Study on propellant management device in plate surface tension tanks

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Abstract
Surface tension tanks exploit the liquid surface tension in liquid transport and gas–liquid separation to provide gas-free propellant for the thruster. High transport efficiency of deflectors can ensure liquid relocation in the microgravity environment within a short period of time, which is helpful for providing gas-free propellant. This paper explores transport efficiency of deflectors through drop tower experiments and numerical simulations with the volume of fluid method. The experimental and numerical results show that both the liquid flow speed and the mass flow rate along deflectors increase as the widths of deflectors increase. Besides, a new type of propellant management device, which consists of four deflectors and four anti-sloshing baffles, is verified with numerical simulations and drop tower experiments. Moreover, long-term conditions are predicted by using similarity theories. These results can provide important references for the design of plate tanks.

Keywords Surface tension tank · Capillary driven flow · Drop tower · Volume of fluid method

1 Introduction
Under microgravity conditions, the influences of gravity basically vanishes and minor forces such as surface tension play a dominant role, so liquid behaviors in microgravity environment will be evidently different from that on the ground. Liquid and gas are usually co-existing in the propellant tank, and accurate control of liquid for delivering gas-free propellant is the biggest challenge in the tank design. Surface tension tanks exploit the liquid surface tension in liquid transport and gas–liquid separation. In 1975, the National Aeronautics and Space Administration (NASA) launched the Viking satellite for the pirate program [1]. Pirates 75 satellite’s tank is the first plate surface tension tank for flight in the world. The propellant management device (PMD) consists several deflectors and a liquid accumulator is its major structure. As the second generation of surface tension tank, the plate type tank has characteristics of easy processing, simple structure, and high reliability, which represents the developing trend of the surface tension tank. The transport efficiencies of deflectors determine the time period required for achieving the static equilibrium after entering microgravity environment and liquid relocation after the orbit adjustment.

Many researchers analyzed liquid behaviors in various containers as early as in 1960s, which laid the foundation of PMD’s design. Concus and Finn [2, 3] studied liquid equilibrium interface in vessels with internal angles and proposed the famous Concus-Finn condition, which provided theoretical basis for capillary driven flow. In 1991, Jaekle [4] analyzed transportation mechanisms of deflectors, accumulators, traps, grooves, and corridors of PMD under microgravity, laying the foundation of design and analysis of the second generation of surface tension tank. In 1995, Dong and Chatzis [5] explored imbibition and flow of a wetting liquid along the corners of a square capillary tube, and both of theoretical and experimental results showed that the imbibition rates were in proportion to $(\sigma/\mu)^{1/2}$. In 1998, Weislogel et al. [6] explored the capillary flow in interior corners and analyzed the equations describing capillary flows in containers with interior corners under the constraints of slender fluid column, slight surface curvature along the flow direction, low inertia, and low gravity. These theoretical results
are quite useful for design of PMD. In 2002, Collicott and Weislogel [7] used Surface Evolver to carry out the three-dimensional numerical simulation of liquid flow in the plate tank in the vented tank resupply experiment (VTRE) project under microgravity, and obtained the three-dimensional interface distribution during fluid transportation, which verified the correctness of Surface Evolver as an accurate mean of designing PMD. In 2006, Li et al. [8] studied propellant’s behaviors in plate tanks, and simulated steady and unsteady flows. Yue and Wang [9] numerically studied the dynamic problem of three-dimensional free surface. In 2011, Wei et al. [10] studied the equation of capillary flow at the inner corner. By correcting the calculation of radius of curvature, the relationship between the section and the radius of curvature was found, so that it could be applied to different contact angles and different dihedral angles. In 2012, Li et al. [11] studied asymmetric interior corner flow under microgravity conditions. And the equivalent interior corner was proposed to solve this problem. Wu et al. [12] explored capillary driven flow along curved interior corners and proposed a new equation which could predict liquid flow distance vs time along curved interior corners. This was much closer to the flow in spherical tanks. Li et al. [13] studied dynamic behaviors of liquid in partially filled tank under short term microgravity. In 2018, Chen et al. [14] explored the influence of the gap between deflector and the tank wall on liquid transport speed. It was founded that liquid transport speed wouldn’t increase monotonically as the width of the gap decreased. Chassagne et al. [15] numerically studied capillary driven flows in axisymmetric geometries. Cheng et al. [16] studied capillary flows in tubes with variable diameters. Li et al. [17] conducted the numerical simulation for capillary driven flow in the capsule-type vane tank with clearances under microgravity. Chen et al. [18] studied capillary driven flows in oval tubes under microgravity and proposed a new flow model. Normally, PMD includes pipes, such as liquid-collecting pipes, and this study could provide a reference for the design of these pipes.

