List	
No.	Description
1	Air pump
2	Air Flow control
3	Glass beads
4	Data logger
5	Heater
6	Power Supply
7	Thermocouple
8	Wire net 0.1mm
9	Computer

Fig. 3.1 schematic of the experimental device for measuring heat transport in granular packed bed

The thermometry system consists of the 16 lines of the Cr-Al thermocouple. The distributions of temperature are recorded by a data logger connected to a computer. The air temperature, heating flat temperature and particle layer temperature from the start of the experiment are recorded to thermometry at fixed time intervals.

2.2 Experimental method is shown below.

1) Glass particle were set in the packed bed under laboratory conditions to fill the sample container.

2) There is no air leakage through the secured cover.

3) The air pump is operated, the air is sent into the sample container.

4) Flow is adjusted.

5) The power switch is turned on, electric current and voltage are grasped, and the experiment is started.

6) The heating surface and temperature distribution of the inside layer are measured at fixed times.

7) Verifying that temperature distribution becomes stationary, it ends the experiment.

3. Results and Discussion

In this study, the effect of supplied air flux and supplied heat flux to the temperature distribution is investigated.

The temperature distributions over time are graphically shown in Figs. 3.1 and 3.2. When a wall is heated by heater attached on a vertical copper plate surface, the heat is transferred from the top of the wall to the interior.

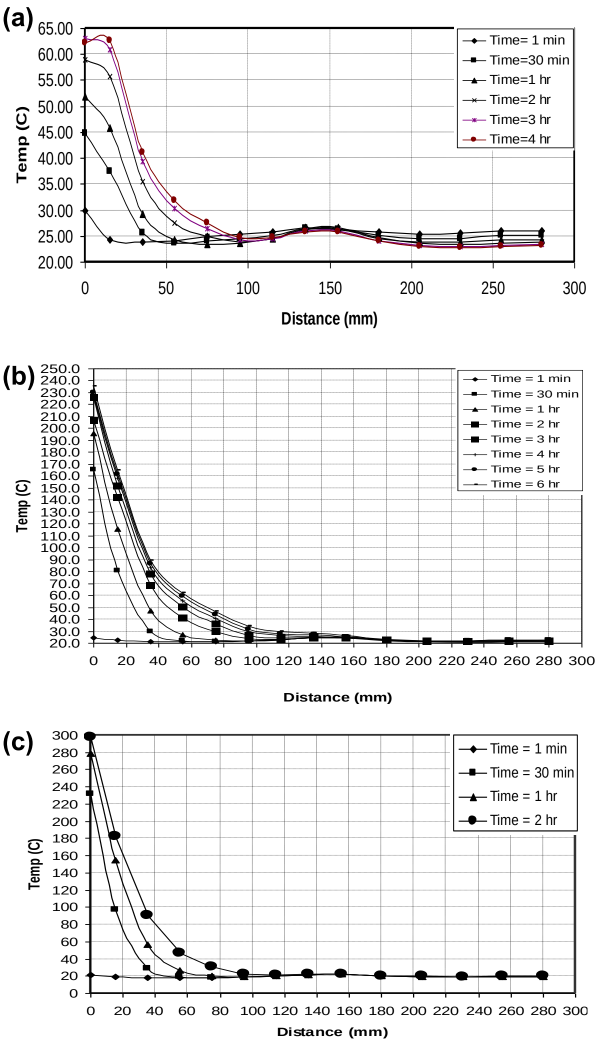


Fig. 3.1 Temperature distribution in a porous packed bed, glass beads size 0.15 mm, as a function of depth and time from the heated plate in the case (a) no air flux and 1350 w/m^2 heat flux (b) 0.003 kg/m^{2}s air flux and 7700 w/m^2 heat flux (c) 0.003 kg/m^{2}s air flux and 14400 w/m^2 heat flux

Therefore, the temperature gradient is formed in the wall. It is obvious that, at each period, the temperature reaches its highest at the heated surface due to the effect of the heater. At the locations away from the hot surface, the temperature decreases and becomes equal to the ambient. The steep curve near the hot surface indicates a high heat transfer rate. In addition, the overall temperature increases with time. However temperature distributions tend to a reach steady state at 4 hr.

