The Experimental Investigation of Heat Transport and Water Infiltration in Granular Packed bed due to Supplied Hot Water From the Top (Influence of Supplied hot water flux and Particle sizes)

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Abstract

This paper proposes to study the effect of the particle sizes and supplied water flux to the temperature distribution, water saturation and infiltration front. The experimental was studied for one – dimensional assuming the local thermal equilibrium among water and particles at any specific space. The particle sizes used were 0.15 mm and 0.40 mm in diameter and supplied hot water flux 0.1 kg/m^{2}s and 0.2 kg/m^{2}s. From the experimental results, it was found that the granular packed bed with larger particle size results in faster infiltration rate and forms a wider infiltration layer, especially in the direction of gravity and permeability. And the temperature distribution in granular packed bed rises due to water infiltration. The increase of the supplied water flux of water corresponds to higher water saturation and forms a wider in filtration layer. However, an extension of the heated layer is not as much as that of the infiltration layer because the temperature of water infiltration gradually drops due to upstream heat transport.

Keywords: Porous media, Water infiltration, Numerical modeling

1. Introduction

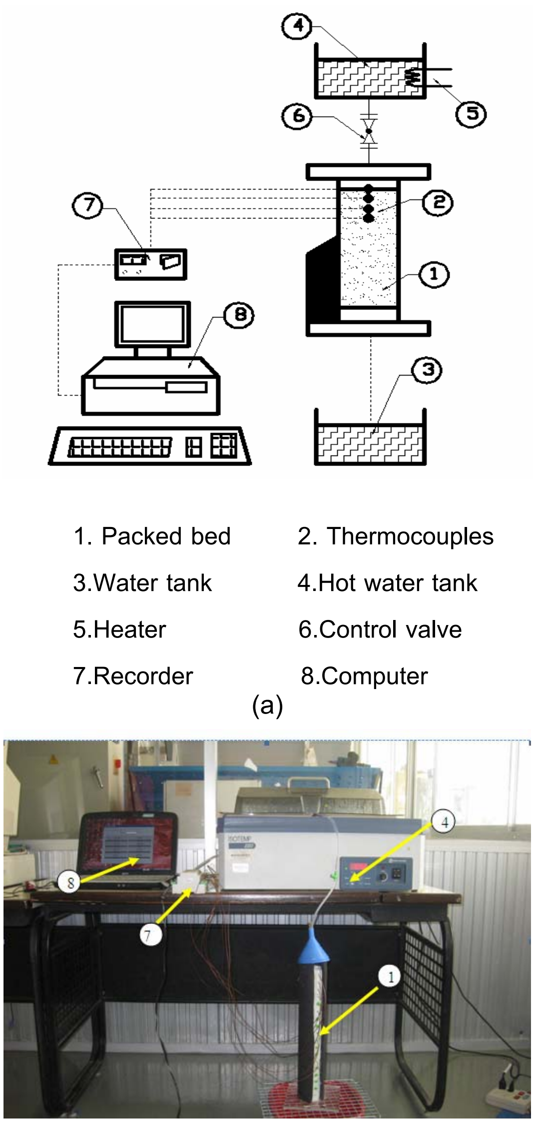
The phenomenon of water infiltration is an important process in many fields such as soil science, agriculture, geothermal science, chemical engineering and civil engineering. In the past, the problem of heat transport in granular packed bed with water infiltration due to capillary action is concerned in a variety of soil science and chemical engineering applications such as in temperature control of soil, recovery of geothermal energy, thermal energy storage, and various reactors in chemical industry.

For water infiltration in porous media or granular packed bed, many investigators including Campbell [1], Bear [2], Haverkamp et al. [3], Parlange [4] and Schrefler and Xianoyong [5] have been studied in the fields of soil science, agriculture, civil engineering, and chemical engineering. However, few research reports have been published for problem of heat transfer in granular packed bed coupled with unsaturated flow.

This research is extended from the work of Aoki et al.[6] for completely analyzing heat and water infiltration in porous pecked bed. The purpose of this work is to study the effect of the particle size and supplied water flux to the temperature distribution, infiltration front, and water saturation with one-dimensional unsaturated flow experimentally. The result presented here provides a basis for fundamental understanding of heat transport and unsaturated flow in porous media.