This paper focuses on the design of deflectors and PMD according to the theory of capillary driven flow and carries out drop tower experiments and numerical simulations with the volume of fluid (VOF) method. 3D computational models are created correspondingly. The influence of deflectors’ width on liquid transport is first investigated. Then the liquid flow speed and the mass flow rate are both taken into consideration to examine the effect. And a new PMD which has good transport and anti-sloshing performances is verified. In addition, the propellant relocation process in microgravity environment in the model is also monitored.

2 Theories of capillary driven flow and similarity

The effect of surface tension is reflected by the Bond number (Bo), which is defined as.

\[
Bo = \frac{\Delta \rho g L^2}{\sigma},
\]

where \(\sigma\) is the liquid surface tension, \(\Delta \rho\) is the difference in density between the two phases, \(L\) is the characteristic length, and \(a\) is the acceleration. When \(Bo\) is much smaller than 1, the surface tension will play a dominant role and propel the liquid to flow along the interior corner between the deflector and the tank wall and form a liquid belt. This is called the capillary driven flow, as Fig. 1 shows.

According to the Laplace equation

\[
\Delta P = P_{\text{gas}} - P_{\text{liquid}} = \sigma \left( \frac{1}{R_1} + \frac{1}{R_2} \right),
\]

where \(R_1\) and \(R_2\) represent the principal radii of curvatures of the liquid belt. The curvature radii of the liquid belt along flow direction \(R_2\) is considered to be \(\infty\). And \(R_1\) in different cross sections of the liquid belt is different, which is the source of pressure gradient. It can be calculated as below

\[
\Delta P_{\text{drive}} = P_{\text{up}} - P_{\text{down}} = \sigma \left( \frac{1}{R_{\text{down}}} - \frac{1}{R_{\text{up}}} \right).
\]

For a polygonal cylinder that has an initially flat interface \((Bo \gg 1)\), when the gravity acting in the normal direction suddenly disappears, the liquid will flow upwards along the corner due to the capillary force, as shown in Fig. 1. According to

Fig. 1 Capillary driven flow. The liquid flows along the interior corner between the deflector and the tank wall and form a liquid belt.
Ref. [11], the leading edge position, $z$, is calculated by the equations below

$$z = 1.702G^{1/2}H^{1/2}t^{1/2},$$  \hfill (4)  

$$G = \sigma F_i \sin^2(\alpha/\mu f),$$  \hfill (5)  

where $H$ is the constant height of the liquid belt in a certain position, $F_i$ is the flow resistance, $\alpha$ is the half angle of the corner, and $f$ is a function of $\alpha$ and contact angle $\theta$.

In the capillary driven flow, the Weber number ($We$) reflects the effect of surface tension, and it is the ratio of inertial force to surface tension, that is

$$We = \frac{(\Delta \rho)Lv^2}{\sigma},$$  \hfill (6)  

where $v$ represents the liquid flow speed. When $We$ is much smaller than 1, the surface tension has a significant influence.

