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Experimental Studies on Reduction of Reverse Phase Point in Heavy Crude Oil by Ultrasonic Irradiation

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ABSTRACT

In order to decrease transportation cost, experimental studies on viscosity reduction of heavy oil-water system and on viscosity changing rules by ultrasonic wave have been carried out. The results show that ultrasonic wave process can reduce reverse phase point of oil-water system, the water-cut decreases from 50%-60% to 20%-30% by ultrasonic wave, oil-water system changes into emulsion oil-in-water or oil floating in water dispersed system, it can reduce the water amount of transportation. And ultrasonic wave has definite impact on component of heavy oil, peak value of heavy oil decreases gradually when power increases, cavitation tends to saturate at a certain power, and component keeps stable essentially.

1. INTRODUCTION

Because of more weight component, poor flow properties and high viscosity of heavy oil, these occasions have brought many problems to its production and transportation. Various conventional techniques such as heating method and viscosity depressant can be used to decrease viscosity. However, these means are not always suitable, primarily because of the drawback of large cost and low efficiency.

There is a renewed interest in the effect of ultrasonic wave on heavy crude oil in both academic studies and petroleum industry [1]-[2], to some extent, mainly as a result of the demand for clean, effective and economical method in viscosity reduction of heavy oil. The viscosity reduction of heavy oil is also an important environmental concern of the petroleum industry. Ultrasound can decrease viscosity of heavy oil, production wells trend to yield more after ultrasonic irradiation, ultrasonic waves can decrease the inter-facial forces between oil and water [3] and can enhance the oil recovery [3]-[6], ultrasonic waves have been already applied in treatment of petroleum-contaminated soils [7]-[9], in addition, ultrasonic irradiation become more popular owing to its non-contamination to environment.

The effect of ultrasonic treatment on viscosity reduction of heavy oil production fluid was explored through laboratory experiments, and the effect of ultrasonic treatment on reverse phase point of heavy oil was studied, so as to explore new methods for heavy oil transportation. In addition, no previous studies have been carried out on the effect of ultrasonic wave on the components of crude oil. By studying the relationship between ultrasonic wave action and components of heavy oil, the effect of ultrasonic wave action on reverse phase point of heavy oil produced liquid is further analyzed in depth.

The mechanism of reduction of reverse phase point has not yet been investigated. In subsequent studies, experiments have been implemented to explore the influence of ultrasonic irradiation on reverse phase point, furthermore, some supplementary experiments such ad component analysis, SEM experiment and so on were carried out to in order to further explain the mechanism in more details.

2. EXPERIMENT METHOD

In this experimental study, three experimental methods were carried out, namely the experiments about reduction of reverse phase point of the heavy crude oil irradiated by ultrasonic wave, component analysis and SEM experiment.

The experiments about reduction of reverse phase point provided the oil samples prepared for subsequent research work and the data about reverse phase point before and after ultrasonic irradiation.

In the experiments, heavy crude oil at different water-cut were irradiated by ultrasound so as to study its influence on reverse phase point.

The schematic diagram of the experimental apparatus is shown in Figure 1. Experimental apparatus includes Brook-field DV-III programmable rheometer (from USA), super temperature controlled bath (CS601), ultrasonic processor, computer acquisition system. In this study, an ultrasonic generator (Genesis XG-500-6, CREST) was used to supply the ultrasonic waves of frequency 20 kHz and power (50W, 100W, 150W,

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200W) to a water bath. The viscosity of the fluids was determined using Brook-field DV-III programmable rheometer at different temperatures. The characteristics of formation water in this study is shown in Table 1.

The test samples involved in the experiments are heavy crude oil from Shengli Petroleum Administrative Bureau. In order to achieve the goal, firstly, prepare heavy crude oil at different water-cut and make sure they are at a certain temperature by means of super temperature controlled bath. After that, start ultrasonic processor to irradiate test samples at different power outputs, then measure their viscosity through Brook-field DV-III programmable rheometer and calculate viscosity reduction. In addition, the experiments were repeated three times in order to check for repeatability.

