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NUMERICAL MODEL OF SUSPENDING SOLID PARTICLES BY MEANS OF MIXING RADIAL TURBINES

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Abstract: *The random distribution of two or more phases (liquids, solids and/or gases) initially separated in order to form a homogenous phase is a process of special interest for industry. The equipment used to mix the phases are called agitators or mixers. The paper describes the numerical simulation of forced convection of one solid phase (titanium dioxide) through a fluid one (water) by an open mixing radial turbine. Using the Eulerian multiphase flow model one can gain an in-depth view of the mixing process allowing for the optimization of turbine's characteristics in order to minimize the time and power required to mix the separated phases into the homogenous one.*

Keywords: *mixing radial turbine, suspension, multiphase flow.*

1. INTRODUCTION

Mixers and agitators are simple tools used commonly in the chemical industry to mix initially separated phases using forced convection. A variety of mixer designs is available and one broad basis for classification is the viscosity of the phases.

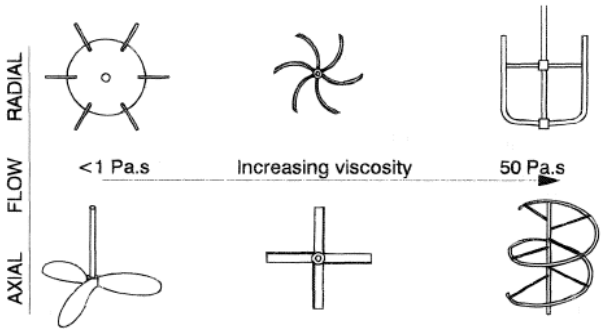

Figure 1 Flow based classification of turbines

Low viscosity phases are typically processed using small turbines while high viscosity phases will require larger designs. Other sources of classification are the way in which the turbine generates flow (shear stress or pressure) and the flow pattern they produce (axial, radial or tangential).

The paper describes the mixing process of titanium dioxide (TiO_2) with water using a low viscosity open mixer with 6 bladed radial turbine. The vessel diameter is D_t=240mm, equal to the water height H=240mm, the turbine is mounted with a bottom clearance E=24mm and its diameter is D_a=105mm. The blade's geometry (n=6) has W=40mm and l=15mm.

The 3D discretization of the computational domain consisted of three regions: one region filled with the secondary phase (titanium dioxide) at the bottom of the mixer with approx. 40000 tetrahedral cells, one region filled with the primary phase (water) with approx. 450.000 hexahedral and tetrahedral cells and one region around the turbine with 235.000 tetrahedral cells. This split allows us to use a rotating reference system for the

turbine region and to initialize the layer of TiO_2 at the bottom of the vessel.

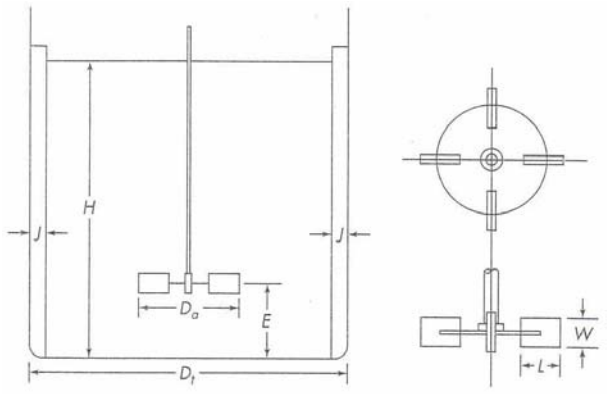

Figure 2 Measurements of the simulated mixer [1]

2. MULTIPHASE FLOW MODEL

Since we are interested in the time history of the mixing process we have chosen to compute the unsteady solution using a sequential solve for the flow equations. The Eulerian-Eulerian multiphase flow model used with the two phases (one liquid and one solid) uses a single pressure field for all phases and solves momentum, enthalpy and continuity equations for each phase and tracks volume fractions.

The volume fractions represent the space occupied by each phase and are defined by:

$$V_q = \int_V \alpha_q dV \text{ where } \sum_{q=1}^{n} \alpha_q = 1$$

The effective density of the phase q is:

$$\hat{\rho}_q = \alpha_q \rho_q$$

The conservation of mass equation for the phase q is:

$$\frac{\partial}{\partial t}\alpha_q \rho_q + \nabla \cdot \alpha_q \rho_q \vec{u}_q = \sum_{p=1}^{n} \dot{m}_{pq} \qquad (1)$$

where $\vec{u}_q$ is the velocity of phase q and $\dot{m}_{pq}$ is the mass transfer from phase p to phase q.

