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Technical exploration of horizontal screw centrifuge in solid-liquid separation of flowback liquid in offshore production

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Abstract. This paper introduces the structure and working principle of horizontal screw centrifuge with large length diameter ratio and its technological process in the separation of liquid-solid liquid in the flowback of offshore production. The effects of different water addition ratio, rotating speed and demulsifier content on the separation effect of centrifuge were investigated by indoor experiments. The orthogonal test was used to optimize the parameters, and the optimal combination of parameters was as follows: water ratio was 1.5/1, rotating speed was 3000r / min, demulsification was achieved The dosage was 400mg / L. The optimum rotating speed of the centrifuge is 2000r / min, and the field pilot test is carried out for 10 consecutive days with the best combination of parameters. The results are as follows: the average mechanical impurity rate of oil phase produced by horizontal screw centrifuge is 0.465%, and the average oil content in water phase is 183mg / L. The separation effect is stable.

1 Introduction

As offshore oilfield production increases, the volume of flowback liquid generated in oil and water treatment systems on offshore platforms has surged. These flowback liquid are primarily stored in slop tanks/closed discharge tanks and wastewater tanks, and then pumped into the oil and water treatment process [1]. The impurities in the flowback liquid mainly include suspended solid, waxes, colloids, bacteria, corrosion products, and polymeric agents, which are characterized by high solids content, high viscosity, high oil content, and high emulsion stability [2]. Therefore, the solid-phase impurities would infinitely circulate in the oil and water treatment systems. Resulting from this, the mechanical impurity content in the oil treatment system would increase. Also, the oil content and the equipment failure rate in the water treatment system would rise and the burden on the wastewater treatment system and the cost of pharmaceuticals would build up [3-4]. The current solution is to open the offshore closed-loop oil and water circulating treatment system at a specific point so that the solid-phase impurities in the system can be separated. In doing so, the "waste" in the oil and water system can be gradually cleared out through “dialysis”, and then the "purification" of the oil and water treatment system can be achieved. However, due to the limitations of the offshore platform conditions, how to achieve a high-efficiency and maximum "dialysis" of the "waste" is an urgent problem to be solved.

With the continuous development of related technologies at home and abroad, horizontal screw centrifuge is widely used in oil exploration and other industries. Compared with other separation machinery (such as filter press, filtration equipment), horizontal screw centrifuge has many advantages, such as small size, small infrastructure investment, a high degree of automation, simple operation, no secondary pollution [5]. Therefore, the centrifuge is more suitable for solid-liquid separation of the flowback liquid in the offshore platform. Research shows that different water addition ratio and demulsifier content have different effects on the separation effect. Meanwhile, the parameters of horizontal screw centrifuge, such as separation factor (rotational speed), length-to-diameter ratio, also affect the separation effect. Therefore, this paper investigates the effects of different water addition ratio, demulsifier content, and separation factor (rotational speed) on the separation effect through indoor experiments. Through the orthogonal test, the parameters are optimized and the optimum combination of the three parameters is obtained, which are then testified by means of the field pilot test.

2 Materials and Methods

2.1 Materials

2.1.1Source and Physical Property Analysis of Flowback Liquid

The flowback liquid in offshore production is produced from oilfield platform operations, mainly including the backwashing of swashplate, air-float oil recovery, and

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walnut shell filtration, the collection operation of open and closed discharge systems, and the clearing of the sludge from the bottom of the tank, and high content, severe emulsification, and high separation difficulty of mechanical impurities. The specific source is shown in Figure 1. The main physical properties are shown in Table 1

