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The testing study of the temperature limit for oil-gas-water mixed transportation during oil production with special high water-cut

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Abstract: With oil extracting, the water-cut in rude oil increased continuously in Daqing oil field. About 90 percent of the liquid production is water in most of the oil wells. With the increase of water-cut, the energy consuming to gather and transport per ton rude oil has grown sharply. In order to gather and transfer oil safely without heating, reduce the energy consuming and production cost, we set up a suit of device in Daqing oilfield. We test the pressure drop and the flow pattern of oil-gas-water that is produced in No.6 Oil Extraction Factory with different temperature, different water-cut, different output capacity, and different gas capacity. The results of the test indicate that if the water-cut of mass exceeds 85%, the amount of produced liquid is between 11 and 105t/d, the ratio of gas and oil is between 40 to 60m^3/t, the flow rate of oil-gas-water mixture is from 0.2 to 2m/s and the conversion rate of the gas is from 0.15 to 1.8m/s, the flow of oil- gas- water in the horizontal pipe belong to slug flow. Sometimes the oil and water are separated and oil floats on the water, sometimes the oil is wrapped and is dispersed by water. By analyzing the test results, we conclude that the temperature limit of oil-gas-water for safe mixed transportation is lower than condensation point of oil with super high water-cut. It is 23 during testing range in Daqing oil field.

Key Words: Super high water-cut; Oil production; Oil-gas-water; Mixed transportation; Flow pattern; Temperature; Limit; Test

1 Introduction

The oil is the olefin-based in most oil fields of our country. The flow of oil-gas-water mixture that produced from oil well belongs to the multiphase flow in horizontal pipeline. Heating up technique of gas-burning is adopted widely when oil field was developed early for oil flow easily. It consumes 20~30m^3 natural-gas to transport per ton crude oil[1]. The gas consuming in heater is increasing sharply with the ascending of general water-cut. The technique of mixing hot water into oil-gas-water pipelines is adopted in Daqing oilfield. Oil fields has entered state with supper high water-cut since 1980s, it consumes 27m^3 natural-gas to transport one ton crude oil and $13\times10^8$$m^3$natural gas annually, which occupy 78% of the total energy consuming in ground projects.

No heating is one of the main methods to reduce the oil gathering and transferring energy consuming. The least gas consuming to gather and transport per ton oil is 4.17 m^3in overseas, 6.3 m^3~8.3 m^3in our country, and the mean level is 17.9 m^3 in our country [3]. Daqing oil field lied in severe cold region and the heat consuming is very large for oil and gas gathering and transporting pipeline. Daqing oil field has been studded unheated technique of oil-gas gathering and transferring since 1975[2]. Until now, temperature limit of oil-gas gathering and transferring without heating were all based on that the returning oil temperature in measuring space was not lower than 32~35 in Daqing oil field[4~6].

With the deeply exploring, the water-cut of rude oil increased continuously in Daqing oil field, water cut of most of oil wells output has ascended 85%. Take Daqing oil field for example, from No.1 to No.6 Oil Extracting Factory the respective water cut is 88.69%、88.35%、

92.37%、89.05%、88.46%、92.69%. One of marked characters is the total liquid output manifolds ceaselessly and the wellhead temperature increase when Daqing oilfield entering super high water-cut. Most wells have the condition to gather and transport oil all the year or seasonal without heating. Because of lack of in-depth research in methods of confirming the boundaries limits for gathering and transferring oil-gas without heating and oil-gas-water flow pattern during the supper highly-watery stage, unheated gathering and transporting application scope is restricted.

We set up a suit of equipments in Daqing Oilfield. According to testing the pressure drop and flow pattern of oil-gas-water that is produced in Oil Extraction Factory No.6 with different temperature, different water-cut, different output capacity, and different gas capacity, we provide temperature limit of safety transportation without both of any medicine and heating during the supper highly-watery stage in Daqing oilfield.

2 The test equipment and project

2.1 The introduction of test equipment

In order to study on the oil-gas-water flow pattern and temperature limit of its mixed transportation under different temperature, we developed a set of testing devices. The technical flow is showed in Fig.1

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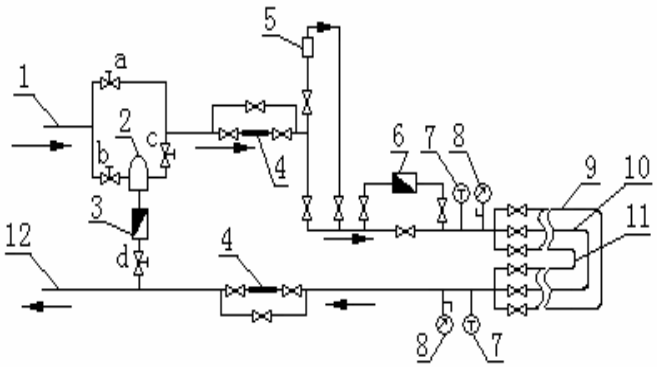

