HYDRODYNAMICS AND SOLID SUSPENSION IN CHAMBER OF FORCE CIRCULATED EVAPORATIVE CRYSTALLIZER

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Abstract: Evaporation crystallization process strongly depends on the fluid hydrodynamics in evaporation chamber. The fluid hydrodynamics in two types of evaporation chamber were simulated by computational fluid hydrodynamics method in this work. The effect of the operation conditions on the fluid hydrodynamics in evaporation chamber has been studied. The effect of the fluid hydrodynamics on the solid suspension and its effect on evaporation crystallization process were analyzed.

Key words: CFD simulation; two-phase flow; evaporation; crystallization

The design of multi-effect evaporation process was mostly aimed to improve the heat-transfer efficiency, to reduce the energy consumption and to increase the specific production rate of equipment. However, a few attention was put on the structure of evaporation chamber, operation style and the influence of fluid hydrodynamics on evaporation process. On the other hand, the functions of evaporation chamber do not only separate the steam from liquid, but also provide the crystallization environment.

Recently, several authors have studied the solid volume fraction distribution in different position of crystallizer. Zhou Quan[1] had analyzed the crystallization process according to vertical velocity distribution of evaporation chamber in different feeding modes. Results show that the crystallizer with reverse circulation and axis feeding can product large size crystals effectively. Wei Zong-sheng[2] had discussed the key technique of crystallizer design, and improved the structure of evaporation crystallizer. However, all studies were not able to obtain the information of flow field and solid suspension distribution. The Computational Fluid Hydrodynamics (CFD) can simulate the multiphase flow field through the method of numerical calculation. It is known as the powerful tool to simulate the crystallization process. CFD method has been used to analyze the crystallization process and improve the equipment structure by several authors [3-6]. The results of simulation have significant guiding for optimizing crystallization operation and equipment design.

In this work, commercial software CFD of ANSYS 10 was employed to simulate the evaporation crystallization process in different structures of evaporation chamber. The fluid hydrodynamics and crystal suspension distribution in different feeding mode were analyzed.

1 MODELING

Using Eulerian-Eulerian approach, the transport equations of all parameters in multiphase flow system can be expressed as follows:

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha \Phi_\alpha)+\nabla\cdot[\varphi_\alpha(\rho_\alpha U_\alpha \Phi_\alpha-\Gamma_\alpha \nabla\Phi_\alpha)]$$
$$=r_\alpha S_\alpha+\sum_{\beta=1}^{N_p} c_{\alpha\beta}(\Phi_\beta-\Phi_\alpha)+\sum_{\beta=1}^{N_p}(\dot{m}_{\alpha\beta}\Phi_\beta-\dot{m}_{\beta\alpha}\Phi_\alpha) \quad (1)$$

Phases are labeled by subscripts α, β and γ, and the number of phases is denoted by Np. The volume fraction of each phase is denoted by r, and. The term cαβ(Φβ-Φα) describes the inter-phase transfer of variable Φ between phases α and β. Thus, cαα=0 and cαβ=cβα. Hence, the sum over all the phases of all the inter-phase terms is zero. The term $\dot{m}_{\alpha\beta}\Phi_\beta-\dot{m}_{\beta\alpha}\Phi_\alpha$ only arises if inter-phase mass transfer takes place.

The continuity equation of the phase α is expressed by:

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha)+\nabla\cdot[r_\alpha \rho_\alpha U_\alpha]=S_\alpha \quad (2)$$

The momentum equation for the phase α is:

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha U_\alpha)+\nabla\cdot[r_\alpha(\rho_\alpha U_\alpha\otimes U_\alpha-\mu_{eff,\alpha}(\nabla U_\alpha+(\nabla U_\alpha)^T))]$$
$$=-r_\alpha\nabla P+\sum_{\beta=1}^{N_p} c_{\alpha\beta}^{(d)}(U_\beta-U_\alpha)+r_\alpha S_\alpha \quad (3)$$

