Study on installation of the submersible mixer

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Abstract: Study on installation of the submersible mixer for sewage treatment has been limited. In this article, large-scale computational fluid dynamics software FLUENT 6.3 was adopted. ICEM software was used to build an unstructured grid of sewage treatment pool. After that, the sewage treatment pool was numerically simulated by dynamic coordinate system technology and RNG k-ε turbulent model and PIOS algorithm. Agitation pools on four different installation location cases were simulated respectively, and the external characteristic of the submersible mixer and the velocity cloud of the axial section were respectively comparatively analyzed. The best stirring effect can be reached by the installation location of case C, which is near the bottom of the pool 600 mm and blade distance the bottom at least for 200 mm wide and wide edge and narrow edge distance by 4:3. The conclusion can guide the engineering practice.

1. Introduction
In recent years, China has attached more and more importance on the environmental protection, so sewage treatment plants are built every day. As a result, as the primary equipment for fluid stirring, sewage treatment mixer has been growing in demand for the sewage treatment in agriculture, industry and so on.

The installation location and angle are very important for the submersible mixer in the pool. The stirring effects are different if the installation location and angle are not the same. The author has deep study for the installation angle of the submersible mixer before, but there is no reference in engineering practice nowadays, for nobody has made such research at home and abroad. This article will study and analyze the installation location to determine the best installation location of the submersible mixer.

2. Model
As is shown in Fig. 1, WJ0.75-4-210 is the sewage treatment mixer, and the impeller is two-blade stainless steel impeller. The diameter for the blade is D=200 mm, and for the hub is d₀=70 mm. When
numerical stimulation, the motor outline is simplified as a cylinder with diameter \(D = 144\) mm, length \(l = 300\) mm.

![Figure 1. Model](image)

![Figure 2. Installation position diagram](image)

The pool without a lid, length×width×height = 5000 mm×4000 mm×2000 mm, is composed of installation face, opposite face, wide edge face, narrow edge face and the bottom. To suspend the activated sludge, the sewage treatment mixer is installed in the central part or below that. The four locations A, B, C, D are chosen, as is shown in Fig. 2: A is the most central part; B is the center of installation face 600 mm away from the bottom (the distance from stirring axis and bottom is 600 mm); C and B are installed on the same height, in the location of wide edge and narrow edge distance by 3:4. D is installed below C, 200 mm in height away from the bottom.

3. Numerical simulation setting

3.1 Calculation equation

In calculation, the fluid is set as water with density \(\rho = 1000\) kg/m\(^3\) in normal temperature 25º and pressure.

Equation of continuity

\[
\frac{\partial u_i}{\partial x_j} = 0
\]  

(1)

\[
\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_j^2} + \rho f_i
\]  

(2)

Renormalization group (RNG) \(k-\varepsilon\) turbulence model equation

\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho k u_i)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \alpha_i \mu \frac{\partial k}{\partial x_j} \right] + G_k + \rho \varepsilon
\]  

(3)

\[
\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho \varepsilon u_i)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \alpha_i \mu \frac{\partial \varepsilon}{\partial x_j} \right] + \frac{C_{\mu}}{k} G_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k}
\]  

(4)

\(i,j = 1,2,3;\) \(t\) is time; \(\frac{\partial u_i}{\partial t}\) is non-stationary term; \(\mu\) is dynamic viscosity; \(u_j \frac{\partial u_i}{\partial x_j}\) is convection term; \(\mu \frac{\partial^2 u_i}{\partial x_j^2}\) is diffusion term; \(f_i\) is mass force; \(C_{\mu} = 1.42\) is empirical constant; \(C_{2\varepsilon} = 1.68\) is empirical constant; \(k\) is Turbulent Kinetic Energy, m\(^2\)/s\(^2\); \(\varepsilon\) is dissipation rate, m\(^2\)/s\(^3\); \(G_k\)
is the output of Turbulent Kinetic Energy generated by average velocity gradient\(^{[3-17]}\).

3.2 Grid independence analysis
Because the blades of sewage treatment mixer have been twisted seriously, and the sizes of stirring impeller and pool vary considerably, this article adopted Gambit large-scale grid software to generate the tetrahedron and hexahedron hybrid grid in order to improve the adaptivity and enhance the work efficiency. The value of \(y^+\) is set between 30~500, which is to ensure the validity of wall-function method. To study the influence of grid node to numerical simulation result, this article has selected five different hybrid grid with different grid nodes, as is shown in Table 1, and compared the external characteristic parameters of the sewage treatment mixer.

| Table 1. Unstructured grid parameters |
|--------------------------------------|
| Simulation | mesh 1  | mesh 2  | mesh 3  | mesh 4  | mesh 5  |
| area       | (ten thousand) | (ten thousand) | (ten thousand) | (ten thousand) | (ten thousand) |
| blade      | 49.9    | 49.9    | 92.5    | 92.5    | 153.4    |
| pool       | 65.8    | 166.1   | 166.1   | 213     | 277.7    |
| whole      | 115.7   | 216     | 258.6   | 305.5   | 431.1    |

Figure 3. External characteristic parameters Figure 4. Error analysis

From the curves in Fig 3 and Fig 4, we can easily find that grid quantity affects the computed result, and the prediction of external characteristic for the five grids was basically consistent with the experimental results, but with slight difference. From Table 3, we can know as the increase of grid, the calculated hydraulic thrust and torque are close to the experimental value, and Grid 4 and Grid 5 have been consistent with the test values. From Table 4, we can know that the relative error of the predicted hydraulic thrust, torque is within 5%. With overall consideration, this article will select Grid 4 to conduct numerical simulation.

