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Liquid Rise in Uniform Screens under Normal Gravity and Microgravity Conditions

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Abstract – Metallic screen waves have been widely used in space devices such as heat pipes and propellant management devices. They provide effective capillary force to drive liquid flow under mirocrgravity condition. Proper design of the screen waves is critical to the safe operation of the space devices, and thus the flow dynamics of liquid within screen waves should be well understood. In this paper, experiments are performed to investigate the transient flow of liquids in a single layer of screen mesh. The flow pattern and the development of marching interface are shown clearly. Four types of screen mesh with different mesh densities are considered and three complete wetting fluids are used. The processes both on ground and in a drop tower are tested following a similar experimental procedure. With these efforts, the dynamics of liquid rise in screen mesh under normal gravity and microgravity are compared in detail. The influences of screen pore sizes and fluid properties have also been discussed.

Keywords**:** Liquid rise, Interface, Screen Mesh, Microgravity.

1. Introduction

Capillary flows are of great importance in space technology, because the capillary force is sometimes the only force to drive liquid flow under a microgravity condition [1-2]. Two important applications of capillary transport in spacecraft are heat pipes and Propellant Management Devices (PMD). In heat pipes, porous materials or structured surfaces are used in the liquid storage reservoir (LSR) and in the evaporator to transport liquid back to the hot end. In PMDs, a porous structure, usually a metallic screen wave, is used to permeate liquid but block the gas out. With these methods, gas and liquid are separated passively under a zero microgravity environment. A thorough understanding to the dynamics of liquid flow in these screen waves is critical to the new designs of the porous structures and to the safe operation of LSR and PMDs.

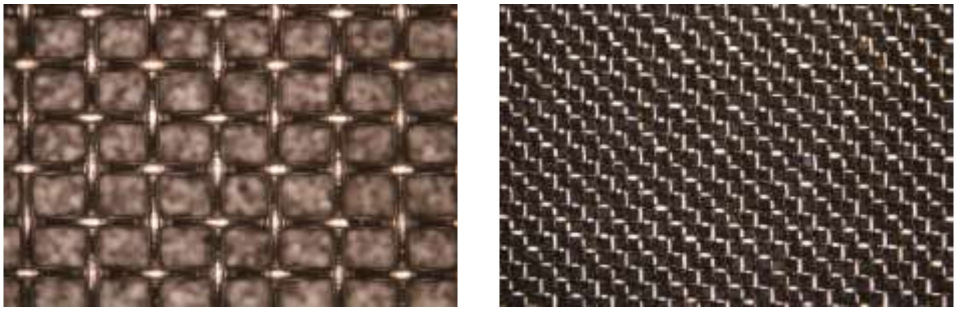
To data, limited results have been reported referring to the liquid rise in the porous mesh screen on earth or in microgravity. Because the liquid flow in the three-dimensional screen waves are hard to be visualized in experiment, and also because the expense is always high in microgravity experiment. In this paper, a specific study is made on the liquid flow in uniform screen wave. To see clearly the marching interface, a single layer of screen mesh is considered. Experiments are performed both on ground and in a drop tower, following a similar procedure. The dynamics of fluid marching with the thin layer of screen mesh are well demonstrated, and the influence of main factors are discussed.

2. Materials and Methods

The metallic screen mesh, which has been widely used in LSRs and in PDMs, is considered in the experiment. The screen sheet is made of 304 stainless steel. Magnified photos of the screen sheet is shown in Fig. 1. It is plain-weaved by warp wires and shuttle wires and the pores are in a regularly square shape. This type of screen sheet can be seen homogeneous in both horizontal and vertical directions. To visualize the marching behaviour of liquid inside the screen mesh, a single layer of screen sheet is used. However, the single layer of sheet has shortcomings in stiffness as well as in full contact of liquid in the experiment. We put the single layer of screen sheet between a pair of glass plates. The plates provide good supply of liquid for the screen sheet while it has a weak influence on the liquid rise in the porous screen, because the thickness of the screen sheet is much larger than the diameter of thread and the pore size. Four types of screen mesh are considered in the experiment. The parameters for each screen mesh is given in Table 1. They are named by the mesh density per inch, i.e. 100

mesh, 200 mesh, 300 mesh and 400 mesh. The corresponding thickness of each single layer of screen was from 0.70 mm to 0.077 mm.