The conservation of momentum equation for phase q is:

$$\begin{aligned} &\frac{\partial}{\partial t}\alpha_q \rho_q \vec{u}_q + \nabla \cdot (\alpha_q \rho_q \vec{u}_q \otimes \vec{u}_q) = \\ &-\alpha_q \nabla P + \nabla \cdot \alpha_q \bar{\bar{\tau}}_q + \alpha_q \rho_q \vec{F}_q + \\ &+ \sum_{p=1}^{n} (R_{pq} + \dot{m}_{pq} \vec{u}_{pq}) \end{aligned} \qquad (2)$$

where $\bar{\bar{\tau}}_q$ is the phase q tensor given by:

$$\begin{aligned} &\bar{\bar{\tau}}_q = \alpha_q \mu_q (\nabla \vec{u}_q + \nabla \vec{u}_q^T) + \\ &+ \alpha_q (\lambda_q - \frac{2}{3}\mu_q) \nabla \cdot \vec{u}_q \bar{\bar{I}} \end{aligned} \qquad (3)$$

Here μ_q and λ_q are the superficial viscosity and the viscosity of phase q.

The conservation of enthalpy equation for phase q is:

$$\begin{aligned} &\frac{\partial}{\partial t}(\alpha_q \rho_q h_q) + \nabla \cdot (\alpha_q \rho_q \vec{u}_q h_q) = \\ &-\alpha_q \frac{dp_q}{dt} + \bar{\bar{\tau}}_k : \nabla \vec{u}_q - \nabla . \vec{q}_q + s_q + \\ &+ \sum_{p=1}^{n} (Q_{pq} + \dot{m}_{pq} h_{pq}) \end{aligned} \qquad (4)$$

where h_q is the specific enthalpy of phase q, $\vec{q}_q$ is the heat flux, s_q is a source term and Q_{pq} is the phase heat change intensity.

The Eulerian multiphase flow model was closed with the *k-eps* turbulence model and in the regions near the vessel's walls we applied the standard functions to avoid a finer discretization. Since the Stokes number is much smaller than 1 and the phase densities ratio is approx. 4, the kinetic energy of TiO_2 particles will be close to the water's kinetic energy allowing us to use the multiphase model of turbulent dispersion to the general *k-eps* model.

The gravitational effect was also considered by the definition of a $9.82 m^2/s$ acceleration about the -z axis.

3. RESULTS AND DISCUSSIONS

The mixing of the two phases was simulated with two different concentrations for the homogenous solution: 15% and 20%. The diameter of secondary phase particles was chosen 50μm, the superficial viscosity was

computed with the Syamlal-Obrien model and the granular viscosity with the Lun model. Given the agglomeration coefficient of 0.7 and the concentration of the secondary phase, we could calculate the height of the TiO_2 layer as 10mm for 15% and 16mm for 20%. The semi-empirical drag law model of Gidaspow was imposed for the interaction of the two phases.

The boundary conditions posed no problems for the vessel walls but a special treatment was applied to the fluid region around the turbine. To simulate the rotational effect, this region was defined in to a rotational reference system imposing 500rpm for the 15% concentration and 1000rpm for the 20% concentration.

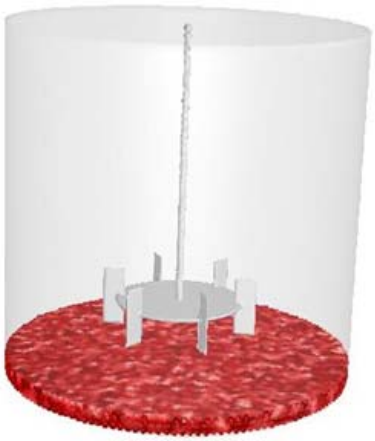

Figure 3 TiO_2 pigment layer at initialization

The unsteady solution was computed after the initialization of the stratified secondary phase: the fluid region from the bottom of the vessel was initialized with a 0.7 volume fraction of TiO_2.

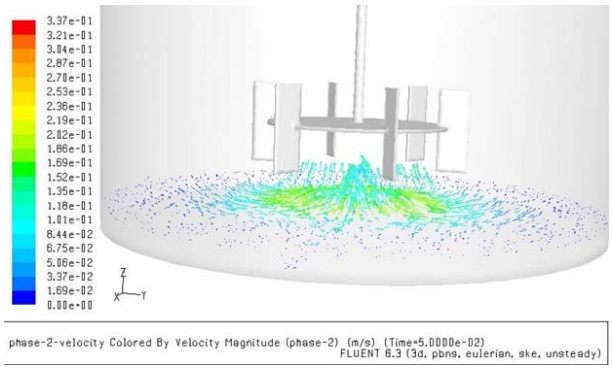

Figure 4 Velocity profile of water phase colored by velocity magnitude (t=0.05s)

The time step used to advance in time was chosen equal to 0.005s for the first 100 steps in order to avoid the divergence of the solution. Every 10 time steps, the solution was saved for post-processing. After the initial 100 steps, the time step was increased to 0.05s and the solution was monitored and saved every 2 time steps until homogenization.

In both cases, 15 seconds were sufficient for the total mixing of the phases. At 0.5 seconds after initialization one can visualize the particles of TiO_2 as they begin to mix with the water. The tangential motion of the water due to the radial turbine combined with the ascending current stir the TiO_2 layer and mixes it.

