

Research and application of oil sludge resource utilization technology in oil field

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Abstract. After oilfield development enters middle and late period, the increasingly high-water content in the oil produced would cause a large accumulation of oil sludge in the transportation system. To solve this problem, three kinds of sludge profile control agent to be used through slug composition in the profile control plugging for heavy oil steam huff-puff wells have been developed with different kinds of oil sludge as the main raw material of profile control agent, and additives added such as proper chemical agent and solid phase particle based on analysis of sludge combination and particle size in oilfield sewage treatment station. This application not only saves the cost of profile control, but also solves the sludge treatment problems. Therefore, it is worth promoting.

1. Introduction

Oil sludge refers to an oily solid substance which cannot be separated in the process of crude oil extraction, gathering and transportation. It is generally divided into the ground oil sludge, tank bottom oil sludge resulted in the joint station production operations and the oil sludge produced in the operation of sewage stations. According to statistics, China's annual oil sludge production had reached nearly 3 million tons, and only three major oil fields in Daqing, Shengli, and Liaohe produce more than 2 million tons of oil sludge each year. Sludge contains benzene, phenols, anthracene and other substances, and is accompanied by foul odor at the same time. If it directly contacts with the soil, water and vegetation, serious pollution would be caused, and resources would be wasted [1-2]. Therefore, whether considered from the perspective of environmental protection or recycling energy, an effective treatment technology for harmless treatment of oil sludge should be urgently studied [3-5].

2. Mechanism of oil sludge profile control in heavy oil

The sludge profile control technology is a technology that utilizes the sludge produced in the oilfield sewage system. Oil sludge, originated from the reservoir, is resistant to temperature shear and high compatible to the stratum. It can be made into high temperature profile control agent for heavy oil thermal well control profile. The mechanism behind is the diversion function of the flow ratio change and physical blockage, as well as adsorption and residual resistance. After the emulsion reaches a certain depth into the stratum, it would be affected by the underground water release and the adsorption of the stratum rocks. Then the emulsified suspension system decomposes, in which the mud adsorbs gum bitumen and wax, and through their adhesion together forms a larger size of the aggregate structure and then becomes the sedimentation in the large pores, narrowing the large pores'



space, blocking the high permeability zone, forcing into the steam steering into medium and low permeability layer to improve the longitudinal use of oil layer.

3. Evaluation of sludge Properties

Sludge is complicatedly composed. It can be divided into water, emulsified oil or oil adsorption, solid particles, inorganic salt. As their nature are different, it is necessary to study on characteristics of sludge in the laboratory to examine its feasibility as profile control agent.

3.1. Analysis of basic components in oil sludge

Three kinds of sludge in a certain amount in Liaohe Oilfield sewage treatment system were taken. The water content was measured by distillation and repeated with the mixed solvent of petroleum ether and acetone until the residue did not contain oil. In the end, the solid content was measured, and its feasibility was taken as the particle profile. The experimental results are shown in Table 1.

Table 1. Analysis of sludge composition

Sample Name	Water/%	Mud/%	Oil/%	Total/%	Sample appearance
Flotation machine scum	56.36	25.08	18.56	100	Black oil sands powder
Sedimentation tank bottom mud	61.58	19.17	19.25	100	Black viscous liquid
Sewage plant active sludge	74.91	13.10	11.99	100	Black viscous liquid

From Table 1, the mud-containing components account for 25.08%, 19.17% and 13.1% of the sludge component respectively, with the highest content of scum and the lowest of active sludge. The solid content in conventional particle profile control agents is usually 10-30%, therefore, the solid phase content of three types of sludge is in line with the application standards, thus the sludges have the possibility of making into a particle profile control agent. At the same time, the sludges have high water content in more than 50%, making them easy to be pumped to the target oil layer. The solid content of the active sludge is low, and it is necessary to add a certain amount of solid plugging agent in the system to increase its sealing strength [6-7].

3.2. Analysis of sludge dispersion suspension

The measured sludge particle size test data shows that the sludge is mainly composed of clay particles of different diameters. To transport the sludge to the profile layer, that is, the high permeability layer, it is necessary to require the sludge profile control agent to have a certain suspension performance. If the sedimentation rate is too fast, the sludge will accumulate in the wellbore, affecting the subsequent injection process. Therefore, the samples were diluted according to different water ratio to observe the dispersion and suspension stability. The experimental results show that the stability of the active sludge is good, and it can be used as a profile control agent after the different proportions of mixed water. The sediment and mud scum, due to high content of water in the composition, when mixed with a higher proportion of water, would have a layered phenomenon. Therefore, a certain amount of thickening agent should be added to improve the performance of sand suspension, reduce sedimentation rate, improve the stability, to meet the construction requirements of the site.