Three liquids are selected in this work, i.e. HFE-7100 (3M™ Novec™), ethanol, and silicone oil (polydimethylsiloxane, 5cs). Their properties are given in Table 2. The static contact angles (CA) is close to zero for all liquids on the surface of screen mesh and thus they are complete wetting on the screen mesh.



a) 100 mesh b) 400 mesh

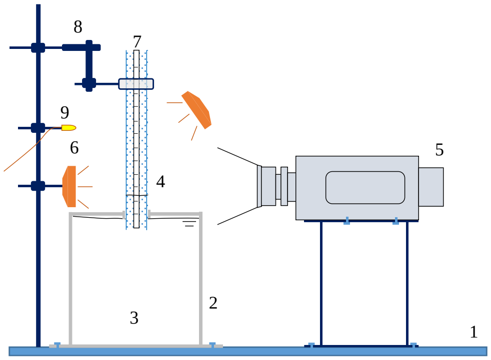
Fig. 1: Caption for figure goes at the bottom.

Table 1: Parameters of the screen mesh.

Name	Case 1#	2#	3#	4#
Meshes per inch	100 mesh	200 mesh	300 mesh	400 mesh
Thickness of the screen sheet	0.170 mm	0.119 mm	0.101 mm	0.077 mm
Diameter of thread	0.08 mm	0.05 mm	0.04 mm	0.03 mm
Pore size	0.15 mm	0.074 mm	0.049 mm	0.037 mm

Table 2: Fluid properties.

Fluid Name	Density, ρ (kg/m^3)	Viscosity, μ (mPa·s)	Surface Tension, σ (mN/m)
HFE-7100	1520	0.93	13.6
Ethanol	785	1.08	21.9
Silicone Oil	913	4.57	19.7



(1) Operation platform;
(2) Transparent vessel;
(3) Working medium;
(4) Capillary structure;
(5) High speed camera;
(6) Diffusive light source;
(7) Transparent tape ruler;
(8) Position regulator;
(9) Microgravity indicator light.

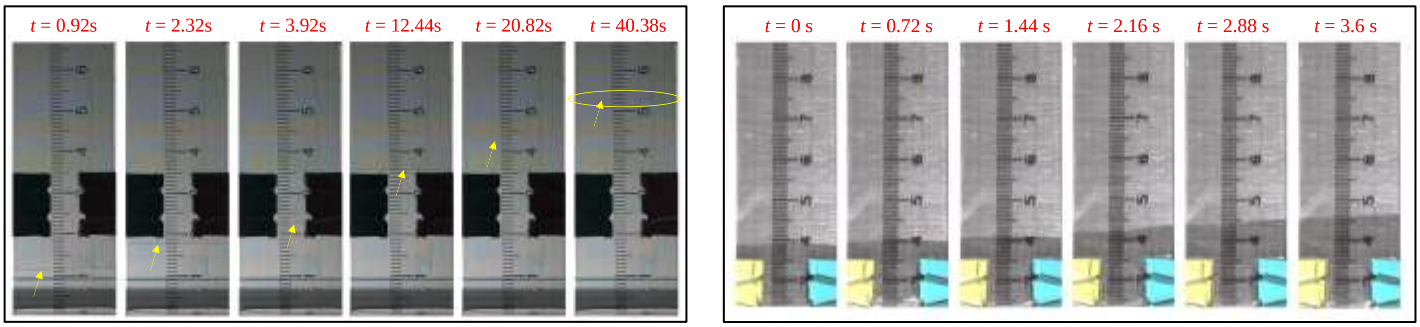
Fig. 2: Sketches of the main body of the experimental systems.

Fig. 2 shows the sketches of the experimental system. The screen mesh is fixed by a mechanical clamp mounted on a group of crossed guide rails. The moment of liquid rise in the capillary structures is recorded by a high-resolution camera (Sony FDR-AX45) at a speed of 50 f/s. A ruler is placed aside the capillary structures to check the position of meniscus macroscopically during the experiments. For the microgravity experiment, the drop tower in the National Microgravity Laboratory of China is used. It provides an effective dropping height of 60 m out of the total height of 116 m overground. A single capsule mode is used, *i.e.* the capsule was dropped in the air environment. The microgravity level is below 10^{-3}~10^{-2}g and lasts for about 3.6 s.

