Analysis of the influence of the vane width on the fluid transmission performance in the vane-type tank

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Analysis of the influence of the vane width on the fluid transmission performance in the vane-type tank

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Abstract. Fuel tanks are a core component in satellites that manage the propellant. This study numerically analyzed the fluid transport with parallel guide vanes in a vane type surface tension tank. In this paper, the numerical simulation analysis is carried out for the fluid transmission performance of the parallel vane of the new generation plate surface tension tank, and the influence of vane width on the transmission performance of vane is studied. The results show that, in the whole capillary flow stage, the liquid flow rate increases with the increase of the width a of the guide plate.

1. Introduction

The literature has many studies of propellant transport in microgravity. For example, Li et al. studied liquid sloshing in a vane type tank in microgravity [1]. Lapilli et al. studied the microgravity fluid dynamics in a sphere slosh experiment. Li et al. numerically analyzed the fluid mechanics of capillary flow in microgravity in a fan-shaped asymmetric interior corner [2]. They analyzed the effect of the contact angle on the rise height in the corner and developed a Concus-Finn condition for the capillary flow in the corner. Han and Chen studied the effect of the geometry on merged droplet formation in a double T-junction microchannel using three-dimensional numerical simulations using the level-set method. The fluid motion in a spherical tank in microgravity conditions was investigated by Dalmon et al. through comparisons of data from the FLUIDICS experiment in the ISS with Direct Numerical Simulations of the two-phase flow [3]. Gaulke et al. numerically studied capillary transport of a liquid between parallel perforated plates in microgravity with various geometries to show how the capillary transport capability correlated with the perforation diameter and plate porosity [4]. Bolleddula et al. reviewed capillary rise flows and drop tower investigations and developed an analytical solution for flows along planar interior edges[5]. Kang et al. described a microgravity experiment investigating thermocapillary convection in an open cylindrical annular pool to be done on the SJ-10 satellite [6]. Ground experiment results showed the temperature oscillations, surface oscillations, and flow patterns. Li et al. presented the governing equation for capillary driven flow in a cylindrical interior corner with an approximate analytical solution and showed that capillary driven flow in cylindrical interior corners satisfied the Concus-Finn condition in microgravity [7]. The also presented a relationship for the variation of the liquid front position with time which was then compared with the results of drop tower experiments and numerical simulations. Zhang et al. experimentally investigated the migration and interaction of two axisymmetric drops in a vertical temperature gradient on the ground with a

discussion of the influence of the dimensionless initial distance between the drop centers on the drop migration [8].

2. Computational Model

Fig. 1 shows the vane dimensions. The flow channel is based on the dimensionless flow channel ratio $m=\varepsilon/\alpha$. The vane width is α and the clearance between the midpoint of the vane and the tank wall is ε. Anhydrous ethanol was used as the medium with the constant properties listed in Table 1. The fluid was assumed to be an incompressible Newtonian fluid. The fluid was assumed to be laminar with consideration of the effect of viscosity.
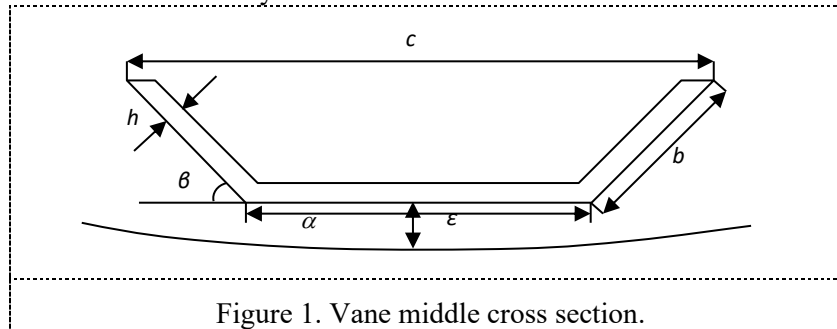

Figure 1. Vane middle cross section.

Table 1. Physical parameters for an anhydrous ethanol tank at 20°C.

| Name	Molecular formula	ρ (kg/m³)	σ (N/m)	μ (Pa·s)	Contact angle (PMMA)	Grade
Anhydrous ethanol	C_2H_5OH	789	0.02246	0.01096	0	analytical purity

3. Influence of different vane width on transmission performance

Increasing the number of baffles will undoubtedly increase the liquid transfer capacity of the baffles, but it will also increase the overall weight of the tank. Another way to increase liquid transport is to increase the width of the vane. By simulating the capillary flow in the tank under different vane width, the influence of different vanes width on the transmission efficiency of a single vane is studied. The number of vanes is 4. When discussing the influence of the width a of the vanes on the transmission performance, the parameters m and h are kept constant. Table 2 shows the parameters used in the simulation.

Fig. 2 shows the time-varying relationship between the leading edge position L^2 of the vane and the time interval of 0.1s when the width of the vane is a = 4.8mm, 6.0mm, 7.5mm and 9.0mm. It can be seen from the figure that the leading edge climbing speed increases with the width of the vane a. When the width a increases from 4.8mm to 6.0mm, the climbing speed increases obviously. When the width a increases from 6.0mm to 9.0mm, the speed increase decreases.