To predict long-term liquid flow phenomenon in space based on results in a shorter period of time on the ground, this study uses a scale model to carry out experiments. The internal liquid flow in the plate tank is mainly decided by surface tension, gravity and inertia force. According to similarity theories

$$\left(\frac{\rho aL^2}{\sigma}\right)_m = \left(\frac{\rho L a^2}{\sigma}\right)_p = Bo,$$  \hfill (7)  

$$\left(\frac{\rho Lv^2}{\sigma}\right)_m = \left(\frac{\rho L v^2}{\sigma}\right)_p = We,$$  \hfill (8)  

and from Eq. (6), we can obtain $We$ with a time term

$$We = \frac{\rho L^3}{\sigma t^2}.$$  \hfill (9)  

Based on the equality between $We$ of the flow in the model and that in the prototype, we can obtain the time that is needed for the liquid in the prototype to flow to the corresponding position:

$$t_p = \sqrt{\frac{\rho_p L_p^3}{We \sigma_p}} = t_m \left(\frac{\mu_m}{\mu_p}\right)^{1/2} \left(\frac{L_p}{L_m}\right)^{3/2}, \quad \beta_m = \left(\frac{\sigma}{\rho}\right)_m.$$  \hfill (10)  

According to theories of capillary driven flow and similarity, this paper carries out study on different types of PMD, including a PMD only with deflectors and a new PMD with deflectors and anti-sloshing baffles.

3 PMD with deflectors

3.1 Experiments under microgravity

Three types of tank models are designed, as shown in Fig. 2a. The shell of the tank model consists of two hemispheres and a cylindrical section. And the interior of the tank model is the PMD assembly, which includes 8 identical deflectors and a center column. The inner diameter of the hemisphere is about 99 mm and the length of the cylindrical section is 22 mm. The gaps between the deflectors and the tank wall are all the same in 3 types of models. In order to maximize the use of capillary driven force, the width of gap narrows from 1.2 mm to 0.8 mm in the direction from the
liquid inlet to the outlet (hereinafter, for convenience, the gaps are considered to be 1.0 mm wide). The only difference between 3 types of models is the width of deflectors, which is 3 mm, 5 mm, and 7 mm respectively, as shown in Fig. 2b.

The experiments are carried out in Beijing drop tower. To compare liquid behaviors in different models, images interior of two models are captured at the same time in each drop tower experiment. The experimental platform is a disc with a diameter of 860 mm. On the disc, there are two tank models, two model holders, a lighting equipment, two image acquisition devices, a microgravity indication system, and so on, as shown in Fig. 3. Two tank models are made of transparent polymethyl methacrylate (PMMA). Scale paper is stuck on the outer wall of tank models for measuring liquid flow speed. The image acquisition device can take 50 frames per second. During the experiment, the platform is fixed in the drop cabin which falls freely for 3.5 s from the top of the drop tower. There is wireless image transmission equipment installed in the drop cabin, so the images of liquid behavior can be observed in real time.

Anhydrous ethanol stained with rhodamine is selected as the experimental liquid. Its physical properties are shown in Table 1. The contact angle between anhydrous ethanol and PMMA is 1°, and the angle between deflectors and the tank wall is 90°. According to Concus-Finn theory [10], when the surface tension plays a dominant role, if the contact angle of the liquid and the solid wall is smaller than 45°, the spontaneous capillary flow (SCF) will happen in the corners formed by deflectors and the model’s wall. During drop tower experiments, the acceleration is about 0.02 m/s². The density difference is considered to be the liquid density because the air density is very small. L is the width of gap between deflectors and the tank wall. According to Eq. (1), the maximum of Bo is 0.00074, which means that the surface tension force plays a major role. Hence, the SCF will occur when anhydrous ethanol is used to carry out experiments. Moreover, the smaller the contact angle, the better the spreadability of anhydrous ethanol on PMMA, and the easier the SCF in the tank under microgravity.

