International Journal of Energy
ISSN: 2957-9473 | Vol. 6, No. 1, 2025

Research Progress and Prospects of Catalytic Aquathermolysis of Heavy Oil

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Abstract: Heavy oil, as an important energy resource, faces many challenges in its extraction and utilization. With the gradual reduction of global crude oil reserves, the extraction and utilization of heavy oil have become particularly important. The catalytic aquathermolysis technology for heavy oil has received widespread attention as an effective method for heavy oil processing. The research shows that this technology can reduce the viscosity of heavy oil and improve oil recovery by hydrolyzing the colloidal asphaltene in heavy oil at high temperature and cracking it into small molecular structure. In the specific reaction process, organic sulfide plays a key role, and the reaction temperature range is 200~350℃. The experimental data showed that the viscosity of heavy oil decreased significantly and the proportion of saturated hydrocarbons and aromatic hydrocarbons increased after adding catalyst. In addition, the paper also introduces a number of research results and the research and development ideas of new catalysts, which provides a reference for the further development of heavy oil catalytic aquathermolysis technology. Research in this field not only helps to solve the problem of heavy oil extraction, but also opens up new avenues for the sustainable utilization of energy resources.

Keywords: Heavy Oil; Catalyze; Aquathermolysis; Research Progress.

1. Introduction

Although the use of oil has been recorded since the 10th century BC, it was not until the invention of the internal combustion engine and the development of large-scale chemical industry in the mid-19th century that oil really became the blood of industry. In today's society, oil and its derivatives are almost everywhere in clothing, food, housing and transportation. It has a profound impact on the pattern of the world and everyone's daily life. In the 20th century, the oil reserves were sufficient, the production cost was low, and the oil field quality was very good. But with nearly 100 years of exploitation and use, there are some serious problems in the current oil industry [1]. First of all, the world's total proved crude oil reserves have reached a peak, and it is estimated by existing technical means that the total crude oil reserves will begin to decline. The proved reserves were 1.4×10^{13} barrels in 2006 and 1.7×10^{13} barrels in 2016, with an average annual growth rate of only 2.3% over the past 10 years [2]. Since 1970s, the growth rate of new proved reserves of traditional oil and gas has been slower and slower. After 2010, the growth rate has decreased year by year. In 2015, the proved reserves did not increase but decreased. In 2017, the world's newly proved crude oil reserves were 7 billion tons, with an equivalent increase of only 0.4%. At present, the remaining proved oil reserves are 226.28 billion tons [3]. Secondly, the global annual reserve production ratio of crude oil has been as low as 57.6 (that is, the total proved reserves can be exploited for 57.6 years at the current exploitation rate). With the depletion of high-quality oil fields and the rise of oil production costs, China's oil production has fallen for two consecutive years, with a 3.1% reduction in 2017, with a total output of about 194 million tons. The large-scale development of oil has a history of more than 150 years. For various reasons, oil companies will give priority to the exploitation of oil fields with low viscosity, shallow formation and good exploitation. The crude oil reserves of thin oil fields are running out, and the crude oil reserves of heavy oil fields account for an increasing proportion. According to the data of 2017, the global geological reserves of heavy oil are about 900 billion tons, which has exceeded 70% of the total amount of remaining oil in the world [4]. According to the prospect of the current development of science and technology, the new energy technology that can replace oil is far away. Within 100 years, mankind still needs to rely on oil to provide energy, so the exploitation of heavy oil will be the top priority. At the same time, the global demand for crude oil showed explosive growth. In 2017, the global crude oil consumption was 4.26 billion tons, an increase of 1.77% year on year. Among them, China's crude oil consumption continued to grow at a medium speed. The annual apparent consumption of crude oil was 610 million tons, and the import of crude oil was 419 million tons, an increase of 10.11% over 2016 [5]. The crude oil gap was extremely large. In order to solve the problem of oil security in China, increasing the production of domestic oil fields and increasing the proportion of independent oil production have become an important means to solve the problem. As of December 2016, China's remaining recoverable reserves of crude oil have reached 21 billion tons, and the proven reserves of heavy oil have reached 6.55 billion tons, accounting for about 30% of the total reserves of crude oil. However, the average recovery rate of the exploited heavy oil fields is less than 20% [6]. Therefore, it is urgent to develop some low-cost and effective production technologies for heavy oil with huge reserves but relatively high production costs, so as to improve China's crude oil production and alleviate oil safety problems.

