Review on new heavy oil viscosity reduction technologies

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Abstract. Lots of gum and asphaltene in heavy oil caused high viscosity, high density and poor fluidity, which makes it very difficult to exploit and transport heavy oil. This paper introduces the mechanism and application of five new viscosity reduction technologies, including microbial viscosity reduction technology, biosurfactant viscosity reduction technology, ultrasonic viscosity reduction technology, magnetic treatment viscosity reduction technology and supercritical carbon dioxide viscosity reduction technology. At present, single viscosity reduction technology is difficult to solve the problem of heavy oil production and transportation. So the development direction of heavy oil viscosity reduction technology is the composite use of various technologies. In the future, it is necessary to develop new viscosity reduction technologies suitable for heavy oil production and transportation from the perspective of studying the structure and performance of heavy oil.

1. Introduction

Heavy oil accounts for a large proportion of the world's oil and gas resources. The world's reserves of heavy oil, super heavy oil and natural asphalt are about 1×10¹² t. Canada, Venezuela, the United States, China and Indonesia are rich in heavy oil resources [1]. With the acceleration of energy consumption in the world and the non-renewable of light crude oil, the exploitation of heavy oil has become a hot spot for scholars all over the world. However, heavy oil has special characteristics of high viscosity and high freezing point, so there are some technical problems in the development, gathering and transportation, and application of heavy oil. Therefore, effective reduction of crude oil viscosity is the key problem. Traditional viscosity reduction technologies include heating, dilution and emulsification. The heating technology for heavy oil transportation has high energy consumption, and has safety issue when the transportation is stopped; the dilution technology will increase energy consumption and reduce the physical properties of the oil; the emulsification technology has the disadvantages of large water content, large investment, and difficulty in later dehydration [2]. In a word, the traditional viscosity reduction technologies have their insurmountable shortcomings. Therefore, it is very important to develop new high-efficiency viscosity reduction technologies. In this paper, the principle and application of new heavy oil viscosity reduction technologies are discussed.

2. Composition and characteristics of heavy oil

Heavy oil is rich in gum and asphaltene and contains many elements and vanadium, and the content of light fraction is relatively low. With the increase of gum and asphaltene content, the density and viscosity of heavy oil increase [3]. Therefore, high viscosity, high density and poor fluidity are the main characteristics of heavy oil, which are also the main indexes different from ordinary light crude oil.
3. High viscosity mechanism of heavy oil

Generally, the pour point of crude oil is related to the number of n-alkanes, and the viscosity is determined by the content of gum and asphaltene. The high viscosity of heavy oil refers to the formation of the macromolecular structure by strong intermolecular force. The gum asphaltenes in heavy oil are combined with glial molecules by hydrogen bond or π-π bond. The high viscosity of crude oil is due to the formation of a large number of micelles through the connection of hydrogen bonds between granules [4]. In addition, the metal atoms (Ni, V) in heavy oil also have a great influence on its viscosity. The metal heteroatom and its associated main body (asphaltene and gum) are the main internal factors affecting the viscosity of crude oil. Therefore, the viscosity of crude oil will be effectively declined by reducing the content of metal heteroatom, as well as asphaltene and gum in crude oil [5].

4. New heavy oil viscosity reduction technologies

4.1. Microbial viscosity reduction technology

Microorganisms are injected into the stratum through production wells or injection wells in microbial viscosity reduction technology, and they will grow and propagate based on heavy components in crude oil as carbon source so that the light components in the crude oil increase. This process causes the viscosity of the crude oil decrease under the stratum conditions. There are four mechanisms of microbial viscosity reduction technology: 1) Microorganisms can decompose long-chain alkanes, glial asphaltenes and paraffins, to degrade long-chain saturated hydrocarbons into medium and short-chain hydrocarbons, and hence reduce the viscosity of crude oil. 2) Microorganisms can produce surfactants through microbial metabolism, and the surfactants can reduce the interfacial tension between oil and water, which will emulsify crude oil and then reduce the viscosity of crude oil. 3) Some gas producing bacteria will produce gas underground, which makes crude oil expand and thus reduce the viscosity. 4) Microorganisms can degrade crude oil and produce short chain organic acids and alcohols, thus increasing rock porosity and reducing crude oil viscosity [6]. Potter et al. [7] carried out biodegradation of heavy oil asphaltene by adding microorganisms and carbon and nitrogen sources in the aerobic culture at 37°C for 2 months, and the degradation rate of heavy oil asphaltene reached 40%.

At present microbial viscosity reduction technology is widely used, which has the advantages of high efficiency, low cost, no pollution, and easy treatment of the output liquid. This technology is suitable for heavy oil with high water content and low recovery rate, which greatly improves the oil recovery rate. However, there are some limitations in microbial viscosity reduction technology, such as it is difficult to cultivate and screen strains. Heavy oil is generally in the condition of high salt content, high temperature and high metal ion content, and this condition is not suitable for the survival of strains [8]. Therefore, the future development goal is to cultivate high salt content resistant, high temperature resistant and high metal ion content resistant strains.

