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Research on Flow Field Distribution and Structure Improvement of Gravity Sedimentation Tank Contained Polymer Sewage in Oilfield

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ABSTRACT

Gravity sedimentation tank is the key equipment in the process of sewage treatment in oilfield, whose separation performance has a significance in the treatment effect of sewage. In order to analyse the distribution of flow field in gravity sedimentation tank, the 1200m^3 gravity sedimentation tank contained polymer sewage in oilfield was simulated. The distribution characteristic of three-dimensional flow in the tank is given. Then through the analysis of fluid trace distribution and the droplets movement, the non-uniformity of the flow field in the tank and existence of swirl flow and back mixing flow are discovered. On the basis of mentioned above, taking the oil removal efficiency as the evaluation index, the structure of liquid distributing device of gravity sedimentation tank is improved. It makes the oil removal efficiency increased by 8.4%.

INTRODUCTION

Considerable oily sewage, which will be produced during the development of oil field, needs to get standard treatment before reinjection to maintain formation pressure. To do so, not only the environment damage of sewage will be prevented, but also the utilization of water resources will be improved. The conventional sewage treatment process of oilfield is the "twice-sedimentation and one time filtering". Gravity sedimentation tank is a separating device which works with the difference of oil-water density. As the first process of sewage treatment process, it has many advantages, such as simple structure, large treatment volume etc. With the popularization of polymer flooding technology, it comes some problems of sewage, such as the polymer concentration is large in aqueous phase, viscosity is high of sewage, oil-water separation is more difficult etc. So the separation efficiency of gravity sedimentation tank is low, resulting in excessive load effect of filter tank and affected the quality qualification rate of filtered water. The complex flow field of gravity sedimentation tank is one of the critical factors that decide the separation performance, however it is a weak link in the present research.

Yaojun Lu etc. analysed the interaction among the droplets, the droplet profile, the internal circulation for the effect of droplet movement in the gravity oil-water separation equipment from the point of theory. They put forward plug flow model, transverse mixing model and back mixing model of oil-water gravity separation, revealed the relationship among separation efficiency, the device structure, working conditions and properties, established the calculation model of efficiency and equipment of oil-water gravity separation. Major components of oil-water gravity separation test model were screened by using particle image velocimetry (PIV) and image processing program (Lu et al. 1993, Lu & Xue 1999, Lu & Pan 1994, Lu et al. 1994).

However, experimental study has the disadvantages of high investment, long period, in contrast, numerical simulation technology has the advantages of less investment, high computing speed. It can reveal flow field comprehensive in-depth and thus improving the structure and greatly shortening the development time. It has important engineering value. A.Tamayol etc. conducted the flow field simulation and optimization of structural parameters of settling tank (Tamayol et al. 2008, Brennan 2001, Flamant et al. 2004, Fujisaki & Terashi 2007). Cullivan J. C. etc. conducted flow field simulation and optimization of structural parameters of hydrocyclone (Cullivan & Williams 2004, He et al. 1999, Sehuetz et al. 2004, Avci & Karagoz 2003). This paper conducted a study of flow field and structure about the gravity sedimentation tank with numerical simulation on the reference of the study.

THE NUMERICAL SIMULATION METHOD

Physical model: Taking 1200m^3 volume of gravity sedimentation tank as the prototype, whose inlet height is 12m, outlet height is 1.5m, the diameter of tank is 10.31m, height of tank is 14.39m. It is necessary to simplify the internal structure and the establishment of the physical model is shown in Fig. (1). The discrete grid is shown in Fig. (2).

The Mathematical model: Basic control equation of the mixture model:

1) The continuity equation

$$\frac{\partial}{\partial t}(\rho_m)+\nabla\cdot(\rho_m\overrightarrow{v_m})=0 \qquad ...(1)$$

Where v_m is mass average velocity of the mixture,

$$\overrightarrow{v_m}=\frac{\sum_{k=1}^{n}\alpha_k\rho_k\overrightarrow{v_k}}{\rho_m};$$

ρ_m is mixture density,

$$\rho_m=\sum_{k=1}^{n}\alpha_k\rho_k;$$

α_k is volume fraction of the k phase.