Fig.1 The technical flow chart of the testing device

1－mixture inlet pipeline from measuring space；2－three phases segregator ；3－gas flow meter；4－transparent quartz pipeline；5－water-cut measure meter；6－water flow meter；7－digital thermometer；8－digital pressure meter；9－new polyurethane heat insulating pipeline（300m）；10－new bareness pipeline (300m)；11－old bareness pipeline (150m)；12－testing medium outlet pipeline (to measuring space)

For the sake of testing the flow pattern under different temperature, the whole device is installed in the open air. As showed in Fig.1, at first the oil-gas-water mixture arrive at measuring space by gathering and transporting pipeline, then flow into the test equipment. Because the veracity of water-cut measure meter is affected by gas, a valve is closed and b valve was opened when test begin. Then we adjust the single well or multi-well mixed output properly, and test the gas production output, water-cut and liquid production output. When multiphase flow test is done, we open valve a, close valve b, c and d. Oil-gas-water mixture flows through valve a, transparent glass pipeline, thermometer and pressure meter, three different testing pipelines, thermometer, pressure meter, second transparent glass pipeline, into confluent pipeline in measuring space at last. When oil-gas-water flow into the first transparent glass pipeline, its inlet state is tested. When it flows out of the testing pipeline into the second transparent glass pipeline, its outlet state was tested. The typical flow pattern kinescope and photo are taken. All the pipelines are the same with practical pipelines, their diameters is 66mm.

2.2 Testing project

In order to study on the oil-gas-water flow pattern and temperature limit of safety transportation with different liquid output, different gas output and different water-cut, a series of test were done. All of the liquid flux, water-cut, gas flux, inlet /outlet temperature and pressure were measured with different conditions. And the flow pattern kinescopes were taken.

The testing device is installed in a measuring space in Daqing No. 6 Oil Extracting Factory, seven typical wells were select for test. The testing project like this:

Single well was opened with different water-cut. Different flux was adjusted by valve. The testing lasts out from 20th in Sep to forth in Dec in 2003 for obtaining environment temperature from 19 to -20 . The gas production was test with different condition。

3 Flow pattern testing result and analysis

Oil-gas-water multiphase flow is very complicated Because oil and water can not dissolve each other. So the multiphase flow pattern is more complicated than the gas-liquid two-phase flow [8~9]. The existence of gas makes the flow pattern changes frequently, energy consuming is large between different phases and the flow is unsteady. Oil and water are often regarded as one phase in fact projects. According to the Alves method to sort flow pattern, when gas flux is more and more, the flow in horizontal transparent pipeline can be seen: Bubble flow, Plug flow, Stratified flow, Wavy flow, Slug flow, Semi-Annular flow, Annular flow and Spray flow etc[10].

The study on oil-water two-phase flow is very important for oil-gas-water multiphase flow. But the oil-water complicate is despised compare to the gas-liquid two-phase flow, so its research is relatively laggard[7]. Trallero&Brill publicize their research result in 1996[8~11]. They based on former results and sorted flow pattern of oil-water horizontal pipeline into two kinds including six varieties: Separated flow included Stratified flow and Stratified flow Mixed interphones; Dispersed flow included oil dispersed on water layer, oil-in-water emulsion, oil and water stratified or oil–in-water-in-oil emulsion-suspension liquid of water-continuous phase.

The test was done with more than 80 different conditions. the seven different water-cut are from 85% to 96.3%, the amount of produced liquid is between 10 and 105t/d, the ratio of gas and oil is between 40 to 60m^3/t, the flow rate of oil-gas-water mixture is from 0.2 to 2m/s and the conversion rate of the gas is from 0.15 to 1.8m/s.

Within the testing scope, the flow pattern of oil-gas-water is slug flow, the oil-gas-water temperature is lower than condensation point of oil mostly, some oil has already been conglobation.Oil floated on water and dispersed oil in water, detailed depiction as follows.