2. Experimental Apparatus

The experimental was studied for one – dimensional assuming the local thermal equilibrium among water and particles at any specific space. The particle sizes used were 0.15 mm and 0.40 mm in diameter and supplied hot water flux 0.1 kg/m^2s and 0.2 kg/m^2s. Figure 1 (a) and (b) shows the experimental apparatus for one-dimensional heat transport in granular packed bed with unsaturated flow. The test column, 60 mm inner diameter and 400 mm in height, is made of acrylic resin and equipped with stainless steel screen at the bottom of the bed to prevent the movement of particles. Spherical soda lime glass beads with average sizes of 0.15 and 0.4 mm, are used as a sample of granular packed bed. The water supplied from a tank is heated at a certain temperature to the top of granular packed bed through a distributor. The test column is covered with insulation to reduce heat loss. The distributions of temperature within granular packed beds are measured with Cu-C thermocouples with diameter of 0.1 mm. These thermocouples are set up at 20 mm interval along the axis of granular packed bed. The distributions of temperature are recorded by a data logger connected to a computer.



1. Packed bed 2. Thermocouples
3.Water tank 4.Hot water tank
5.Heater 6.Control valve
7.Recorder 8.Computer

(a)

(b)

Fig. 1. Experimental apparatus for measuring heat transport and unsaturated flow in one dimension porous layered
(a) Schematics diagram, (b) Actual diagram

The position of infiltration front in the packed bed was recorded by using digital camera together with timer as shows in Fig 2. Fig. 3 shows the experimental apparatus for measuring water saturation. At the end of test run the test column was cutout into five sections in order to measuring the water saturation. The water saturations in the non-hygroscopic porous packed bed were defined as the fraction of the volume occupied by water to volume of the pores. They were obtained by weighing dry and wet mass of the sample .The water saturation formula can be described in the following form.[20]

$$S = \frac{M_p \cdot \rho_s \cdot (1-\phi)}{\rho_w \cdot \phi \cdot 100} \quad (1)$$

Where S is water saturation; ρ_s is density of solid; ρ_w is density of water; ϕ is porosity and M_p is particle moisture content dry basis.

Initially, the water saturation and the temperature are uniformed within packed bed are 0.06 and 25 °C respectively. The experiments are carried out for the conditions of constant supplied water flux and constant temperature of hot water.

Fig. 2. Experimental apparatus for measuring infiltration front of water

Fig.3. Experimental apparatus for measuring water saturation

3. Result and Discussion

The effect of the particle sizes and supplied water flux to the temperature distribution, water saturation and infiltration front. The experimental is studied for one – dimensional assuming the local thermal equilibrium among water and particles at any specific space. The particle sizes used are 0.15 mm and 0.40 mm in diameter and supplied hot water flux 0.1 kg/m^{2}s and 0.2 kg/m^{2}s.

The obtained results in Fig. 4 shows the infiltration front of the packed bed with particle size of 0.15 mm and 0.4 mm. It is found that a larger particle size in the packed bed corresponds to a faster infiltration front than smaller particle size. The effect of the fast response depends on the permeability and the capillarity properties of the particles.

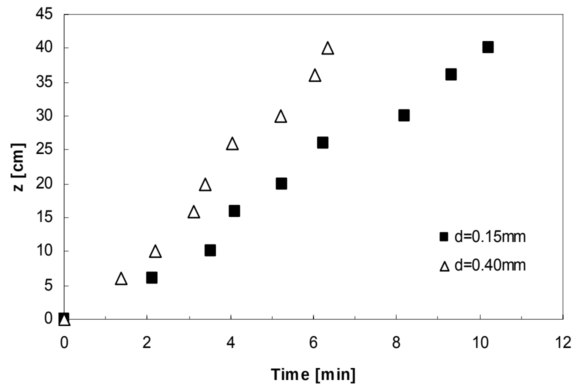


Fig.4. Infiltration front of the saturation with particle size of 0.15 mm and 0.4 mm at supplied water flux of 0.2 kg/m^{2}s

It is evident from Fig.5 that the distribution of water saturation and temperature profiles at various elapsed times as a parameter of supplied water flux of 0.1 kg/m^{2}s and 0.2 kg/m^{2}s with the same particle size of 0.15 mm. It was found that using the higher supplied water flux results in a faster infiltration rate and forms wider infiltration layer, especially in the direction of gravity. The main transport mechanisms that enable fluid movement are: liquid flow driven by capillary pressure gradient and gravity while the vapor is driven by molecular diffusion. Liquid phase migration is related to capillary pressure gradient as well as temperature, whereas the vapor phase is driven by the gradient of the partial pressure of the evaporating species [22].