2) The momentum equation

Add all single-phase momentum equation to obtain mixture momentum equation . Its expression is:

$$\frac{\partial}{\partial t}(\rho_m\overrightarrow{v_m})+\nabla\cdot(\rho_m\overrightarrow{v_m}\overrightarrow{v_m})=-\nabla p+\nabla\cdot[\mu_m(\nabla\overrightarrow{v_m}+\nabla\overrightarrow{v_m}^{T})]+ \rho_m\vec{g}+\vec{F}+\nabla\cdot(\sum_{k=1}^{n}\alpha_k\rho_k\vec{v}_{dr,k}\vec{v}_{dr,k}) \qquad ...(2)$$

Where $\vec{F}$ is volume force; μ_m is the viscosity of the mixture,

$$\mu_m=\sum_{k=1}^{n}\alpha_k\mu_k;$$

$\vec{v}_{dr,k}$ is the drift velocity of the k phase; n is the number of phase.

3) Volume fraction equation of the second phase

From the continuity equation of the second phase, the second phase volume fraction equation is obtained:

$$\frac{\partial}{\partial t}(\alpha_p\rho_p)+\nabla\cdot(\alpha_p\rho_p\vec{v}_m)=-\nabla\cdot(\alpha_p\rho_p\vec{v}_{dr,p}) \qquad ...(3)$$

4) The relative (slip) speed and drift velocity

The relative sliding velocity is the velocity difference between the speed of the minor phase (p) and the main phase (q), namely:

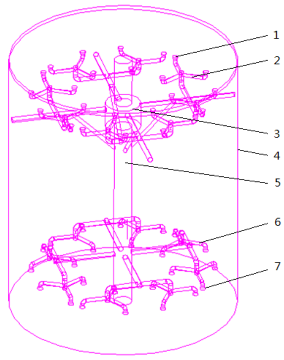


Fig. 1: Physical model.
1-inlet, 2-liquid distributor,
3-liquid distribution bucket,
4-wall, 5-center cylinder,
6-water collecting pipe, 7-outlet

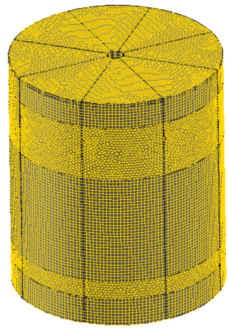


Fig. 2: Discrete grid.

$$\vec{v}_{qp}=\vec{v}_p-\vec{v}_q \qquad ...(4)$$

The relationship between the drift velocity ($\vec{v}_{dr,p}$) and the relative velocity ($\vec{v}_{qp}$) is:

$$\vec{v}_{dr,p}=\vec{v}_{qp}-\sum_{k=1}^{n}\frac{\alpha_k\rho_k}{\rho_m}\vec{v}_{qk} \qquad ...(5)$$

5) Two-phase same time interval flow equations

$$\frac{\partial\rho_m}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho_m\mu_{m,i}\right)+\frac{\partial}{\partial x_i}\left(\overline{\rho'_m\mu'_{m,i}}\right)=0 \qquad ...(6)$$

$$\begin{aligned}\frac{\partial}{\partial t}(\rho_m\mu_{m,j})+\frac{\partial}{\partial x_i}(\rho_m\mu_{m,i}\mu_{m,j})=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}\mu_m\left(\frac{\partial\mu_{m,i}}{\partial x_j}+\frac{\partial\mu_{m,j}}{\partial x_i}\right)+\rho_m g_j+F_j\\ +\frac{\partial}{\partial x_i}(\alpha_o\rho_o\mu_{Do,i}\mu_{Do,j}+\alpha_w\rho_w\mu_{Dw,i}\mu_{Dw,j})-\frac{\partial}{\partial x_j}\left(\overline{\rho\mu'_{mj}\mu'_{m,j}}\right)\\ -\frac{\partial}{\partial x_j}\left(\overline{\rho'_m\mu'_{m,i}\mu'_{m,j}}\right)-\frac{\partial}{\partial x_j}\left(\mu_{m,j}\overline{\rho'_{mj}\mu'_{m,i}}\right)-\frac{\partial}{\partial x_j}\left(\mu_{m,i}\overline{\rho'_{mj}\mu'_{m,j}}\right)\end{aligned} \qquad ...(7)$$

$$\frac{\partial}{\partial t}(\alpha_o\rho_o)+\frac{\partial}{\partial x_i}(\alpha_o\rho_o\mu_{m,i})+\frac{\partial}{\partial x_i}\left(\overline{\alpha'_o\mu'_{mj}}\right)=-\frac{\partial}{\partial x_i}(\alpha_o\rho_o\mu_{Do,i}) \qquad ...(8)$$