3.3. Analysis of oil sludge fluidity

When the liquid viscosity is less than or equal to 600mPa · s, normal flow and tube transport can be ensured. Therefore, the samples were diluted according to different water ratio, and the viscosity of the mixed solution at different moisture content were examined to check the pumping capacity.

Table 2. Oil Sludge Fluidity

Sample	Sludge viscosity with different moisture content (mPa.s)				
	65%	70%	75%	80%	85%
Tank bottom mud	21494	1165	219	89	68
Scum	\	3312	323	128	86
Sewage plant active sludge	13933	967	182	21	5.7

It can be seen from Table 2 that when the blending rate of each kind of sludge is more than 75% and the sludge viscosity is less than 600 mPa · s, it has good fluidity and can be smoothly pumped into the stratum. However, if the moisture content is too high, the solid content and viscosity of sludge would be caused to decline, affecting its sealing capacity. Thus, in the field use, moisture content of the sludge should be controlled within 75% -80%.

4. Development of Oil Sludge Profile Control Agent

The characteristic analysis results show that the oil sludges have the possibility of making the profile control agent, but because of the oil content in the sludge, the steam erosion resistance is poor. When applied to the heavy oil thermal recovery well, it is difficult to stay in the stratum for a long time. To avoid the sludge re-injected into the stratum to come back to the ground with the liquid and once again become sludge, different modified chemicals were added to develop a series of different formulations to improve its blocking performance. As the active sludge, tank bottom sludge and scum do not share the same solid content and water content, different additives were added according to different characteristics of the three kinds of sludge, which were separately configured into different performance profile control agents for the different slug combination injection in different reservoirs.

4.1. The basic formula of sludge profile control agent

4.1.1. Oil sludge polymer profile control agent. The formula is composed of tank bottom mud, adding a small amount of polyacrylamide and flocculant. Because the mud content in the tank bottom mud is relatively high, the profile control strength of the system is relatively large. The performance of oil sludge polymer profile control agent can be reached: mixing viscosity: 80-500mPa.s adjustable; gelling time: 12h-24h adjustable.

4.1.2. Particle sludge profile control agent. This system uses activated sludge as raw materials. As the activated sludge solid content is low, the fluidity performance is good, therefore, in the system more than 200 mesh of solid particles were added, as well as suspending agent and dispersant in proper amount, formulating the sludge into particle profile control agent. After it been injected into the stratum, the bridge function will be produced to block small pores in the stratum. The performance of super fine particle profile control agent can reach: particle suspension > 6h; plugging rate: 50%-90% adjustable.

4.1.3. High temperature sealing agent. This system is composed of sludge scum, rare earth curing agent, suspension agent in proper proportion. By controlling the reaction temperature and the amount of rare earth curing agent, the glue rate and gel strength were adjusted. The system is low in viscosity and favorable for pumping. It has high strength and good temperature resistance in the stratum and can meet the requirement of heat resistance and erosion resistance under steam injection condition and is effective for a long time. The performance of high temperature sealing agent can reach: the gelling temperature: 40-95 degrees; gelling time: 8-72 hours adjustable.

4.2. Plugging performance of sludge control agent

The application of heavy oil in thermal recovery wells requires a high temperature resistance. A single sand filled pipe model is used to investigate the plugging ability of sludge profile control agent in high

permeability layer. Therefore, different types of oil sludge profile control agent were injected at 300 °C, and then plugging test was conducted to determine the plugging rate and sealing strength.

Table 3. Influence of different types of sludge profile control agent on plugging rate

Item	Profile control agent type	Pre-plugging permeability/ μm^2	Post-plugging permeability/ μm^2	Breakthrough pressure /Mpa	Plugging rate /%	Residual resistance coefficient
1	Particle sludge profile control agent	2.047	0.246	11.2	88.0	8.3
2	Oil sludge polymer profile control agent	2.046	0.839	5.5	59.0	2.4
3	High temperature sealing agent	2.044	0.099	23.6	95.2	20.0

From the experimental results in Table 3, we can see that different types of sludge control agents have a certain plugging ability, to a certain extent to meet the needs of stratum plugging. The sludge modified high temperature sealing agent has the best plugging effect and the best plugging strength, with its plugging rate up to 95%.