2. Current Situation of Heavy Oil in China

API gravity is used internationally to classify crude oil. API gravity (American Petroleum Institute gravity) is an oil specific gravity index adopted by the American Petroleum

Institute. According to this index, crude oil can be divided into four categories: light, medium, heavy and ultraheavy. The classification method is shown in Table 1. Heavy oil is an energy resource with huge reserves. According to the current research data, the reserves of heavy oil, super heavy oil and asphalt in the world account for more than 70% of the crude oil reserves, and are widely distributed in Venezuela (48%), Canada (23%), Russia, the United States, China and other oil producing regions. At present, the proven reserves of heavy oil in China are 6.55 billion tons. Liaohe Oilfield has the largest reserves, followed by Shengli Oilfield, Karamay Oilfield and Henan Oilfield. Offshore heavy oil is concentrated in the Bohai area [7]. Most of the onshore heavy oil reservoirs in China are Mesozoic Cenozoic continental deposits, and a few are Paleozoic marine deposits. There are many types of oil reservoirs with complex geological conditions, mainly composed of multi-layer interbedded combinations, and about 1/3 of the reserves are thick massive reservoirs. The reservoir is dominated by clastic rocks, which are characterized by high porosity, high permeability and loose cementation [8].

Table 1. International crude oil classification standards

Classification of crude oil	Main indicators API/(mPa·s)	Secondary Indicators Viscosity /(mPa·s)
Light	<31.1	
Medium quality	31.1~22.3	<100
Heavy quality	22.3~10	100~10000
Ultraheavy mass	10~0.1	>10000

Heavy oil and conventional oil often have a symbiotic relationship, which is affected by factors such as biodegradation and oxidation in secondary migration. In an oil and gas accumulation zone, it gradually thickens from the middle of the sag to the edge. Heavy oil is mainly distributed in the shallow layers of the slope zone at the edge of the basin, the edge of the bulge, the low bulge or the rift anticline zone in the sag. Due to the influence of low maturity, Continental heavy oil has low asphalt content and high gum content, so its relative density is low, but its viscosity is high. At present, Liaohe oil region in the Northeast has the largest heavy oil reserves, followed by Shengli Oil Region in the East, and Karamay oil region in Xinjiang in the northwest. The reservoir depth is generally less than 2000m, in which the heavy oil reserves with a depth of more than 800m account for about 80% of the proved reserves, and about half of the reservoirs are buried in 1300~1700m [9]. In recent years, heavy oil reservoirs with a depth of 2700~3200m have been found in Turpan Hami Basin [10]. The characteristics of heavy oil in China are slightly different from those in the world, mainly due to the high content of gum (20%-40%) and the low content of asphaltene (about 5%). Therefore, different classification standards are adopted: viscosity value is used as the first index to classify heavy oil, density is used as the second index to classify heavy oil, and heavy oil is divided into three categories: ordinary heavy oil, extra heavy oil and super heavy oil [11]. The specific classification indicators are shown in Table 2. Petroleum is a homogeneous mixture composed of a large number of organic substances with different compositions. Generally, it is divided into four parts according to its family composition: saturated hydrocarbon, aromatic hydrocarbon, resin and asphaltene. Compared with thin oil, heavy oil has high density, high viscosity and is extremely sensitive to temperature. It has high colloidal asphaltene and is rich in heteroatoms and metal elements such as sulfur, nitrogen and oxygen. Glial asphaltene is a kind of complex mixture of macromolecular compounds, which can not be accurately analyzed by the existing characterization methods. There are only some speculated structural models, of which the more consistent model with the experimental observation is described as follows: glial asphaltene has a similar closely associated supramolecular structure, which is similar to graphite structure. It is formed by polycyclic aromatic hydrocarbons with aliphatic branched chains to form sheet units first, and then stacked layer by layer to form a three-dimensional cage structure.