The definite conditions: The treatment capacity of gravity sedimentation tank is 150 m³/h. The oil volume concentration at the inlet of tank is 5%. Oil density is 866 kg/m³. Oil droplets diameter is 35μm. The viscosity of polymer-contained sewage is 1.5 mPa·s, when it is 40°C. The boundary condition of inlet is velocity-inlet. The boundary condition of outlet is outflow. The wall boundary is no slip solid wall.

Solution method: Based on the finite volume method, the

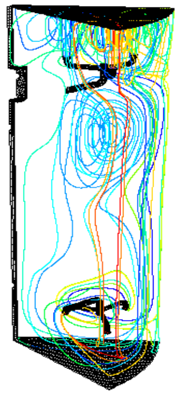


Fig. 3: Trace lines.

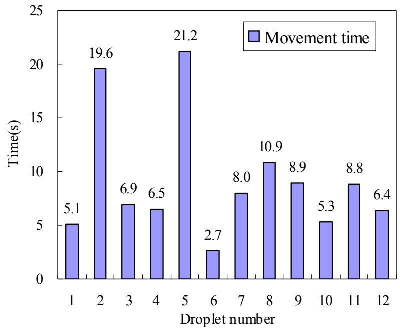


Fig. 4: Movement time.

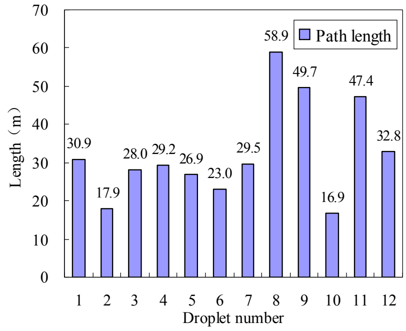


Fig. 5: Path length.

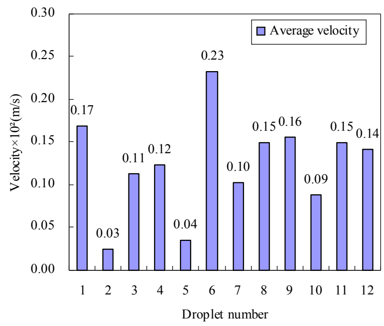


Fig. 6: Average velocity.

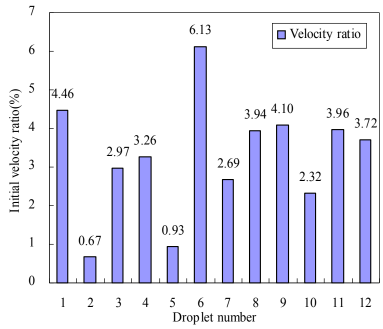


Fig. 7: Ratio of velocity decay.

control equation was transformed into algebraic equations that can be solved by numerical method. According to the unsteady state characteristics of the problem, SIMPLE algorithm is used for the pressure-velocity coupling. For the space discretization, diffusion term is with two order accuracy central difference scheme, QUICK format is used in the discretization of the convection term. The first order implicit scheme is used in the time discretization to ensure the accuracy and improve the computational efficiency. Because a large number of calculation grid and algebraic equations, the multigrid method is used to solve equations.

RESULT ANALYSIS

Trajectory: As is shown in the Fig. (3), it is the trace line picture inside the gravity sedimentation tank. Droplets enter into the tank from the inlet with a vertical upward speed which deposit under the gravity and flow out of the tank from the outlet. The flow field inside the gravity sedimentation tank is disorder. Swirl flow and back mixing is formed below the liquid distributor and in the middle region of the tank. The vertical settlement track is only a fabulousness.