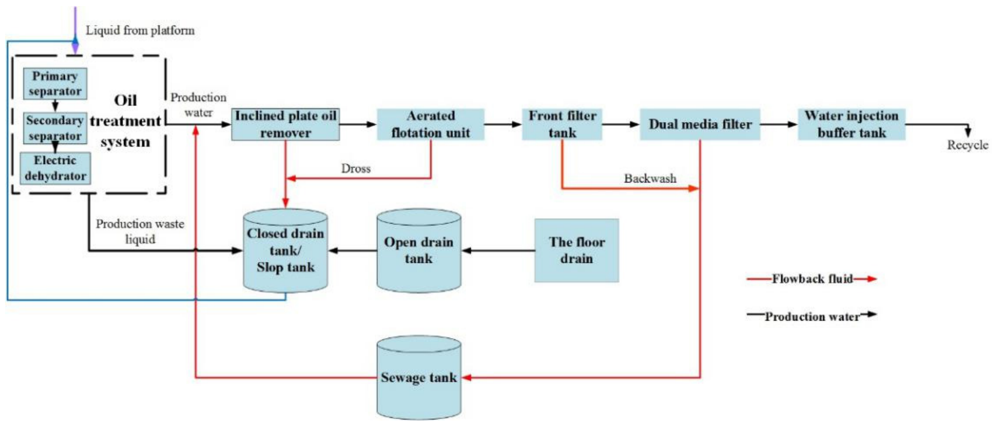


Fig. 1 Source of flowback fluid

Table 1 Physical Property Analysis of flowback fluid

Parameter	Soild content（%）	Water content（%）	Oil content（%）
Percentage	11.43	77.31	11.26

2.1.2 Experimental Materials and Instruments

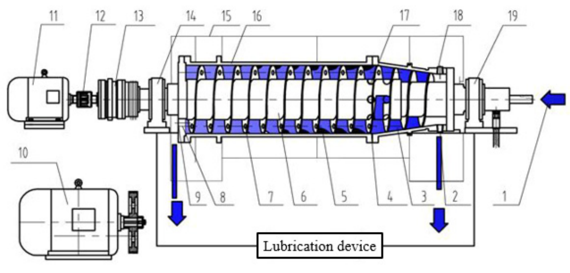
The flowback liquid used in the experiment is from an offshore oilfield platform. Other materials: carbon tetrachloride, sodium chloride, anhydrous sodium sulfate, gasoline, demulsifier (BP-03), distilled water, and so on.

German Sigma-6 benchtop low-speed centrifuge, infrared oil detector, constant temperature water bath, oscillator, analytical balance, electric constant temperature drying oven, distribution funnel, filter paper, and so on.

2.2 Methods

2.2.1 Structure and Working Principle of Horizontal Screw Centrifuge

The horizontal screw centrifuge mainly consists of a rotary drum, screw pusher, drive device, and protection device[6]. The flowback liquid arrives at the rotary drum through the screw pusher. Due to the speed difference, the lighter liquid will be developed into a liquid loop in the rotary drum and then discharged from the overflow drain, while the heavier solids will settle down on the walls of the rotary drum under the effect of the centrifugal force and then be thrown out of the equipment through the residue drain outlet[7-8]. The structure of the horizontal screw centrifuge is shown in Figure 2.



1: feed port; 2: slag outlet; 3: cone-end dehydration area; 4: inlaid welded carbide plate; 5: straight section settlement area; 6: screw propeller; 7: clear liquid guide hole; 8: liquid outlet; 9: adjusting plate; 10: main motor; 11: auxiliary motor; 12: elastic coupling; 13: differential; 14: bearing seat; 15: cover; 16: drum; 17: wear-resistant sleeve at discharge port; 18: wear-resistant sleeve at slag outlet; 19: bearing seat

Fig. 2 Structure of high efficiency horizontal screw centrifuge

2.2.2 Process Flow

Pump the flowback liquid generated from the oil field into the homogenization tank, and add water and demulsifier to precipitate and buffer, and then pump them into the horizontal screw centrifuge through the input pump for treatment. The liquid discharged from the liquid drain outlet of the centrifuge is an oil-water mixture, which needs to be sent into the liquid-phase treatment system for further treatment. The solids discharged from the residue drain outlet of the centrifuge is recycled into the rock chip box or sludge tank, and then transported back to the terminal treatment plant for treatment, as shown in Figure 3.

