

Parallel Computational Fluid Dynamics Conference (ParCFD2013)

# Study on the Influence of Phase Change Rate on Cloud Cavitation

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## Abstract

Cavitation is an important phenomenon in hydraulic engineering. In order to understand better the impact of the phase change rate on cavitation, both theoretical and numerical study are taken in this paper. On one side, theoretical analysis are carried out on Singhal full cavitation model and Kunz cavitation model. The results show that phase change time is much less than the flow time in cavitation. We get that cavitation is insensitive to phase change rate theoretically. On the other side, we apply the two cavitation models to simulate the cloud cavitation of axisymmetric body under different phase rates. The numerical results show that phase change rate has little influence on cavitation form within a certain range and thus verifies the theoretical analysis.

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Selection and peer-review under responsibility of the Hunan University and National Supercomputing Center in Changsha (NSCC)

**Keywords:** cavitation; phase change rate; theoretical analysis; numerical simulation

## Nomenclature

$C_c$	condensation rate coefficient
$C_v$	evaporation rate coefficient
$P_v$	saturated vapor pressure(Pa)
$P_\infty$	hydrostatic pressure(Pa)
$\bar{R}_B$	average radius of bubbles(m)
$\alpha$	the volume fraction of vapor
$\rho$	density of mixture(kg/m <sup>3</sup> )
$\rho_l$	density of liquid(kg/m <sup>3</sup> )
$\rho_v$	density of vapor(kg/m <sup>3</sup> )

## 1. Introduction

Cavitation is a common phenomenon in underwater issues. People have taken a number of studies on it and got a lot of valuable results many of which have been put into use. With the deepening research on cavitation, many cavitation model are developed. But these models are very different at expression and parameter. Thus how to select suitable cavitation model an parameters is an important issue. In this paper, we study on it from both theoretical analysis and numerical simulation.

## 2. Theoretical Analysis

The impact of phase change rate and convection on cavitation is analyzed theoretically. At present, cavitation models are mainly divided into two types: one type is based on simplified Rayleigh-Plesset equation, such as Singhal full cavitation model, Schnerr model and Zwart model; the other type is based on Ginzburg-Landau equation, such as Kunz model.

To Singhal full cavitation model,

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$$R_e = \frac{\rho_v \rho_l}{\rho} \alpha (1 - \alpha) \frac{3}{\Re_B} \sqrt{\frac{2(P_v - P_\infty)}{3 \rho_l}} \quad (1)$$

$$R_c = \frac{\rho_v \rho_l}{\rho} \alpha (1 - \alpha) \frac{3}{\Re_B} \sqrt{\frac{2(P_\infty - P_v)}{3 \rho_l}} \quad (2)$$

$$t_e = \frac{\rho_v}{Re} \quad (3)$$

where  $Re$  is the evaporation rate,  $R_c$  is the condensation rate and  $t_e$  stands for the action time of phase change. In a typical case where  $P_\infty$  is 1atm and the incoming flow is 17m/s, the  $t_e$  is about 0.1ms while the periodic flow time is around 7ms. The latter is two orders larger than the former. Thus the effect of phase change is far less than the convection.

In Kunz model, the evaporation rate, the condensation rate and the action time of phase change are respectively

$$\dot{m}^+ = \frac{C_v \rho_v \alpha \min[0, \bar{p} - p_v]}{(1/2 \rho_l U_\infty^2) t_\infty} \quad (4)$$

$$\dot{m}^- = \frac{C_c \rho_v \alpha^2 (1 - \alpha)}{t_\infty} \quad (5)$$

$$t_e = \frac{\rho_v}{\dot{m}^+} \quad (6)$$

We can get

$$t_e / t_\infty \sim \frac{\rho_v / R_e}{c_{dest} \rho_v / R_e} = 1 / c_v \quad (7)$$

where  $C_v$  is about  $10^3$ . Thus the phase change time is far less than flow time.

From above, we get the conclusion: the process of phase change is so fast that it has less impact on cavitation with respect to the convection.

### 3. Numerical Simulation

Singhal full cavitation model and Kunz model are applied in the numerical simulation of cloud cavitation around axisymmetric body.

#### 2.1. Simulation based on Singhal model

Commercial CFD code (Fluent) is applied to simulate cloud cavitation based on Reynold Average Navier-Stokes equations together with mixture model to describe the cavitation combined with Singhal full cavitation model to describe the mass transfer process. Fig.1 gives the results under different phase change rates. The two pictures are nearly the same to each other. One can get that phase change rate which magnifies or lessens 10 times has little influence on the cavity form.

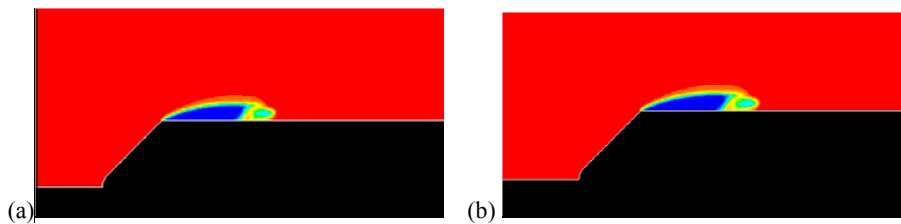


Fig.1. The form of cavity at different phase change rates (a)the contour of  $\alpha$  under certain phase change rate (b) the contour of  $\alpha$  under 10 times phase change rate of (a)

#### 2.2. Simulation based on Kunz model

We describe an approach to simulate dynamic cavitation behavior based on large eddy simulation of the governing flow, using a single fluid, two-phase mixture description of the cavitation combined with Kunz model for mass transfer. Analysis

about the cavitation under different phase change rates shows that the cavity form has small difference under different phase change rates. That is the cavitation is insensitive to phase change rate.

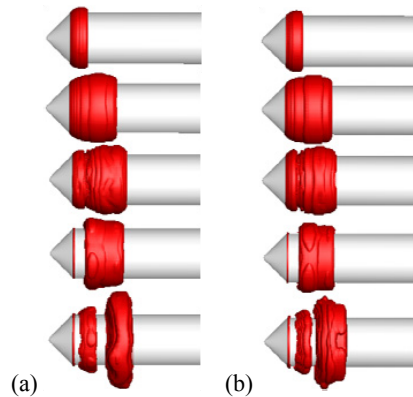


Fig. 2. Illustration for contour of  $\alpha$  (a) under  $C_v=C_c=1000$ , (b) under  $C_v=C_c=2000$

#### 4. Conclusion

The former numerical simulation verifies the theoretical analysis. The impact of phase change rate is far less than the convection of flow.

The theoretical analysis and simulation are specific to the model in this paper, the results need further analysis and verification when the conditions of flow field and model change.

#### 5. Acknowledgement

This research was sponsored by National Natural Science Foundation of China under Contract 11202215 (Yiwei WANG, Program Manager).

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