Study and Application of Chemical Production Stimulation Process in Heavy Oil Reservoir Production Wells

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Abstract. Heavy oil reservoirs are widely scattered across China with proved reserves over 10 billion tons, most of which are unconsolidated sandstone reservoirs. As a consequence, some problems are encountered as to the choice of production stimulation and stabilization process. This paper attempts to provide a summary of the geological characteristics of heavy oil unconsolidated sandstone reservoirs and the difficulties of production stimulation reconstruction process, in order to preferably choose the system for cleaning, viscosity reducing, acidizing and unplugging, optimize the construction process of viscosity reducing and acidizing, guarantee that service fluids can enter reservoirs uniformly, and improve the deliverable of chemical production stimulation, which would be taken as a good reference for chemical production stimulation construction of heavy oil unconsolidated sandstone reservoirs.

1 Introduction

Heavy oil reservoirs, accounting for a large share in global oil and gas resources, have over 800 billion tons of geological reserves. Typical overseas examples are the Alberta Region, Canada, and Orinoco Heavy Oil Belt, Venezuela. In China, 70 heavy oil fields scattered in Liaohe, Xinjiang and Bohai, accounting for more than 20% of aggregate oil resources, with proven reserves over 10 billion tons, have been discovered, most of which are unconsolidated sandstone reservoirs. As a consequence, some problems are encountered as to the choice of production stimulation and stabilization process.

collapsing, the formation is at a low pressure and of low dissolved gas oil ratio and fluidity, the initial yield of horizontal well cold production is low, and the curvature radius of shallow horizontal wells is large, which in turn imposes more limits on production process.

Fig. 1. API gravity plan distribution of crude oil in the block^[1]

2 Geological Condition of the Block

The target of Block JUNIN is unconsolidated sandstone reservoir, whose lithological character is principally medium-fine sandstone and the reservoir space is dominated by primary intergranular pores. The reservoir is loosely cemented with exceptionally high permeability, formation temperature measured at 45°C, average porosity of 34%, mean permeability of 5.2D, vertical depth of 400-600m, and horizontal section length generally over 1000m, the reservoir section is constructed with the water-based polymer system without clay phase inhibition. The relative density of crude oil at 50°C is 0.9575 g/cm³, the viscosity of degassed crude oil is about 2×104mPa·s, solidification point at 38°C, oil is characterized by high viscosity, density and heavy metal content, making it difficult to recover and transport. The reservoirs are buried shallow, loosely cemented, prone to sand producing and

3 Difficulties of Production Stimulation Reconstruction Process

3.1 Invasion damage

Unconsolidated sandstone reservoirs feature high porosity and permeability, large radius of pore throat, low formation pressure, and vulnerability to invasion of solid and liquid phases during works. The positive pressure difference during well drilling, cementing, and completion will cause a large amount of working fluids and solid particles to enter the reservoir, resulting in reservoir pollution. If the cement slurry contains a lot of high-valent metal ions and anion treating agents, and the drilling fluid and completion fluid contain a certain amount of carboxylate, cation, and carbonate, it would be likely to precipitate if both contact with each other s^[2]. In addition, the higher amount of working fluid as an

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extraneous fluid leaks into the formation is associated with the greater resultant damage.

3.2 Plugging of reservoir

The heavy oil reservoirs in Block JUNIN feature high viscosity and freezing point, the circulation and invasion of working fluid is likely to change temperature, pressure and other conditions. As a result, the crude oil of the reservoirs will solidify and settle, thereby reducing fluidity and plugging screen pipe; the crude oil in the near-wellbore pores will emulsify and from the flowing perspective, the original single-phase flow (oil) is turned to two-phase flow (oil, water). Due to differences between the interfacial tension and the rock wettability, oil and water may be emulsified to droplets to increase the oil flow viscosity and reduce the effective fluidity of oil and gas. Some changes in rock wettability of the reservoir leads to water locking damage and Jamin effect damage, increase the resistance of crude oil flow, and dramatically reduce the effective permeability of oil and gas^[3].