4.3. Combined process of oil sludge profile control agent

In view of the development contradiction of different heavy oil blocks, we choose slug combination, and the concrete combination method is shown in table 4. For example, for heavy oil reservoirs with large stratum losses, the first section of the reservoir is constructed with a large strength sludge polymer system to build the wall of the reservoir, and the plugging strength is established. In the second section, a fine particle sludge system with good fluidity is used to treat the oil layer in the well, filling the small pore throat in the high permeable layer. The third section is sealed with clay oil high temperature sealing agent. After the profile control agent system is solidified, a protective slug for high temperature steam erosion is formed.

Table 4. Optimization of construction technology

Item	Applicable reservoirs	Slug combination	Construction purpose
1	High permeability reservoirs	Oil sludge polymer profile control agent + Particle sludge profile control agent + High temperature sealing agent	Improve the injection pressure and sludge injection volume
2	Medium and low permeability reservoirs	Particle sludge profile control agent + High temperature sealing agent	Adjust suction section and increase production level

5. Field Application and Effect Analysis

Based on the theoretical research, we selected different heavy oil blocks of Luoyang Oilfield Du 813 Xinglongtai, Du 84 Xinglongtai, Du 210, etc. This kind of heavy oil reservoir has good physical properties, high porosity and high permeability, with an average permeability of $2.37\mu\text{m}^2$ and effective porosity of 32.6%. At the same time, the heterogeneity in the longitudinal direction is serious, and the single layer of steam is easily formed. The maximum permeability difference is 203, which is suitable for the sludge control. A total of 26 experiments have been conducted since 2015.

5.1. Site work process

Because there are many preparation processes in formulating oil sludge profile control agent, the field preparation process flow is designed, as shown in Figure 1. The sludge is transferred to the preparation tank by means of a conveyor, and the emulsifier, the suspending agent and the diluent are added to the

preparation tank oil slurry, stirred and shaken. When the viscosity meets the design requirements after the detection of mud density, the mud pump plugs the sludge into the well. During the injection process the pressure should be strictly controlled to keep the injection under low pressure. According to the actual situation, the injection speed, the agent density and viscosity are to be adjusted. To ensure the normal preparation of the plugging agent injection, injection pumps with large displacement, controllability and wear-resistance and tanks with reserve function are selected, and to prevent too much sludge from landing, multi-level filter are set.

5.2. Measures effectiveness analysis

Compared with the pre-cycle of measures, the pressure of steam injection increased by 2.1MPa on average, and increased oil reached 2583 tons in the stage, indicating a good result. On March 7, 2015, measure well Du 813-48-K57 conducted the 10th cycle of steam injection, with the injection pressure of 12.94MPa, cycle production days of 45.3 days, cycle liquid production of 427 tons, and oil production of 9 tons. On June 10, 2015, sludge profile control technology was implemented with the cumulative injection of sludge 956 tons, after the measures the well injection pressure reached 14.4MPa, which was 1.5MPa higher than that before the measures, indicating that the low permeability layer of the well has been used in a certain degree. After the measures the well conducted cycle production for 117 days, and produced 476 tons of oil, indicating a good effect. Compared with the 9th and 10th cycles, over the same period, 151 tons and 467 tons of oil were increased respectively, showing that the measures had reached an obvious effect.

5.3. Economic benefit analysis

26 profile wells used a total of 8.19×10^4 tons of raw materials. According to the Liaohe Oilfield sludge treatment costs of 600 yuan / ton, the processing cost of 49.14 million yuan were indirectly saved. At the same time the production of measure wells increased 2583 tons of oil. If calculating with heavy oil prices by 850 yuan / ton, the economic benefits of 2.19 million yuan was directly produced. The successful application of the measures had obtained a total of 51.33 million yuan of economic benefits. Fully consider that the 2 oil injection pumps worth 1 million yuan, the cost of additives of 2.6 million yuan, and the construction costs of 520,000 yuan, etc., the total investment on the measures was 412 million, resulting the input - output ratio of 1: 12.4.

6. Conclusion

Sludge, as a profile control agent, has excellent performance in salt tolerance, temperature resistance and erosion resistance. It adapts well to the Liaohe Oilfield heavy oil reservoir profile control work needs. Sludge profile control construction process is simple, low cost, and has a good sealing effect.

Therefore, it can be extended to fire drive, SAGD, steam drive development and other fields. Based on the laboratory experiment, three kinds of sludge control agents with different strength were studied, and the sealing rate in high permeability large pores was over 90% through different combinations of slugs.

The practice principle shows that the sludge control agent is suitable for the heavy oil reservoir, and the construction cost is low and the economic benefit is obvious. It provides a feasible new technology for the treatment of oilfield sludge and solves the problem of environmental pollution caused by sludge effluent and has a good prospect of popularization and application.

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