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Numerical simulation of multi-layer agitator blade in high temperature floating two-phase flow field

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ABSTRACT

The mixed model in Eulerian multiphase fluid was adopted to simulate the macroscopic speed field of glass-semisolid aluminum-silicon alloy slurry in agitator bath of multi-layer agitator. Speed, viscosity, pressure, and temperature distribution were forecasted by this model. The forecasting results showed that radial and tangential speed were dominated in impeller area. The maximum value of axial speed was achieved in the lower and middle layer blade, while the maximum value of each layer blade existed in the edge and near axis place of the blade. The tangential speed of lower layer blade varied by the largest extent, which maximum value appeared in the edge and near wall place of the blade. The comparison between simulation and experimental results indicated the choice of this kind of agitator had advantage of the glass particles dispersion.

KEYWORDS

Floating two-phase system; Numerical simulation.

INTRODUCTION

The familiar suspension problem is suspension and dispersion of particles, which are heavier than liquid phase, into the main liquid phase. However, the glass particles should be dispersed into non-Newtonian aluminum-silicon alloy slurry fluid in high temperature during the preparation of glass aluminum based composite materials. The density of glass particles which used as dispersion phase is lower than that of aluminum-silicon alloy slurry. So the particles should be pulled into the matrix material. The fluid mechanics and transformation characteristics of solid and liquid flow are influenced directly by the movement behavior of solid particles. In the agitator bath, the interaction between solid particles and turbulence can cause momentum, heat, and mass transformation, making the flow more complex in the agitator bath. It is very difficult for traditional and theoretical research method to make clear the two phase flowing characteristic and interaction mechanism of the two phases. Besides, experimental research is always limited by measurement methods, costs a lot, and has a long research period. At present, the new research methods about two phase system flow are relaying the development of modern computer technology. Experimental researches on floating particles two phase flow are rare in home and abroad. The experimental research on floating particles system which can be searched is a series of research about water- polystyrene-compressed air three phase system[1-8]. This kind of research is mainly focused on their transparent and normal temperature situation. In this work, glass –semisolid aluminum-silicon alloy two phase flow is in high temperature and non-transparent situation. The turbulence structure of semisolid aluminum-silicon alloy slurry will vary with the different addition amount of glass particles. The variation of turbulence structure dominant the momentum and mass transformation of flow system, and influence the pulsation of semisolid aluminum-silicon alloy. The dispersion of mass and momentum of glass particles phase is influenced by impact of liquid turbulence pulsation on glass particles and the collision between glass particles.

In this study, mixed model in Eulerian multiphase fluid is used to forecast the macroscopic speed, temperature, pressure filed, temporal average velocity and viscosity distribution of glass-semisolid aluminum-silicon alloy slurry in the agitator bath of multi-layer agitator, and the effect of glass particles addition on flow filed is studied as well.

HYDROMECHANICS MODEL

Continuity equation[9-10]:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \bullet (\upsilon_m \vec{v}_m) = \dot{m} \quad \textbf{(1)}$$

Where $\vec{v_m}$ is the mass average speed, and ρ_m is mixture density.

Momentum equation

The momentum equation of mixed model is calculated by summation of momentum equation of each phase.

$$\frac{\partial}{\partial t}(\rho_m \vec{v}_m) + \nabla \bullet (\rho_m \vec{v}_m \vec{v}_m) = -\nabla p + \nabla \bullet [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}^T{}_m\, 0] + \rho_m g + \vec{F} + \nabla \bullet (\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k}) \quad \textbf{(2)}$$

Where n is the phase number, $\vec{F}$ is body force, and μ_m is mixture viscosity.

Relative slip flow speed

The relative slip flow speed is defined as the speed of secondary phase (p) with relative to the speed of main phase (q).

$$\vec{v}_{qp} = \vec{v}_p - \vec{v}_q \quad \textbf{(3)}$$

$\overrightarrow{v_{qp}}$ is the drift speed. The mixed model in FLUENT uses algebraic slip formula. The basic hypothesis of algebraic slip mixed model is stipulate the algebraic relationship of relative speed. The local balance of each phase should be reached in short space length scale.

