

# Numerical Simulation on Flow and Heat Transfer in Pulsating Heat Pipe with Different Models

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**Abstract.** Based on Mixture and Euler model, numerical simulation was used to study the flow and heat transfer in pulsating heat pipe by unsteady method. By comparing the gas volume fraction and gas velocity by different models at different time, the results showed that both models could simulate the evaporation and condensation process of the working fluid, and the liquid plug and gas plug were formed in the tube. By comparing the gas volume fraction and gas velocity at 5s and 10s, it was indicated that the fluid dynamics and heat transfer were more violent by Mixture model in the tube.

## 1 Introduction

The heat transfer process of pulsating heat pipe involves many multiphase problems, such as phase change, convection, bubble formation and fracture [1,2], so there is no unified heat transfer mechanism up to now. At present, many scholars at home and abroad mainly adopted experimental research, numerical simulation and theoretical analysis to study, the experimental research [3-5] was mainly used to study the influence of different factors on the heat transfer performance, the theoretical analysis [6,7] was mainly used to establish the physical and mathematical models of flow and heat transfer in the pulsating heat pipe, the numerical simulation [8-10] method was mainly adopted the finite difference or finite element method to establish the discrete equations. At present, some scholars had used numerical simulation methods to study the pulsating heat pipe, in this paper, the flow and heat transfer in pulsating heat pipe was simulated by Mixture model and the Euler model to study the flow and heat transfer.

## 2 Geometric Model and Governing Equation

### 2.1 Geometric model and boundary conditions

In this paper, two-dimensional geometric model of pulsating heat pipe was established as shown in Fig. 1, the pulsating heat pipe inner diameter was 0.004m and the total height was 1 m, the work area was divided into evaporation section, adiabatic section and condensation section, the working medium was anhydrous alcohol, the liquid filling rate was 59.82%. There were about 200000 structural grids in total, the first type boundary conditions was adopted for evaporation section and

condensation section, with 573.15k and 372.15k respectively, the second type boundary conditions was adopted for adiabatic section, the heat flux was set to 0.

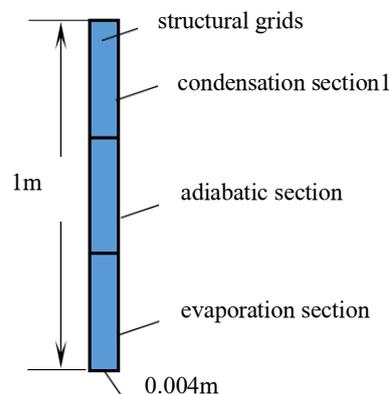


Fig. 1. Schematic of the simulation system

### 2.2 Governing equation

#### 2.2.1 Mixture model

Mixture model was suitable to simulate multiphase flow composed of two or more fluids.

The continuous equation of Mixture model was shown as:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \cdot (\rho_m \vec{v}_m) = m \quad (1)$$

where  $v_m$  was the mass-averaged velocity, and  $\rho_m$  was the mixture density.

The volume fraction equation of the second term was calculated as:

$$\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla \cdot (\alpha_p \rho_p \vec{v}_m) = -\nabla \cdot (\alpha_p \rho_p \vec{v}_{dr,p}) \quad (2)$$

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Relationship between drift speed and relative speed ( $\vec{v}_{qp}$ ) was defined by Eq. (3) as

$$\vec{v}_{dr \cdot p} = \vec{v}_{ap} - \sum_{k=1}^n \frac{\alpha_k \rho_k}{\rho_m} \vec{v}_{qk} \quad (3)$$

### 2.2.2 Euler model

Euler model is the most comprehensive and complex multiphase flow model in numerical calculation method, the governing equations of each phase are solved independently (compared with Mixture model).

Continuous equation of q phase was computed as follows:

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q) = \sum_{p=1}^n m_{pq} \quad (4)$$

Where  $v_q$  is the velocity of phase  $q$  and  $m_{pq}$  characterizes the mass transfer from the  $p^{th}$  to  $q^{th}$  phase.