Table 2. Simulation parameters with different width a

Working condition	1	2	3	4
Vane width a/mm	4.8	6.0	7.5	9.0
Clearance ε/mm	1	1	1	1
Angle β/°	45	45	45	45
Analog medium	Absolute ethanol			
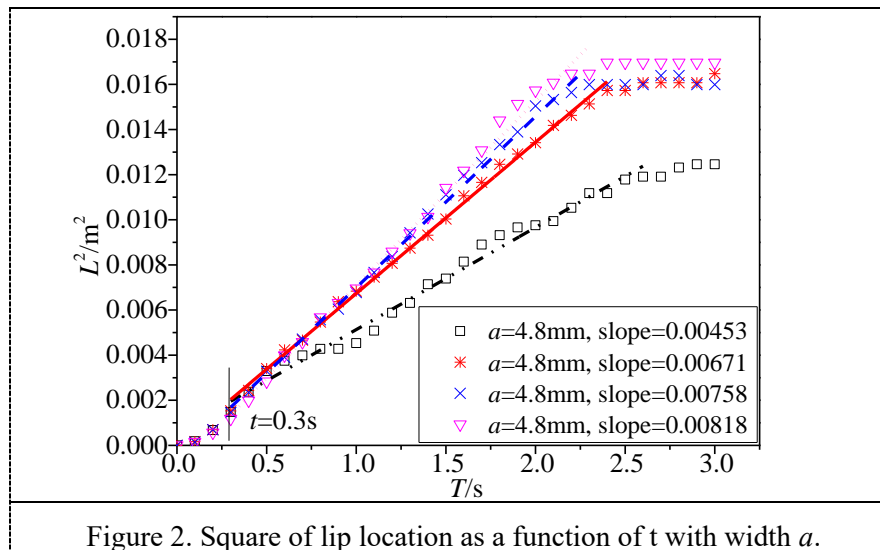
Figure 2. Square of lip location as a function of t with width *a*.
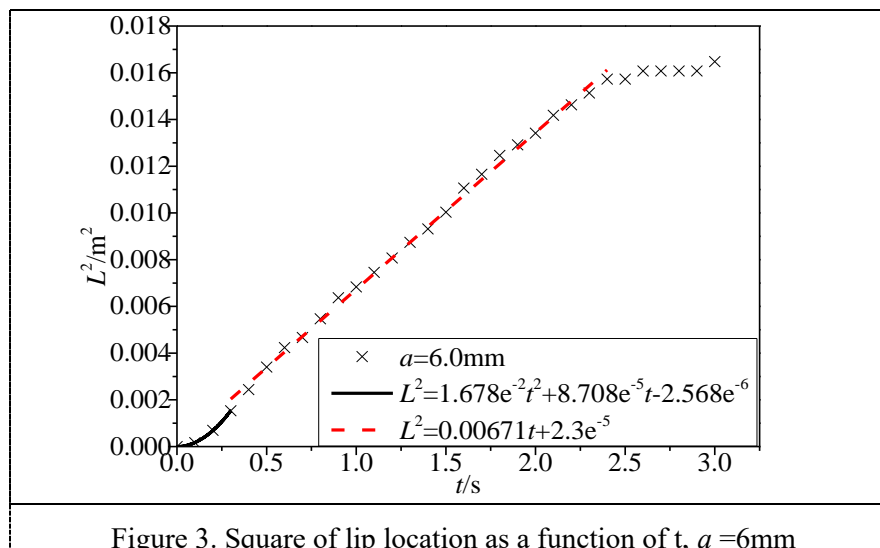
Figure 3. Square of lip location as a function of t, *a* =6mm

In order to further investigate the movement law of the leading edge L of the vanes in the tank, the relationship between the leading edge L^2 and the time change was made when $a = 6mm$. Combined with Fig. 2 and Fig. 3, we draw the following conclusions:

There are two main stages in the liquid climbing process of the vanes in the tank. That is the liquid level relocation stage and the stable transfer stage of the vanes after the sudden disappearance of gravity.

When $0 < t < 0.3s$ is the first stage. In this stage, the leading edge positions of different vanes width a basically coincide. This is because during the repositioning process, there will also be liquid climbing due to the sudden disappearance of gravity on the tank wall. By fitting the equation, it can be found that when $t = 0.1s$ (minimum time), the primary term and constant term of t can be ignored compared with the secondary term of t. The fitting equation shows that the liquid front L^2 is in direct proportion to time t^2, that is, the front L is in direct proportion to t.

When t > 0.3s, it is the second stage, in which the leading edge capillary is mainly driven by the capillary force between the vanes and the wall, and the position of the leading edge varies with the vane width a. By fitting the curve, it is found that there is a linear relationship between L^2 and t, that is, L and $t^{1/2}$ are in direct proportion.

In the simulation, the last two points of the climbing law of the front edge of the liquid on the vane and the capillary flow law in the cylindrical vessel proposed by stange have been observed all the time.

Because the time interval is not small enough, no flow stage with l-approximation proportional to t^2 has been observed.

4. Conclusion

There are two main stages in the liquid climbing process of the vanes in the tank. That is the liquid level relocation stage and the stable transfer stage of the vanes after the sudden disappearance of gravity.

In the whole capillary flow stage, the liquid flow rate increases with the increase of the width a of the guide plate.

Acknowledgements

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