3.3 Impact of sand producing

Sand producing in oil wells refers to the phenomenon in which the skeleton particles comprising the reservoir rock moves and flows to the well bottom along with the formation fluids. Unconsolidated sandstone reservoirs are buried shallow and loosely cemented, the crude oil of heavy oil reservoirs features high viscosity and relatively strong sand-carrying capacity, so it is almost inevitable to see sand production from the reservoirs. As the reservoirs can be easily compacted and particles are migrated, the physical properties of unconsolidated sandstone reservoirs will continue to become poor during actual development, resulting in rapid decrease in well yield^[4].

4 Preferred Choice of Chemical Production Stimulation Process

Chemical production stimulation of heavy oil reservoirs, characterized by economical cost, user-friendly process, and large extent of viscosity reducing, has been consistently applied as one of the primary technical means. Current processes in use are primarily based on chemical viscosity reduction and acidizing production stimulation.

4.1 Preferred choice of cleaning and viscosity reducing system

The cleaning and viscosity reducing technology is used in the initial stage of the heavy oil reservoir production, which can effectively reduce the viscosity of crude oil and enhance its fluidity, and unplug the heavy oil asphaltene deposits in screen pipe and the near-wellbore water locking damage.

Available viscosity reducers mainly consist of water-soluble viscosity reducers and oil-soluble viscosity reducers. Most of water-soluble viscosity reducers are surfactants, which can be used to reduce viscosity by three means:

(1) Viscosity reducing by emulsification, an alternative to reduce viscosity where the water-in-oil (W/O) emulsion is reversed by an active agent to oil-in-water (O/W) emulsion, the emulsion is required to stabilize, added or generated by reaction of some chemical reagents with naphthenic acid;

(2) Viscosity reducing by demulsification, an alternative to reduce viscosity where the W/O emulsion is demulsified by an active agent to generate free water, and "suspended oil" and "floated water oil" according to volume and flow rate of free water;

(3) Viscosity reducing by absorption, an alternative to reduce viscosity where the molecules of an active agent are adsorbed between reservoirs to reduce frictional resistances^[5].

Table 1. The properties of the oil samples.

API Gravity	Viscosity (mPa.s)	Solidification point (°C)	Asphaltene (%)
7.3	21580	38	12.54

The viscosity reducer system is preferably chosen by evaluating its viscosity reducing rate and emulsification dispersibility in an experiment with the heavy oil specimens from Block JUNIN. The properties of the oil samples are shown in Table 1.

Table 2. Evaluation on properties of viscosity reducers.

Viscosity Reducer	Emulsification Dispersibility	pH Value
ZCS-11	The mixture liquid is highly dispersed with good stability. Not adhered to walls, hard to polymerize, with better dispersion stability	7
HQ-1	The mixture liquid is pasty and forms some O/W emulsion, but the emulsification efficiency is low. Slightly adhered to walls, heavy oil is likely to polymerize, with low dispersion stability	9
BRC-1	The mixture liquid is flocculent, the emulsion is stable with some dispersibility. Not adhered to walls, appear to be flocculent, with better dispersion stability	9
ACE-918	The mixture liquid is flocculent, the emulsion is stable with some dispersibility. Slightly adhered to walls, with better dispersion stability.	12

The screened viscosity reducer should feature low usage and good emulsion fluidity. The viscosity reducer is mainly screened based on the stability and viscosity of the viscosity reducing system, and the viscosity reducer with the optimum effect of viscosity reduction is initially

chosen s^[6]. Results show that ZCS-11 and BRC-1 have a better effect of viscosity reduction, with no heavy oil adhered to walls, and good dispersion stability. However, the emulsification viscosity reducing system has to consider the subsequent needs for acidizing reconstruction, so it is preferred to choose neutral ZCS-11 specimens.

Table 3. Evaluation on properties of cleaning components.

Viscosity Reducer	Cleaning Capacity
ZCS-10	Hanging net is cleaned utterly, the solution is uniform after the cleaning work is done
QE-605	Hanging net is cleaned utterly, some precipitation appears after the cleaning work is done
BH-Q	No obvious change in the hanging net

It is also required to preferably choose cleaning components, dissolve and disperse deposited flocculates, and avoid the accumulation of asphaltenes, in order to unplug the asphaltene deposits in screen pipe and near-wellbore zone. Results show that ZCS-10 has strong cleaning capacity and solubility.

Table 4. Orthogonal experimental tables.