Movement distance and time: Twelve droplets are chosen randomly for the research of flow characteristics. As shown in the Fig. (4), time distribution is varied with different droplets. The droplet 5 stay in the tank for 21.2 hours which is the longest time while the droplet 6 stay the shortest time for only 2 hours. These droplets should stay in the tank for 8 hours in theory. Therefore, not all the droplet is influenced by the method of settling time improvement and the reduce of handling capacity.

As shown in the Fig. (5), the path length of all the droplets are longer than the vertical height 14.39 m, which is the height of the gravity sedimentation tank. The droplet 8 has the longest length for 58.9 m. These explain that the droplet has rotation movement and back mixing movement. In other words, it forms a swirl inside the tank. The droplet 5 and droplet 8 have the longest time and the longest path length respectively, but their movement time and movement distance is out of proportion. These explain the existence of back mixing flow and swirl flow. As shown in Fig. (6) and Fig. (7), different droplets have different average velocity. The biggest difference can reach one order of magnitude. This has a big attenuation compared with the initial velocity.

Flow field analysis: ***Observation point selection:*** Fig. (8) shows the gravity sedimentation tank local cross section. Three adjacent inlets are named into in1, in2, in3. Taking the inlet of in1, in3 as an example, 6 vertical lines are chosen with a same distance between them. The vertical line starts at the tank bottom (0m high) and end in the free surface (14.39m) and there are 20 points with equal interval on it. A dashed line is shown in Fig. (8) to analysis the flow

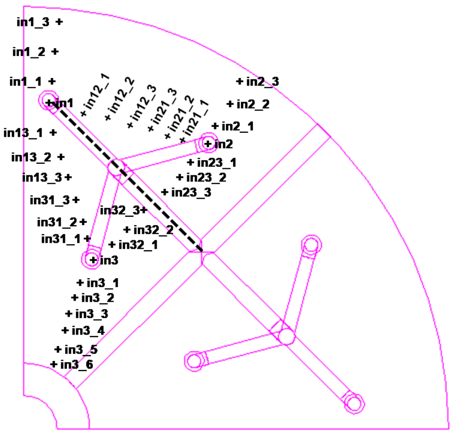
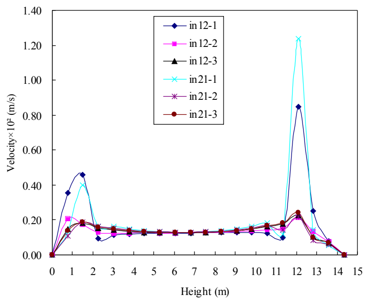
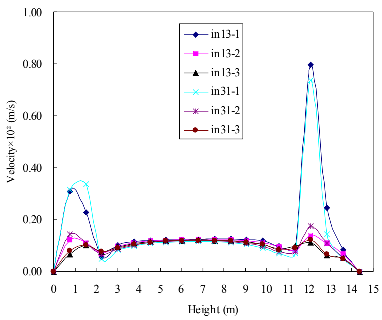


Fig. 8: Location of the observation points.



(a) in1-in2



(b) inl-in3

Fig. 9: Whole flow field.

field of settling region, which is between the liquid distributor and water collecting pipe.

Whole flow field: As is shown in Fig. (9), the height of inlet and outlet of gravity sedimentation tank, where the flow speed is higher than other places, are respectively 12m and 1.5m. The speed present two peaks in the curve, relatively speaking, the section of the middle vertical velocity changed little. The speed of points in the vertical lines slow down with the increase of the inlet horizontal distance and the fall range of speed is smaller and smaller. It is the velocity of two high-speed region of inlet and outlet flow that decreases most obviously.