In the multiphase flow field, interaction between the phases is the main effect of the flow field of different phases. There are several interface forces between dispersed phase and continuous phase. Only drag force is considered in this model. The total drag force is most conveniently expressed in terms of the dimensionless drag coefficient:

$$C_D=\frac{D}{\frac{1}{2}\rho_\alpha(U_\alpha-U_\beta)^2 A} \quad (4)$$

For spherical particle, the momentum transfer coefficient $C_{\alpha\beta}^{(d)}$ may be express as:

$$C_{\alpha\beta}^{(L)}=\frac{3}{4}\frac{C_D}{d}\gamma_\beta\rho_\alpha\left|U_\beta-U_\alpha\right| \quad (5)$$

For Newtonian incompressible fluid, resistance coefficient, CD, depends only on Reynolds number:

$$C_D=\begin{cases}24/\mathrm{Re} & (\mathrm{Re}\ll 1)\\ 0.44 & (1000\le \mathrm{Re}\le 1\text{–}2\times10^5)\end{cases} \quad (6)$$

Where, the Reynolds number was defined by:

$$\mathrm{Re}=\frac{\rho_\alpha\left|U_\beta-U_\alpha\right|d_\beta}{\mu_\alpha} \quad (7)$$

Mostly, the flow in industrial crystallizer is turbulence. Several models can be used to describe turbulent flow, for instance, the κ-ε model, k-ω model and the Re-stress model. In this work, the standard κ-ε model was employed because it was widely used in industrial process simulation. According to the standard κ-ε model, the turbulent viscosity is defined as:

$$\mu_{T,\alpha} = C_{\mu}\rho_{\alpha}\frac{\kappa_{\alpha}^{2}}{\varepsilon_{\alpha}} \quad (8)$$

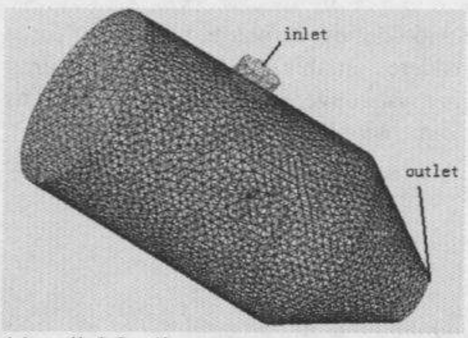
2 SIMULATION

2.1 Configuration and Simulation Gridding

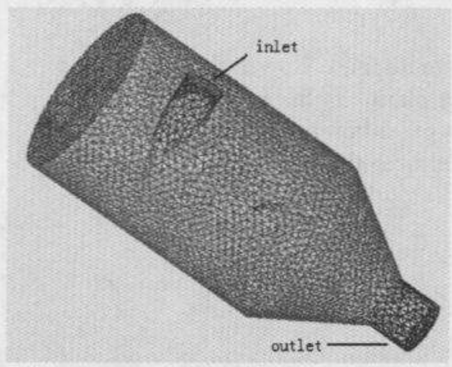
The aim of this work is to simulate the fluid hydrodynamics in evaporation chamber and to analyze the flow field and its influence on evaporation crystallization process. The structure of evaporation chamber in forced circulation evaporator which was adopted in CFD simulation. The dimensions and the mesh of the crystallizer are listed in Table 1 and in Fig.1.

Table 1 Geometry of evaporation chamber

cylinder diameter /m	cylinder height /m	inlet diameter /m	inlet distance to top /m	outlet diameter /m	conical bottom joint angle
2	2.9	0.45	1.3	0.3	60°



