Numerical Simulation Study of Self-rotary Blade Pipeline Mixers

Yang LU and Yang-lin LI
Taizhou Polytechnic College, China

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Abstract. According to the requirements of the online mixing, the new type of blade spin-rotary pipe mixer was designed innovatively and the feature of mixer was analyzed by the numerical simulation method. The result shows that the features of mixer with small size, simple structure, small pressure loss, easy maintenance and good mixing effect meet the usage requirements of online mixing.

Introduction

The mixing is the important working process of plant protection machinery, environmental machinery and food machinery, and it is the development trend for the online mixing with the big advantage on the space and time. It use the way of metering pump or use computer to control the mixing amount at home and abroad to get a stable mixing ratio [1]. But it usually required the additional mechanical stirring for the well-distributed mixture of liquid and media, and this method which has a complex structure and is easy to cause pollution, has the large pressure loss with the maximum value of 30~40%. The medium in the pipeline (usually is water) is mixed non-uniformly. The simulation results show that working medium like emulsion is outstanding in this phenomenon [2, 3]. The solution of different liquid nozzle usually cause toxicity on the one side, while on the other side is not enough for the protection due to the uneven mixture in the practice of plant protection machinery. Therefore, it has a great significance to develop the online mixing mechanism in the plant protection, food, environment and other fields [4, 5].

The Structure of self-rotary Pipeline Blade Mixers

According to the situation above, a self-rotary blade pipeline mixer is designed as a auxiliary device, and it is showed in Fig.1. The main working part in the pipe is the rotor which has the leaf inclined with axis line(inner circle generation).The blade was set in the skewed slot of the rotor inside(by the line cutting processing), and it is fixed by the straddle nail. The rotor is supported by the axial ball. The two shell is connected by the screw thread and both side of the shell is connected with the pipe. The rotor and the pipe have the same internal diameter.

During the work, the fluid flows through the blade self-rotary pipeline mixer. As the blades have a certain angle, the blade is rotated automatically under the dynamic pressure, and the sucked liquid moves along the circumferential and radial direction, so as to achieve the aim of mixing[6].

Figure 1. Structure of on line pipeline mixer.
In most machinery, the small fall pressure, simple structure and low cost were required besides the uniformly mixing process. In order to optimize the structure, it is required to study the influence of various parameters to the mixing uniformity, pressure loss and their influenced rule.

**Self-rotary Pipe Mixer Modeling Blade**

The study of flow field of self-rotary blade pipeline mixer can adopt three methods at present, and there are experimental method, theoretical calculation and numerical simulation.

Fluent numerical simulation was adopted at first in this paper. In order to assure the accuracy of the mathematical model, mixing effect of the varicus parameters was verified, and then the mixing effect of various parameters was studied so as to achieve a better result.

**The Mesh of Blade Self-rotary Pipeline Mixer**

Cylindrical coordinates system is adopted in the paper. Take the circumferential direction of the mixing chamber(in radials) as x coordinates, the radius direction as y coordinate, and the axis direction as Z coordinates. The divided mesh is shown in Fig.2, and the number of node is 4450-6000.

![Figure 2. Mesh generation of the mixer.](image)

**The Entrance and Boundary Conditions**

<table>
<thead>
<tr>
<th>Name</th>
<th>Flow Condition</th>
<th>Source of Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import</td>
<td>Pipeline flux=0.056kg/s</td>
<td>External environment</td>
</tr>
<tr>
<td>export</td>
<td>pressure=0.0 pa</td>
<td>not applicable</td>
</tr>
<tr>
<td>Pipe wall</td>
<td>not applicable</td>
<td>not applicable</td>
</tr>
</tbody>
</table>

Based on the boundary condition as shown in tab.1, the flow belongs to three-dimensional flow.

**Governing Equation**

Each differential control equations were gained in the Cartesian coordinate. Xi (i = 1, 2, 3) represented the three coordinate components of Cartesian coordinate and ui (i = 1, 2, 3) represented the three velocity components of Cartesian coordinate respectively. x, y, z represented the three coordinate components of Cylindrical coordinates, and u, v, w represented the three velocity components of Cylindrical coordinates respectively[7,8,9].

Correspondence between the two kind of coordinates is:

\[ x = \arctan(X_2/X_1) \]  \hspace{1cm} (1)

\[ y^2 = X_1X_2 + X_2, \quad z = X_3 \]  \hspace{1cm} (2)

1. Continuity equation:
\[ \frac{\partial u_i}{\partial t} = 0 \]  

\[ u_i \cdot \frac{\partial u_i}{\partial x_j} = f_i - \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{1}{\rho} \frac{\partial}{\partial x_i} (\rho u_i u_j) \]  

(3)

2. Momentum equation:

\[ \frac{\partial \phi}{\partial t} + u_j \frac{\partial \phi}{\partial x_j} = K \frac{\partial^2 \phi}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j} (\rho u_j) + r \frac{\partial u_j}{\partial x_j} \]  

(4)

3. Energy transport equation

\[ \frac{\partial \phi}{\partial t} + u_j \frac{\partial \phi}{\partial x_j} = K \frac{\partial^2 \phi}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j} (\rho u_j) + r \frac{\partial u_j}{\partial x_j} \]  

(5)

\[ \phi \]—Where, \( \phi \) is the average amount of energy of time;  
\[ r \] is the pulse energy.