Table 2. Classification standard of crude oil in China

Heavy oil classification		Main indicators Viscosity /(mPa·s)	Secondary Indicators Relative density (20 ℃)
Designation	Rank		
Light oil		<50	
Common heavy oil	I-1	50~100	>0.920
	I-2	100~10000	
Extra heavy oil	II	10000~50000	>0.950
Super heavy oil	II	>50000	>0.980

This structure is the result of the joint action of three forces, which are also the main contributors to the viscosity of heavy oil. The first is that the conjugated π bonds of polycyclic aromatic hydrocarbons can form large delocalized π bonds between multiple molecules, making polycyclic aromatic hydrocarbons form sheet units. At the same time, the branched chain of aromatic hydrocarbons can assist the stability of sheet unit structure through van der Waals force attraction. There are many polar atoms such as s, O, N on the second heterocyclic aromatic hydrocarbon and aromatic ring branch chain. These atoms form hydrogen bonds with each other, so that different lamellar units can be connected with each other. There are trace heavy metal ions mainly V, Ni, Mo and Fe in the third crude oil. These ions can form stable complexes with non-metallic atoms such as S, O and N, which makes the lamellar units gather more closely. These three forces work together to form a stable cage structure of glial asphaltene stacked by lamellar units. The difference between gum and asphaltene is that the number of polycyclic aromatic hydrocarbons in gum is small, the side chain is long, the flakes are loose, and the content of heteroatoms and metals is low. The model structure is shown in Figure 1. In the heavy oil, the polar part of the colloid is connected with the asphaltene molecule with the largest molecular weight and the most compact structure, and the non-polar part is adsorbed with the light component saturated hydrocarbons and aromatics with less aromaticity, forming a homogeneous and continuous heavy oil sol [12,13]. In recent years, the development technology of shale gas and shale oil with huge reserves has advanced by leaps and bounds, and the exploitation cost has been declining, resulting in the low level of international oil prices for more than three years. Therefore, it is urgent to develop more economical and effective heavy oil recovery technology.