3. Results and Discussion

3.1. Flow pattern

The visualized results of liquid rise in the screen mesh is shown in Fig. 3. The transient photos both on earth and in microgravity are given. The air-liquid interface is almost flat in the screen sheet during liquid rise on earth. For the three complete wetting fluids, the liquid invades quickly into the porous screen after toughing. A smooth climbing process was observed in the experiment. We assumed a small influence of the plates on liquid rise in the mesh screen, because the pore size of screen mesh is much smaller than the slot width of the plates. The dominated capillary forces is provided by screen mesh instead of the plates for the fully wetted fluids. In microgravity, the liquid initiates from the equilibrium position of interface on earth. It climbs again once the microgravity condition starts. The marching process seems to be much slower in microgravity than on earth at the beginning of experiment. The interface is slightly tilted in the later stage in microgravity without the restriction of gravity force.

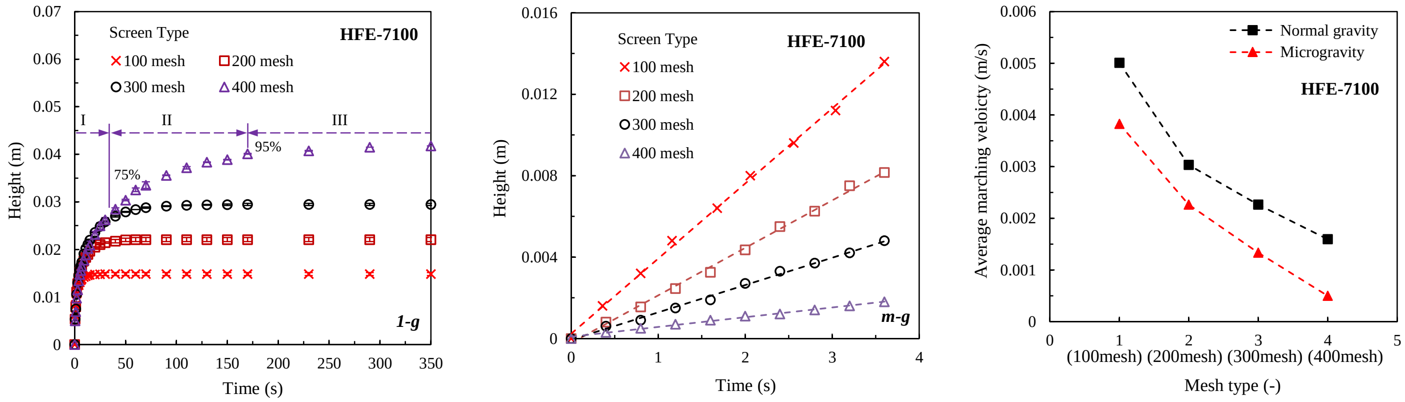


a) normal gravity b) microgravity

Fig. 3: Visualized results of liquid rise in the screen mesh. a) in normal gravity, the screen type is 200 mesh and fluid is ethanol; b) in microgravity, the screen type is 100 mesh and fluid is HFE-7100.

3.2. Influence of mesh density

The quantitative results are compared in Fig. 4. A quite long time is used on earth to reach the equilibrium height for liquid rise in the screen mesh. Generally, the total process can be seen in three stages, i.e. a fast rising stage, a deceleration stage and a quasi-steady stage. The marching process of interface is very short during the fast rising stage and the velocity is limited by inertia effect. Since the path is prolonging, viscous effect takes over and it leads to the deceleration process of liquid rise. The final height is limited by gravity and the quasi-steady stages is long. With an increase of mesh density, the pore size deceases. The equilibrium height is increasing while the deceleration stage is prolonging. This is because the finer mesh provides higher capillary forces but also higher flow resistance to the liquid. The flow paths in different mesh types coincide during the fast rising stage and they begins to diverge in the deceleration stage.