As well as the volume of the source term and gravity of the fluid, the molecular transport items and viscous forces was omitted in these formulas.

In order to solute these equations, the Reynolds stress \((\rho_{u}, u)\) and energy flux should \((\rho', r')\) be determined, thus the standard k-ε turbulence model was introduced, that is:

\[ \frac{\partial}{\partial x_j} \left[ \rho u_j k - \left( u + \frac{u_j}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] = \rho (p_k - \varepsilon) \]  

(7)

\[ \frac{\partial}{\partial x_j} \left[ \rho u_j \varepsilon - \left( u + \frac{u_j}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] = \rho \frac{\varepsilon}{k} (C_1 p_{\varepsilon} - C_2 \varepsilon) \]  

(8)

Where,  
\[ p_k = \frac{u_j \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j}}{\rho} \] is the production term of the turbulent kinetic energy,  
\( C_u, \sigma_k, \sigma_\varepsilon, C_1, C_2 \) is the Turbulence model coefficients.  
\( C_u = 0.09, \sigma_k = 1.0, \sigma_\varepsilon = 1.3, C_1 = 1.44, C_2 = 1.92 \)

Simulation Results Analysis

According to the numerical simulation equation, some flow field data could be gained, such as pressure, velocity field and concentration field. Since the concentration is connected with the pressure, velocity, the mixing effect is related with the pressure and velocity.

The Trajectory of Liquid in the Mixer

The most important parameter in the mixer is blade angle. Due to influence of the pipeline structure, the big blade angle is difficult to process. In order to fully description the questions of the mixer, the blade angle is took as 3 degrees, 5 degrees, 8 degrees, and the change of the flow field is observed.

![Figure 3. Trajectory of Pesticide in mixer.](image-url)
The trajectory was shown in Fig. 3. When the fluid is through the mixer, it is restricted by the mixing element and the diversion, confluence and rotation is produced, which lead to uniform mixing.

Meanwhile, it is obvious that the possibility of the fluid movement in the pipe diameter is lower with a smaller blade angle. Figure 3 respectively represent the trajectory of the angle with 3 and 5, and when the angle is 5, the trajectory in the radial motion is significantly greater than that when the angle is 3 degrees.

**The Velocity of Liquid in the Mixer**

The mixer mechanism is not the same as the laminar flow and the turbulence. During the laminar flow, static mixer regularly effects on the fluid to achieve the mixing, repeating the action of "Segmentation - displacement- re-convergence". During the turbulence, in addition to the above effect, because of the eddy current generated by the fluid in the flow section, the small portion of the fluid is further divided to mix.

Based on the Kinematics Law, the fluid velocity determines its trajectory, and the trajectory motion determines the mixing ability. Therefore, the difference speed reflects the mixing quality.

![Figure 4. Velocity field distribution of Pesticide in mixer.](image)

Calculating based on table.1, with the blade angle increasing in different sections, the speed difference is also improving with the linear growth, indicating that with the increase of the angle of the blade, the mixing effect is also improved in the linear growth.

**The Pressure of Liquid in the Mixer**

Due to the power of the plant protection machinery is moving and the working condition is general in the field, the machinery is driven by the diesel engines or other engines. The power (in essence that is energy) is very valuable. The pump pressure is an important indicator of the parameters in the plant protection machinery, and the higher the pressure is, the larger the cost is. So it often requires smaller pressure drop when design the mixer.

![Figure 5. Pressure distribution(the blade angle is 3).](image)
From the axial and radial pressure distribution, because of the effect of the mixer’s blade, the pressure distribution in the radial direction tends to equilibrium, indicating that the middle liquid flows to circumferential with a constant pressure. Meanwhile, due to the continuous spin of the blade in the axial direction, the surrounding liquid will not keep single axial movement, and the liquid rotate on the radial. The liquid flowing into mixing field from the surrounding is sucked by the jet pump. Therefore, the liquid mainly rotate radially and mix with the middle liquid to achieve the aim. The simulation results show that the pressure loss is greater with a bigger blade angle. The mixing quality is higher when the blade angle is bigger [9].

But overall, we can see the pressure drop of the self-rotary blades pipe mixer is too small, related to the dynamic or static mixer in the chemical industry. For plant protection machinery, the pump pressure usually about 2.0MPa, and nozzle pressure is between 1.0 and 1.2 MPa, the rest is the loss of pipe and mixing. Above all, $10^{-4}$MPa loss is acceptable, and this loss can be ignored to the whole system, which is the biggest advantage of the mixer.

With the blade angle increasing, the pressure loss increases gradually. But the bigger blade angle have a greater mixing effect.

**Conclusion**

In this paper, a large eddy annular, which could make the fluid stirring fully in the mixer and strengthen the effect, can be seen between the blades from the velocity distribution. From the pressure distribution, it can be seen in Fig.5 that the fluid swirl is strengthen behind the blade, which is considerable. It is obvious that it is caused by the strong shear flow in this region from Fig.4. The coincident position of high concentration gradient region and high turbulence intensity region means that it can effectively enhance the turbulent mixing effect and such kind of mixer can allocate the energy to the place where the liquid mixes.

The discussion results show that the numerical calculation and the design is consistent, and static blade self-rotary pipeline mixer is reasonable.

**References**