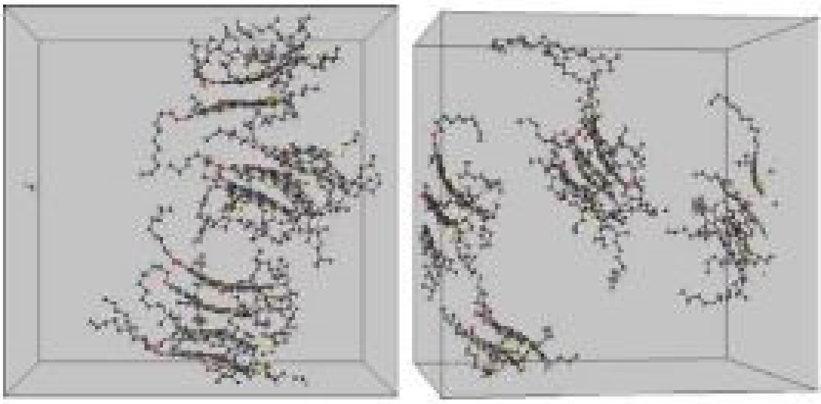

Fig 1. Structural diagram of colloidal asphaltene

3. Catalytic Viscosity Reduction Technology of Aquathermolysis

Clark [14] et al. found that cracking heavy oil molecules and reducing the carbon number of heavy oil molecules can fundamentally reduce the viscosity of heavy oil. The content of resin and asphaltene, especially asphaltene, in heavy oil determines the grade of heavy oil and the difficulty of upgrading and viscosity reduction. The influence degree of heavy oil components on its viscosity from large to small is: Ni>V=gum=residual carbon≈asphaltene>N>S>wax [15]. In 1983, Hyne [16] found that a series of reactions would occur after heavy oil contacted with steam at 250-300°C, including polymerization, organic sulfur cracking, water gas conversion, hydrogenation ring opening, etc. He named the whole reaction aquathermolysis catalytic reaction. After that, many scholars, including Hyne, studied the aquathermolysis reaction of heavy oil around the world under different conditions, summarized its rules, and concluded the following conclusions: (1) after the reaction, the proportion of saturated hydrocarbons and aromatic hydrocarbons in the oil sample increased, and the proportion of glial asphaltene decreased; (2) After the reaction, the sulfur content in the oil sample decreased significantly; (3) The gas mass produced in the reaction ranged from large to small, which were CO_2, H_2, CH_4, H_2S, CO and a small amount of olefins; (4) After the reaction, the content of thioether in the solute decreases and the content of thiophene increases [17].

3.1. Principle of Catalytic Viscosity Reduction in Aquathermolysis

According to the laws summarized and the follow-up in-depth research, scientific researchers have put forward and improved the catalytic reaction mechanism of aquathermolysis. The theory widely accepted by the academic community at present is that the catalyst catalyzes the high-temperature water and the colloidal asphaltene in heavy oil to play a role in a wide temperature range. After a series of reaction steps, it will be cracked into a process of small molecular structure, in which the organic sulfide plays a key role. Figure 2 shows the temperature range of different thermal reactions of crude oil. The temperature range of aquathermolysis reaction is 200~350 ℃, which is between slow thermal maturity and thermal cracking. At this temperature, the main chemical bond destroyed by the reaction is the C-S bond [18,19]. It is well known that water at high temperature has completely different chemical properties from room temperature. The first is the dielectric constant. As the temperature increases from room temperature to water, the dielectric constant decreases sharply from 78.4 to 21.2, which means that the polarity of water at high temperature is far less than room temperature, and more organic matter can be dissolved. Secondly, the kW value of water increases with the increase of temperature. At 300 ℃, k_W=11, which means that the C (H^+) and C (OH^-) in water in this state are 316 times higher than those at room temperature, and its reaction activity is greatly increased.

According to the table [20], the C-S bond energy is 272 kJ mol^{-1}, the C-O bond energy is 360 kJ mol^{-1}, the S-H bond energy is 368 kJ mol^{-1}, and the C-S bond energy is the smallest and the most prone to fracture. The large electronegativity difference between S atom and C atom makes H^+ ionized from water molecules at high temperature very easy to attack S atom. This leads to the breaking of C-S bond of organic sulfide in heavy oil as the initial step in the process of aquathermolysis. The complexes formed by the transition metals in the fourth period are generally sp^3d and sp^3d^2 hybrid, and the hybrid orbitals are L acid centers, while the H_2O in them dissociates H^+under the action of the metal centers on both sides and becomes B acid centers, so it has catalytic activity. The complex reaction between transition metal ions and organic sulfur exists, which can weaken the C-S bond. In this reaction process, the intermediate products coordinated with transition metals will be hydrolyzed to produce H_2S, and the catalyst will be regenerated to produce CO, CO_2 and H_2 [21].