The mechanical impurity rate in the oil phase is tested according to GB/T 511-1988 Petroleum products and additives-Determination of mechanical impurities-Gravimetric method [9]. The oil content in the water phase is tested according to HJ 637-2012 Water quality-Determination of petroleum oils and animal and vegetable oils-Infrared spectrophotometry [10].

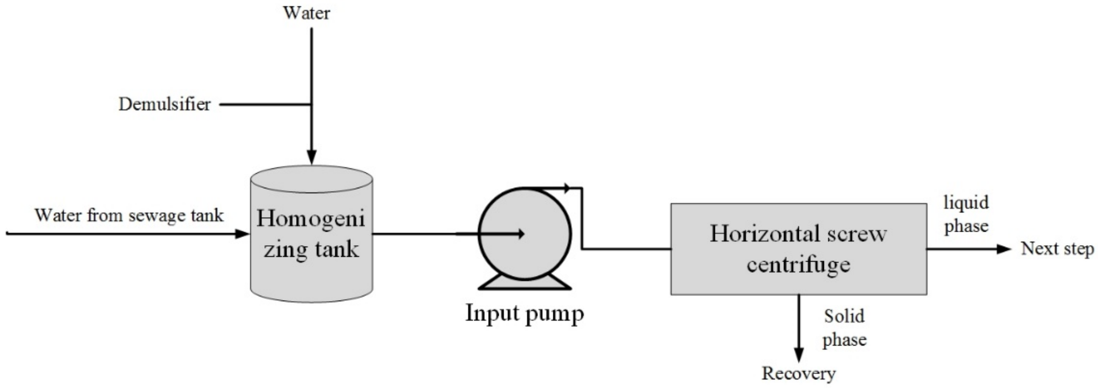


Fig. 3 process flow chart

2.2.3 Experimental Design

Fix the rotational speed of the centrifuge at 2500 r/min, fix the demulsifier content at 500 mg/L, and then adjust the water addition ratio. Fix the water addition ratio at 1/1, fix the demulsifier content at 500 mg/L, and then adjust the rotational speed of the centrifuge. Fix the water addition ratio at 1/1, fix the rotational speed of the centrifuge at 2500 r/min, and then adjust the demulsifier content. The specific gradient setting is shown in Table 2. According to the results of the single-factor test, the orthogonal test is used to optimize the parameters. In this way, the optimum rotational speed, water addition ratio, and demulsifier content can be obtained.

Table 2 Gradient setting table

Water addition ratio	1/4	1/3	1/2	1/1	1.5/1	2/1	—
Rotational speed（r/min）	1000	1500	2000	2500	3000	3500	4000
Demulsifier content（mg/L）	200	300	400	500	600	700	800

3 Results

3.1 Result of Indoor Experiments

3.1.1 Analysis of Single-Factor Test Results

（1）The effect of different water addition ratios on the separation effect of centrifuge

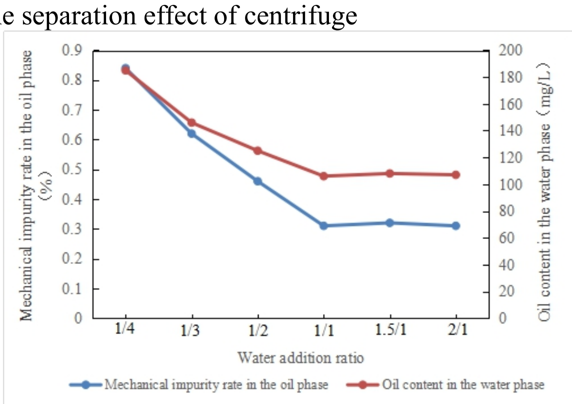


Fig. 4 Effect of different addition ratio on separation effect

As we can see from Figure 4, when the rotational speed and demulsifier content of the centrifuge are fixed, with the increase of water addition ratio, the mechanical impurity rate in the oil phase and the oil content in the water phase would first decline and then remain stable. The turning point of both appears when the water addition ratio of 1/1. At this time, the mechanical impurity rate in the oil phase is 0.31% and the oil content in the water phase is 106mg/L.