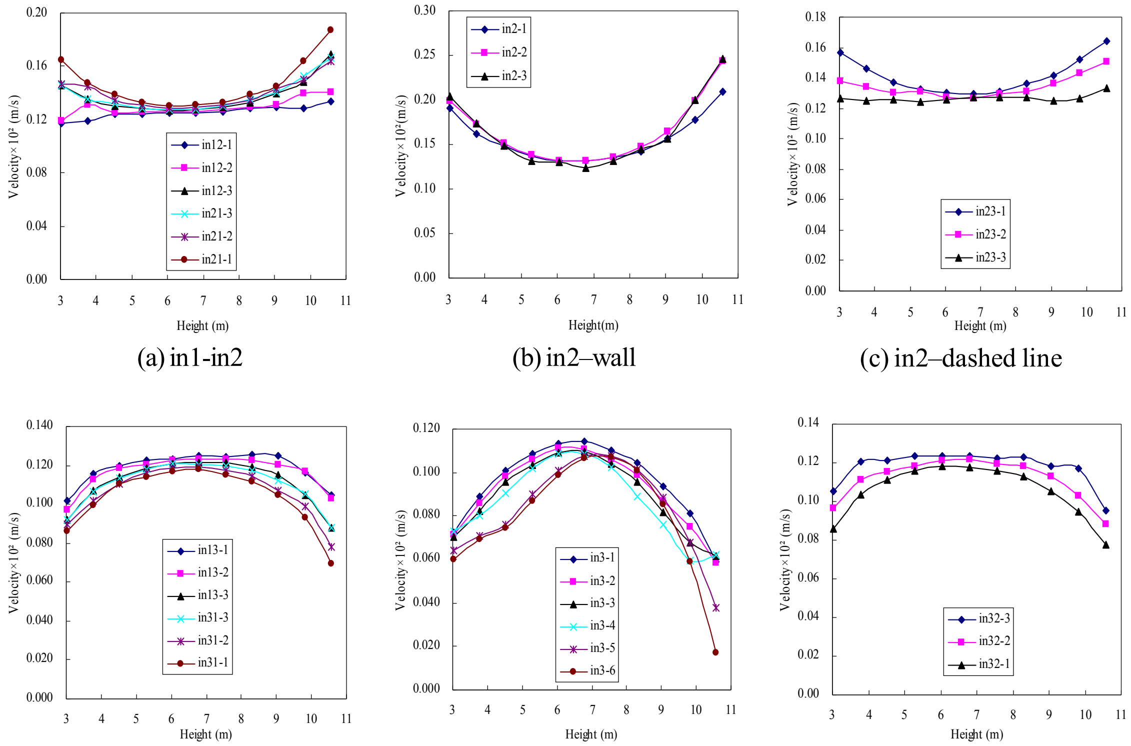
Settling region flow field: The settling region is important for gravitational separation. As is shown in the Fig. (10), the rule of the speed changing on vertical line at the same region of the dashed line is the same, while the rule of the speed changing on vertical line at both sides of the dashed line is opposite. The speed of sewage between the dashed line and the wall of the tank is higher than the one between the dashed line and the centre cylinder on the whole. A large amount of the sewage is settlement in the area between the dashed line and the wall of the tank, which is consistent with the performance of the trace lines relatively dense close to the wall of tank and trace lines relatively sparse near the centre of the cylinder, so the flow field in the gravity sedimentation tank is non-uniformity.

The aqueous phase concentration distribution: Fig. (11) is the aqueous phase concentration distribution picture, which is through the inlet of the longitudinal profile. The colours in the picture show the distribution of different concentration of the aqueous phase. Oil and water are separated under the action of gravity, water is deposited in the bottom of the tank. Compared with the inlet, the volume concentration of aqueous phase increase from 95% to 98%. Oil droplets floating on top of the tank transform into oil layer, the volume concentration of oil phase increase from 5% to 28%.

The low oil concentration on top of the tank shows that with the application of polymer flooding technology, the polymer increases the viscosity of aqueous phase, the droplet coalescence is difficult. So it is not conducive to the accumulation of oil layer and the oil-water separation effect is poor. The oil removal efficiency is only 59.3%. There is oil-water accumulation phenomenon on the upper and lower end faces of cylindrical liquid distribution bucket and around the liquid distributor and water collecting pipe where the location of low speed zone.

STRUCTURE IMPROVEMENT

Based on the evaluation index in oil removal efficiency, a set of structure improvement plan of gravity sedimentation tank liquid distributing device is put forward to get uniformity distribution of sewage and improve the flow field in the tank. The improved liquid distribution device structure is shown as Fig. 12. The structure of liquid distributor is changed from plum blossom shape to two laps inside and outside. There are some inlets above it at equal distance. The shape of liquid distribution bucket is changed from cylinder to truncated cone. The other structures and size of the tank remain the same, so as the physical parameters and operating conditions.