Volume fraction of secondary phase

Volume fraction equation of p phase can be obtained from the continuous equation of p phase:

$$\frac{\partial}{\partial t}(\alpha_p \rho_p) + \nabla \bullet (\alpha_p \rho_p \vec{v}_m) = -\nabla \bullet (\alpha_p \rho_p \vec{v}_{dr,p}) \quad (4)$$

COMPUTATIONAL DETAIL AND SIMULATION MATERIAL FIELD

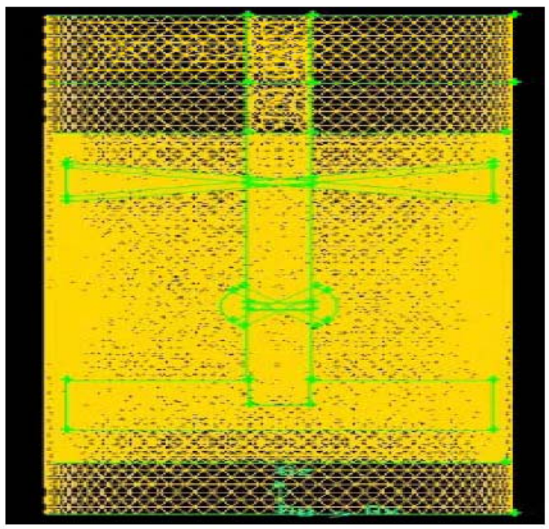


Figure 1: Grid model

For solid particle phase, the simulation material is glass particle, whose density ρ is 2500 kg/m^3, particle size is 80 mesh (180 μm), volume fraction is 13%, and temperature is 585 °C. The meshing area is divided into two parts: glass area, semisolid aluminum-silicon alloy slurry area, in which the semisolid aluminum-silicon alloy slurry area can further be divided into dynamic and static areas. The mesh model is shown as Figure 1.

SIMULATION RESULTS AND DISCUSSION

Macroscopic speed filed

The flow filed speed distribution diagram of cross section X=0 and Y=0 are shown in Figure 2 and Figure 3. Typical axial-flow type agitator blade flow type appears between the upper blade and free liquid surface. A circulating eddy current exists in the nearby area of semisolid aluminum-silicon alloy liquid surface, and the semisolid aluminum-silicon alloy liquid starts to turn to other direction before it reaches the liquid surface in the bath. Three circulating eddy current areas exist in the agitator blades, whose areas are smaller than the area between the upper blade and semisolid aluminum-silicon alloy free liquid surface. The flow speed of materials below the lower blade and semisolid aluminum-silicon alloy free liquid surface is extremely low, which is the dead zone of semisolid aluminum-silicon alloy liquid flow. The liquid in front of the 45 ° inclined blade agitator is continuously supplied to the bottom of the blade, forming a pressure difference between vertical and horizontal directions and new negative pressure zone. The liquid in front of the 45 ° inclined blade agitator flows along the blade and forms a large vortex at the longitudinal section. The liquid below the 45 ° inclined blade agitator flows to two different directions after blocked by the bottom of tank bottom: one direction is along the radial inwards, and is collected to agitator axis and flow upwards along the agitator axis. Then the liquid flows to the bottom of 45 ° inclined blade agitator. The other direction is along the radial outwards, and moves upwards along the agitator wall, in this way the radial flow forms convection and circulation in the agitator bath, the axial flow forms local secondary circulation in the agitator bath. And the mass and energy exchange of the two liquid phase take dominantly effect on mixture and dispersion of glass particles. The lower layer flat straight blade is a kind of radial flow agitator blade, forming bicirculating nowed forming in the flow field of agitator bath. Rotating paddle generates high speed radial jet in paddle area, which is divided into two parts by meeting the cell wall, one part flow upward along the cell wall, flowing downward along the stirring shaft to paddle area when reaching the liquid level of semisolid alusil alloy; the other part flow downward to cell bottom, and then flow upward to paddle area. Moreover, the 45°slanting agitator blade belongs to axial flow agitator blade, the flow field who generates in agitator bath has the typical "entirety circulation" flow form: the fluid speed up in paddle area, then move to cell bottom in jet flow form, upturning to cell wall, flow upward along the cell wall after hitting the cell wall, flow downward to paddle area when reaching the liquid level.

