De-oiling Test of New Type Cyclone for Treatment of Wastewater Containing Polymer

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Abstract. When the polymer concentration in the produced fluid increases, the viscosity of the sewage will increase, the overall flow velocity of the fluid in the cyclone will decrease, the kinetic energy will decrease, the wall friction resistance will increase, and the tangential velocity will decrease overall. The performance of the cyclone is degraded. The structure and parameters need to be adjusted and optimized. By optimizing the design of the structure and parameters of the inlet fluid channel, the oil-receiving port, etc., a new type of oil-water cyclone is designed. Numerical experiments show that the new type of oil-water cyclone is effective for the separation of low oil content of polymer-containing sewage. Through indoor experiments and on-site pilot scale-up, 5# cyclone was modified with a new type of oil-water cyclone in the West II Joint Processing Station. The field test and production daily report data show that the improved 5# cyclone is effective. The polymer-containing sewage treatment can obtain stable results. The oil content of the effluent is better than the original cyclone indicator. When the oil content of the polymer-containing sewage at the inlet is 100-300mg/l, the average oil content of the outlet is less than 100mg/l, Meets the design requirements, indicating that the improved cyclone structure and parameters are suitable for the treatment of polymer-containing sewage, and the newly designed cyclone is effective for the treatment of polymer-containing wastewater.

1. Introduction

West II Joint Processing Station is a comprehensive station that combines functions of oil and gas separation, crude oil dehydration, sewage treatment, and sewage re-injection. It is responsible for the separation of incoming liquid oil, gas, and water, as well as sewage treatment and re-injection. The produced water treatment system is located on the north side of the joint station. The five hydro-cyclone separators put into use in 2000’s are used for oily sewage treatment, with a processing capacity of 13000 m³/d, and the oil content in the liquid sewage can be about 300ppm in the future. Reduced to below 100 mg/l. With the increase in liquid production and changes in development methods, the concentration of incoming liquid gradually rises, and the viscosity of sewage increases, which increases the difficulty of treatment. The performance of the five hydro-cyclone separators decreases and the oil removal ability deteriorates. In addition, due to a series of reasons such as changes in the composition of the oily wastewater and the wear and tear of the original equipment, the current wastewater treatment capacity in the station has declined, and the water quality is deteriorating. Therefore, it is necessary to introduce new technical measures, transform the original cyclone separator, and use the new cyclone separation technology to treat polymer-containing sewage.
Hydro-cyclones are the key equipment for oil-water separation. Due to the increase in the viscosity of the polymer-containing sewage, its performance is significantly reduced. Many scholars have also carried out research on the influence of different media viscosities on the cyclone field. Ren et al. [1], Murthy et al. [2] Through numerical calculations, it is found that the maximum static pressure at each cross-section of the cyclone shows a decreasing trend as the viscosity of the continuous phase increases. The decrease in static pressure is related to the decrease of the tangential velocity of the fluid. Poor performance when viscous mixed media. Aiming at the high viscosity of the produced fluid, Xu Baorui and others designed a three-phase separation cyclone for gas, liquid and sand [3, 4]. Numerical calculations and experimental studies found that when the viscosity increased to 15mPa•s, the demanding efficiency decreased significantly. When the viscosity increases, the overflow pressure drop of the cyclone will decrease, and the underflow pressure drop will increase. Yang Lin et al. [5] and Jiang Minghu et al. [6] separately studied the cyclone separation of polymer-containing sewage and produced fluid. The results showed that the tangential velocity decreased with the increase of viscosity, while the axial velocity and radial velocity the relative change is small.

This paper analyzes the physical parameters of sewage, optimizes the design and numerical simulation of the structural parameters of the inlet flow channel, the oil-receiving port, etc., first conducts indoor tests, then on-site pilot tests, and finally transforms the original separator. The problem of the on-site wastewater containing polymer is solved. The on-site test results show that the equipment is operating normally after the transformation and the effect is good.

2. Dopy principle of cyclone separator

The cyclone separator uses centrifugal force to separate oil and water, and the stable flow rate and pressure difference ratio can form a stable oil-water envelope surface, thereby obtaining a stable oil-water separation effect. The cyclone separator mainly uses centrifugal force to separate oil and water. The centrifugal force is as follows:

\[ F = (\rho_w - \rho_o) V r \omega^2 \]

Where:
- \( r \omega^2 \) - centrifugal acceleration
- \( \rho_w \) - water density
- \( \rho_o \) - oil density
- \( V \) - tangential speed.

![Figure 1](image.png)

Figure 1. Schematic diagram of structure of the cyclone.

Figure 1 shows the structure diagram of the cyclone, which is mainly composed of the inlet of the cyclone, the column section, the cone section, the underflow port and the overflow port. The separation process of the cyclone is when the oily sewage enters the tangential direction from the inlet after the cyclone, the fluid is forced to make a top-down rotational movement (external swirl), using the density difference between oil and water. The greater the density, the greater the centrifugal force it receives, and the water phase is thrown toward the inner wall. It spirally moves downwards along
the wall and flows out from the bottom orifice. Due to the uneven pressure distribution in the radial direction when the liquid generates a high-speed rotating flow field, the closer to the axis, the smaller the pressure, and the vicinity of the axis becomes a low pressure area, which causes the dirty oil to move in the axial direction, and the overflow port of the swirl cavity. The (oil outlet) is in the low pressure area, and the dirty oil moves to it, thus forming an upward rotating movement (inner swirling flow), the dirty oil is discharged from the overflow port, and finally the effect of oil-water separation is achieved.