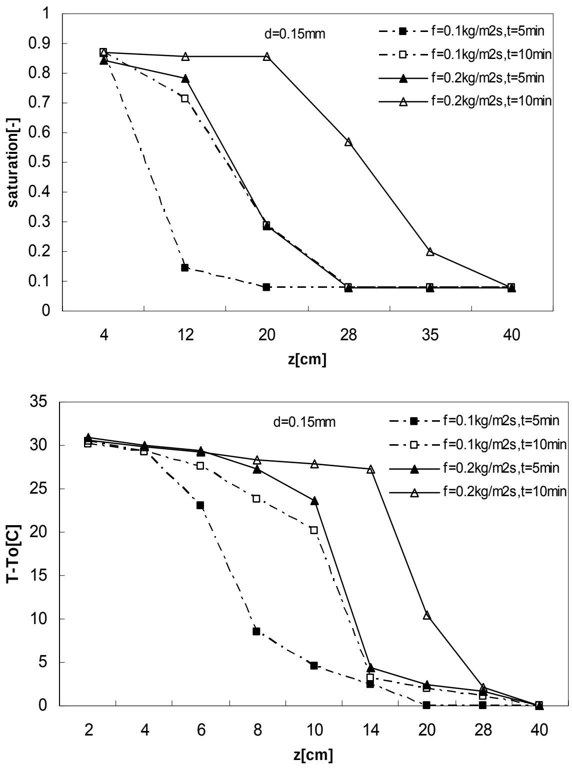


Fig.5. Distribution of water saturation and temperature profiles at various elapsed times as a parameter of supplied water flux

Fig. 6 shows the influence of particle sizes on the distributions of saturation and temperature profiles under same supplied water flux of water 0.1 mm/s with particle size of 0.15 mm and 0.4 mm. The results show that a larger particle size leads faster temperature distribution than smaller particle sizes. The temperature in granular packed bed rises due to water infiltration. The water saturation of the larger particle has more distribution than the water saturation of the smaller one. The effect of the fast response depends on gravity gradient stronger than the effect of the capillary pressure. And the permeability of the coarse particle has the effect to infiltration rate faster than the fine particle. The temperature in the granular packed bed rises due to water infiltration, but the heated layer does not extend as much as the infiltration layer. This means that heat transport hardly occurs in the layer closed by the infiltration front because the temperature of water infiltration there has already dropped due to heat transport upstream.

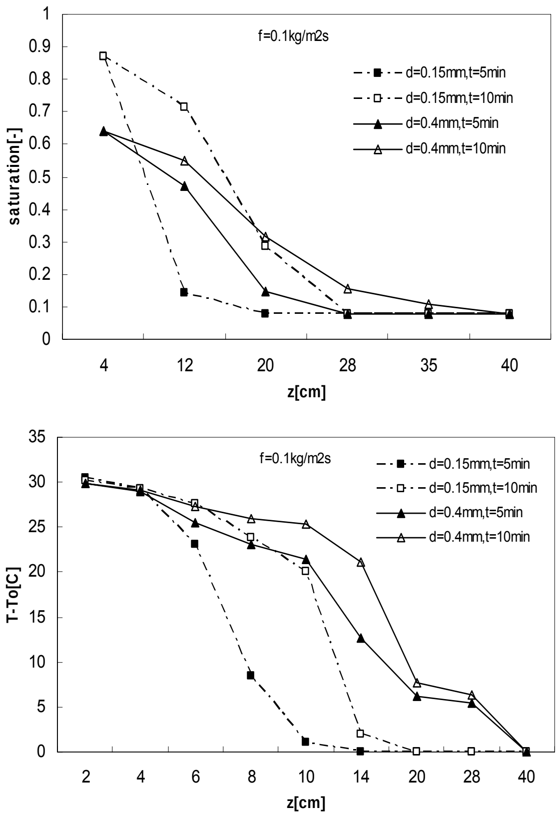


Fig.6. Distribution of water saturation and temperature profiles at various elapsed times as a parameter of particle size

4. Conclusions

The heat transport and water infiltration in granular packed bed with unsaturated flow is investigated. The following are the conclusions of this work:

1. As comparing the distribution profiles between heated layer and infiltration layer, it is observed that the heated layer does not extend as much as the infiltration layer. This means that heat transport hardly occurs in the layer close to the infiltration front because the temperature of water infiltrating gradually drops due to heat transport upstream. Furthermore, the effect of particle size on the discrepancy of heated layers is smaller compared to that of the water content layers.
2. It is found that the gravity and capillary pressure have clearly exhibited influence on the infiltration and heated layers.

5. References

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