3.3 Boundary Conditions
Because the impeller of sewage treatment mixer is stainless steel, the stirring axis and blades are set as non-slipping wall boundary condition, and roughness is 0.25mm; the pool face is cement face, roughness is 0.5mm; the rotate speeds of stirring blade and axis are the same as that of motor. The contact surface of inside and outside subdomains is set as interface to ensure the intercouple of inside and outside subdomains in calculation\(^{[3-17]}\).

4. Numerical simulation comparison

4.1 External characteristic
From Table 2, for case C, the average velocity of pool fluid is the highest, and for case A, case B and case D, the average velocity is about 0.25m/s, while for case C, the average velocity is the highest, to 0.27m/s. The sequence of the efficiency of the sewage treatment mix is C>A>D>B, and the efficiency
of case C is the highest.

|        | thrust/ | torque/(N-m) | Average velocity/(m/s) | efficiency/ |
|--------|---------|--------------|------------------------|-------------|
| Case A | 293.8   | 9.85         | 0.2508                 | 55.38147    |
| Case B | 300.75  | 10.59        | 0.2502                 | 53.35013    |
| Case C | 299.34  | 10.03        | 0.2736                 | 55.93314    |
| Case D | 281.5   | 9.31         | 0.25                   | 54.65939    |

4.2. Flow field analysis

As is shown in Fig. 5, the zone in the pool, in which the fluid’s velocity is below 0.05 m/s, where fluid cannot be fully stirred, is called dead zone.

![Figure 5. Dead zone](image)

Fig. 6 is the velocity nephogram perpendicular to axial section of the bottom in case A and case D. Fig. 7 is the velocity nephogram parallel to axial section of the bottom in case A and case D.

To compare the axial section velocity nephogram in case A and case D, we can find that fluid rotates through the stirring impeller and obtains certain velocity to rush out the exit, and forms a red cylindric high velocity zone along the axial location, while the fluid velocity of other parts in the pool is much lower than that of this region. As the thrust of the sewage treatment mixer, the cylindric high velocity zone appears to migrate first to the bottom and narrow edge and then uplift, which may be related to the action of gravity and wall attachment effect. From Fig. 6 and Fig. 7, we can easily observe that in case C, the fluid velocity is well distributed and the number of dead zones and their areas are the least.

![Figure 6. Velocity nephogram](image)

![Figure 7. Velocity nephogram](image)

To combine the analysis and comparison of Table 2, Fig. 6 and Fig. 7, we can know, the sewage treatment mixer is installed according to case C. Thus, the stirring efficiency is the highest, the average
velocity in the pool is the highest, and the fluid stirring is the most balanced, that is, the stirring effect is the best.

5. Conclusion

Through the comparison of the numerical simulation results, this article comes to the conclusion that the sewage treatment mixer should be installed according to case C, that is axis should be near the bottom of the pool as 600 mm and blade distance from the bottom at least for 200 mm, and wide edge and narrow edge distance by 4:3. Thus the best stirring effect can be reached. The conclusion can guide the engineering practice.

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Reference

[1] Yan J H, Huang D J and Teng G R 2009 Journal of Anhui Agricultural Science 37 (20) 9606-07 (in Chinese)
[2] Shi W D, Tian F and Chen B 2011 Transactions of the Chinese Society for Agricultural Machinery 42(3) 96-99 (in Chinese)
[3] Zhang D S, Shi W D, Wang C, et al 2012 Journal of Drainage and Irrigation Machinery Engineering 30(2) 167-170
[4] Chen B, Zhang K W, Shi W D, et al 2011 Journal of Drainage and Irrigation Machinery Engineering 29(5) 437-440
[5] Tian F, Shi W D, Chen B, et al 2011 Fluid Machinery 39(1) 1-4 (in Chinese)
[6] Tian F, Shi W D, et al 2009 Simulation and experiment of water thrust of wastewater-treatment mixer Conf. on Computational Intelligence and Software Engineering (Wuhan, China, 11-13 December 2009)
[7] Tian F, Shi W D, et al 2010 Study on installation position of sewage treatment mixer ASME FEDSM2010 (Montreal, Canada, 1-5 August 2010)
[8] Tian F, Shi W D, et al 2011 Mixing Performance of Sewage Treatment Mixer at Different Rotational Speed ASME IMECE (Denver, Colorado, 11-17 November 2011)
[9] Zhang Q H, Tian F, et al 2010 PRZEGLAD ELEKTROTECHNICZNY 88(9B) 70-74
[10] Shi W D, Tian F, et al 2012 Journal of Advanced Manufacturing Systems 11 91-97
[11] Shi W D, Zhang L, Chen B, et al 2012 Journal of Drainage and Irrigation Machinery Engineering 30(3) 260-5
[12] Shi W D, Sun X Q, Lu W G, et al 2011 Journal of Drainage and Irrigation Machinery Engineering 1 6-12
[13] Li W, Shi W D, Zhang H, et al 2012 Journal of Drainage and Irrigation Machinery Engineering 30(2) 176-180
[14] He Z G 1999 Journal of Dalian University of Technology 39(6) 807-870
[15] He Zigan, Rodi W and Frohlich J 2006 Journal of hydrodynamics A 15(2) 191-201
[16] Tian F, Shi W D, et al 2012 Study on Velocity Distribution in a Pool by Submersible Mixers
[17] Shi W D, Tian F, et al 2012 *Applied Mechanics and Materials* **197** 18-23