The component analysis including analysis of crude oil family component and saturated hydrocarbon component was implemented to explore heavy crude oil components in a series of experiments at different ultrasonic power outputs, according to petroleum standard SY/T 5119-1995 SY/T and 0542-1994. Experiments about heavy crude oil family components and content changes of saturated hydrocarbon in different oil samples helps to uncover mechanism analysis in reduction of reverse phase point.

The SEM experiment was carried out to study the influence of ultrasonic wave on quantity, magnitude, distribution of paraffin crystals in heavy crude oil after ultrasonic irradiation directly and also provide visual evidence for the mechanism analysis in reduction of reverse phase point.

Table 1. Formation water analysis report.

Analytical Item	Content(mg/L)
Na^{+}+K^{+}	8,690.5
Ca^{2+}	124.0
Mg^{2+}	63.2
Cl^{-}	13,652.1
CO_3^{2-}	0.0
HCO_3^{2-}	186.1
SO_4^{2-}	57.6
PH	7.0
salinity	22,774
water type	$CaCl_2$

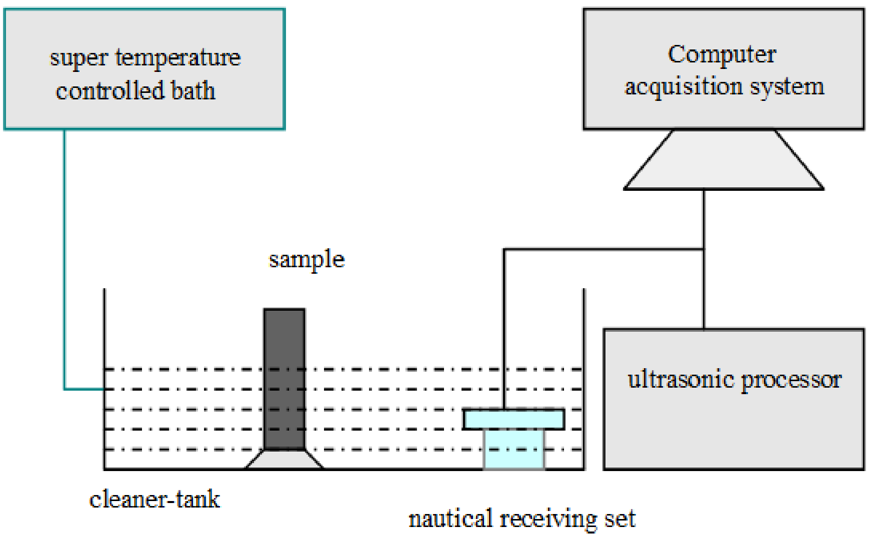

Fig. 1. Schematic diagram of experimental apparatus.

3. OUTCOMES AND DISCUSSION

3.1 Experimental Analysis of Reduction of Reverse Phase Point

Figure 2 depicts the relationship between viscosity reduction and water-cut of oil samples without any ultrasonic irradiation at different temperatures of 30°C, 40°C, 50°C, 60°C, 70°C and 80°C in the experiments. As can be seen from Figure 2, the viscosity reduction gradually increases with an increase of the water-cut of oil-water systems. The results indicate that at different temperatures, there is no apparent difference in the curve of relation curve of viscosity reduction rate vs water-cut (without ultrasonic wave, except that when temperature reaches 40°C, the viscosity reduction slightly increased. When the water-cut was less than 50%, the viscosity reduction gradually increased with an increase of the water-cut; but once the water-cut reached 50%,the viscosity reduction substantially increased, which indicates that at this point heavy crude oil emulsion type conversed from W/O to O/W from when its water-cut rose to revolution point. The water proportion in transportation of heavy crude oil without ultrasonic irradiation should not be less than 50 - 60%.

