Character of crystallization particle in bitten transfer pump

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Abstract. In order to understand the flow pattern of salt-out particles in a bittern transfer pump, the population balance model (PBM) coupled with mixture two-phase was applied to calculate the particle flow. User-defined particle growth and nucleation models were used in this study to consider the actual dynamic behavior of the crystallization particle, such as particle growth, nucleation, aggregation and breakage. The result shows that the average particle size is smaller and more evenly distributed among area of the impeller inlet. The size of crystal particles is different at different regions in the impeller passages with the characteristics of small crystal particles near suction side and large crystal particles near pressure side. In addition, the distribution of average particle size near pressure and suction side has an upward trend from inlet to outlet. The distribution of crystal particles on the blade near the tongue is different from other blades whether it is in the pressure surface or suction surface.

1. Introduction
Crystallization is a process that solid particle separates out from salt aqueous, which mainly includes Potassium and sodium ions. As the crystallization phenomenon appears frequently in many transportation process, crystal particle will be adsorbed on the inner wall of pipeline and pump, which has a negative impact on relevant equipment operations [1-2]. In the transportation process, the liquid-solid two-phase flow with crystallization phenomenon has many microscopic behaviors of particle, such as particle growth, nucleation, aggregation and breakage. In order to consider the microscopic behaviors of particle, the population balance model was applied to improve the accuracy of simulation and to establish connection between behaviors of particle and macroscopic properties. In order to explore pattern of the average of particle size in the pump and describe phenomenon which actually exists in two-phase flow, the population balance model was applied to couple calculation of flow field. Liu [3-4] used Particle Image Velocimetry (PIV) to analyze the two-phase velocity fields in a centrifugal pump through developed image processing method. Qian [5] discovered the efficiency and head were closer to the experimental value based on the population balance model. Wang [6] found that the blade outlet angle is bigger, more particles gather in the suction surface, causing more collision in the blade outlet.

It is not inconsistent with actual fact that some scholars only consider the particle aggregation and breakage, therefore, this study consider the particle growth and nucleation based on the previous research. In order to reveal comprehensive pattern of the liquid-solid two-phase flow with crystallization phenomenon in the pump, FLUENT was applied to calculate the flow pattern of salt-out particles in a bittern transfer pump.
2. Model and its related parameters
The main design parameters are as follows: specific speed $n_s = 403$, the design flow rate $Q = 1390 \text{m}^3/\text{h}$, design head $h = 10 \text{m}$, rotational speed $n = 740 \text{r/min}$, the impeller diameter $D_2 = 390 \text{mm}$, blade number is four.

![Figure 1. Computational grids of model.](image)

3. Verification of numerical method
Inlet boundary condition is specified as velocity inlet. It is assumed that the solid phase distribution is uniform and the velocity is equal to the liquid phase. Outflow is selected as the outlet boundary condition. Besides, no slip condition is imposed on wall surface regarding the wall boundary condition. The population balance model is set up to achieve the Microscopic behaviors of particle, such as particle growth and nucleation, specific settings are as follows:
Using following formula to define nucleation kinetics of sodium sulfate crystals [7].

$$B = 1.71 \times 10^4 \exp \left( \frac{-36214.8}{RT} \right) \rho^{0.37} M^{0.87} \Delta C^{2.1}$$  \hspace{1cm} (1)

$T$ is temperature, $M$ is Crystal density, $\rho$ is Density of solution, $\Delta C$ is Supersaturation of solution
Using following formula to define growth kinetics of sodium sulfate crystals.

$$G = 3.06 \times 10^{-8} (1 + 0.76d)^{0.82}$$  \hspace{1cm} (2)

The PIV was applied to measure the inner field of a centrifugal pump. The particle size distribution was obtained by processing the experimental data with a developed image processing software and the commercial software Insight 5.0. By comparing the particle size distribution in the passageway of the impeller in figure 2, it is discovered that modified model is closer to the actual value [8]. But the result of the simulation and the result of the experiment has some differences, the experiment near the entrance has a small amount of large particle size. The reason for the analysis of the model used for the aggregation and breakage of the particle is luo model, which is not suitable for the calculation of liquid-solid two-phase flow. The applicability of the numerical calculation for the crystallization problem should be further verified. The second reason is that the computational complexity of the grouping method is large, and the precision of the calculation software is limited, which makes the experimental value and the simulation value have some differences.

