Research on the effect of the mounting location of the ruston turbine on two phase flow field

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Abstract. Mixed flow fields of water and low density particles in the stirred tank of the single size six-blade ruston turbine are calculated by the large eddy simulation and multiphase flow model. The effect of the mounting location of the paddle on two phase flow field is studied. The result shows that with the lower mounting location of the paddle, the scale of the vortex near the paddle is smaller and the intensity is lower. When the height of mounting location is amount to the middle of the stirred tank, there are a large number of vortex structures near the paddle. And the strength is high. These vortexes are major contributors to the mixing. While when the height of mounting location is too low, the upper material and the lower material can not effectively mix with each other, which is unable to reach the using effect.

Introduction

The mixing is widely used in many industrial processes, such as chemical industry, metallurgy, biochemistry and food. Generally the mixing process and the speed are vitally important for the operation. Understanding the local flow and the mixing can not only improve the process, but also guide the design of reactor to boost efficiency. Recently with the development of CFD, local information obtainment by numerical simulation is real for some. CFD method can not only saves a lot of funds, but also gets the data which can not be obtained from the experiment. CFD has revolutionized the development of the stirred tank [1-3]. In this paper the effect of the mounting location of the ruston turbine on two phase flow field is studied by the large eddy simulation and multiphase flow model.

Fluid model

Large eddy simulation control equation is the averaged equation after filtering the N-S equation.

$$\frac{\partial \overline{u_i}}{\partial t}+\frac{\partial}{\partial x_j}\left(\overline{u_i u_j}\right)=-\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i}+\nu\frac{\partial^2 \overline{u_i}}{\partial x_j^2}+f_i \tag{1}$$

The micro compressible flow field model is used in the continuity equation.

$$\frac{\partial P}{\partial t}+K\frac{\partial \overline{u_i}}{\partial x_i}=0 \tag{2}$$

In the above equation, horizontal line presents the quantity after filtering. Relation between the filtration rate $\overline{u_i}$ and actual speed u_i in the large eddy model is $u=\overline{u_i}+u_i'$. K is the square of fluid elastic wave velocity. Nonlinear term exits in the momentum equation. $\overline{u_i u_j}=\overline{\overline{u_i u_j}}+\overline{u_i'\overline{u_j}}+\overline{\overline{u_i}u_i'}+\overline{u_i'u_j'}$. The first item is large scale component and the other three items are small scale components, that is sub-grid reynolds stress. Then it can be expressed as $\overline{u_i u_j} = \overline{\overline{u_i u_j}} + R_{ij}$. R_{ij} is the new unknown after filtering, so sub-grid reynolds stress model is established. Then box-filter function is used and the equation (1) can be expressed as follows.

$$\frac{\partial \overline{\mathrm{u}}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\overline{u_i u_j}\right) = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + \nu_t \frac{\partial^2 \overline{u}_i}{\partial x_j^2} - \frac{\partial \tau_{ij}}{\partial x_j} + f_i \tag{3}$$

According to the average concept of the turbulence energy generated and dissipation, Smagorinsky assumes $\nu_{\mathrm{t}} = (C_s \Delta)^2 \left(2\overline{S_{ij}}\,\overline{S_{ij}}\right)^{1/2}$ and $\overline{S_{ij}} = \frac{1}{2}\left[\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_i}{\partial x_i}\right]$. Δ is filter width, generally it is grid spacing and $\Delta = \left(\Delta_x \Delta_y \Delta_z\right)^{1/3}$. C_s is not only the model coefficient but also empirical constant. When it is taken as 0.1 the result consistent with the experiment can be obtained. So in this paper C_s is 0.1.

The mixing process between water and low density particles are described by mixture model, which can simulate the multi-phase flow with different velocities. Assuming local equilibrium in the spatial scale, continuity equation of the mixture model is as follows:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \cdot (\rho_m \vec{v}_m) = 0 \tag{4}$$

The momentum equation of the mixture can be obtained by the sum of momentum equation of all phases, which can be described as follows:

$$\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \cdot (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla \cdot [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] + \rho_m \vec{g}_m + \vec{F} + \nabla \cdot (\sum_{k=1}^{n} a_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k}) \tag{5}$$

ρ_m is the mixture density, $\vec{v}_m$ is the average velocity of the mass, μ_m is the mixed viscosity coefficient, $\vec{F}$ is the body force, *n* is number of phases, a_k is *k* phase volume fraction, ρ_k is *k* phase density and $\vec{v}_{dr,k}$ is *k* phase flowing speed.