(a) radial feeding



(b) tangential feeding

Fig.1 The geometry and meshes of evaporation chamber

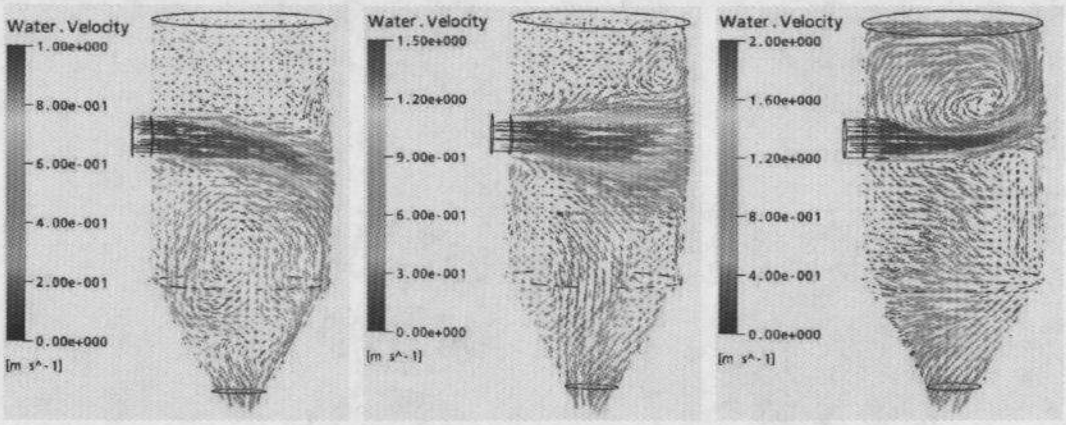
2.2 Simulation Condition and Simulation Method

The simulation is based on the two-fluid model mentioned above. Water was defined as continuity phase, the viscosity is 10-3 N s/m2, the density is 1000kg/m3, and the initial volume fraction is 0.95. The particle was considered as dispersed phases, the characteristic parameter is particle size. Fluid hydrodynamics of dispersed phases and correlating parameters in evaporation chamber will change with the change of particle size. The density of the crystal is 1980 kg/m3 and the initial volume fraction is 0.05. Initial conditions in simulation were set as same as feed. The simulation was based on the assumption of full suspension. Because of the aim of simulation is to analyze the influence of fluid hydrodynamics on evaporation crystallization process in evaporation chamber, circulation was simplified as inlet and outlet. Radial and tangential feeding was adopted in structure of evaporation chamber.

3 RESULTS AND DISCUSSION

3.1 Radial Feeding

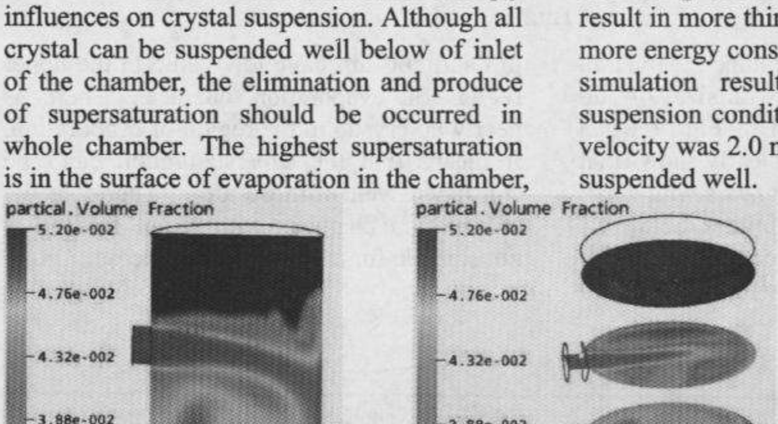
The fluid hydrodynamics of different phases in the crystallizer are the external condition for crystallization. The simulated fluid hydrodynamics of liquid phases with different feeding velocities are given in Fig. 2. It is shown that the feeding velocity had strongly influence on flow field. The circulation of fluid with high temperature was located below of inlet, when the feeding velocity was 1.0m/s. In this situation, the fluid with fed temperature is difficult to reach the surface of evaporation. As a result, the hot fluid can not be evaporated well so that the high temperature liquid goes through the chamber and results in temperature loss in heat transfer process. The production capacity of evaporation crystallizer will be decreased. The liquid with high temperature can reach the surface of evaporation partly when feeding velocity was 1.5m/s. The simulation result shown that the flow field distribution was ideal when feeding velocity was 2.0m/s.