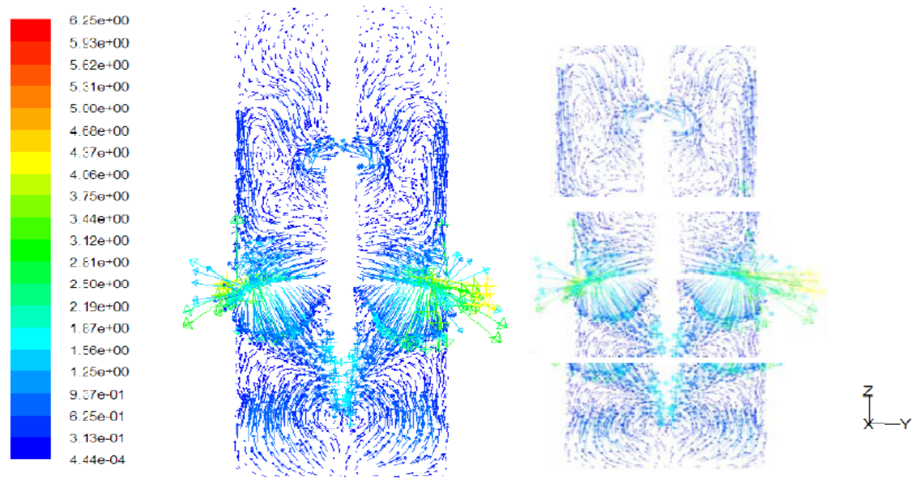


Figure 2: x=0 macro speed flow field diagram

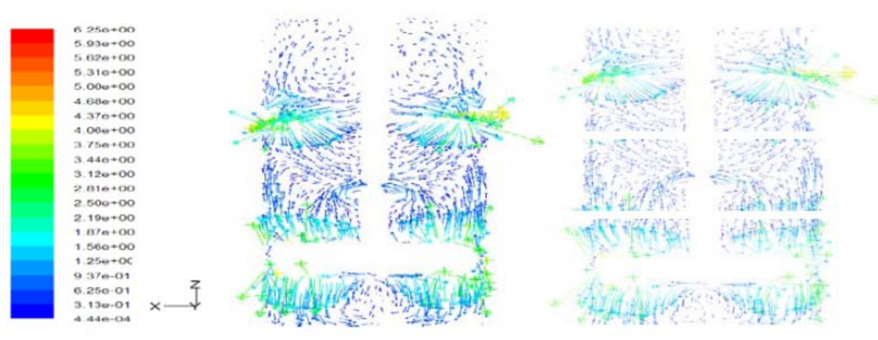
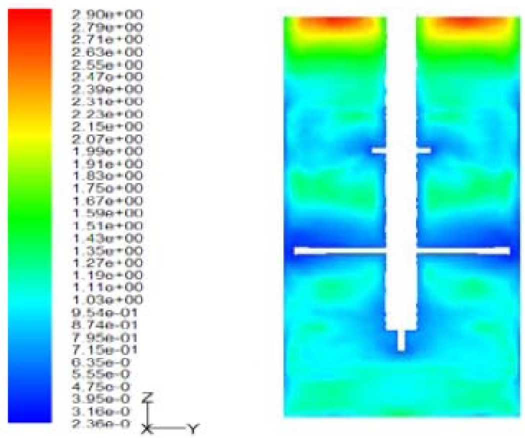


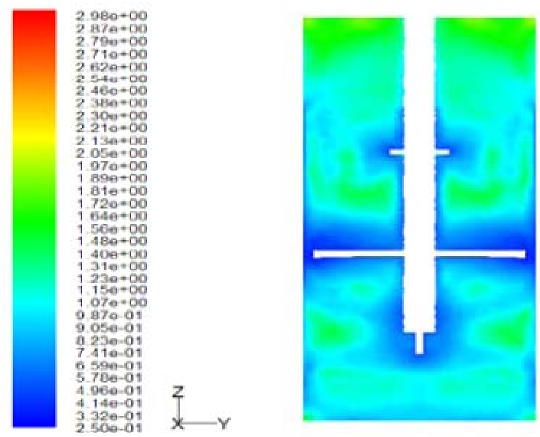
Figure 3: y=0 macro speed flow field diagram

