CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci
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DOI: 10.3303/CET0917108

Study with fluidized bed crystallizer with CFD simulation

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The effect of geometry and operation condition on the flow field and suspension density distribution in a fluidized bed crystallizer with total volume of $95m^3$ was studied with CFD simulation. The multi-fluid flow model was used in the simulation by consideration of different sizes of particles as different phases. Different geometries of draft tube were used in the simulation.

1. Preface

Fluidized bed crystallizers (FBC) have been widely used in industrial crystallization processes because the simple structure and crystals classification. The suspension of the crystals and crystallization kinetics were mainly considered in the design and operation of FBC (Lin et al, 1998). The most researches were, however, concentrated on crystal growth rate (Gürbüz et al, 2005; Aldaco et al, 2007), and few focused on suspension.
The suspension distribution in crystallizer is hard to be obtained by experimental method. The Computational Fluid Dynamics (CFD) was considered as a powerful tool for predicting the solid suspension by using multi-phase simulation. CFD was more and more used in the progress analysis, equipment design, and the operation optimization (Sommerfeld et al, 2004; Huang et al, 2007).
The aim of the present work was to study the impact of crystallizer configurations and operating conditions on the solid suspension distribution in the FBC and to analyze the effects on the crystallization process.

2. Modeling

Multi-phase flow can be described by following general equation for all parameters in the system.

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

Phases are labeled by the subscripts α and β, and the number of phases is denoted by Np. The volume fraction of each phase is denoted by φ. The term $c_{\alpha\beta}(\Phi_\beta - \Phi_\alpha)$ describles the

Please cite this article as: Sha Z.L., Zheng Q. and Wu S., (2009), Study of fluidized bed crystallizer with cfd simulation, Chemical Engineering Transactions, 17, 645-650 DOI: 10.3303/CET0917108

inter-phase transfer of variable Φ between phase α and β. Thus, $c_{\alpha\alpha}$=0 and $c_{\alpha\beta} = c_{\beta\alpha}$. Hence, the sum over all the phases of all the inter-phase transfer term is zero.
The continuity equation for phase α is:

$$\frac{\partial}{\partial t}(\varphi_\alpha \rho_\alpha) + \nabla \cdot [\varphi_\alpha \rho_\alpha U_\alpha] = 0 \tag{2}$$

The momentum equation for phase α is:

$$\frac{\partial}{\partial t}(\varphi_\alpha \rho_\alpha U_\alpha) + \nabla \cdot \left[\varphi_\alpha \left(\rho_\alpha U_\alpha \otimes U_\alpha - \mu_{eff.\alpha}(\nabla U_\alpha + \nabla U_\alpha^T)\right)\right] = \varphi_\alpha S_\alpha + \sum_{\beta=1}^{N_p} c_{\alpha\beta}^{(L)}(U_\beta - U_\alpha) \tag{3}$$

The flow in industrial crystallizer is mostly turbulence. There are many models to describe turbulent flow. In this work, the standard κ-ε model was employed because it was widely used, simple and suitable for isotropic flows with high Re-numbers.
The κ-ε model is based on the eddy viscosity concept, so the μ_{eff} in Eq. (3) is defined as:

$$\mu_{eff.\alpha} = \mu_\alpha + \mu_{T.\alpha} \tag{4}$$

Where $\mu_{T.\alpha}$, is the turbulence viscosity and be calculated by:

$$\mu_{T.\alpha} = C_\alpha \rho_\alpha \frac{\kappa_\alpha^2}{S_\alpha} \tag{5}$$

3. Simulation

The studied structure of the crystallizer was schematically shown in *Fig.1*. The total volume of the crystallizer is 95m^3. The cylindrical part with a diameter of 5000mm and a height of 2000mm, and the conical part with the angle of 77° and height of 5500mm. The crystallizer with spherical-bottom was equipped with a draft tube, a center inlet pipe and four outlet pipes at the top. The geometry of the draft tube was varied in the simulation in order to determine the optimal structure of the crystallizer.