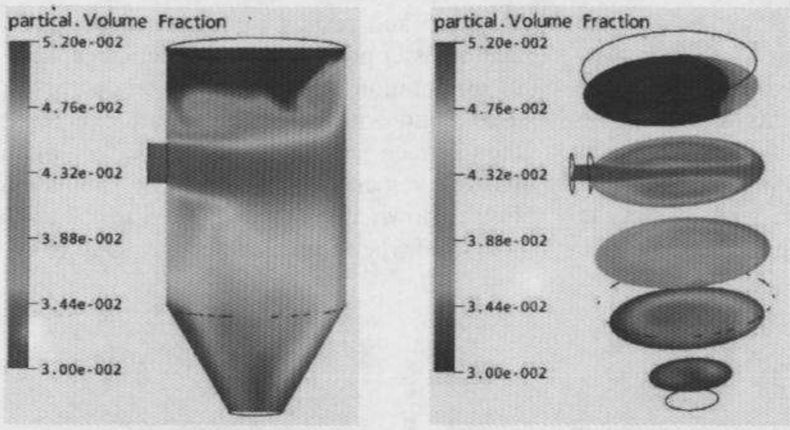
(a)1.0m/s (b)1.5m/s (c)2.0m/s

Fig.2 The liquid velocity distribution at different feeding velocity (0.1mm)

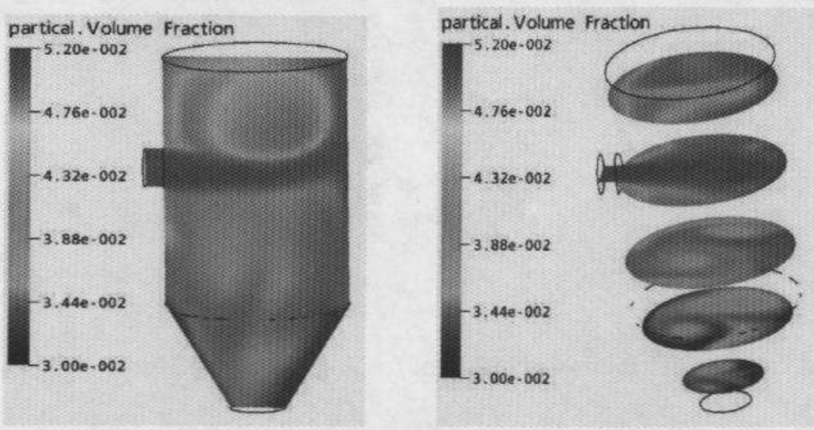
The simulated volume fraction distributions of 100μm crystal at different feeding velocity are given in Fig. 3. It is shown that the flow field distribution strongly influences on crystal suspension. Although all crystal can be suspended well below of inlet of the chamber, the elimination and produce of supersaturation should be occurred in whole chamber. The highest supersaturation is in the surface of evaporation in the chamber, crystal surface should be enough to consume the supersaturation in the surface area, otherwise, the primary nucleation will occur and bring excessive thin crystal. This will result in more thin crystal in final product and more energy consume in dryness process. The simulation result shown that the crystal suspension condition was ideal when feeding velocity was 2.0 m/s for crystal size of 100μm suspended well.