4.2. Biosurfactant viscosity reduction technology

Biosurfactant is a kind of metabolite with surface activity, which contains hydrophilic group and lipophilic group and is produced when microorganisms are cultured in hydrophobic media. It can be divided into glycolipid, lipopeptide, phospholipid, fatty acid, neutral oil, polymer and so on. Biosurfactants have the common features of chemical surfactants, but they have more advantages than chemically synthesized surfactants [9]: (1) Since it has low interfacial tension, it can significantly reduce the surface tension and improve the interfacial properties, and thus reduce the viscosity of heavy oil; (2) It has excellent temperature resistance ability and salt resistance ability; (3) It can be easily biodegraded and is environmental friendly; (4) It is easy to demulsificate. Nelson et al. [10] injected 80L kerosene and 15L biosurfactant into three oil production wells in the United States, which increased oil production by 5 times.

There are two ways to apply biosurfactant to MEOR (Microbial Enhanced Oil Recovery). One is to use a biosurfactant produced by microorganisms as an oilfield chemical agent for oil displacement,
which is surface MEOR. The other one is the underground MEOR, that is to say, take the reservoir as a huge bioreactor, and inject the bacteria that can produce biosurfactant into the underground oil layer, and inject the substrate and nutrient solution that can maintain the growth, reproduction and metabolism of the microorganism at the same time, to promote the production of biosurfactant and thus reduce the viscosity of heavy oil and improve the oil recovery [11].

The chemically synthesized surfactants are usually difficult to degrade, which will cause serious environmental pollution problems [12]. However, the oil displacement efficiency of biosurfactant produced by microorganisms is 3.5-8 times higher than that of chemically synthesized surfactants, and the cost is much lower with no secondary pollution, so this technology has a good development prospect. The disadvantage of biosurfactant technology is the instability of biological culture. The extreme conditions of different oil layers are easy to cause microbial death or no production of surfactant.

4.3. Ultrasonic viscosity reduction technology

Ultrasonic viscosity reduction technology uses ultrasound to modify heavy oil and to irreversibly change the chemical components of heavy oil, and then improve the rheological property of heavy oil, to reduce the viscosity of heavy oil rapidly. The principle of ultrasonic viscosity reduction technology is the perfect combination of thermal effect and non-thermal effect by ultrasound. The thermal effect is utilization of the uneven glial asphaltene distribution in heavy oil. During the microwave heating process, the temperature of asphaltene molecules will be higher than the pyrolysis temperature of glial asphaltene, resulting in local overheating, and some glial asphaltene will undergo thermal cracking, thus reducing the viscosity of heavy oil. The nonthermal effect is generation of high-speed and powerful microwave radiation through cavitation, which breaks the macromolecules and glial asphaltene molecules in crude oil and achieves the purpose of viscosity reduction [13].

Zhaomin Li et al. [14] carried out ultrasonic viscosity reduction experiments on Shengli shallow water dehydrated crude oil in the laboratory with different sound intensity, frequency and action time. The best combination of parameters for ultrasonic viscosity reduction was obtained through orthogonal experiments, and the viscosity reduction rate reached 70.6%.

The absorbed ultrasound is converted into heat energy in the ultrasonic viscosity reduction application process, so this technology is high-efficient, fast speed and clean. At the same time, the chemical composition of heavy oil has been changed completely and the fluidity of heavy oil has been improved irreversibly. However, there are still some problems in ultrasonic viscosity reduction technology. Ultrasound is harmful to human body and has low economic benefits. It is only suitable for the exploitation of small amount of crude oil [15].

4.4. Magnetic treatment viscosity reduction technology

The main mechanism of magnetic treatment viscosity reduction technology is to prevent the coalescence, growth and formation of wax crystals in crude oil by magnetic treatment, and change the crystalline state of wax crystals, so as to reduce the viscosity of crude oil. In addition, under the action of the external magnetic field, magnetization destroys the intermolecular force of heavy oil hydrocarbons, leading to the change of molecular aggregation state and the weakening of intermolecular polymerization force, in which the gum and asphaltene are dissolved in the heavy oil in the dispersed phase rather than the congruent phase, so that the viscosity of heavy oil is reduced and the fluidity is enhanced [16].