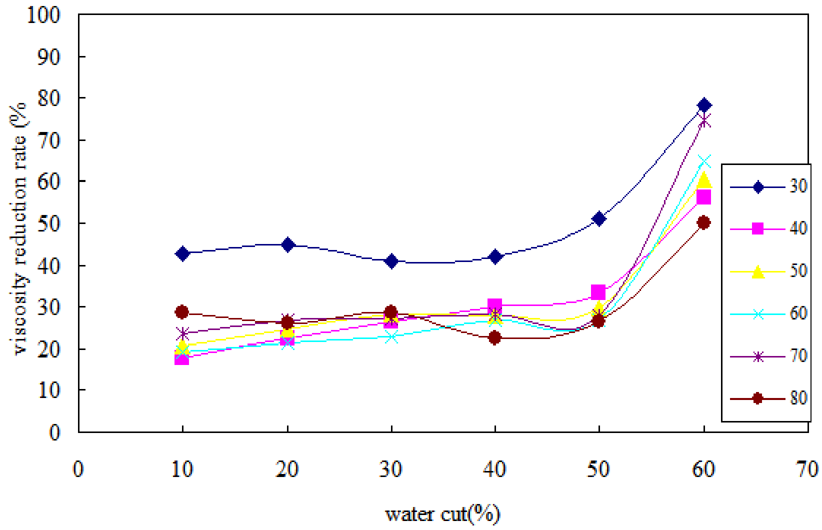

Fig. 2. Relation curve of viscosity reduction rate vs water-cut at different temperature (without ultrasonic wave).

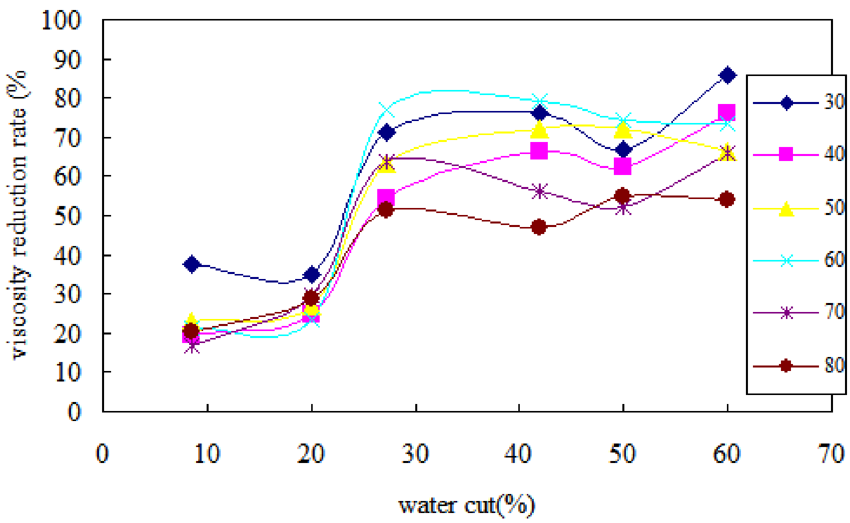

Fig. 3. Relation curve of viscosity reduction rate vs water-cut at different temperature (by ultrasonic wave, 100W, 30min wave).

In this experimental study with a novel method, the effects of ultrasound on reverse phase point for various temperatures of 30°C, 40°C, 50°C, 60°C, 70°C and 80°C were investigated. Figure 3 demonstrates the relationship between viscosity reduction and water-cut of oil samples by 30 min ultrasonic irradiation at the power output of 100W at different temperatures in the experiments. A similar feature can also be found in it. The presence of ultrasonic irradiation makes an apparent decrease in heavy crude oil viscosity compared with Figure 2. As can be seen from Figure 3, Viscosity reduction showed an increase trend with the increase of water-cut, when the water-cut reached 20%, the viscosity of heavy crude oil apparently declined and the viscosity reduction substantially increases, indicating that when the water-cut reached 20%, heavy crude oil emulsion type conversed from W/O to O/W type. The water proportion in transportation of heavy crude oil by ultrasonic irradiation should not be less than 20% - 30%, compared with above-mentioned result without ultrasonic irradiation, the water proportion in transportation of heavy crude oil decreased. Apparently from both Figure 2 and Figure 3, it should be noted that presence of ultrasonic irradiation made the reverse phase point reduce to 20% - 30%. After ultrasonic irradiation, the water volume can decrease by 50-60%.

The effect of ultrasonic can reduce the water-cut of heavy oil during phase conversion, thus realizing the reduction of reverse phase point of heavy oil produced liquid by ultrasonic. Ultrasonic action can significantly reduce the amount of water in heavy oil transportation, this can reduce the cost of heavy oil transportation, reduce the cost of oil field water treatment, and avoid or reduce the pollution of oil field development to the environment.