All tank models are fixed in the same direction with the liquid inlets at the bottom. Before the cabin is released, liquid is gathered at the bottom of the tank model with a filling ratio of 25%, as shown in Fig. 4. Once the cabin is released, liquid starts to climb up along 8 deflectors and form 8 liquid belts. The cross-sectional area of the liquid belt varies along the flow direction. The closer the liquid belt is to the leading edge, the smaller the cross-sectional area will be. According to some simple geometric relations, we can infer that R₁ of the cross section that is close to the leading edge is smaller than that of the cross section that is far from the leading edge. This is the reason why there is pressure gradient in the liquid belt along the flow direction and why liquid can climb up along deflectors continuously. And owing to the pressure gradient, the liquid flows much faster along deflectors than tank wall, and will form a concave interface on the wall. At about 1.5 s, the leading edges of liquid belts reach the outlet.

Table 1 Physical properties of anhydrous ethanol with a rhodamine B concentration of 1/150,000 at 22 °C

| Liquid            | Density $\rho$ (kg/m³) | Surface tension coefficient $\sigma$ (N/m) | Dynamic viscosity $\mu$ (Pa·s) | Contact angle $\theta$ (°) |
|-------------------|------------------------|---------------------------------------------|-------------------------------|--------------------------|
| Anhydrous ethanol | 789                    | 0.0213                                      | 0.00117                       | 1                        |

Fig. 4 Gas–liquid interface at different times in the tank with 5 mm-wide deflectors during drop tower experiments
Considering the symmetry of SCF in the tank model, one-eighth of the tank model is meshed with structured hexahedron grids to reduce calculation time. Since the capillary flow along deflectors is the main factor considered, some simplifications are made for convenience. The mathematical model consists of five parts: one-eighth of the tank wall, deflectors, center column, and symmetric internal fluid domain, as shown in Fig. 5a and b. Boundary layers are established near all solid walls. The expansion ratio is 1.2 and the height of the first layer is about 0.6 mm. The total number of grids is about 1.1 million.

At the beginning, liquid is gathered at the liquid inlet on the bottom of the tank model, as shown in Fig. 4. Liquid accounts for 25% of the volume inside the model. During the drop tower test, the drop cabin falls freely in atmospheric environment and reaches microgravity level of 10⁻²–10⁻³ g. Therefore, the acceleration in the simulation is set to be 0.002 m/s², which equals to 0.002 g. The movement of contact line is almost perpendicular to the flow direction, so contact angle is set to 1°, which is the static contact angle.

The characteristic scale of liquid flow is about 1 mm, which is the width of gap, and the characteristic velocity of liquid flow is estimated to be about 80 mm/s. Reynolds number \( Re \) is defined as

\[
Re = \frac{\rho vl}{\mu}.
\]

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\( Re \) of liquid flow in the tank is approximately 54, so the flow mode is considered to be laminar flow in the simulation. The pressure–velocity coupling equation is numerically solved by the SIMPLEC algorithm. The SIMPLEC algorithm uses a relationship between velocity and pressure corrections to enforce mass conservation and obtain the pressure field. The time step size is 0.0001 s and 30 iterative calculations are done per time step. PRESTO is used for spatial discretization of pressure equation. The spatial discretization of gradient equation is based on the least square cell. The spatial discretization of momentum equation uses a second-order upwind scheme. And the Geo-Reconstruct scheme is used for the spatial discretization of volume fraction equation. When the iterative residual decreases to 10⁻⁶, the calculation is regarded as converged. The relaxation factor for each equation is set by default.

During calculation, the Courant number \( (Co) \) is smaller than 1 most of the time, which indicates that the calculation process is quite stable. The Courant number is significant for transient flow. For a one-dimensional grid, it is defined as:

\[
Co = \frac{u \Delta t}{\Delta x},
\]

where \( u \) is the liquid flow speed, \( \Delta x \) is the mesh length, and \( \Delta t \) is the time step size.