The calculation grid of the cyclone tube adopts a hexahedral structured grid. The total number of grids is 578160, and the maximum grid skewness is 0.44. When the flow calculation is stable, when the oil outlet split ratio is 3%, 5% and 10% respectively, the oil content of the water outlet of the cyclone tube is 170ppm, 131ppm and 68ppm respectively; the oil removal rate of the cyclone tube is about 40.8%, 55.35% and 78.1%; among them, when the oil outlet split ratio is 10%, the maximum pressure loss of the cyclone tube is 55kPa. Figure 2 shows the contour distribution color map of the volume phase holdup of the oil phase in the cyclone tube when the split ratio of the oil outlet is 10%.

3. Numerical simulation calculation and analysis of swirl tube

According to the calculation requirements, a single cyclone tube selects a processing capacity of 5m³/h, in which the main pipe diameter is 10-40mm, the inlet is 4×20mm, the top oil outlet pipe diameter is 8mm, and the bottom lateral water outlet pipe diameter is 12mm. According to site requirements, the calculated fluid physical parameters include oil density of 940kg/m³ and viscosity coefficient of 50mPa•s; water phase density of 1000.2kg/m³ and viscosity of 1mPa•s; oil content of the mixed liquid is 300mg/l. The diversion ratios of the oil collection port are set to 3%, 5% and 10%; the corresponding diversion ratios of the water outlet are respectively 97%, 95% and 90%.

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![Figure 2](image-url)  
*Figure 2.* When the split ratio of the oil outlet is 10%, the contour color map of the volume phase holdup of the oil phase in the cyclone.

(Respectively the upper section A, middle section B and lower section C of the cyclone tube)

The calculation results and analysis show that as the oil outlet split ratio increases, the oil content of the bottom water outlet gradually decreases; when the oil outlet split ratio reaches 10%, the oil
content of the bottom water outlet drops to within 70 mg/l, indicating that the current cyclone tube is used for processing. The oil-water separation of sewage with low oil content is effective.

4. Field test

The field test was carried out in the West II Joint Processing Station of Dagang Oilfield. The effluent quality of the 2000m³ oil-water settling tank was used as the inlet water quality of the hydro-cyclone sewage treatment system. The temperature was 35°C, the oil content of the sewage was 200-300mg/l, and the polymer concentration content was 20-60 mg/l, oil density 921.8kg/m³, oil viscosity 191.6(35°C) mPa.s, belongs to low pour point and low viscosity crude oil, incoming liquid water salinity is 6240mg/l, there are 5 hydro-cyclones in total on site, named as 1#, 2#, 3#, 4#, 5#. Among the 5 cyclones, because the 5# cyclone has the worst treatment effect, so the 5# cyclone was selected as the sample for this test. The object is to improve the 5# cyclone’s processing performance, and use a new type of cyclone pipe internally, with a total treatment liquid volume of 150m³/h. After the sewage is pumped to increase the pressure to 0.6MPa, the sewage enters the improved 5# Cyclone, as shown in Figure3.

![Figure 3. Improved 5# cyclone.](image)

Figure 4 shows the sampling comparison of the oil collection port, water outlet and total inlet of the unimproved 1#, 2#, 3#, 4# cyclone and the improved 5# cyclone. It can be seen that the When the same polymer-containing sewage is treated, the improved 5# cyclone has the best oil collection effect and effluent water quality. Figure 5 shows the improved 5# cyclone test results. The chart data comes from a month’s production daily report, from March 7 to April 7, 2021. Statistics for this month can be seen: The improved 5# cyclone drops from the average inlet oil content of 177.45 mg/l to 98.76 mg/l, and the oil removal efficiency reaches 44.35%. Through field testing and iterative improvement, the improvement of the original 5# cyclone is successful. The field test results show that the improvement of the 5# cyclone meets the expected requirements. For the treatment of polymer-containing sewage, the new structure parameters are separated. The index is better than the index before improvement and can be applied to the treatment of sewage containing polymer.

![Figure 4. Comparison of sampling of oil collection port, water outlet and total inlet of 1#–4# and improved 5# cyclone.](image)
Comparison of the inlet and outlet oil content of the improved 5# cyclone.

A Comparison of the improved 5# cyclone inlet and outlet.

Figure 5. Evaluation of the separation effect of the improved 5# cyclone

5. Conclusion

By optimizing the design of the structure and parameters of the hydro-cyclone inlet flow channel, oil collection port, etc., a new type of oil-water cyclone is designed. Numerical experiments show that the new type of oil-water cyclone tube is effective for the separation of low oil content of polymer-containing sewage, the newly designed oil-water cyclone tube was used to improve the performance of 5# cyclone, and then the wastewater treatment test of West II Joint Processing Station's polymer-containing sewage was carried out. The results showed that the cyclone tube designed by the Institute of Mechanics of the Chinese Academy of Sciences is effective for the treatment of polymer-containing sewage. Based on the results of on-site testing and daily production data, the following conclusions can be drawn:

1) Through the improvement of the 5# cyclone, the polymer-containing wastewater treatment can obtain stable results, and the oil content of the effluent is better than the original cyclone indicators.

2) With a stable inlet flow rate, a relatively stable outlet water quality can be obtained. When the oil content of the polymer-containing sewage at the inlet is 100-300mg/l, after the improved 5# cyclone’s performance, the average oil content of the outlet is less than 100mg/l, which meets the design requirements, indicating that the improved cyclone structure and parameters are feasible in the treatment of polymer-containing sewage.

3) When the polymer concentration in the produced fluid increases, the viscosity of the sewage will increase, the overall flow velocity of the fluid in the cyclone will decrease, the kinetic energy drop will decrease, the wall friction resistance will increase, and the tangential velocity will decrease overall, but through optimization of structural parameters, the performance of traditional hydro-cyclones can be improved.

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