3.2 Mechanism Analysis of Reduction of Reverse Phase Point

In order to further explore the mechanism analysis of reduction of reverse phase point, the experimental studies on the content changes of the saturated hydrocarbon and family component of heavy crude oil from Shengli Petroleum Administrative Bureau were implemented with oil samples exposed to ultrasonic irradiation.

Figure 4 shows the result of saturated hydrocarbon content analysis of samples irradiated by 30 min ultrasound at different power outputs of 50W, 100W, 150W and 200W, respectively. The first curve stands for heavy crude oil without any ultrasonic irradiation and the rest of the curves refer to samples irradiated by ultrasound of different power outputs.

The results indicate that the saturated hydrocarbon components of the heavy crude oil irradiated by 30min ultrasound at 50W were close to those without any ultrasonic irradiation and with the increase of power output, the differences between irradiated oil samples and the initial one gradually became larger, which indicated that after ultrasonic power output rose to a certain value, ultrasonic cavitation became apparent and it resulted in the content differences of the saturated hydrocarbon components between the irradiated heavy crude oil and the initial ones. The differences between the second curve and the first one were the C24 content slightly rose from 4.1% to 4.3% and the content of heavy components(C16+) rose while the content of light components(C8-C16) decreased at the same time. This change can be attributed to the boiling effect resulting from generated heat and the ultrasonic boiling effect accelerates the evaporation of light components. The boiling effect can be observed by 5min ultrasonic irradiation.

The heat effect of ultrasound can be explained by the relation curve of temperature increment vs. ultrasonic irradiation [10]. As illustrated in Figure 5, it is easy to see that an increase of ultrasonic power output and irradiating time can result in more temperature increment. Only 5min ultrasound at 200W can easily enhance the temperature of heavy crude oil by 13°C and further increase of irradiation time cannot lead to a proportional increase of temperature. And in the experiment, it was found lots of large bubbles generated from the surface of oil samples and the oil color changed from black to black brown, which was consistent with the boiling effect.

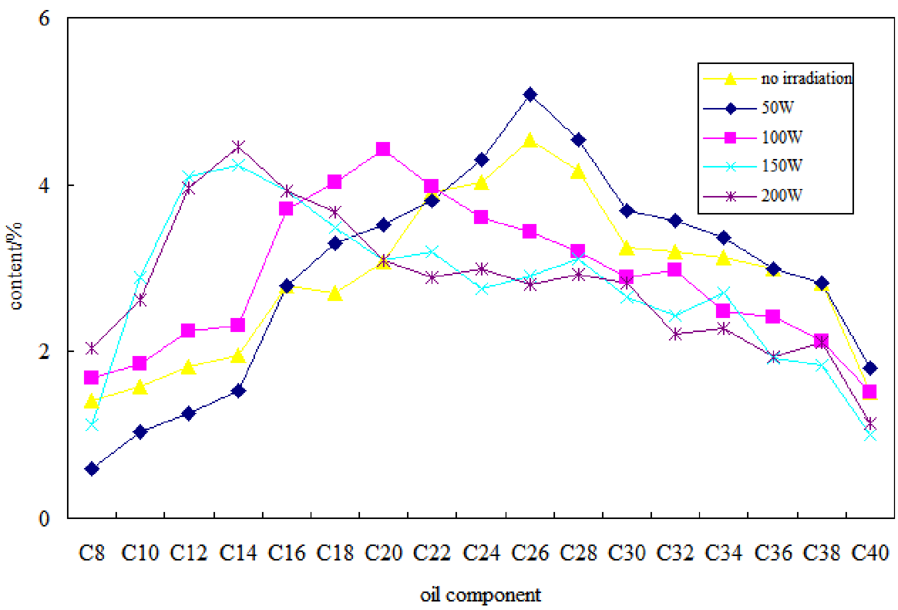

Fig. 4. Relation curve of heavy oil component vs. ultrasonic wave treatment.