(a) feeding velocity 1.0m/s



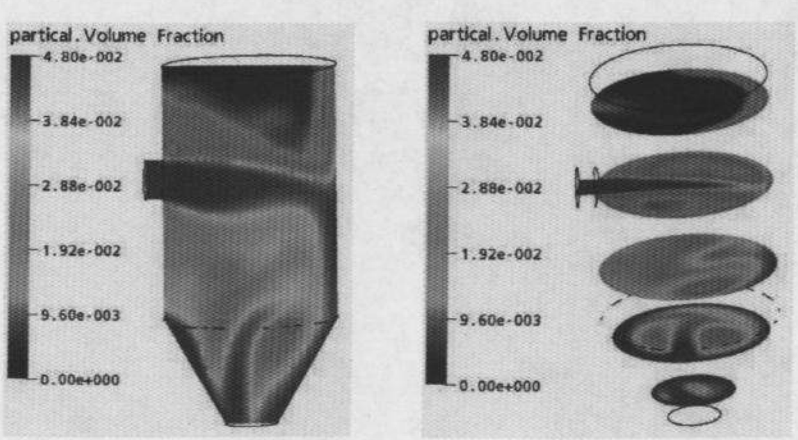
(b) feeding velocity 1.5m/s



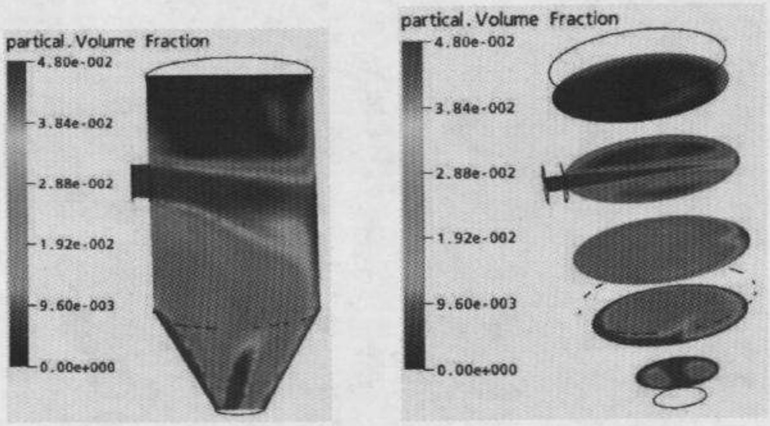
(c) feeding velocity 2.0m/s

Fig.3 The volume fraction distribution of crystal at different feeding velocity (crystal size 0.1mm)

The simulated volume fraction distributions of the crystals with sizes of 300 μm and 500 μm are shown in Fig. 4 when feeding velocity is 2 m/s. It clearly shows that the volume fraction of the crystals with small size have uniformed distribution below of inlet in evaporation chamber. However, the volume fractions of crystal with sizes of 300 μm and 500 μm have low value in the upper region of evaporation chamber. There is nearly no crystal in the region of evaporation. It means that the superstaturation can't be consumed well in those areas. Therefore the evaporation chamber with radial feeding is not suitable for crystallization process.



(a) crystal size 0.3mm

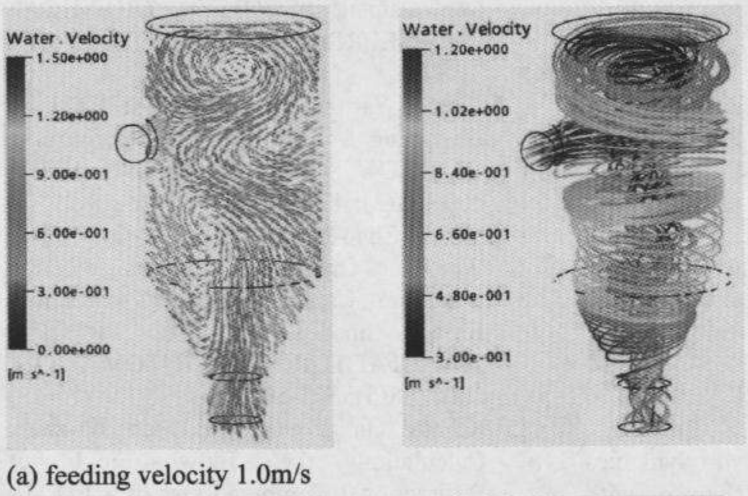


(b) crystal size 0.5mm

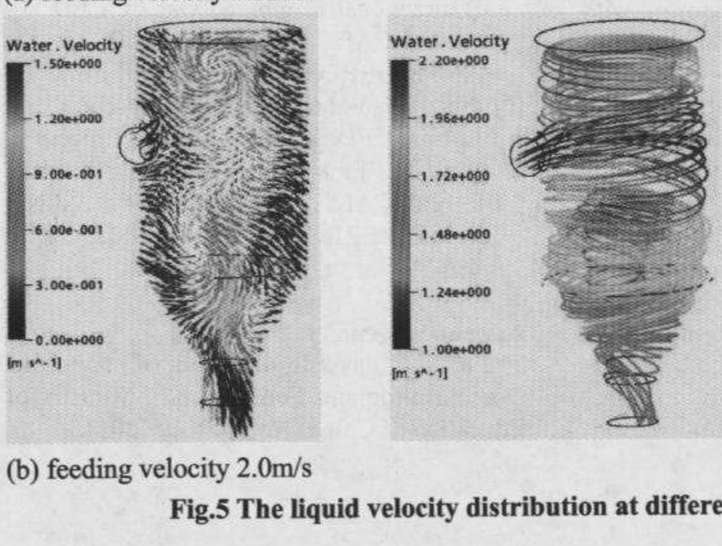
Fig.4 The volume fraction distribution of different crystal size(feeding velocity 2.0m/s)