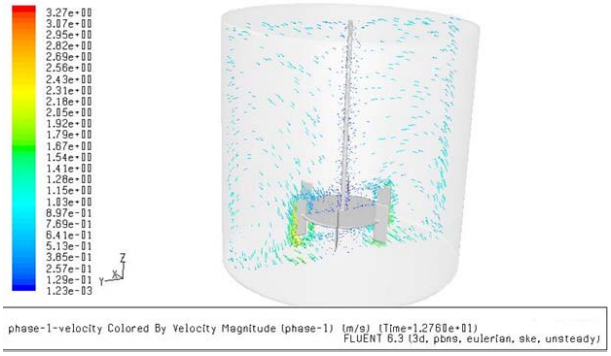

Figure 5 Velocity profile of TiO_2 phase colored by velocity magnitude (t=12.7s)

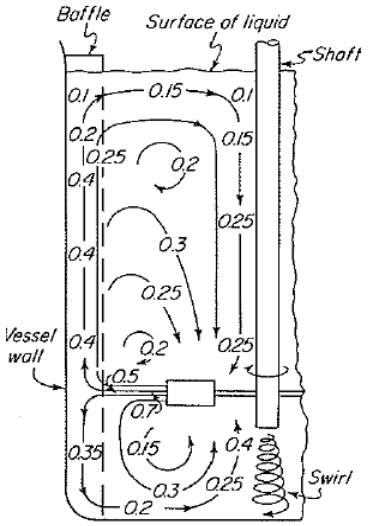

Figure 6 Velocity patterns in a turbine agitator [1]

In Figure 5 one can see that the volume of fluid circulated by the turbine is sufficient to sweep out the entire vessel in a reasonable time. Also, the velocity of the stream leaving the turbine is strong enough to carry the currents to the remotest parts of the vessel. The velocity of the fluid at any point has three

components: the radial component acts in a direction perpendicular to the shaft of the turbine, longitudinal component acts in the direction parallel to the shaft and rotational component acts in a direction tangent to a circular path around the shaft. The components that provide the flow necessary for the stirring action are the radial and the longitudinal ones.

Comparing Figure 5 with the velocity patterns in a turbine agitator published by Morrison (Figure 6), one can see that they are in good agreement.

Figure 7 shows the velocity pattern of liquid flowing radially from the blade. The radial velocity is a maximum in the plane of the middle of the blade and decreases towards the upper and lower edges. Computing the volumetric flow rate q with the formula:

$$q = K\pi^2 D_a^2 nW\,(1\text{-}k)\tan\beta_2' \qquad (5)$$

one can obtain the flow number N_Q defined as:

$$N_Q = \frac{q}{nD_a^3} \qquad (6)$$

For a standard flat-blade turbine N_Q may be taken 1.3.

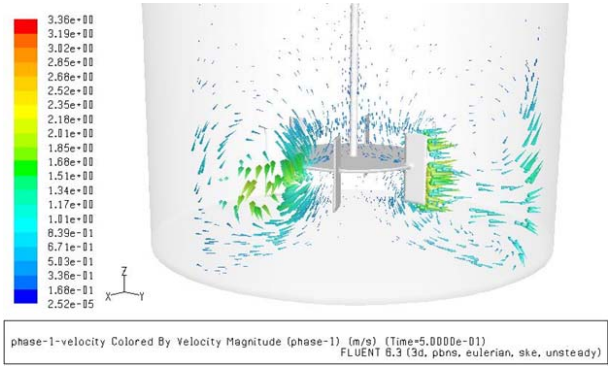

Figure 7 Velocity profile of TiO_2 phase colored by velocity magnitude (t=0.5s)

An important consideration in the design of a mixing vessel is the power required to drive the turbine. When the flow is turbulent, the power requirement can be estimated from the product of the flow q produced by the turbine and the kinetic energy E_K per unit volume of fluid. These are:

$$q = nD_a^3 N_Q \qquad (7)$$

and:

$$E_K = \frac{\rho(V_2')^2}{2g_c} \qquad (8)$$

In dimensionless form, the power requirement is given by the power number N_P:

$$N_P = \frac{Pg_c}{n^3 D_a{}^5 \rho} \qquad (9)$$

For the standard six-bladed turbine N_P=5.2.

To conclude, the numerical model described above can be used to design new tanks and turbines for the mixing processes. At the same time one can optimize the design by visualizing the flow pattern, the quality of the mixing and by minimizing the time and the power needed to homogenize two or more separate phases.

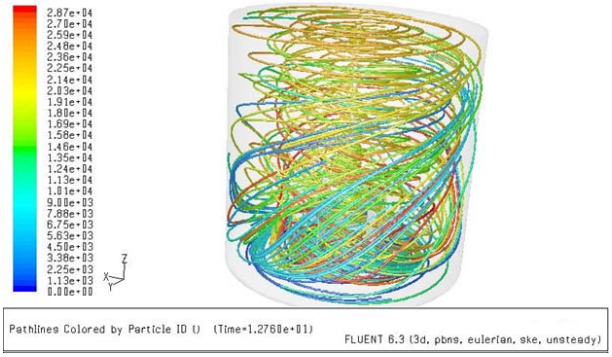

Figure 8 Pathlines colored by particle ID (t=12.7s)

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