（2） The effect of different rotational speeds on the separation effect of centrifuge

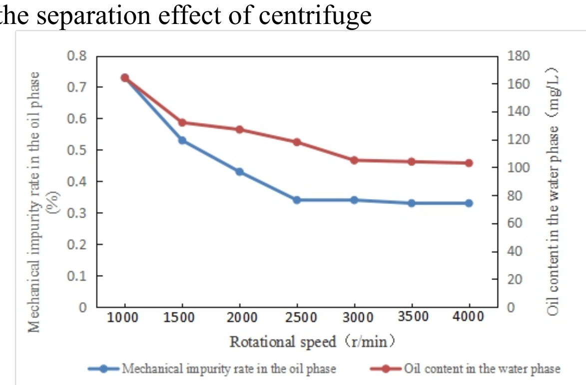


Fig. 5 Effect of different rotating speed on separation effect

As we can see from Figure 5, when the water addition ratio and demulsifier content are fixed, with the increase of rotational speed, the mechanical impurity rate in the oil phase and the oil content in the water phase tend to decrease first and then stabilize. The mechanical impurity rate stabilizes at 0.34 when the rotational speed is 2500r/min, while the oil content stabilizes at 105mg/L when the rotational speed is 3000r/min.

（3） The effect of the demulsifier content on the separation effect of centrifuge

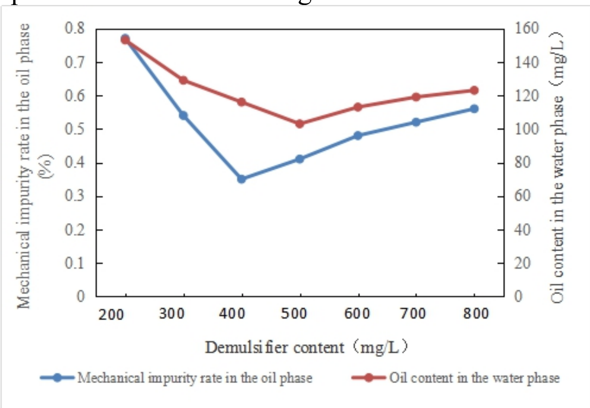


Fig. 6 Effect of different demulsifier content on separation efficiency

As we can see from Figure 6, when the water addition ratio and the rotational speed are fixed, with the increase of the demulsifier content, the mechanical impurity rate in the oil phase tends to increase and then decrease, and the lowest point is 0.35% when the demulsifier content is 400mg/L; the oil content in the water phase also tends to increase and then decrease, and the lowest point is 103mg/L when the demulsifier content is 500mg/L.

3.1.2 Analysis of Orthogonal Test Results

Through the analysis of the single-factor test result, it is found that three factors, namely, the water addition ratio, the rotational speed, and the demulsifier content, have a great influence on the separation effect of the centrifuge. Therefore, this study aims to use the orthogonal test method to optimize the process. The orthogonal test factor level table, test result table, and range calculation table are separately shown in Table 3, Table 4, and Table 5. As we can see from the range calculation table, the optimum combination of the mechanical impurity rate in the oil phase is A2B3C1. Due to RC>RA>RB, the demulsifier content affects the mechanical impurity rate in the oil phase the most. The optimum combination of the oil content in the water phase is A2B3C2 or A2B3C3. Due to RB>RA>RC, the demulsifier content has the third greatest effect on the oil content in the water phase. Therefore, the optimum combination is A2B3C1, that is, the water addition ratio is 1.5/1, the rotational speed is 3000r/min, and the demulsifier content is 400mg/L.