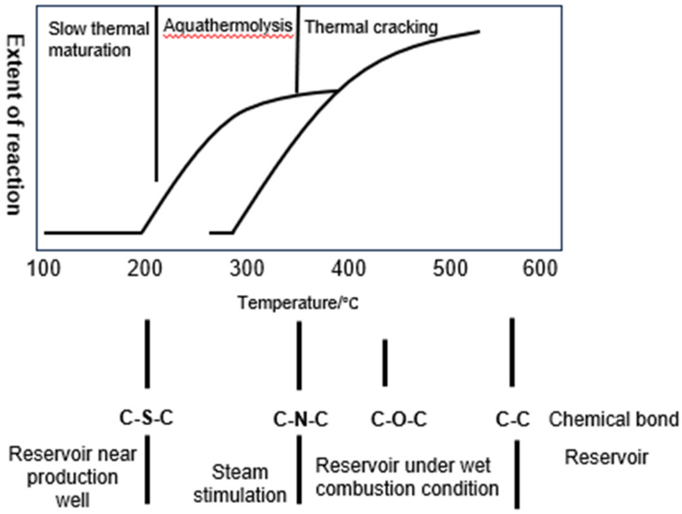

Fig 2. Temperature range of different thermal reactions of crude oil

Although different heavy oils have different specific reaction steps due to different molecular structures, there may also be some aquathermolysis reactions that have not been observed at present. However, the current research shows that the general reaction steps are carried out as shown in Fig. 3 and Fig.4. First, the O atom in the water molecule coordinates with the transition metal in the catalyst to form a complex, then the metal ions carry the water molecule to attack the C-S bond in the organic sulfide, the C-S bond breaks to generate C-S free radicals, and then mercaptan and enol (1) are generated. One side reaction of this step is free radical polymerization to generate high viscosity polymer (2) After a series of reactions such as rearrangement and decarbonylation of enol, small molecular alkanes and CO (3,4) are generated. Water gas conversion reaction (WGSR) occurs between CO and steam to generate CO_2 and H_2 (5). H_2 participates in the hydrodesulfurization of mercaptans to generate H_2S and hydrocarbons (6). This is the basic process of heavy oil aquathermolysis. The type of gas molecules produced by aquathermolysis. experiment is consistent with the model, which also confirms that the model is a more reasonable theoretical explanation [22].

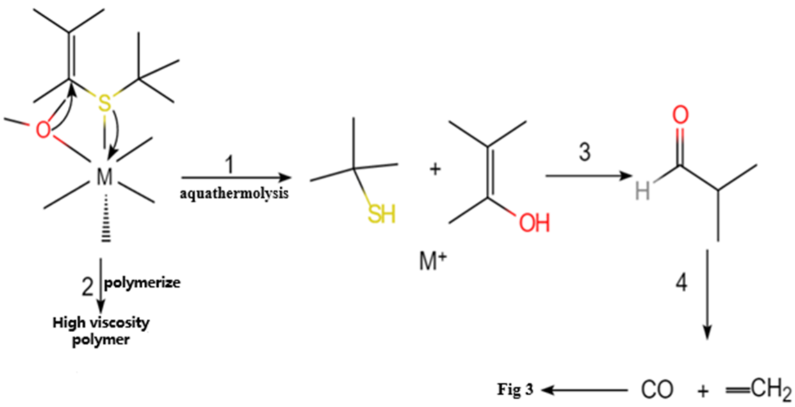

Fig 3. Initial process of aquathermolysis

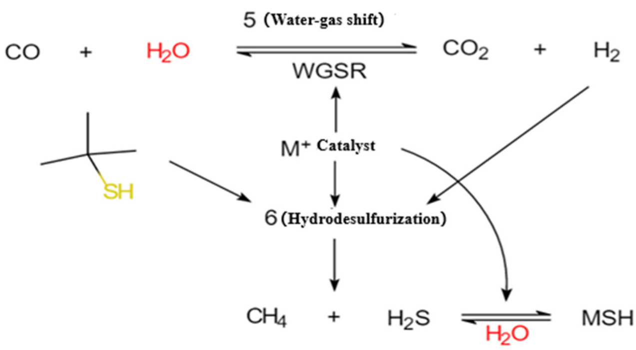

Fig 4. Subsequent process of aquathermolysis reaction

The initial pyrolysis of organic sulfides in heavy oil can produce enols, and CO will be produced after rearrangement and decarbonylation. The generated CO generates H_2 through WGSR reaction, and the generated H_2 can participate in heavy oil hydrocracking or hydrodesulfurization upgrading reaction. It can be seen that the essence of aquathermolysis reaction is that hydrogen in water is combined with oil to modify heavy oil. At the same time, many free radicals will be produced in the aquathermolysis reaction of heavy oil, and the free radicals can undergo re-polymerization reaction, while the introduction of active groups such as hydrogen can inhibit the re polymerization of free radicals. However, the amount of hydrogen produced by the water gas conversion reaction (WGSR) is limited. If a small amount of hydrogen donor is added, it will undoubtedly increase the effect of aquathermolysis [23].