Run Order	Component (V)	Component (C)	Reducing Rate (%)	Dispersion Rate (%)	Dissolution Rate (10 ⁻³ mN/m)
1	0.7	0.3	78	77	4.7
2	0.75	0.25	83	75	5.6
3	0.85	0.15	85	61	4.2
4	0.9	0.1	82	69	3.1
5	0.8	0.2	91	72	3.9

The cleaning components and the viscosity reducing components are formulated through the orthogonal experiment, and the ratio of cleaning components to viscosity reducing components is determined and evaluated using 2% concentration, viscosity reducing rate of heavy oil in Block JUNIN at 50°C, dispersion rate, and asphaltene dissolution rate. Given the cost factor of raw materials, the ratio of viscosity reducing components to cleaning components is chosen as 0.8:0.2.

The cleaning and viscosity reducing system is formulated into solutions of concentrations by using the simulated formation water, then mixed by 1:1 (the oil-water ratio) at 50°C to test its emulsification and viscosity reduction. Results show that where the dosing concentration of the cleaning and viscosity reducing system $\geq 3\%$, the viscosity reducing rate of crude oil specimens from the interested block will not significantly increase anymore, and it can meet the evaluation index $\geq 85\%$, so the on-site optimum dosing concentration is chosen as 3%.

Fig. 2. Optimal concentration of the cleaning and viscosity reducing system

The cleaning and viscosity reducing system is formulated into solutions of concentrations by using the simulated formation water, then mixed by 1:1 (the oil-water ratio) at 50°C to test its emulsification and viscosity reduction. Results show that where the dosing concentration of the cleaning and viscosity reducing system $\geq 3\%$, the viscosity reducing rate of crude oil specimens from the interested block will not significantly increase anymore, and it can meet the evaluation index $\geq 85\%$, so the on-site optimum dosing concentration is chosen as 3%.

Table 5. Evaluation of heavy oil treatment capacity

Blocks	Viscosity (mPa.s)	Post-treatment Viscosity (mPa.s)	Reducing Rate (%)	Dissolution Rate (10 ⁻³ mN/m)
Z35	7896.71	844.95	89.3	3.76
Z78	1642.32	308.76	81.2	1.98
J25	12987.14	571.43	95.6	4.57
G141	6921.55	574.49	91.7	2.73

To further evaluate the application of the cleaning and viscosity reducing system, the heavy oil specimens from different blocks are mixed by 3% concentration, the oil-water ratio 1:1 and at 50°C, and the viscosity reducing rate is tested using six-speed rotational viscometer. Results show that this system can function well in cleaning and viscosity reduction.

4.2 Preferred choice of the acidizing fluid system

The acidizing and unplugging technology is used for heavy oil unconsolidated sandstone service well which has produced sand and led to plugged zone in the near-wellbore belt. In this case, the plugging of the reservoirs is primarily caused by the removed solid particles absorbing heavy components of the produced fluid and accumulating in the near-borehole wall zone, resulting in the plugging of flowing channel. To prevent the tendency of sand production increase following the

acidizing, it is advised to reduce the acid concentration of the main acidic fluid, extend the operation distance, and avoid excessive consumption of the acidic fluid in the near-wellbore zone which may otherwise damage the skeleton of the reservoirs. The lithological character of unconsolidated sandstone reservoirs in Block JUNIN is principally medium-fine sandstone, siltstone and mudstone are locally developed; the detrital minerals are mainly composed of quartz, with a smaller amount of feldspar particles and rock debris; the content of clay minerals is generally lower, but more heterogeneous, with a smaller amount of acid-sensitive minerals such as pyrite.

Fig. 3. Rock debris in Block JUNIN

The acidizing and unplugging system based on main acidic fluid is preferably chosen by evaluating the dissolving power of hydrochloric acid, mud acid, and autogenous retarded mud acid subject to stepwise ionization on the rock debris from Block JUNIN after the reaction at 50°C for 2 hrs.

Fig. 4. Experiment with acid dissolution of the rock debris

The experimental phenomena and findings show that 10% hydrochloric acid barely reacts with, and poorly dissolves rock debris. Mud acid reacts intensively with rock debris in a short duration, with a certain dissolving power for debris ($\geq 39.2\%$). Autogenous retarded mud acid (AR-mud acid) subject to stepwise ionization reacts at a relatively flat rate with debris in a long duration, and its dissolving power is similar to the mud acid system ($\geq 36.6\%$). For extended operation distance of acidic fluid, autogenous retarded mud acid subject to stepwise ionization is chosen as the main acidic fluid.