Volume of  $q$  phase defined:  $V_q$  can be calculated as:

$$V_q = \int_V \alpha_q dV :$$

And

$$\sum_{q=1}^n \alpha_q = 1$$

The following equation was used to calculate Momentum conservation equation of  $q$  phase:

$$\begin{aligned} \frac{\partial}{\partial t}(\alpha_q \rho_q \vec{v}_q) + \nabla \cdot (\alpha_q \rho_q \vec{v}_q \vec{v}_q) &= -\alpha_q \nabla p \\ + \nabla \cdot \tau_q \sum_{p=1}^n (R_{pq} + m_{pq} \vec{v}_{pq}) & \\ + \alpha_q \rho_q (\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}) & \end{aligned} \quad (5)$$

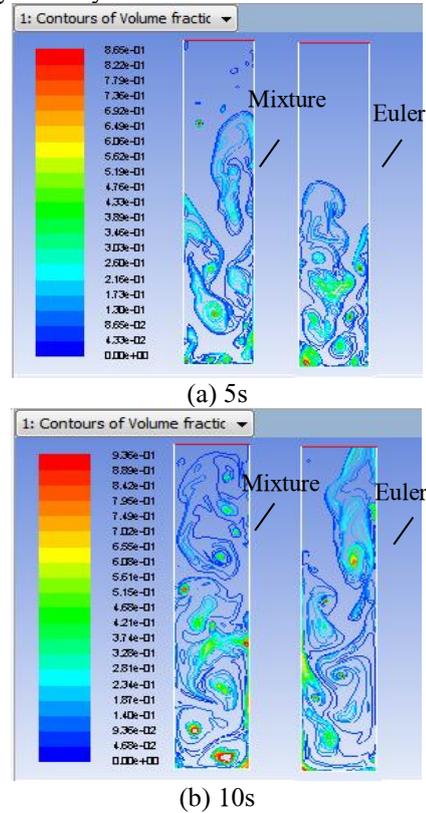
where  $\tau_q$  was the  $q^{th}$  phase stress-strain tensor.

## 3 Results Analysis and discussion

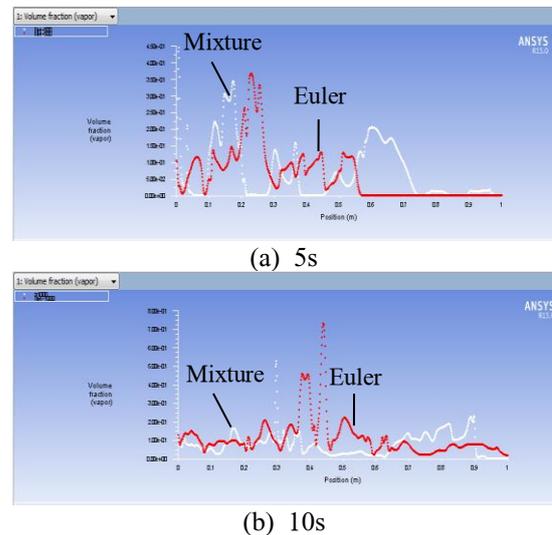
From Fig. 2, it found out that there were gas phases generated at 5s and 10s, and they were non-uniform distribution in the pulsating heat pipe, indicating that the evaporation- condensation process of working medium in the pulsating heat pipe could be simulated by using two numerical models, this flow of working medium was consistent with the experiment[11], which could prove the correctness of the numerical method. The gas phase volume fraction in the heating section and the insulation section were relatively more at the some time by Mixture model, as increasing heating time, the condensation section also appeared gas phase, it was explained that the phase transition was very intense, it followed that the heated liquid working medium transformation into bubble were simulated in the pipe. There were gas phase in the condensation section of the pulsating heat pipe of the two models at 10s, which indicated that the pulsating heat pipe has been fully started in 10s.

In contrast, Mixture model at 5s could be simulate the gas phase precipitation in evaporation and adiabatic

section, while Euler model could only simulated the gas phase precipitation in the lower part of the adiabatic section, it concluded that the working medium heat transfer start-up time in pulsating heat pipe was relatively short by Mixture model.



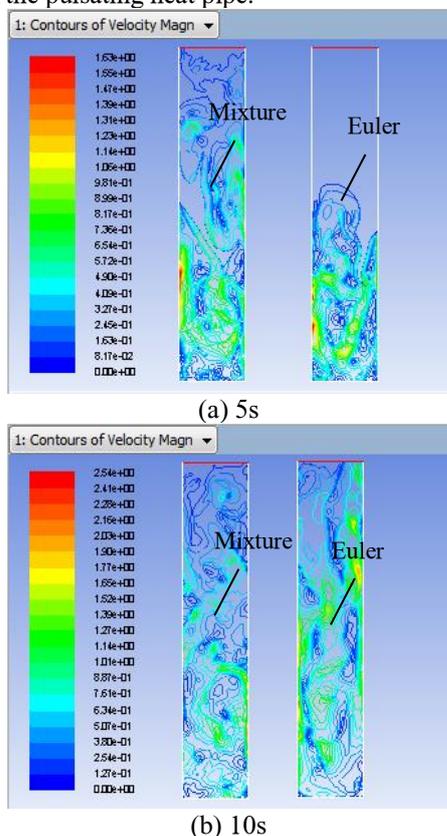
**Fig. 2.** Contours of gas volume fraction in pulsating heat pipe simulated by Mixture and Euler model at different times