3.2 Tangential Feeding

The simulated moving contrails of 100μm crystal at different feeding velocities are given in Fig. 5. It is shown that the fed fluid with high temperature could be rapidly mixed with the fluid in evaporation chamber with tangential feeding. When feeding velocity was 1.0m/s, the fed fluid couldn't reach on surface of liquid as same as radial feeding. The simulation results shown that some of the fed fluid would reach on the fluid surface at 2.0m/s feeding velocity.

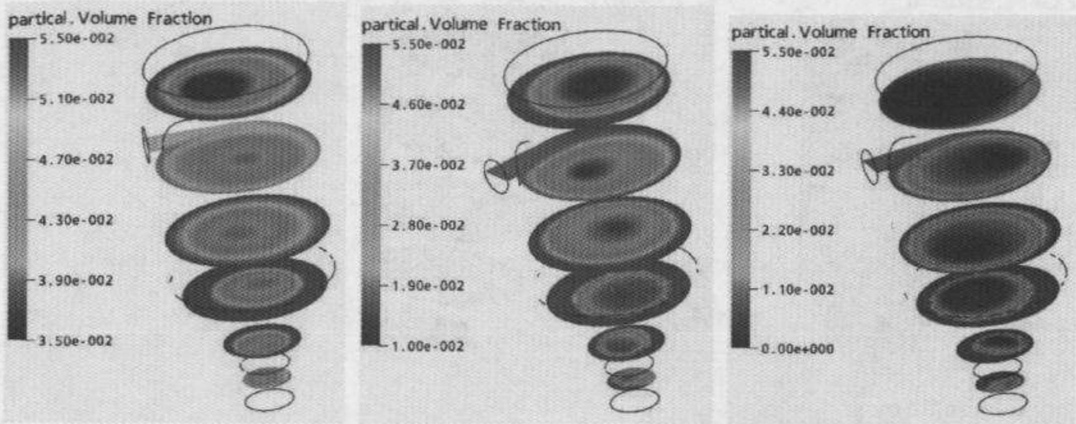


(a) feeding velocity 1.0m/s



(b) feeding velocity 2.0m/s

Fig.5 The liquid velocity distribution at different feeding velocity



(a) crystal size 0.1mm (b) crystal size 0.3mm (c) crystal size 0.5mm

Fig.6 The volume fraction distribution of different crystal size (feeding velocity 2.0m/s)

The simulated volume fraction distribution of different sizes crystals at same feeding velocity is given in Fig. 6. It is shown that crystals are concentrated nearly the crystallizer wall, especially in conical bottom. This is because of the centrifugal force of the crystals. The crystal suspension was not well considering the crystallization process.

For the smallest size, 100μm, crystals were well suspended. While crystal size increases gradually, the homogeneity of the crystal suspension is decreased correspondingly. Crystals could not be well suspended when crystal size was 500μm. As a result, crystals were separated from liquid with tangential feeding. Therefore, the tangential feeding is not suitable for the evaporation crystallization operation.

4 CONCLUSIONS

In this work, the fluid hydrodynamics was simulated in evaporation chamber with different feeding style, and its influence on crystallization process was analyzed. Results show that the small size crystal could suspend well with radial feeding style in higher feeding velocity. The problem is short-cut-circuiting of the high temperature fluid. Tangential feeding style is not suitable operation for crystallization process because of crystals were separated from liquid. The better structure of crystallization-friendly crystallizer need to be further studied.

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