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Infiltration rate in unsaturated glass beads porous media under various gravity made by parabolic flight

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Introduction

The Global Exploration Roadmap targets the realization of Mars manned exploration by the 2030s. It is necessary to understand water movement in porous media under low-gravity to establish a plant growth system for crop production for astronauts to produce food in outer space. In this study, the water movement in porous media under different gravities was observed and compared with the water movement theory derived by extending Washburn (1921) equation.

Materials and Methods

The 0.4 and 0.6 mm diameter glass beads were used as porous media with distilled water as an imbibition solution. Columns filled with the glass beads were vertically installed and connected to water reservoirs from the lower end of the columns. After low gravity conditions, microgravity (μG), 1/6G, and 1/3G, were made by parabolic flights using a turbojet aircraft "MU-300", we started providing water to the glass beads by opening a solenoid valve just after achieving a low gravity condition. A video camera captured water movements under low gravity conditions, and we calculated imbibition rates by image analysis.

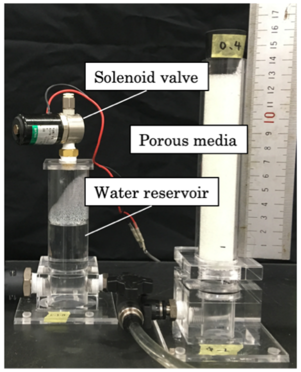

Fig. 1 Experimental apparatus

Theory

Washburn equation (Washburn, 1921) was extended by considering an experimental apparatus (Fig.2) as:

$$\frac{dl}{dt} = \frac{C}{l} - Gg\frac{(l-h)}{l}$$

l : Imbibition distance
t : Elapsed time
g: Gravity acceleration
h: Water head pressure on the lower end of the porous media
C, G : Experimental constant calculated by horizontal and vertical upward imbibition experiment

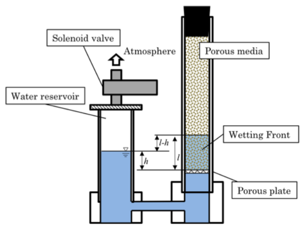

Fig. 2 Experimental system

Experimental constants C and G were determined from horizontal imbibition experiments and vertical upward imbibition experiments conducted under 1G. The infiltration rates under low gravities were estimated using the extended Washburn's equation for the vertical upward imbibition experiments.

Results

0.4 mm Glass Beads

An infiltration rate under μG was smaller than the theoretical value estimated by the extended Washburn's equation. However, decreases in infiltration rates under partial gravities (1/6G, and 1/3G) were smaller than that under μG.

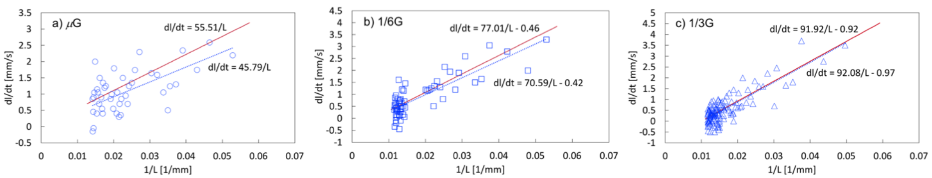

Fig. 3 Imfiltration rates under μG (a), 1/6G (b), and 1/3 (c) in the 0.4 mm glass beads porous media; Plots show measured value and the blue lines are linear regression lines. The red lines indicate predicted values by the extended Washburn's equation for the vertical upward imbibition.

0.6 mm Glass Beads

With 0.6 mm glass beads, the measured value of the infiltration rate was slightly smaller than the theoretical value under μG and 1/3G. The measured value under 1/6G was slightly higher than the theoretical value. As the differences between the theoretical and measured values were less than 5%, we concluded that the differences were not significant.

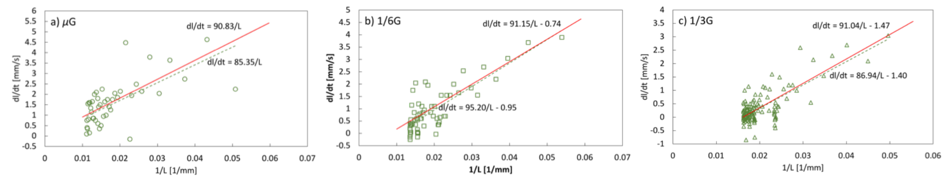

Fig. 4 Infiltration rates under μG (a), 1/6G (b), and 1/3 (c) in the 0.6 mm glass beads porous media; Plots show measured value and the blue lines are regression lines. The red lines inidcate predicted values by the extended Washburn's equation for the vertical upward imbibition.

References

Washburn, E.W. (1921) The dynamics of capillary flow. Physical review, 17(3), 273–283.

Acknowledgment

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