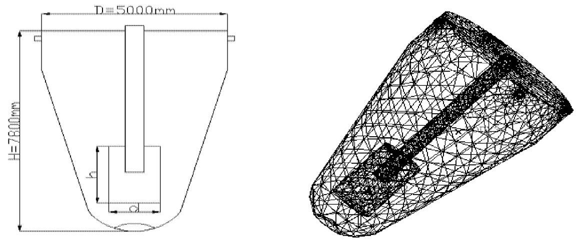


Fig 1 The geometry and meshes of the FBC in the simulation

Table 1 The initial volume fraction of each particle size

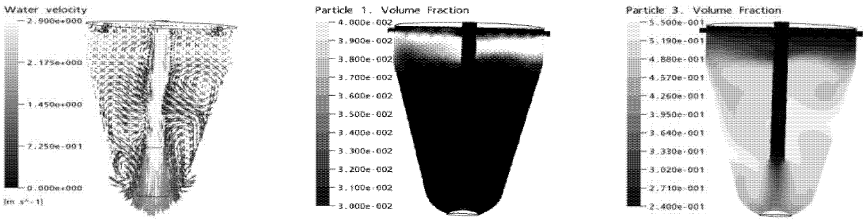
Particle size [m]	0.1×10^{-3}	0.2×10^{-3}	0.4×10^{-3}
Volume fraction	0.03	0.03	0.24

The simulation was carried out based on the Euler-Euler two-fluid model. Water was considered as the continuous phase, and solid particle was considered as the dispersed phase. Three classes of particle sizes were used in the simulation. Each of the particle size class was considered as different phases. The particle size and initial concentrations used in simulation are given in *Table 1*. The total solid fraction was 30%. The particle density was 1277 kg/m^3, and feed rates were 1500m^3/h, 2000m^3/h, 2500m^3/h and 3000m^3/h.

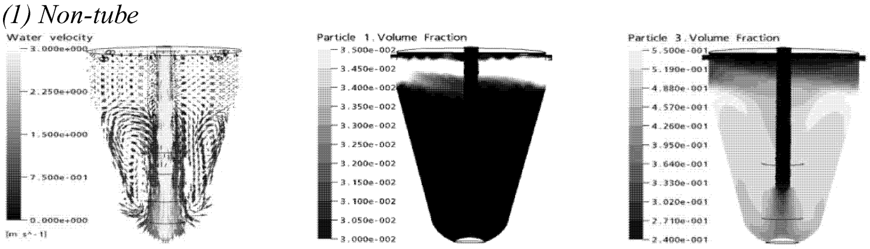
4. Results

4.1 The effect of draft tube structure on flow fields and crystal suspension

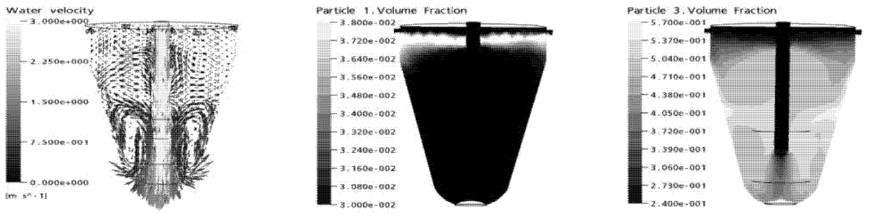
The flow field and crystal distribution in the crystallizer are important information for estimation of the crystallization process. As well known, the structure of the draft tube has strong effect on the flow field and crystal suspension in FBC crystallizer. The simulated water flow fields and crystal volume fraction distributions (VFD) for different sizes of crystals with different structures of draft tube at feed rate of 2000 m^3/h are given in *Fig.2*. It shows that the different structures of draft tube will produce different distributions of liquid velocity. Large vortexes were found at bottom part of the crystallizer and also some of the vortexes in the upper region of the crystallizer for the case without draft tube. It results more particle local circulation in the crystallizer. The local circulation of the crystal will results in more nucleation and effect of the final product size. The liquid circulation was clearly found around the draft tube for the cases with draft tube, which offers a good condition for crystal growth. A larger circulation area was found for the case with higher draft tube. The diameter of the draft tube has no much effect on the flow field and crystal distribution in the studied cases. The draft tube in the crystallizer creates a better condition for crystal growth in the crystallizer than that without draft tube.