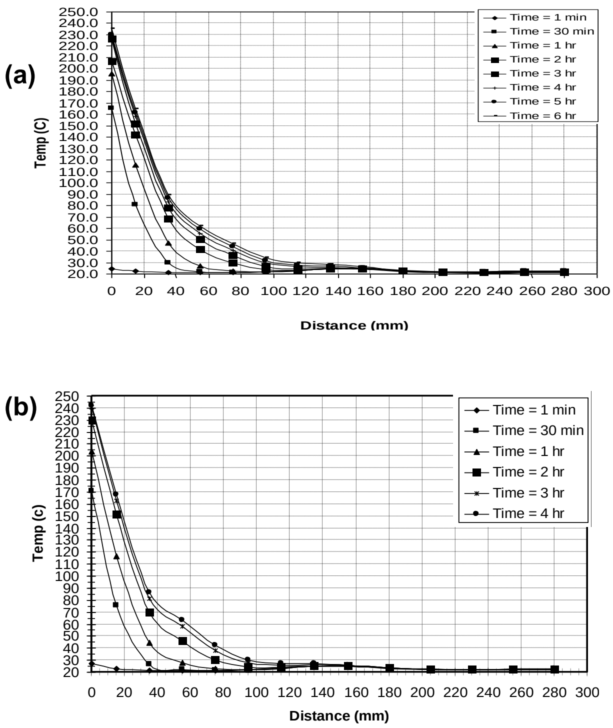
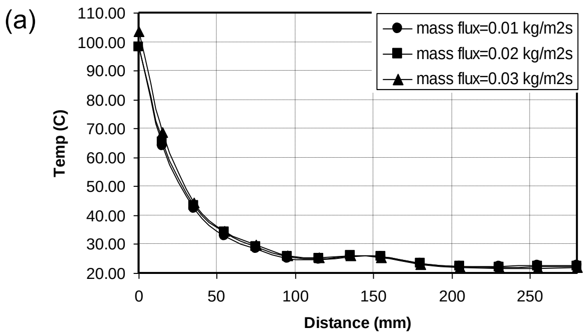


Fig. 3.2 Temperature distribution in a aporous packed bed as a function of depth and time from the heated plate with 7700 w/m^2 heat flux and 0.003 kg/m^{2}s air flux in the case (a) glass beads size 0.15 mm (b) glass beads size 0.40 mm

In fig.3.2(a) using glass beads size 0.15 mm and fig 3.2(b) using glass beads size 0.40 mm, they reach the same steady state at 120 mm which away from heated plate

These results show that different-sized glass beads have little effect on temperature distribution.



(b)

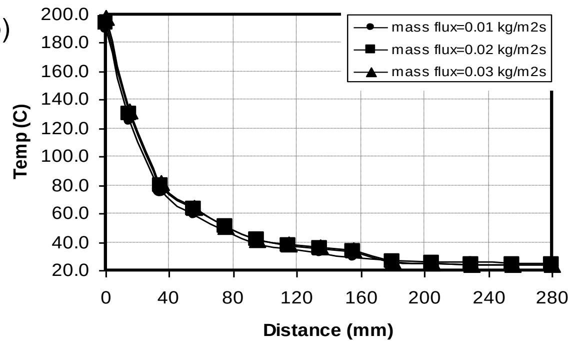


Fig. 3.3 Temperature distribution in a porous packed bed, glass beads size 0.15 mm, as a function of depth from the heated plate when vary heat flux in the case (a) 3100 w/m^2 (b) 5300 w/m^2

Fig. 3.3 shows the distribution of temperature with respect to a function of depth as a parameter of supplied air fluxes (0.01 kg/m^2 s, 0.02 kg/m^{2}s and 0.03 kg/m^{2}s) with the same particle size of 0.15 mm in a granular packed bed.

It is found that using the higher air flux results in not much change in temperature distribution. This is because the higher air flux leads to higher pressure in the packed bed. In fig 3.3 (b), the packed bed is heated with 5300 w/m^2. It is obvious that, the temperature at the vertical plate is higher than the temperature of the vertical plate at 3100 w/m^2.

4. Summary

The following details are the summary of this work:

1. In this experiment, when a wall is heated by heater, the temperature gradient has a trend to reach a steady state at 4 hr, with the location of 120 mm away from the heated plate.

2. It can be concluded that the particle size of glass beads in this experiment have little effect to change the temperature distribution rate.

3. It is found that the higher air flux has not much effect to change the temperature distribution.

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