Apparent viscosity distribution

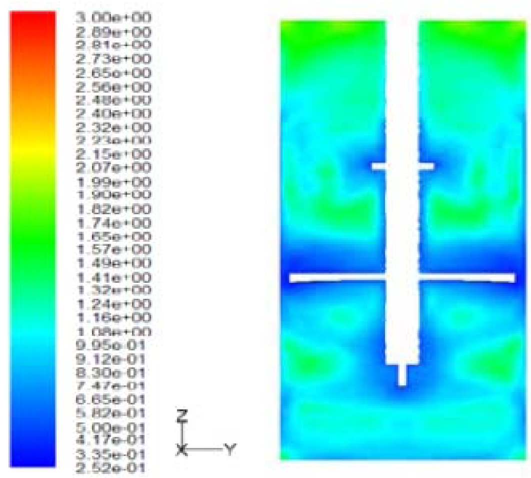
Figure 4 displays the viscosity contour diagram of two-phase system at different time. It can be seen that it is quite non-uniform in agitator bath. The shearing rate is high nearby the paddle, so the viscosity is the smallest. The far it is away from the paddle, the bigger viscosity is showing. Close to the liquid level, the speed gradient is smaller, the shearing rate is lower, and the apparent viscosity is higher. It is also shown in Figure 4 that the condition of apparent viscosity's non-uniform is decreasing by the adding of the glass particles and the stirring.



(a) t＝30s



(b) t＝120s



(c) t＝300s

Figure 4: Viscosity Contour diagram of two phase system at different time

Pressure distribution

Figure 5 shows pressure contour diagram of two phase system at different time. It is observed that the pressure distribution of two phase system at different time is unbalance, and the rule of the unbalance is the same. The stirring negative pressure is the largest in paddle exit, the pressure is decreasing by the adding of the glass particles.

Temperature distribution

Figure 6 shows temperature contour diagram of two phase system at different time. When t is 5s and 30s, temperature is the lowest in the middle of the upside, meaning that the temperature of the adding glass particles is far from the semisolid alusil alloy sizing agent. The temperature is the highest in the bottom of agitator bath, the plastic particles do not reach the bottom of agitator bath at the same time. With the increase of time, the temperature is getting non-uniform inside agitator bath. When t is 150s, the temperature is the lowest near upside of paddle, and the bottom temperature is the highest, showing that when glass particles get into upside agitator bath, at which time, most of them concentrate upon the upside paddle, making the temperature dropping. When t is 300s, the temperature is basically balance, the temperature is low only in individual place.