There are several possibilities for hydrogen activation: (1) Free radicals with sufficient energy in the liquid phase impact the dissolved hydrogen molecules to activate the H-H bond; (2) H_2 produced by the decomposition of heavy oil may play a catalytic role; (3) Nickel ions and vanadium ions in resin and asphaltene are partially removed, and their sulfides activate hydrogen; (4) The polycyclic aromatic structure in heavy oil is easy to be hydrogenated into naphthenic aromatic structure, which acts as a hydrogen donor. However, some scholars believe that the presence of hydrogen does not inhibit the condensation reaction, but only makes the condensation product easier to decompose. Even the primary alcohol methanol [24] has the property of weak hydrogen donor in the vapor phase at high temperature and high pressure (600℃, 9.8 MPa).

3.2. Development of Domestic Catalysts

The research on catalysts in China has made significant progress since the 1990s, which is the result of the joint efforts of several generations of researchers. At present, there are four types of catalysts [25]:

(1) Transition metal water-soluble catalysts are mainly composed of fourth cycle transition metal inorganic salts and water-soluble organic salts.

(2) Transition metal oil soluble catalysts are mainly oil soluble complexes formed by the coordination of transition metals and organic compounds in the fourth cycle.

(3) Acid base catalysts mainly refer to unconventional superacid and superbase systems, such as heteropolyacids and schiff bases.

(4) Ionic liquid catalysts are inorganic salts or water-soluble organic salts of metals other than the fourth period transition metals.

Fan [26] were the first research group in China to conduct on-site experiments on hydrothermal understanding. Their group conducted downhole experiments using nickel cycloalkanoate in the Liaohe Oilfield, and the oil production rate of the experimental well increased by 67%. The viscosity reduction rate of the produced oil sample after catalytic cracking was 94.98%, achieving significant results. Afterwards, Liu and others conducted downhole experiments in other oil fields in China.