3.1 Typical flow pattern

For explaining the flow pattern, we provide five typical photographs, they are showed in Fig.2 to Fig.6.

liquid production output 17t/d, water-cut 90%, temperature 37.5 , inlet pressure 0.375MPa, outlet pressure 0.177MPa

Fig.2 The oil and water are separated and oil floats on the water

liquid production output 95t/d, water-cut 95%, temperature 35.6 , inlet pressure 0.262MPa, outlet pressure 0.182MPa

Fig.3 The mixed flowage of oil and water

liquid production output 43t/d, water-cut 93.2%, temperature 31.8℃, inlet pressure 0.222MPa, outlet pressure 0.186MPa

Fig.4 A fraction oil becomes agglomeration and floats on the water

liquid production output 43(t/d), water-cut 95%, temperature 27.0 , inlet pressure 0.299MPa, outlet pressure 0.177MPa

Fig.5 The oil becomes agglomeration and is dispersed in water

liquid production 43t/d, water-cut 93.2%, temperature 19.1 , inlet pressure 0.418MPa, outlet pressure 0.181MPa

Fig.6 The oil becomes coagulated and takes on the shape of plait

3.2 Testing results and analyze

All the flow patterns of oil-gas-water belong to slug flow, testing results are showed in Table 1. According to the results showed in Table1, analysis as follows:

(1) When liquid temperature is higher than 35℃ and liquid production is lower than 30(t/d), oil and water stratified, both water and oil are continuous at present, oil floats on water layer, it is showed in Fig.2.

(2) When liquid temperature is higher than 35℃ and liquid production is lower than 43 (t/d), oil and water mix, it is showed in Fig.3.

(3) When liquid temperature is between 32℃ to 35℃, water is continuous and oil is discontinuous, oil floats on water, it is showed in Fig.4.

(4) When liquid temperature is between27℃ to32℃, oil presents pieces and floats on water, water takes oil away.

(5) When liquid temperature is between23℃ to27℃, oil coagulates into dollop and disperses in water, there is no pressure drop increase, it is showed in Fig.5.

(6) When liquid temperature is lower than 23℃, oil coagulates into plait, water takes away oil depending on gas pushing. It is showed in Fig.6. Pressure drop increases gradually, it indicates that pipeline has been jammed by coagulated oil somewhere, the diameter becomes little. Pressure drop will not decrease until accident happened, the pipeline is jammed completely.

Table 1 The oil-gas-water flow patterns of highly-watery mixed transportation

Water -cut /%	Liquid tem-perature /℃	Liquid output /t•d^{-1}	Gas output /m^3•d^{-1}	Oil-water state
95.0	33～38	43～95	107~247	Mixed flow
	32～36	18～94	45~244	Oil and water stratified oil floats on water
	26～28	18～95	45~247	Part oil coagulates into dollop
	23	43	107	Oil coagulates into plait
93.0	33～35	17～66	85~330	Oil-water mixed. There is little coagulated oil
	28～32	14.3～43	50~150	Part of oil coagulates into dollop
	19～22	14.3～43	50～150	oil coagulates into plait
90.0	35～40	56～105	280~535	Oil and water mixed
	35～40	17～30	87~150	Oil and water stratified oil floats on water
	27	66	316	oil coagulates into dollop
	23～26	66	297	Majority of oil coagulates into big dollop
85.0	35	72	562	Oil and water mixed
	30～32	12.2～72	91～540	Part of oil coagulates, intermission flow, oil is discontinuous on water
	22.3	20.4	147	oil coagulates into plait
	10	12.2	91.5	Oil accumulated, oil flow through a narrow gap

4 Temperature limit for oil-gas-water mixture safe transportation

Results indicate that the flow patterns of oil-gas-water are all slug flow within testing scope that water-cut is higher than 85%, oil and gas ratio is between 40 m^3 /t to60 m^3 /t, the flow rate of oil-gas-water mixture is from 0.2 to 2m/s and the conversion rate of the gas is from 0.15 to 1.8m/s. We conclude the flow state of oil-water as follow. When the liquid temperature is 32℃，a little of oil coagulated and floats on water. Water is continuous but oil is not; When the temperature is between27℃ to32℃, most of oil has already coagulated, oil presents pieces and floats on water, water is continuous and takes oil away; When its temperature is between23℃ to27℃, oil coagulates into dollop completely, oil flow is discontinuity and water takes away oil by gas pushing. When liquid temperature is lower than 23℃, oil coagulates into plait, the pipeline wall has already covered by oil .Pressure drop ascends ceaselessly. It is improper to transport directly. So the temperature that makes oil-water-gas-transportation safe is 23℃.This temperature limit is lower 12℃ than oil freezing point.

No.6 Oil Extracting Factory of Daqing has already gathered and transferred oil-gas according to the temperature limit without heating. 10^8 m^{3}gas was saved every year. This method to confirm temperature limit of oil-water-gas safe transportation can be used in other oilfields.

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