Every model is calculated three times, and the grid size is adjusted each time to explore the influence of grid. For the same tank model, the mass flow rate differs slightly between results of different simulations. The grid size has little effect on the simulation results. Therefore, the average is taken as the final result.

In drop tower experiments, the liquid inlet is at the bottom and the outlet is at the top. Figure 6 shows liquid distributions on the model’s wall. The red part represents liquid phase, and the blue part represents gas phase. In the beginning, liquid is all at the bottom. As the simulation goes on, the liquid starts to climb up along the deflectors and form 2 liquid belts. It can be seen that the liquid flows quickly near the deflectors, and the flow velocity of liquid that is farther from the deflectors is obviously slower, so a concave liquid surface is formed on the tank wall. The liquid flows upwards continuously and reaches the outlet after about 1.5 s.

The mass flow rate and flow speed of liquid are used to reflect the transport efficiency of deflectors. The plane, where the mass flow along deflectors is measured, is located at the middle height of the tank model, as Fig. 7 shows. It is difficult to measure the mass flow rate in drop tower experiments, so the simulation can just make up for this deficiency. Positions of leading edges of liquid belts are measured to reflect the flow speed, as Fig. 8 shows. And these data can be compared with experimental results.
3.3 Comparison between experimental and numerical results

Comparison between experimental and numerical results of the model with 3 mm-wide deflectors at \( t = 0.5 \) s is shown in Fig. 9a, and comparison of the model with 5 mm-wide deflectors at \( t = 1.0 \) s is shown in Fig. 9b. It can be seen that the interfaces in simulation results are quite similar to those in experimental results. Positions of leading edges of liquid belts and concave curvature of interface on the tank wall are almost the same in experiments and simulations.

Experiments are conducted two times on each model and the average of two results is taken as the final result. Figure 10 shows liquid flow distances obtained by experiments and simulations. Curves 1 and 4 represent experimental and numerical results along 3 mm-wide deflectors, respectively. At \( t = 1.0 \) s, the liquid flow distance is 68.9 mm in the simulation and 71.0 mm in the experiment. Curves 2 and 5 represent experimental and numerical results along 5 mm-wide deflectors, respectively. At \( t = 1.0 \) s, the liquid flow distance is 77.0 mm in the simulation and 76.0 mm in the experiment. Curves 3 and 6 represent experimental and numerical results along 7 mm-wide deflectors, respectively. At \( t = 1.0 \) s, the liquid flow distance is 77.4 mm in the simulation and 78.7 mm in the experiment. It shows that experimental results are in good agreement with numerical
results. Same as in drop tower experiments, the liquid flow distance in the simulation also increases as the width of deflectors increases. At $t = 1.5$ s, the liquid flow distances along 3 mm-wide, 5 mm-wide, and 7 mm-wide deflectors are 91.2 mm, 97.3 mm, and 99.2 mm, respectively. This means that increasing of deflectors’ width is beneficial to SCF.

The liquid mass flow rates obtained by simulations are shown in Fig. 11. In the first 0.2 s, the value is close to 0, because the liquid has not reached the plane where the mass flow is measured. From 0.2 s, the mass flow rate increases as the width of deflector increases. Besides, at about 1.3 s, the mass flow rate reaches the maximum value, and the wider the deflector is, the sooner the mass flow rate reaches its peak. The maximum values of liquid mass flow rates in the 3 types of tank models are 0.00199 kg/s, 0.00279 kg/s, and 0.00323 kg/s, respectively.