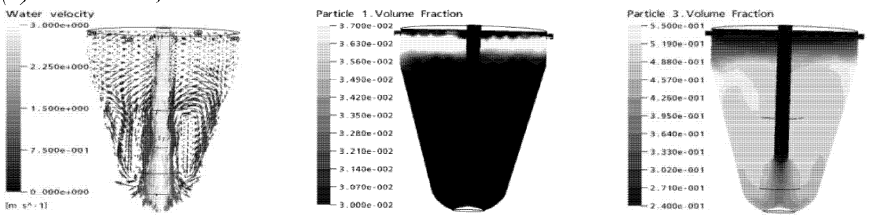
(1) Non-tube



(2) h/H=0.282, d/D=0.28



(3) h/H=0.282, d/D=0.4



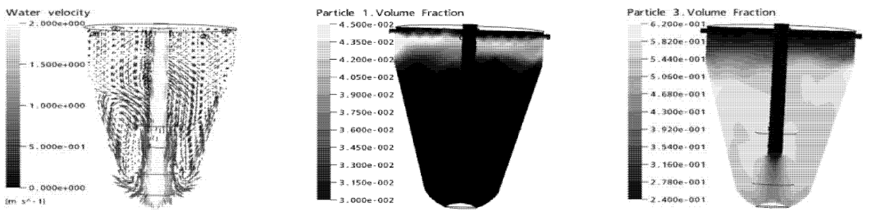
(4) h/H=0.385, d/D=0.28

(liquid velocity) *(VFD partical 0.1 mm)* *(VFD partical 0.4 mm)*

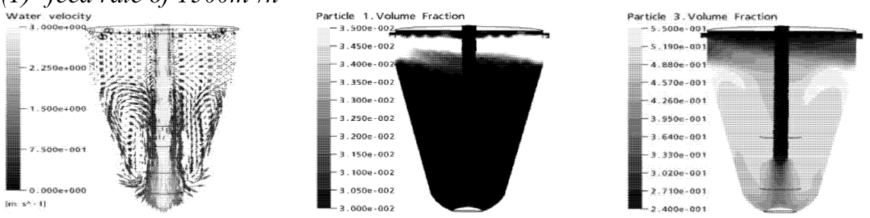
Fig 2 Liquid velocity fields and crystal volume fractions at different structures

4.2 The effect of feed rate on the flow field and crystal suspension

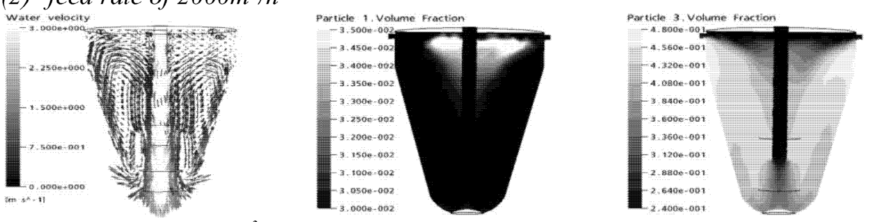
The energy to create flow in the FBC is provided by the feed solution. Study on the effect of the feed rate on the flow field and suspension is very important for the crystallizer design and operation. The simulation was carried out with a fixed structure of the FBC at different feed rates.