Fig. 5. Evaluation on dissolving power of acidic fluid system

Along with the preferred choice of the main acidic fluid with strong dissolving power and longer radius of treatment, the compatibility experiment in respect of acidic fluid and crude oil is conducted to prevent mutual compatibility, which may form acid slag and precipitates. With an appropriate change of formulation, crude oil gradually can soften without producing no acid slag and precipitate as with the temperature rise.

Fig. 6. Compatibility experiment of acidizing and cleaning fluid system and crude oil

4.3 Optimized viscosity reducing and acidizing process

The cleaning and viscosity reducing system and the acidizing and unplugging system, which are preferably chosen in the initial phase, are used for the viscosity reducing and acidizing process. Overpressure viscosity reducing throughput, coupled with deep acidizing and unplugging process is applied to inject cleaning viscosity reducer and acidizing unplugging fluid, which would reduce the viscosity of crude oil, improve the fluidity of crude oil, unplug the formation, make the formation fractures connected, and further expand the crude oil flow channel.

According to preliminary statistics, the horizontal section of each horizontal well in Block JUNIN is longer than 1000m, the target of long section well would have a large area exposed and are more prone to pollution in a wide range during well completion and production. Due to the presence of heel-toe effect and the formation heterogeneity, a part of screen pipe sections which are plugged by drilling fluid pollution, fine silty sand and mud clogging would be subject to uneven distribution of acidic fluids and undermined acid cleaning, if the general acid cleaning process is applied. In this sense,

the reservoirs need to be treated with an appropriate process^[7].

4.3.1 Coiled tubing acid cleaning process

Coiled tubing acid cleaning process, a technology applied to long section horizontal wells, features a small amount of acidic fluids and an effective action upon long section. It not only cleans up the formation pollution, reduces the amount of treating fluids in use, and allows for a rapid induced flow with nitrogen, resulting in better efficiency of fluid discharge and a shorter working period.

4.3.2 Section-to-section acidizing + packed sand control process

Section-to-section acidizing coupled with packed sand control process allows for section-to-section acid cleaning, flow packing, and squeeze pack in one-trip tubing string during the sand control works, which can guarantee the effect of unplugging and sand control in long horizontal sections^[8].

4.3.3 Fixed-point hydraulic jet acid cleaning process

Multi-section fixed-point hydraulic injection tubing string coupled with uniform distributing tube, without adding sand jet acidic fluid or cleaning viscosity reducer, can be used to clean the screen pipe section. It would effectively shock and strip off the heavy components of crude oil deposited on the surface of screen pipe, and distribute acidic fluids uniformly to reconstruct the near-wellbore zone.

5 Field Application

A field experiment was carried out on Well K5-H, a horizontal heavy oil well chosen from the unconsolidated sandstone reservoirs, which was under the low-fluid production after putting into production in March 2014. However, its fluid production was smaller than that of adjacent well within the same block. A possible reason is that the high-viscosity oil was condensed, resulting in the plugging of slotted screen pipe. Therefore, it is advised to perform the acid cleaning, viscosity reducing and unplugging process by the viscosity reducing, acidizing and unplugging system, coupled with a hydraulic jet tool. 50m³ cleaning viscosity reducer was injected during the construction, this well was suspended from production before applying the unplugging fluid. After this treatment, its daily production was stimulated by 4.52t.

Fig. 7. Acidizing construction curve

6 Conclusion

(1) The reservoirs are buried shallow, loosely cemented and prone to sand producing, characterized by high-viscosity oil and difficult recovery. In this regard, chemical viscosity reducing and unplugging provides an effective means for production stimulation of such treated wells.

(2) Given the characteristics of heavy oil unconsolidated sandstone reservoirs, it is advised to reduce the acid concentration of the main acidic fluid and choose an acidic fluid system with a strong retarding property.

(3) For treated wells with long target section, an appropriate process should be chosen such that it can overcome the impact of heel-toe effect and heterogeneity, guarantee that service fluids can enter reservoirs uniformly.

Fund Project

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