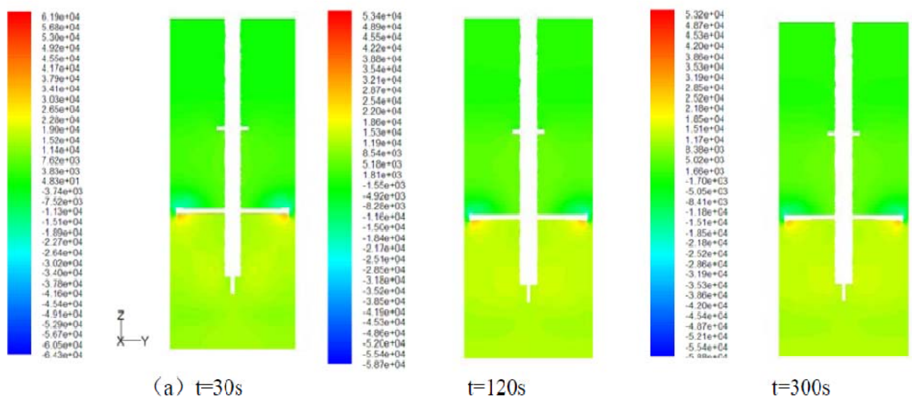


Figure 5: Pressure Contour diagram of two phase system at different time

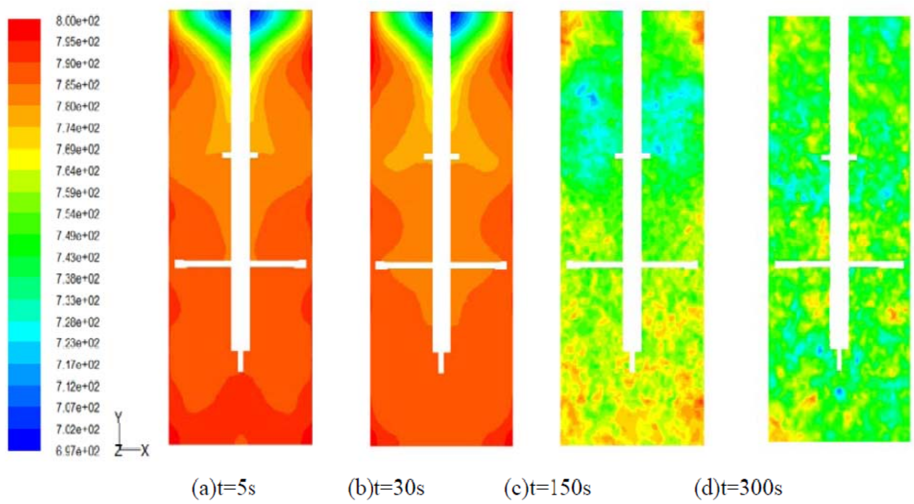


Figure 6: Temperature Contour diagram of two phase system at different time

Mean velocities distribution

The apparent viscosity has difference in different area of the two-phase system, making the difference of flow condition in different area. What's more, by adding the second phase plastic particles, the fluid viscosity increases, so the velocities distribution arise certain rule.

(a) Impeller area

Figure 7 shows speed distributing graph at different height of two phase system. Figure 8 shows axial speed distributing graph of two phase system. It can be seen from both figs that the main speed is radial and tangential; meaning the motion of the fluid in paddle area is radial and tangential motion. In Figure 7a and 8a, except the upward of substrate paddle, the change tendency of axial speed is in agreement, the highest axial speed appears in down and middle paddle area, the highest speed appears in the edge and paraxial. The edge change is the same in middle and up paddle. In Figure 7b and 8b, the change of down paddle radial speed is smooth, the highest speed also appears in the edge of paddle. The pattern of middle and up paddle is the same, so the change of upside edge is consistent. In Figure 7c and 8c, the tangential speed change is the highest in down paddle, the peak value is in the edge and wall side of paddle, which is beneficial in the dispersion of plastic particles.