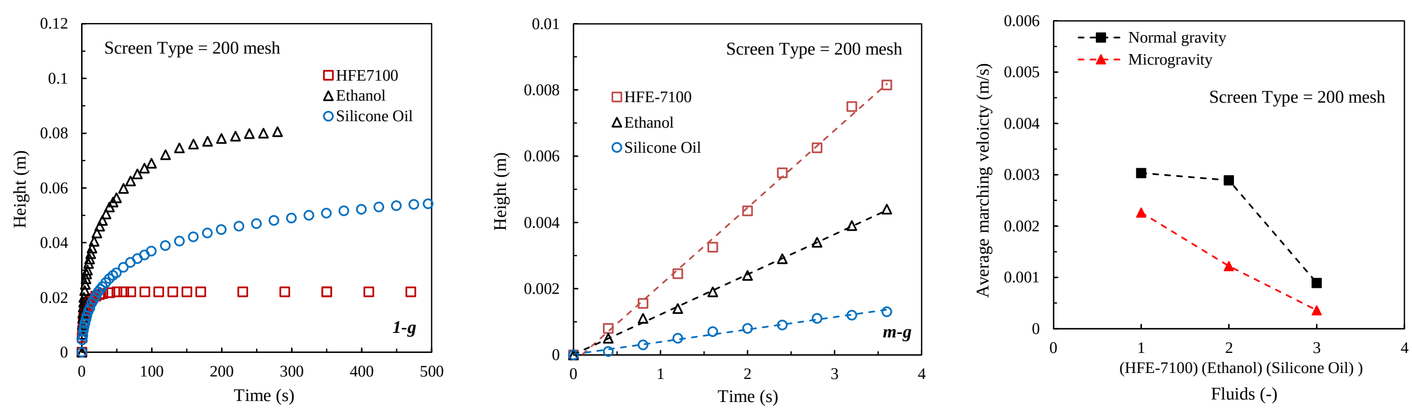
a) liquid rising height on earth b) liquid rising height in microgravity c) average marching velocity of interface

Fig. 4: Comparing the results on earth and in microgravity: influence of mesh density.

In microgravity, the flow process differs significantly. The rise of liquid shows linear patterns in Fig. 4b, and liquid rises faster in the coarse mesh than in the fine mesh. This is due to the flow resistance of coarse mesh is smaller than the fine mesh without the limitation of gravity. We compared the average marching velocity in microgravity with that in the fast rising stage on earth, as seen in Fig. 4c. It is clear that the liquid also rises faster in the coarse mesh than in finer mesh during the fast rising stage on earth. This stage on earth is comparable to the microgravity results. Both are inertia controlled process and the influence of gravity can be seen weak.

3.3. Influence of working media

As shown in Fig. 5, the capillary flow of different media have quite different flow paths. With a fixed mesh type, ethanol reaches the highest equilibrium height on earth, followed by silicone oil and then HFE7100. However, the silicone oils shows a long marching time because of its high viscosity. The deceleration period is very long, e.g. more than 400s. The HFE7100, which has the lowest viscosity but large density, has a high marching velocity at the early stage on earth, and it reaches equilibrium very quickly. The transient rise of fluids in microgravity is mainly determined by the viscosity of medium. As seen in Fig. 5b, the HFE-7100 rises fastest but the silicone oil has a very short climbing height. Without the restriction of gravity, liquid rise will not stop in microgravity. But deceleration will occur due to the increasing friction effect with prolonging flow path. However, the microgravity time is limited in the drop tower. The flow process of liquid rise in the next stage, particularly the deceleration phenomenon has not been seen in Fig. 5. Still, similar dynamics are seen during the fast rising stage on earth to that in microgravity in Fig. 5c. The velocity of interface follows a same trend for the different media.



a) liquid rising height on earth b) liquid rising height in microgravity c) average marching velocity of interface

Fig. 5: Comparing the results on earth and in microgravity: influence of working media.

4. Conclusion

In normal gravity, the liquid rise in screen mesh was featured by a fast rising stage, a deceleration stage and a quasi-steady stage. These stages were restricted by inertia effect, viscous effect and gravity effect respectively. The transient process of liquid rise was affected by mesh density and fluid properties. In microgravity, a linear process of liquid rise was commonly seen. Liquid climbed faster in coarse mesh than in fine mesh. The dynamics of liquid rise during the fast rising stage on earth was analogous to that in microgravity, *i.e.* the average marching velocity of interface was high and the influence of gravity was weak.

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