In recent years, the application of magnetic treatment technology in heavy oil viscosity reduction has developed rapidly. Liaohe Oilfield began to study magnetic technology in 1985, which has been successfully applied this technology to the production process of high pour point and high viscosity oil well. Now it has reached the goal of reducing the freezing point by 6-22°C, and the viscosity reduction rate reached 30%-60%. It has set a precedent for the successful application of magnetic treatment viscosity reduction technology [17].
Magnetic treatment technology has the advantages of clean, fast function and high efficiency, which has a wide application prospect. However, the viscosity reduction effect of magnetic treatment technology is not ideal for super heavy oil with high gum and asphaltene content. In addition, the viscosity reduction effect of magnetic treatment will decline with the extension of time, and the effective holding time is 4 hours. After magnetized for a certain time, the properties of heavy oil will return to the previous state [18].

4.5. **Supercritical carbon dioxide viscosity reduction technology**

Supercritical carbon dioxide viscosity reduction technology is a new technology that has been developed rapidly and successfully applied to crude oil production and transportation in recent years. Supercritical carbon dioxide fluid refers to the carbon dioxide fluid when the temperature is at the critical temperature (31.1°C) and the pressure is at the critical pressure (7.38mpa). The fluid not only has high permeability and low viscosity which is similar to gas, but also has high density which is similar to liquid. The mechanism of this technology is that carbon dioxide is injected into heavy oil to reduce viscosity by reducing intermolecular force. At the same time, the dissolved carbon dioxide in crude oil will destroy the structure of glial asphaltene, and thus the density and the viscosity will be reduced [19].

Zhaiming Wang et al. [20] studied the supercritical carbon dioxide viscosity reduction technology on super heavy oil, and found that the viscosity reduction effect is up to 90% when adding carbon dioxide to heavy oil under a certain temperature and pressure range.

The advantages of this technology are that supercritical carbon dioxide has no harm to the reservoir, and it has low cost, good permeability, wide resource and excellent viscosity reduction effect. At the same time, carbon dioxide in the transported heavy oil is easy to be separated, which has little impact on the quality of heavy oil. This technology is of great significance to heavy oil recovery, and it is also a new technology widely used at present. However, the research of this technology is still in its infancy, and there are still many problems: The carbon dioxide dissolved in heavy oil is easy to escape, which affects the stability of oil transportation; The acid solution formed after the carbon dioxide is dissolved in heavy oil corrodes pipelines and the equipment.

5. **The existing problem of new heavy oil viscosity reduction technology**

The key to solving the problem of heavy oil production and transportation is to reduce the viscosity and improve the fluidity of heavy oil. At present, various new viscosity reduction technologies of heavy oil have made great progress, but there are still many shortcomings that need to be further explored. Microbial viscosity reduction technology is low cost with no secondary pollution, but it has strong pertinence and severe conditions for microbial culture; The production cost of biosurfactant viscosity reduction technology is too high to carry out large-scale industrial production, so it is necessary to find a way to lower the production cost; Ultrasonic viscosity reduction technology is environmental friendly with low production cost, but it is limited by propagation distance and is only applicable to near well zone; Magnetic treatment viscosity reduction technology is high-efficient, clean and pollution-free, but it has limited duration time; Supercritical carbon dioxide viscosity reduction technology is in the initial stage, and there are many problems to be solved.

From the current research situation, many kinds of heavy oil viscosity reduction technologies have been studied and developed greatly, but there are also many problems, mainly as follows: Firstly, single viscosity reduction technology cannot be applied to all kinds of heavy oil; Secondly, the cost of various new heavy oil viscosity reduction technologies is too high. The key to solving these problems is to start from the research of viscosity reduction mechanism. At present, the mechanism of heavy oil viscosity reduction technology has been studied to some extent. However, since heavy oil viscosity reduction is a comprehensive technology based on multidisciplines, the research and understanding of its mechanism depends on the development of related disciplines such as petrochemistry, crude oil rheology, polymer synthesis, surfactant synthesis, oil transportation technology and oil production technology. Therefore, it is necessary to develop composite viscosity reduction technology from the
perspective of commodity technology, synthesize interdisciplinary advantages through system analysis to develop composite viscosity reduction technology.

6. Conclusions
Heavy oil viscosity reduction technology has entered the second development peak and some technologies have become mature, so it is very difficult to achieve original innovation, which should be more integrated innovation on the original basis. In the future, the development trend of heavy oil viscosity reduction technology is combination of the above technologies, or to combine the above new technologies with the traditional heavy oil viscosity reduction technologies. For example, combining thermal viscosity reduction technology with chemical viscosity reduction technology to form thermal composite viscosity reduction technology. Or integrating mining, gathering and transportation, dehydration and refining to form integrated technology.

In addition, the special feature of heavy oil viscosity reduction technology is that the technology with good viscosity reduction effect on one reservoir is not necessarily good for the other reservoir, which is mainly because the geological conditions and heavy oil properties of different reservoirs are quite different, so it is difficult to have universal technology. It is necessary to explore the relationship between structure and performance from the microstructure perspective, and study the internal mechanism of heavy oil in combination with dynamics and theoretical calculation. It is an important task for researchers to develop a comprehensive viscosity reduction technology.

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