**Fig. 3.** Gas volume fraction in pulsating heat pipe simulated by Mixture and Euler model at different times

From Fig. 3, it could be seen that the maximum volume fraction of gas phase of Mixture model appeared at 0.22m in 5s, and there were two velocity peaks at 0.41m and 0.45m in 10s, respectively; the maximum volume fraction of gas phase of Euler model appeared at 0.18m in 5s and at 0.3m in 10s, which indicated that

Mixture model could be better simulation the small bubbles agglomerated into large bubbles, and the liquid plug and gas column were formed by gas-liquid separation, which was more obvious, this phenomenon was consistent with the conclusion in literature[11], it showed that Mixture model was more suitable to study the evaporation and condensation process of working fluid in the pulsating heat pipe.



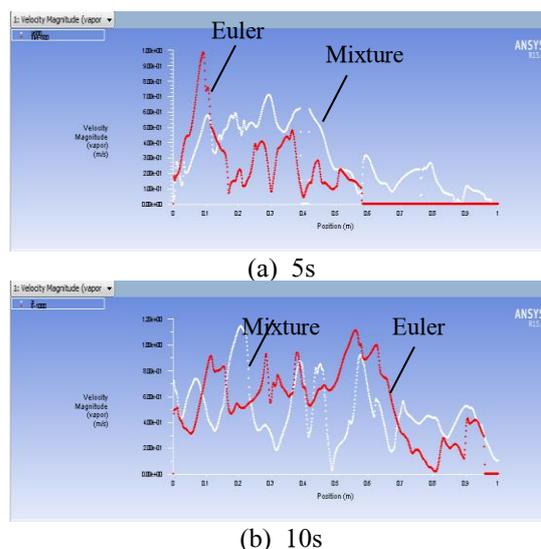
**Fig. 4.** contours of gas phase velocity in pulsating heat pipe simulated by Mixture and Euler model at different times

As shown in Fig. 4, the average gas phase velocity simulated by Mixture model was more than Euler model in 5s in the flow domains of the pulsating heat pipe, it also showed that when the working medium was heated, the anhydrous alcohol was evaporated and expanded, then moved into the condensation section, and condensed, so more latent heat of vaporization were released. In the 10s, the contours of gas phase velocity were basically the same by Mixture and Euler model, it showed that both model could simulate the process of liquid plug and gas column in the pulsating heat pipe, and the movement velocity reached a stable level, no matter 5s or 10s, the maximum value of gas phase by Mixture model was earlier than that by Euler model.

It could be seen from Fig. 5 in 5s that the gas-phase velocity was not 0 in the pulsating heat pipe and the gas-phase velocity curve was basically stable by Mixture model, but the gas-phase velocity was 0 between 0.6-1m in the pulsating heat pipe, and the waveform was unstable by Euler model, it indicated that in 5s, the phenomenon of liquid plug and gas column had been appeared in the pulsating heat pipe, and the relative velocity had been basically stable, indicating that the

both models could carry out numerical simulation for pulsating heat pipe, but the speed of gas-liquid in Mixture was relatively stable, so Mixture model was more suitable for numerical simulation of pulsating heat pipe.

In the 10s, it can be seen that the fluctuation of gas-phase velocity curve by the two models had been reached stability, but the fluctuation of gas-phase velocity curve by Mixture model was smaller, indicating that both models could carry out numerical simulation for pulsating heat pipe, but the relative operation speed of gas-liquid by Mixture model was relatively stable, so the Mixture model was more suitable for numerical simulation of pulsating heat pipe.



**Fig. 5.** Gas phase velocity in pulsating heat pipe simulated by Mixture and Euler model at different times

## 4 Conclusion

In this paper, numerical simulation was performed to investigate the flow and heat transfer characteristics in the pulsating heat pipe by using Mixture and Euler models, based on the control-volume numerical procedure utilizing the semi-implicit method. By comparing the gas volume fraction and the gas velocity at different times, it was known that both models could simulate the evaporation and condensation process of the working fluid changing from liquid to gas in the pulsating heat pipe, but the gas phase velocity by Mixture model was relatively stable, and the oscillation flow in the pipe was more obviously simulated by Mixture model.

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