The slip velocity $\vec{v}_{qp}$ is defined as the velocity of the second phase *p* relative to principal phase *q*. And $\vec{v}_{qp}$ is as follows:

$$\vec{v}_{qp} = \vec{v}_p - \vec{v}_q \tag{6}$$

The relation of flowing speed and slip velocity is as follows:

$$\vec{v}_{dr,k} = \vec{v}_{qp} - \sum_{k=1}^{n} \frac{a_k \rho_k}{\rho_m} \vec{v}_{qk} \tag{7}$$

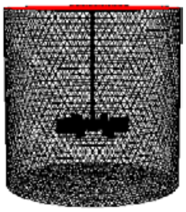
The volume fraction equation of the second phase can be got from the continuity equation.

$$\frac{\partial}{\partial t}(a_p \rho_p) + \nabla \cdot (a_p \rho_p v_m) = -\nabla \cdot (a_p \rho_p v_{dr,p}) \tag{8}$$

Computational model and mesh

The stirred tank of the single size six-blade ruston turbine is taken as the subject in the study. The diameter T is 0.48m, the liquid depth H equals to T, diameter of the paddle is D, width W is D/5, the length L is D/4 and the thickness d is 2mm. The monolithic construction of the stirred tank is shown in Fig. 1. Installations position of the turbine from the ground *C*1 and *C*2 are 1/3*H* and 1/2*H*. Speeds are respectively 120r/min, 180r/min and 240r/min. Mediums in the calculation are water and low density particles. At the early stage of the mixing, low density particles float on the water and the thickness is 0.12mm.

The equation is discrete by the finite volume method and SIMPLE algorithm is used for the pressure-velocity coupling. Moving Reference Frame is used to simulate the axis direction. The top of the stirred tank is pressure outlet. Paddle and the cylinder are set as the wall boundary. Meshes are refined near the paddle and the two-phase interface to satisfy computational accuracy. The relatively sparce meshes are used in the area far away from the paddle and the interface to reduce computational effort. The numbers of grid nodes are 528546 and 528671. Schematic diagrams of grid computing of the two group models are shown in Fig.1.



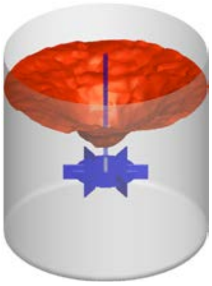
(a) $C1=1/3H$

(b) $C2=1/2H$

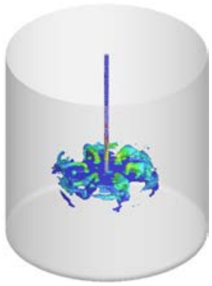
Fig 1 Schematic diagram of the stirred tank and the grid structure

The discussion and analysis of the results

The flow and vorticity distributions with two different installation positions are shown in Fig.2 and Fig.3. It can be seen that when the installation position is near the bottom of the stirred tank, liquid interface formed by the paddle rotation is not contact with the paddle. The two-phase interface is in the upper of the paddle and the scale of the vortex is small. With the installation position rising, liquid interface is contact with the paddle. Then the spiral two-phase interface is formed, which suggests the stirring effect is obvious. From the vortex comparison, when the installation position is low, the scale and the strength of the vortex are small. While when installation position is in the middle of the stirred tank, large number of vortex are formed near the paddle with large strength, which are the main factor of effecting the material mixing.