3.4 Analysis and summaries

Based on the results above, the liquid flow speed is about 75 mm/s. According to Eq. (6), the maximum of $We$ in experiments is 0.21. The values of both $Bo$ and $We$ show that the surface tension force plays a major role in experiments.
It is the capillary driven force that causes the liquid to flow along deflectors in microgravity environment. According to Eq. (4), the position of leading edge is proportional to $H^{1/2}$, and $H$ increases as the width of deflector increases, which indicates that the increase of deflector’s width can contribute to SCF. Besides, in the late stage of SCF, the maximum curvature of the liquid belt is restricted by the width of deflector, as shown in Fig. 12, where $D$ represents the width of deflector, $r$ represents the radius of curvature at the liquid–gas interface in one cross section. This indicates that the maximum radius of curvature at the interface of the liquid belt increases with the increase of deflector’s width. According to Eq. (3), the liquid belt flowing along wider deflectors will generate greater $\Delta P_{\text{drive}}$, such that the SCF will be strengthened. However, due to the limited flow distance in the tank, once the width of deflector exceeds a certain value, the maximum radius of curvature at the interface of the liquid belt can not be obtained before the liquid belt reaches the outlet. This is why the liquid flow speed along the 5 mm-wide deflector and that along the 7 mm-wide deflector are quite close. Moreover, the wider the deflectors, the larger the cross-sectional area of the liquid belt, and therefore the higher the mass flow rate along deflectors.

Both experimental and numerical results show that the liquid flows fast along deflectors and reaches the outlet of the tank at about 1.5 s. It indicates that the design of this kind of deflectors is reasonable. The liquid can be controlled to flow quickly to the outlet, which is helpful to form a liquid seal and ensure the propellant for the thruster to be gas-free. The width of deflectors in the plate tank in space experiments should be 7 mm, which can ensure faster flow speed and higher mass flow rate. The liquid flow speed can reach 66.1 mm/s and the liquid mass flow rate can reach 0.00323 kg/s.

4 New type of PMD with deflectors and anti-sloshing baffles

Based on results above, this paper proposes a new kind of tank whose PMD includes 4 deflectors and 4 anti-sloshing baffles, as Fig. 13a shows. Compared with the PMD discussed in Sect. 3, this one has a good slosh-control performance. There are only two differences between these two types of PMD. First, according to results above, the width of deflectors is decided to be 7 mm. Second, 4 deflectors are replaced with 4 anti-sloshing baffles at the same positions, so the deflectors and anti-sloshing baffles are placed alternately. The baffles are installed on the outlet side, which is helpful to form a liquid seal. There are also gaps between baffles and the tank wall, and the width of gap narrows from 1.5 mm to 0.8 mm. The closer to the outlet, the smaller the width. The computational model is shown in Fig. 13b.

Methylhydrazine monomethylhydrazine (MMH) is the widely used in propellant for satellites. It is dangerous to conduct experiments to explore its behavior in surface tension tanks in the microgravity environment due to its

| Physical properties of MMH at 20°C |
|-----------------------------------|
| Liquid Density $\rho$ (kg/m³) | Surface tension coefficient $\sigma$ (N/m) | Dynamic viscosity $\mu$ (Pa·s) | Contact angle $\theta$ (°) |
| MMH       | 875                      | 0.034                        | 0.000855                         | 10                      |
toxicity. Therefore, this paper only carries out numerical simulation to explore its behavior. The physical properties of MMH are shown in Table 2.

In the beginning, the liquid is all at the bottom of the tank with a filling ratio of 25% or 54%. Figure 14 shows the tank with a filling ratio of 25%. The MMH flows along deflectors fast and reaches the liquid outlet in 1 s after entering into the microgravity environment. It shows that this kind of PMD is efficient. The MMH is transported to the liquid outlet quickly and forms a liquid seal, making sure the gas-free propellant is provided for the thruster.

Besides, under each condition, the numerical simulation and the drop tower experiment are both conducted to explore the behavior of anhydrous ethanol. Figure 15a shows the experimental results and Fig. 15b shows the numerical results. The filling ratio is 54%. The positions of leading edges of the liquid belt are marked with white and red circles. In Fig. 15b, at the beginning, the free surface is flat and does not reach the anti-sloshing baffle. Once entering into the microgravity environment, the liquid flows fast along the deflector and reaches the outlet at about 0.8 s. On the other hand, the free surface reaches the anti-sloshing baffle at 0.2 s, then flows along the baffle, and reaches the outlet at about 1 s. All these features are quite close to those in drop tower experiments. Comparisons of liquid flow distance along the deflector vs time between experimental and numerical results are shown in Fig. 16a and b. When the filling ratio is 25%, the flow distance is 76.2 mm in the experiment and 77.2 mm in the simulation at 0.9 s. When the filling ratio is 54%, the flow distance is 48.1 mm in the experiment and 52.8 mm in the simulation at 0.5 s.