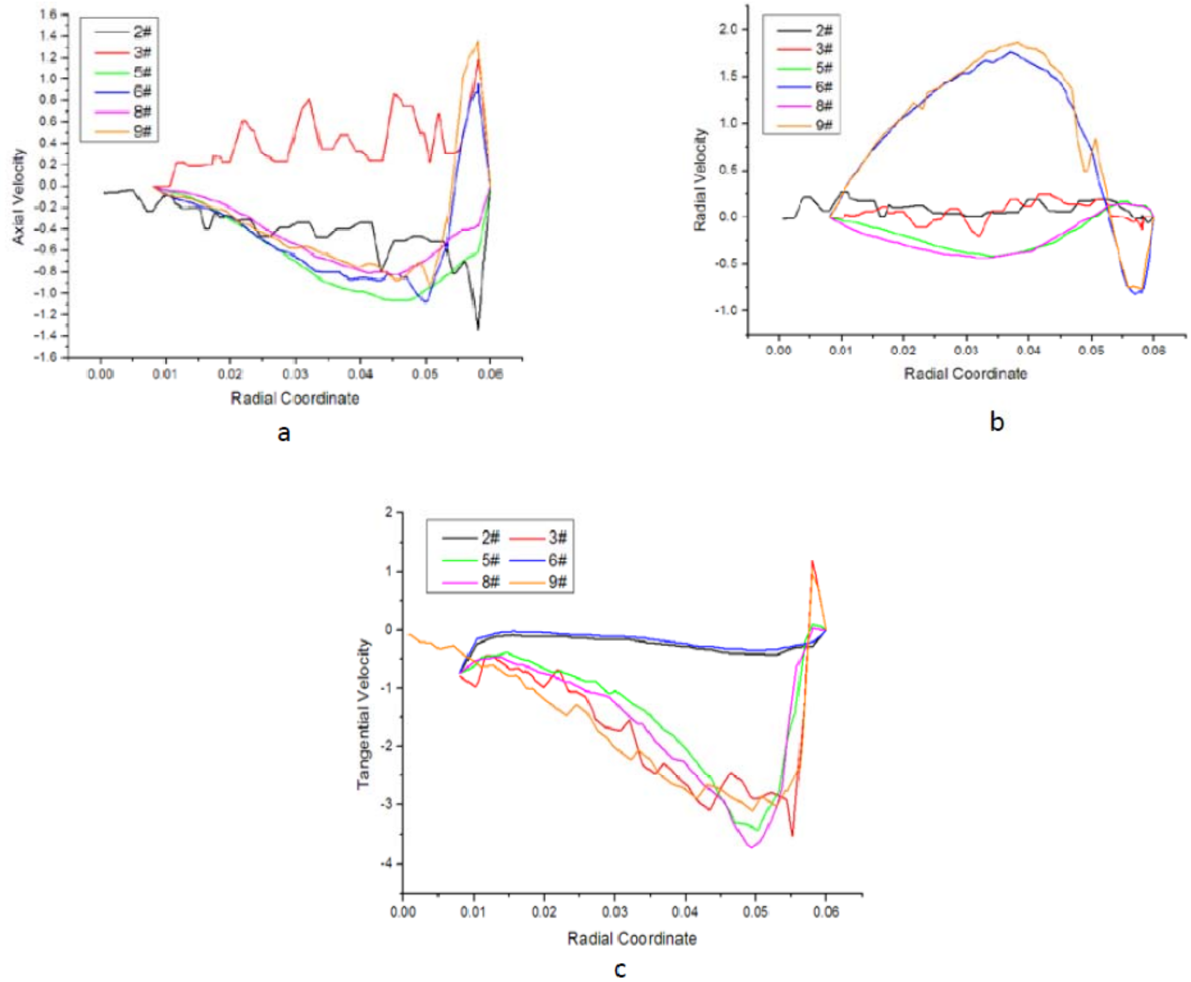
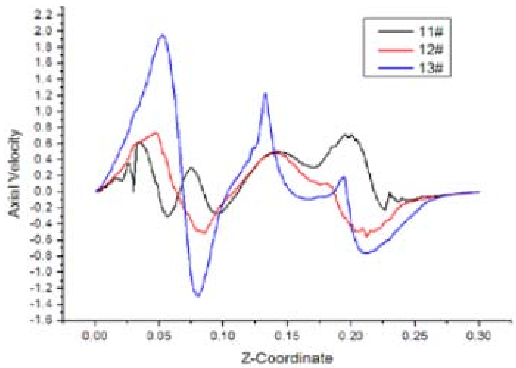


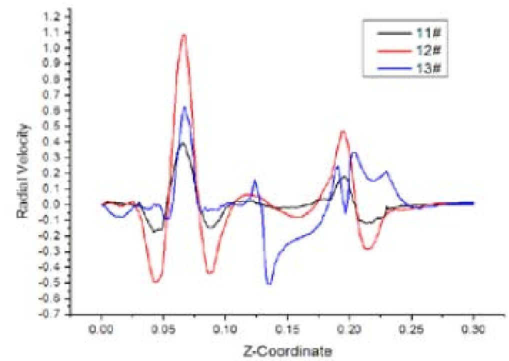
Figure 7: Speed distributing graph at different height of two phase system

(b) Circulation area

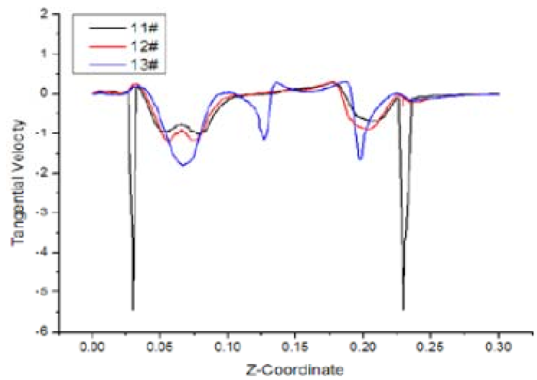
Figure 9 shows speed distributing graph at different height of two phase system in circulation area. It can be seen that due to the motion from top to bottom of plastic particles, the change of liquid level is higher than one phase non-Newtonian fluid. In Figure 8 and Figure 8, the axial speed is the highest in circulation area, so the motion is mainly in axial motion, which is consistent with one phase flow. In Figure 8a and Figure 9a, the axial speed change tendency is not consistent in paddles, there is axial speed up-and-down-ward in agitator bath, and the highest axial speed appears in the middle of middle and down paddles. In Figure 8b and Figure 9b, from free liquid level to down agitator paddle, except free liquid level, the radial speed change a lot among the paddles, meaning that the radial mixing effect of the material in the paddles is good. In Figure 8c and 9c, except the area between down and middle paddles, the rest area have the same tangential speed change, all of them is smooth, and the value is small, proving that the tangential motion is not obvious in circulation area. Compare the speed distribution of impeller and circulation area, we can see that the flow of two phases in agitator bath is mainly in axial, the axial speed of impeller area is smaller than in circulation area. From axial speed distribution, it can be seen that the back mixing area is produced in agitator, which is good for downward transportation of negative pressure area in the middle of plastic particles. The radial speed of the edge is higher than the stirring paddles, the radial speed change is smooth in down paddle, and high in middle and up paddles, reach the maximum in the up edge of middle and up paddles, and the radial back flow is large. The circumferential speed change is smooth in free liquid level, the rest part is large, and the maximum appears between the agitator and cell wall.