Wang, and others [27,28] synthesized a series of transition metal sulfates and transition metal cycloalkanoate salts as catalysts and conducted experiments on the Shanjiasi heavy oil. Its catalysts include water-soluble dispersed catalyst $ViSO_4$ $NiSO_4$, $FeSO_4$, and oil soluble dispersed catalysts cobalt (CoNaph), nickel (NiNaph), and iron (FeNaph) were used. The results showed that the viscosity reduction rate of ultra heavy oil after the reaction was greater than 70%, and the mass fractions of heavy components such as asphaltene, resin, and sulfur in the heavy oil decreased. The hydrogen to carbon atomic ratio increased, and the quality of ultra heavy oil was improved to a certain extent. Chen [29,30] synthesized nanoscale nickel cycloalkanoate as a catalyst, which has a good catalytic effect on Liaohe heavy oil. Before the reaction, the viscosity of the heavy oil was 12130 mPa·s and the sulfur content were 0.45%. After adding 1000ppm catalyst and stirring at 280℃ for 24 hours, the viscosity of heavy oil decreased to 5653mPa·s, with a viscosity reduction rate of 79.87%. Containing 0.23% sulfur, the proportion of saturated hydrocarbons and aromatic hydrocarbons increases, while the proportion of asphaltene decreases. Chen [31,32], and others have conducted thorough and detailed research on the catalytic reaction of aquathermolysis at the molecular level, and have extensively derived the catalytic mechanism of cracking reaction using kinetics, proposing several new catalytic reaction models. We have synthesized some new catalysts under theoretical guidance and predicted the development ideas of many catalysts. Wu [33] synthesized a dual parent catalyst for aquathermolysis of heavy oil in Henan Oilfield. Before the reaction, the viscosity of heavy oil was 7789mPa·s, with saturated hydrocarbons accounting for 54.35%, aromatic hydrocarbons accounting for 28.42%, resin accounting for 14.98%, and asphaltene accounting for 3.87%. After adding 0.5% catalyst and stirring at 200 ℃ for 24 hours, the viscosity of heavy oil decreased to 2653mPa · s, with a viscosity reduction rate of 69.87%. Saturated hydrocarbons account for 58.27%, aromatic hydrocarbons account for 30.14%, resin accounts for 10.91%, and asphaltene accounts for 2.37%. As the proportion of saturated hydrocarbons and aromatic hydrocarbons increases, the proportion of resin asphaltene decreases. The results indicate that this type of catalyst has excellent catalytic performance. The results indicate that this type of catalyst has excellent catalytic performance. Li et al. conducted viscosity reduction experiments on heavy oil in Shengli Oilfield using nickel oleate and nickel bipyridine complex organic nickel homogeneous catalysts at 240℃ and 2MPa conditions. After 24 hours of reaction using nickel bipyridine catalyst, the viscosity reduction rate of heavy oil reached 63.0%. After the reaction, the content of saturated hydrocarbons in heavy oil increases, while the content of aromatic hydrocarbons, resin, and asphaltene decreases. Fan [34] synthesized a series of inorganic salts of transition metals as catalysts and conducted experiments on heavy oil in Liaohe Oilfield. The viscosity of heavy oil at 80 ℃ was measured to be 89357 mPa·s before the experiment. The concentration of metal salt is 0.01 mol/L. After 24 hours of reaction at 240, when inorganic salts such as Fe^{2+}, Co^{2+}, Ni^{2+}, $Cu^{2+}$are added, the viscosity of heavy oil decreases to 23654, 32520, 33520, 42740 mPa·s, with viscosity reduction rates of 73.53%, 63.61%, 62.49%, and 52.17%, respectively. Among them, Fe^{2+} has the strongest ability to reduce viscosity. Chen [35] developed transition metal organic acid salt catalysts and conducted indoor experiments on aquathermolysis and viscosity reduction of heavy oil in Shengli Oilfield. Under the conditions of catalyst dosage of 0.2% (w), H_2O dosage of 20% (w), reaction temperature of 280℃, and reaction time of 36 h, the viscosity of crude oil decreased from 521104mPa·s to 163104mPa·s, and the viscosity reduction rate reached 97.00%. Chen [36] synthesized a complex catalyst of transition metals coordinated with advanced phenols. Before the reaction, the viscosity of heavy oil was 5436 mPa·s, with 54.35% saturated hydrocarbon, 28.42% aromatic hydrocarbon, 14.98% gum and 3.87% asphaltene. After adding 500ppm catalyst and stirring for 12 h, the viscosity of heavy oil decreased to 2050mPa·s, and the viscosity reduction rate was 79.39%. The percentages of saturated hydrocarbon, aromatic hydrocarbon, gum and asphaltene were 60.53%, 32.44%, 7.87% and 0.46%, respectively. The percentages of saturated hydrocarbon and aromatic hydrocarbon were significantly increased, while the percentages of gum and asphaltene were significantly decreased. The results show that this kind of catalyst has good catalytic effect. Wen [37] and others have studied a $SiWO_4$ catalytic system, which uses heteropolyacid as catalyst to synergize with reservoir minerals in super heavy oil of Shengli Oilfield. The test results show that there is a synergetic catalytic effect between the two, and the viscosity reduction rate of super heavy oil after reaction is 73.2%. Zhao [38] and others studied the effects of several hydrogen donors on aquathermolysis reaction, namely methane, hydrogen and water. The reaction results show that the three kinds of hydrogen donors can aggravate the depth of the reaction and are high-quality hydrogen donors. The first is water, which has huge reserves in nature, low cost, environmental protection and no pollution, and is the first choice for hydrogen supply; Secondly, methane also has large reserves, low price, and high hydrogen content, which has great potential. Although hydrogen has a good effect on the aquathermolysis reaction, the price of hydrogen is high. Professional equipment is required for storage, transportation and injection, and a lot of money is invested, so it is not suitable for the aquathermolysis reaction auxiliary. Sun [39] and others explored the synergistic catalysis of methanol on aquathermolysis reaction. After adding methanol with 5% of heavy oil mass at 250°C for 24 hours, the viscosity of heavy oil was reduced from 3368000mPa·s to 22510mPa·s, and the viscosity reduction rate was increased from 16.4% to 34.3%. Zhao [40] and others explored the synergetic catalysis of ethanol on the aquathermolysis reaction. At 200°C, for 24 hours, the catalyst dosage was 500ppm, and after adding 10% ethanol of heavy oil quality, the viscosity of heavy oil was reduced from 5600mPa·s to 1270mPa·s, and the viscosity reduction rate was increased from 76.7% to 91.2%.