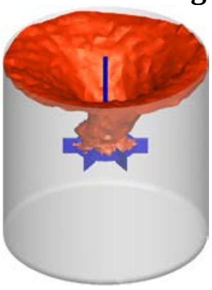


(a) liquid interface distribution

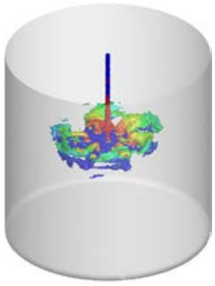


(b) vortex distribution

Fig 2 Flow field distribution with C1=1/3H



(a) liquid interface distribution



(b) vortex distribution

Fig 3 Flow field distribution with C2=1/2H

Speed distribution curves corresponding to two kinds of installation position are shown in Fig.4. Through comparison, it can be found that with low installation position, speed near the liquid interface is relatively slow. While with high installation position, speed exhibits considerable variation. Speed in the upper of the paddle increases rapidly, which indicates that speed gradient is large and obvious pressure differential is formed in Fig.5. The fuels in this domain mix because of the pressure differential. The upper fuel is transported to the area near the paddle. Then in the effect of the vortex, the fuels near the paddle mix with the fuels at the bottom. Vector distributions with different locations are shown in Fig.6. It can be seen that with the low installation position, there is not effective mixing between the upper and the bottom fuels. Finally the using effect is unable to be achieved.

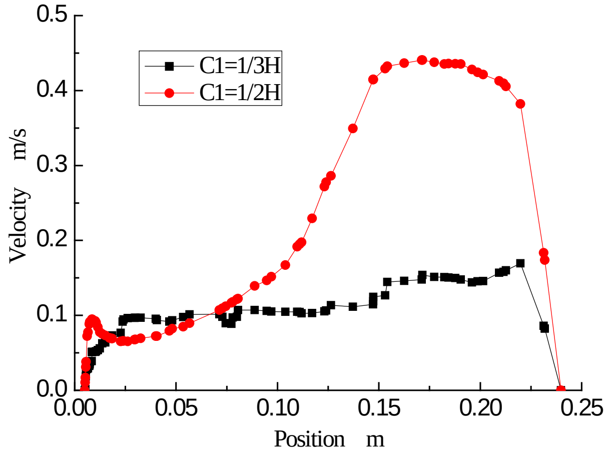


Fig 4 The speed curve

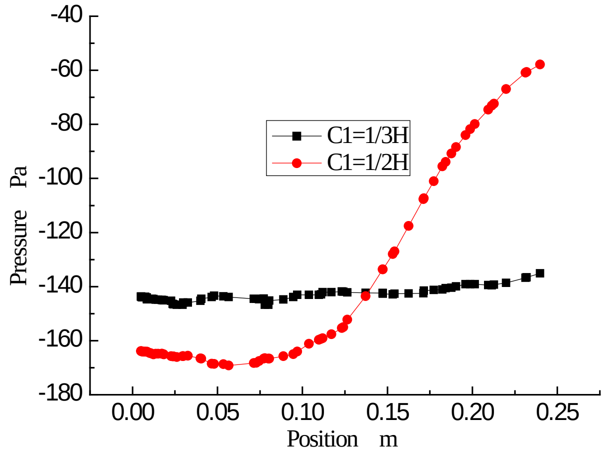
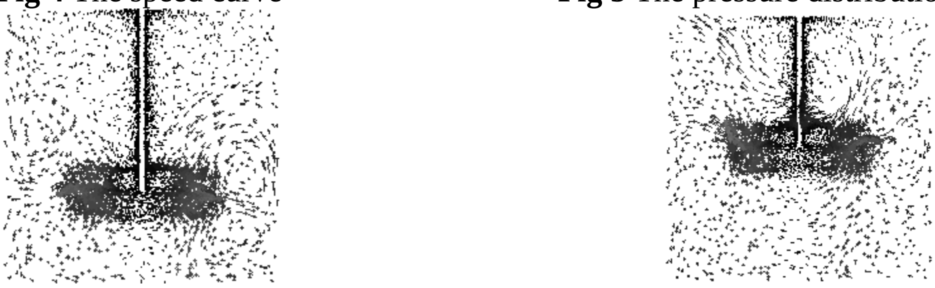


Fig 5 The pressure distribution curve



(a) C1=1/3H (b) C2=1/2H

Fig 6 Vector distribution

Conclusions

Mixed flow fields of water and low density particles in the stirred tank of the single size six-blade ruston turbine are calculated by the large eddy simulation and multiphase flow model. The effect of the mounting location of the paddle on two phase flow field is studied. The result shows that with the lower mounting location of the paddle, the scale of the vortex near the paddle is smaller and the intensity is lower. When the height of mounting location is amount to the middle of the stirred tank, there are a large number of vortex structures near the paddle. And the strength is high. These vortexes are major contributors to the mixing. While when the height of mounting location is too low, the upper material and the lower material can not effectively mix with each other, which is unable to reach the using effect.

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