![Figure 2. The particle size distribution in the passageway of the impeller.](image)
4. Calculation results and analysis

Figure 3(a) shows the distribution of crystal particles in the impeller of a bitten transfer pump at the design flow and solid volume fraction of 0.1%. Focusing on the design condition, it can be concluded that the size of crystal particles is different at different regions in the impeller passages with the characteristics of small crystal particles near suction side and large crystal particles near pressure side. In addition, the distribution of particles along radial direction, a large number of small particles are distributed in the inlet surface eventually, while large particles are mainly located near the pressure side with even distribution in the outlet suction. The reason for this kind of distribution characteristics is the density of solid phase bigger than liquid. In order to observe the flow situation better in different impeller passage, it is necessary to set the monitoring point at the blade suction surface and pressure surface in the calculation process. Figure 3(b) shows the pressure cloud for the blade pressure surface ,which it is marked 40 data monitoring points from the inlet side to the outlet side.

Figure 4 shows the average particle size distribution of the crystal particles near the pressure surface under design condition at the data monitoring points. From this figure, it can be obtained that the average of particle size of the crystal particles tends to increase from the inlet side to the outlet side and the particle size is the smallest at the inlet. The reason for this kind of distribution characteristics is the rate of growth of the particles is greater than the rate of breakage of the particles driven by the supersaturation and the solid particles can carry out the process of mass transfer with liquid phase, which makes the crystal particles increasing from inlet to outlet. In addition, the blade 1 is near the tongue and blade 1 to 4 are arranged in a counterclockwise direction. From this figure, it can be concluded that the particle size in blade 1 near tongue is relatively slow in the later stage, because the flow affects the growth of the particles. While the distribution of crystal particles in other blades is similar except the particle size has some differences on each pressure surface. After all, the growth rate of each blade is still different.

(a)The distribution of crystal particles (b) Pressure contour in pressure surface

Figure 3. The distribution of crystal particles and pressure contour in pressure surface.
Figure 4. The distribution of crystal particles on pressure surface.

Figure 5 shows the average particle size distribution of the crystal particles near the suction surface under design condition at the data monitoring points. From this figure, it can be obtained that the trend of particle size distribution on the blade 1 increases first, then decreases and finally increases compared to particle size distribution on other blades has a upward trend. The reason for this kind of distribution characteristics is the blade 1 near tongue, which affects the flow and lead to the weakened of shear force. Because the shear force becomes weak to make the crystal particles grow rapidly. While the shear force becomes stronger to inhibit growth of the crystal particles after the stability of the flow field. After a period of time, the crystal particles began to grow driven by supersaturation.

Figure 5. The distribution of crystal particles on suction surface.

5. Conclusion
In this paper, the CFD-PBM method is applied to study the distribution crystal particles in a bitten transfer pump with crystallization phenomenon. The results are compared with the experimental ones, which prove that the CFD-PBM method used in this paper is reliable. The following conclusions can be obtained:

The size of crystal particles is different at different regions in the impeller passages with the characteristics of small crystal particles near suction side and large crystal particles near pressure side. In addition, a large number of small particles are distributed in the inlet suction eventually, while large particles are mainly located near the pressure side with even distribution in the outlet suction.
By monitoring the blades on the pressure and suction surface, it can be concluded that the average of particle size of the crystal particles tends to increase from the inlet side to the outlet side and the particle size is the smallest at the inlet.

The distribution of crystal particles on the blade near the tongue is different from other blades whether it is in the pressure surface or suction surface.

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