3.3. Technical Advantages

Compared with other heavy oil recovery methods, this method has the following technical advantages:

(1) Making part of the non recoverable reserves in the oil field can be exploited, which is equivalent to increasing the recoverable reserves.

(2) Irreversibly reduces the viscosity of heavy oil, so it improves the mobility of heavy oil in the reservoir, improves oil recovery, and reduces the cost of heavy oil gathering and transportation.

(3) The heavy components in heavy oil are modified underground, which reduces the difficulty of processing heavy oil in downstream refineries.

(4) The pore of reservoir rock is a natural and cheap "catalytic bed". The catalyst can be adsorbed and fixed by the pore, which can effectively modify the formation heavy oil for a long time.

(5) This technology can be widely used in continental and marine oilfields; It can also be widely used in various kinds of thermal recovery wells.

4. Existing Problems and Prospects

At present, the main reasons restricting the large-scale promotion and application of the catalytic viscosity reduction technology of aquathermolysis are the following two aspects:

(1) The reaction temperature of indoor simulation experiment is too high and the range is very narrow, which can not reflect the real reservoir conditions.

Four zones will be formed after steam injection: steam zone, hot water zone, cold water zone and crude oil zone. Only when the reservoir temperature near the steam injection well can reach 250~300℃ for a short time, the steam area a little further away is basically 100~150℃, while the temperature in the hot water zone and cold water zone is below 100℃. In most indoor studies, the reaction temperature of the simulation experiment is basically above 200℃, which only simulates the catalytic condition of aquathermolysis in the steam zone near the steam injection well, and does not simulate the actual situation of the other three zones in the formation. This may lead to the use of catalyst is not suitable for most areas of the reservoir, so that the effect of field experiment is far less than that of indoor experiment.

(2) The research and development are not systematic, the catalyst has poor catalytic effect at low temperature, poor universality, and the newly introduced transition metals will pollute the quality of crude oil.

First, permanent viscosity reduction at reservoir temperature is a world problem. At present, most of the catalytic viscosity reducers are developed according to the idea of cracking and refining, in order to break some chemical bonds in heavy oil components, such as C-S, etc. these reactions require high temperature, which can not be reached in most areas of the oil well after steam injection, which means that these reactions hardly occur at low reservoir temperature, making the catalytic viscosity reducer unable to play its best effect, and the viscosity reduction effect on heavy oil is very limited.

Secondly, the previously developed catalytic viscosity reducer is only used to reduce the viscosity of heavy oil, and basically has no other effect. In fact, in some production processes, the viscosity of heavy oil has been reduced very low, but the production effect is still poor. This is due to adverse phenomena such as overlap, fingering, gas channeling and so on in the process of steam stimulation and displacement, which makes the steam sweep efficiency very low, and ultimately leads to low recovery.

Moreover, the universality of the developed catalyst is very poor, the properties of heavy oil in different regions are very different, and the heavy oil in different blocks in the same region and even in different oil wells in the same block will also be quite different. However, at present, the research on the mechanism of catalytic viscosity reduction of aquathermolysis is still in the primary stage, and there is no standard model to describe "what type of catalyst is effective for what type of heavy oil, and what type of catalytic viscosity reducer is applicable to what type of reservoir". Therefore, it is unable to give accurate guidance to the synthesis of catalyst, resulting in the current research and development work is empirical blind trial and error, which is often referred to as "shooting an arrow before drawing a target", that is, after developing a catalyst, try and error to see which kind of heavy oil is effective. Often, the developed catalyst can only be effective for the aquathermolysis reaction of a certain heavy oil or a certain kind of heavy oil, but when it is put into use in different regions, it has to re test or re develop the catalyst, which is the biggest bottleneck for the promotion of the catalytic viscosity reduction technology of aquathermolysis.

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