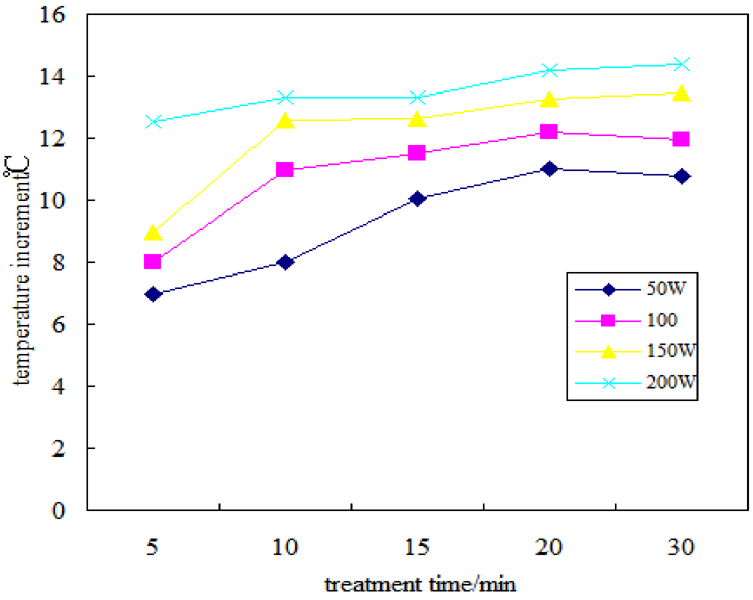

Fig. 5. Relation curve of temperature increment vs ultrasonic wave treatment.

Figure 4 indicates that with the increase of ultrasonic power output, the main components of the heavy crude oil shift from C26-C28 to C12-C14. At 100W, the content of heavy components (C22+) decreased while the content of light components(C8-C22) rose at the same time, the main components of the heavy crude oil shift from C26 to C20.

This change can be attributed to the cavitation effect resulting from ultrasound at higher power output and the cavitation effect accelerates the cracking of heavy components and lightening of the examined heavy fuel oil. The boiling effect can be also apparently observed, a larger number of bubbles in smaller size generated from the surface of oil samples and the oil color changed from black brown to brown. The heat effect improved ultrasonic cavitation. The content change can be attributed to the boiling effect due to generated heat and cavitation phenomenon, which results in breakdown of long carbon length, with the power output increased from 50W to 100W, the cavitation effect began to dominate in the process because heat effect cannot be improved proportionally.

At 150W, the content of heavy components(C20+) decreased while the content of light components(C8-C20) rose at the same time, the main components of the heavy crude oil shift from C26 to C14. An increasingly larger number of bubbles in much smaller size generated from the surface of oil samples and the oil color changed from brown to light brown. When the power output increased to 200W, the components varied slightly, the peak component remained at C14 and this demonstrates the cavitaiton effect got to its maximum at 200W, in the process, no more heavy component can be further changed into light ones and the carbon chain length kept stable at this occasion and the cavitation dominated in the component change, which helps to illustrate the mechanism of mechanism of reduction of reverse phase point.

It is illustrated that through the research on changes in peak components of heavy crude oil at different ultrasonic power output, with the increase in power output, the differentiations of heavy crude oil components got intensified after cavitation dominates at power output over 50W. At low power outputs (50W), component differentiation was not so significant, the component content irradiated at 50W slightly changed compared with that under non irradiation, so cracking of heavy components and long carbon chain did not take place, but once when output was higher than 50W, heavy components got cracked effectively by ultrasonic cavitation, resulting in gradually apparent component differences at higher power outputs.

According to petroleum standard SY/T 5119-1995, experiments were carried out to examine the change of crude oil family component before and after ultrasonic irradiation, such as saturated hydrocarbon, aromatic hydrocarbon, asphaltene and non-hydrocarbon in heavy crude oil, in order to explore the influence of ultrasound on its component. As illustrated in Figure 6, ultrasonic irradiation caused a change in the component compared with samples without any ultrasonic irradiation. The content of non-hydrocarbon of the samples after 30min ultrasonic irradiation at the power output of 150W was close to the samples without any ultrasonic irradiation, and the content of aromatic hydrocarbon slightly decreased compared with that without any ultrasonic irradiation, from 19.22% to 17.17%. The content of saturated hydrocarbon increased from 63.45% before ultrasonic irradiation to 70.71% after ultrasonic irradiation while the content of asphaltene decreased substantially from 10.16% to 5.96%. The content increase of saturated hydrocarbon and the decrease of asphaltene content can be attributed to the influence of ultrasonic irradiation. The cavitation effect can break long carbon chain to make it possible for decomposition of high molecule components such as asphaltene to take place when exposed to ultrasonic irradiation.