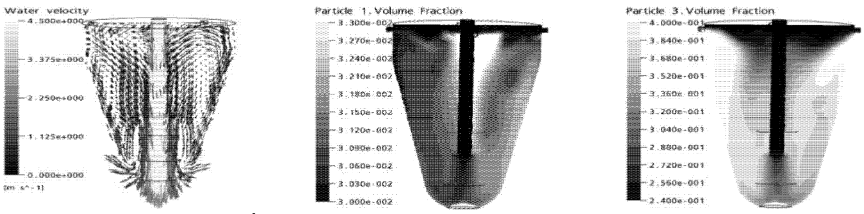
(1) feed rate of 1500m^3/h



(2) feed rate of 2000m^3/h



(3) feed rate of 2500m^3/h



(4) feed rate of 3000m^3/h
(liquid velocity) *(VFD partical 0.1 mm)* *(VFD partical 0.4 mm)*

Fig.3 Liquid velocity fields and crystal volume fractions at different feed rates

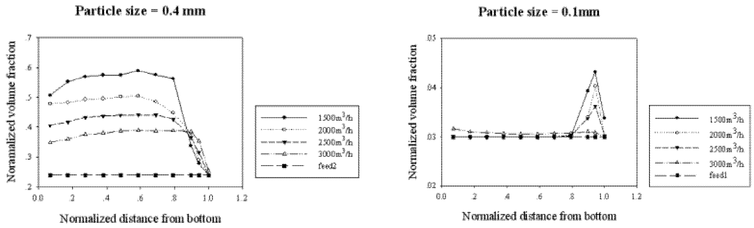


Fig 4 Variation of solid volume fraction in vertical direction with different feed rates

The simulated results are presented in *Figs 3-4*. The liquid circulation area became lager when the feed rate is increased as shown in *Fig 3*. The effect of feed rate on the crystal suspension can be discussed with different sizes cases. For the small crystal size such as 0.1mm, the crystals can be suspended well overall the circulation area, but some accumulation occurs in the upper area of the crystallizer. The concentration of the small crystals in the upper region of the crystallizer increases with decreasing the feed rate. For the lager size of crystals, for example 0.4mm, the uniform distribution area was also increases with increasing feed rate. The accumulation occurs for all studied feed rates for large size of crystals. The amount of the accumulation decreases with increasing the feed rate as can be seen in *Fig 4*. It means that the crystals with this size can be suspended well for growth, but the classification takes place in the upper region of the crystallizer. If the crystallization operated at this condition and product is withdrawn at the middle area of the crystallizer, larger size product with uniformed distribution can be expected.

4.3 Suspension distribution for different crystal sizes

At a fixed feed rate, different sizes of crystals have different suspension distributions in a crystallizer. In order to reveal the dependent of the suspension distribution on the size of crystals, the simulation was done for three sizes of crystals at a constant feed rate of 1500 m^3/h. The overall distribution of different sizes of particles was similar as presented in *Fig 3*. To show the difference of the distribution of different sizes of crystals, the vertical distribution of suspension density in the crystallizer was presented in *Fig 5*. It can be seen, the even distributions of the suspension density were created for all sizes of particles at this operation condition. The concentration of small size of crystals has the same value with the one in the feed solution. But concentration of the larger size of crystals has higher value than that in feed. It caused by the classification of the crystals in the crystallizer for these sizes of particles. The local maximum concentrations were found in the upper region of the crystallizer, which was designed for classification of the crystals.

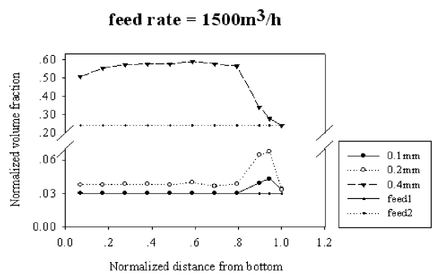


Fig 5 Variation of solid volume fraction in vertical direction with different particle sizes

5. Conclusion

The flow field and crystal suspension distribution have been investigated with CFD in Fluidized Bed Crystallizer with different structures of draft tube and different feed rates. The simulation results indicated: It is obvious that the liquid velocity field with the draft-tube can form a better circulation. Suitable height of draft tube could be existing for the studied crystallizer. By defining different sizes of crystals as different dispersed phases the suspension density distributions for different crystal sizes were obtained in a simulation. The suspension density distribution of crystals was also strongly dependent on the feed rates. The local maximum concentration was found in the upper region where was designed as classification of crystals. For the same particle size, the uniformity of the solid distribution increases with increasing feed rate. The local maximum solid concentration rises with increasing feed rate.

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