(a) in1-in2 (b) in2–wall (c) in2–dashed line

(d) in1-in3 (e) in3-center cylinder (f) in3–dashed line

Fig. 10: Velocity distribution of settling region.

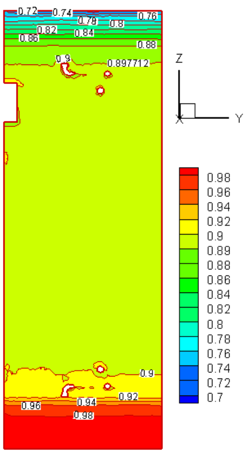


Fig. 11: Aqueous phase concentration distribution.

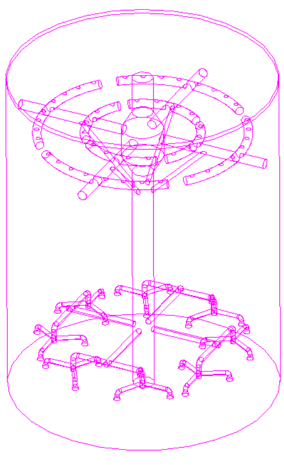


Fig. 12: Physical model of the improved tank.

Fig. 13: Trace lines of the improved tank.

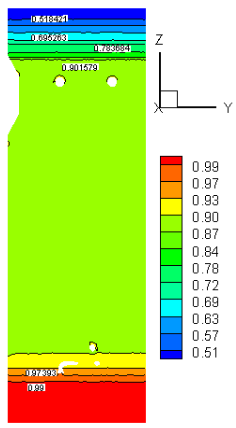


Fig. 14: Aqueous phase concentration distribution of the improved tank.

As is shown in the Fig. 13, compared with the prototype structure, the density of trace lines in the improved tank is uniformity. As the effect of flow liquid, there is only slight swirl flow at the inlet, the trace lines in settling region is straight. The flow field is relatively stable, conducive to the separation of oil and water..

Fig. (14) is the aqueous phase concentration distribution picture of the improved tank, which is through the inlet of the longitudinal profile. The shape of liquid distribution bucket of improved tank is truncated cone, there is hardly the phenomenon of oil-water accumulation. Compared with the prototype tank, the aqueous phase concentration on top of the tank is lower, while it is higher in the lower body. It shows that the improved gravity sedimentation tank has a better separation effect. Oil is accumulated well on top of the tank, water deposit at the bottom of the tank steadily. In the same physical parameters and operating conditions, the oil removal efficiency of the tank increases from 59.3% to 67.7%.

CONCLUSION

1. This paper establishes the physical model and mathematical model of fluid flow in the gravity sedimentation tank contained polymer sewage whose volume is 1200m^3. Based on the finite volume method, SIMPLE algorithm is adopted to the calculation of multiphase flow of gravity sedimentation tank model.
2. Through the analysis of droplet movement distance, movement time and average speed, the movement of droplet is disordered. The movement distance and time of different droplets are different and they are not proportional. The movement distance of all the droplets are longer than the height of the tank, 14.39 m. This explains that the droplet has rotation movement and back mixing movement.
3. As is shown in the trace lines picture, we find that the flow field in the tank is not uniformity. The swirl flow and back mixing flow which are formed below the liquid distributor or in the middle region of the gravity sedimentation tank. Through the analysis of the settling region which is between the liquid distributor and water collecting pipe. The speed of sewage between the dashed line (Fig. 8) and the wall of the tank is higher than the one between the dashed line and the centre cylinder on the whole. A large amount of the sewage is settling in the area between the dashed line and the wall of the tank.
4. The oil-water accumulation phenomenon on the upper and lower end faces of cylindrical liquid distribution bucket and around the liquid distributor and water collecting pipe where is low speed.
5. The structure of gravity sedimentation tank is improved. The structure of liquid distributor is changed from plum blossom shape to two laps inside and outside. There are some inlets above it at equal distance. The shape of liquid distribution bucket is changed from cylinder to truncated cone. The improved structure greatly improves the phenomenon of oil-water accumulation of the tank and the flow field is relatively stable. Under the selected condition, the oil removal efficiency of the tank increases from 59.3% to 67.7%.

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