(a) axial speed

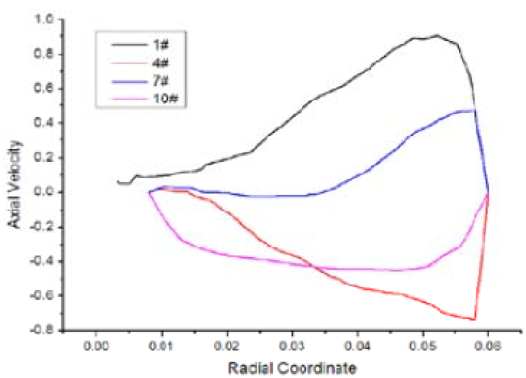


(b) radial speed

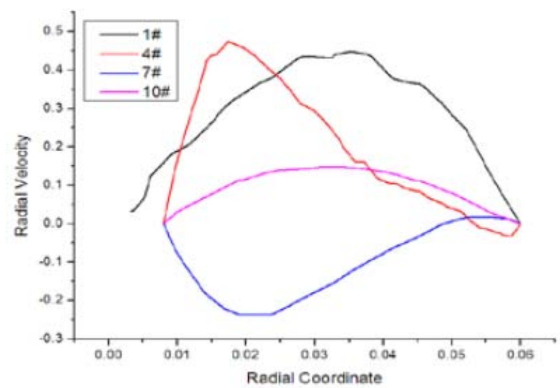


(c) circumferential speed

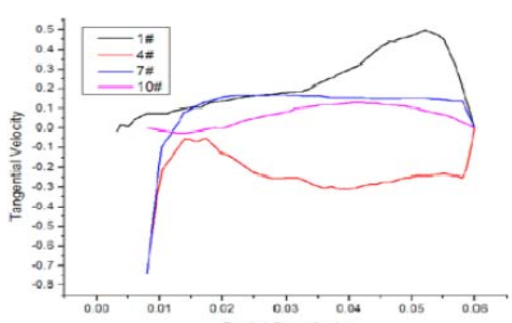
Figure 8: Axial speed distributing graph of two phase system



(a) axial speed



(b) radial speed



(c) circumferential speed

Figure 9: Speed distributing graph at different height of two phase system

EXPERIMENTAL RESULT

24 wt.% glass/ aluminum matrix composite is fabricated, the section scan photos is shown is Figure 10. It is observed that plastic particles distribute uniformly, the origination is dense, no obvious loosen and flaw appears.

Figure 10: Section Stereo scan photos of glass-based waste composite

CONCLUSION

In present, the study of self-floating particle system is not systematic compared with jetsam particle system, especially the distribution of elf-floating particle in high temperature non-Newtonian fluid should be enhanced. The research in this work shows:

(1) Analyzing from the simulated result, it is found that the downward pull produced by up paddle is beneficial for plastic particles entering from the surface into inside of alusil melt.

(2) Main circulation flow is formed in kettle, having a double circulation flow pattern, and it has advantage of decreasing the boundary thickness and death volume of this area

(3) Compared to experimental result, using CFD numerical modeling to study the heat and mass transportation in mixing process of pseudo-plastic fluid is viable, it can supply monition and temperature field of different stirring heat diffusion system as a whole, indicating the improvement of whole flow and the decrease of whole temperature.

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