Table 3 Orthogonal test factor level table

Level	Factor A	Factor B	Factor C
	Water addition ratio	Rotational speed (r/min)	Demulsifier content（mg/L）
1	1/1.0	2000	400
2	1/1.5	2500	500
3	1/1.2	3000	600

Table 4 Orthogonal test scheme and result table

Test No.	Factor			Mechanical impurity rate in the oil phase (%)	Oil content in the water phase（mg/L）
	A	B	C		
1	1	1	1	0.38	109.00
2	1	2	2	0.42	112.00
3	1	3	3	0.37	103.00
4	2	1	2	0.41	104.00
5	2	2	3	0.35	111.00
6	2	3	1	0.32	105.00
7	3	1	3	0.44	108.00
8	3	2	1	0.36	110.00
9	3	3	2	0.43	106.00

Table 5 Range calculation of each evaluation index

	Variable	Factor		
		A	B	C
Mechanical impurity rate in the oil phase	k1	0.39	0.41	0.35
	k2	0.36	0.38	0.42
	k3	0.41	0.37	0.39

	R	0.05	0.04	0.07
Oil content in the water phase	k1	108.00	107.00	108.00
	k2	106.67	111.00	107.33
	k3	108.00	104.67	107.33
	R	1.33	6.33	0.67

3.2 Results of Field Pilot Test

3.2.1 Determination of Rotational Speed of Horizontal Screw Centrifuge

The above orthogonal test shows that the optimum rotational speed is 3500r/m, which corresponds to the separation factor of 1007.1. In the field pilot test, it should also be ensured that the separation factor of horizontal screw centrifuge is 1007.1. Based on the relationship between the separation factor and rotational speed, it can be calculated that the rotational speed of the horizontal screw centrifuge shall remain at 2000r/min.

3.2.2 Test Design

The horizontal screw centrifuge with a large length-to-diameter ratio is used in the field. According to the above orthogonal test result, the optimum water addition ratio and demulsifier content are 1.5/1 and 400mg/L respectively. Keep the rotational speed at about 2000r/min. Then conduct the pilot test for 10 consecutive days.

3.2.3 Test Results

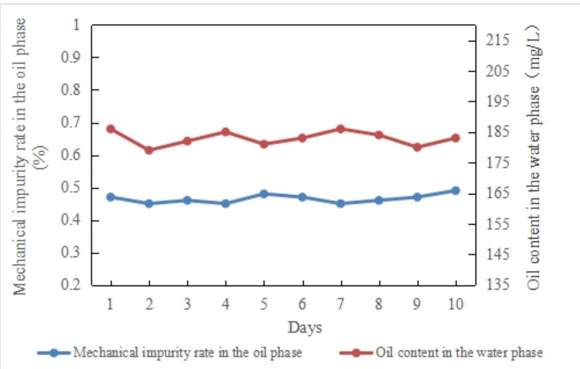


Fig. 7 Analysis of field pilot test results

As we handled 40m3 of flowback liquid with an efficiency of 0.5m3/h for ten consecutive days and worked 8h per day, the average mechanical impurity rate in the oil phase of the horizontal screw centrifuge contained is 0.465%, and the average oil content in the water phase is 183 mg/L. The operation was in good condition and the separation effect was stable.

4 Conclusion

(1) When all other conditions are held constant, the mechanical impurity rate in the oil phase and the oil content in the water phase are 0.31 and 106mg/L respectively when the water addition ratio is greater than 1/1. When all other conditions are held constant, the lowest mechanical impurity rate is 0.34% at the rotational speed of 2500 r/min, and the lowest oil content is 105mg/L at the rotational speed of 3000r/min. When all other conditions are held constant, the lowest mechanical impurity rate is 0.35% at the demulsifier content of 400mg/L, while the lowest oil content is 103mg/L at the demulsifier content of 500mg/L.

(2) Combination of parameters for the optimum separation effect in the indoor experiment: the water addition ratio is 1.5/1, the rotational speed is 3000r/min, and the demulsifier content is 400mg/L.

(3) Results of the field pilot test: The average mechanical impurity rate in the oil phase of the horizontal screw centrifuge is 0.465%. The average oil content in the water phase is 183mg/L. The separation effect is stable, which can meet the requirements of solid-liquid separation of the flowback liquid in offshore production.

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