Though the contact angle of MMH on the wall is larger than that of anhydrous ethanol, the MMH still flows much faster. Figure 17a shows the liquid distribution at $t=0.5$ s when the filling ratio is 54%. Figure 17b shows the liquid distribution at $t=0.9$ s when the filling ratio is 25%. In each pair of pictures, the picture on the left shows the distribution of MMH. The flow distance of MMH is longer than that of anhydrous ethanol. This is due to larger surface tension and smaller dynamic viscosity of MMH.

Liquid flow distance along deflectors vs time is shown in Fig. 18. Curves 1–4 represent the data in the tank with 4 deflectors and baffles. It can be seen that flow speed almost keeps constant before reaching the outlet. When the filling ratio is 54%, flow speeds of MMH and anhydrous ethanol are 151.0 mm/s and 105.6 mm/s, respectively. Flow speed of MMH is 43.0% faster than that of anhydrous ethanol. And when the filling ratio is 25%, flow speeds are 119.3 mm/s and 85.8 mm/s, respectively. And speed of MMH is 39.0% faster than that of anhydrous ethanol. MMH has larger surface tension coefficient and smaller dynamic viscosity than anhydrous ethanol. Larger surface can produce larger pressure gradient and smaller viscosity will reduce viscous resistance, which are both beneficial to capillary driven flow.

Curve 5 reflects the data of anhydrous ethanol in the tank with 8 deflectors when the filling ratio is 25%. In the first 0.5 s, the liquid flow speed is almost the same as that in the conditions of curves 1–4, while in the last 0.5 s, the liquid speeds in the tank with both deflectors and baffles are a little higher than that in the tank only with deflectors. The more the number of deflectors in a tank, the less the amount of liquid obtained by each deflector. In the first half period, the liquid supply is sufficient, so there is no effect. But when the liquid supply is not sufficient in the later period, an obvious difference appears.

Both of these two types of PMD have the ability of complete management of liquid in the tank, and they can ensure that the liquid near the inlet is driven to flow to the outlet and form a liquid seal. Moreover, the PMD with deflectors and anti-sloshing baffles can provide a little higher transport speed of liquid than the PMD with only deflectors does, and it has a good anti-sloshing performance owing to the 4 baffles. Based on the results above, it is more suitable to choose the PMD with deflectors and baffles to carry out further experiments in space.
5 Conclusions

This paper carries out drop tower experiments and numerical simulations with scaled models of plate surface tension tanks to explore the influence of deflectors’ width on SCF in the tank, and examine the performance of a new type of PMD with deflectors and baffles.

The results indicate that this kind of deflectors can ensure highly efficient liquid transport so that a liquid seal will be formed in time to provide gas-free propellant for the thruster. Moreover, the increase of deflectors’ width can contribute to the increases of liquid flow speed and mass flow rate.

The performance of PMD with deflectors and baffles proposed in this study is also verified with drop tower experiments. In the scaled model, MMH can flow fast along deflectors and reach the liquid outlet in 1 s in the microgravity environment. We can infer the behavior of propellant in space by the similarity theory. Besides, compared to anhydrous ethanol, MMH flows much faster, which proves that large surface tension coefficient and small dynamic viscosity are beneficial to SCF.

Compared to PMD with 8 deflectors, PMD with 4 deflectors and 4 baffles is more suitable to carry out further experiments in space. All these results can provide an important reference for the design of plate tanks.

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