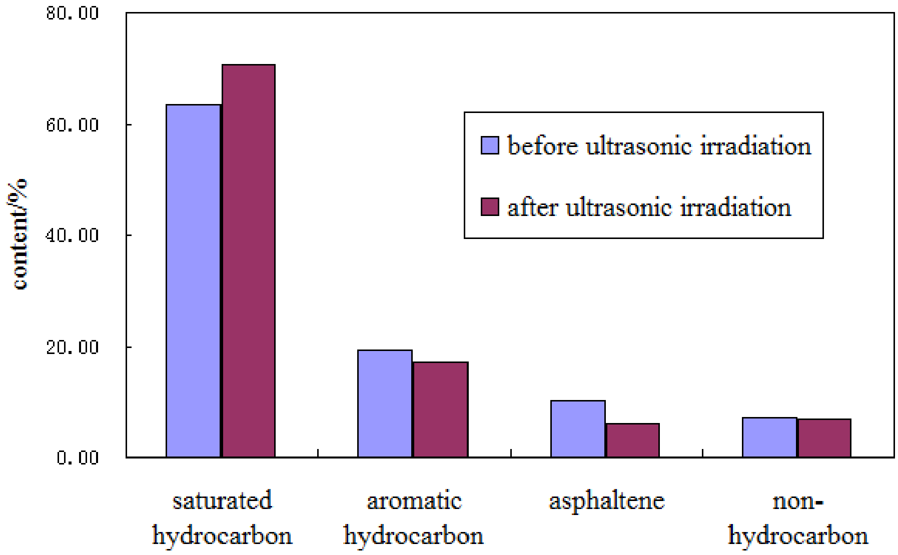

Fig. 6. Effect of ultrasonic irradiation on heavy oil component.

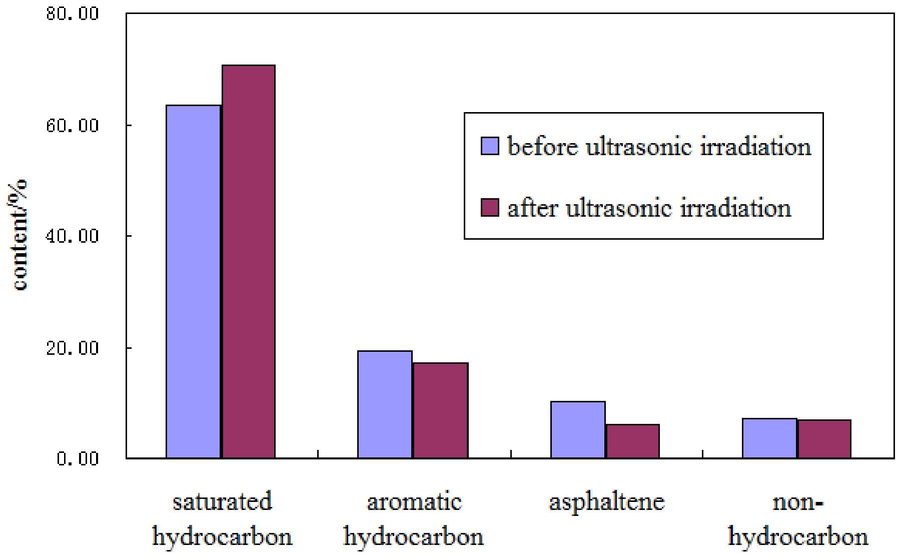

Fig. 7. Comparison of paraffin crystals under irradiation at different water.

For dehydrated heavy oil, the majority of paraffin crystals present in disorder folding of leaflet while the minority of them exist in the form of large flaky independently. In this occasion, most paraffin crystals were closely ranged in disorder and constitute three dimensional net structure, the three dimensional net structure had a preferable stability to make heavy crude oil flows poorly at low temperatures as result of its high viscosity. As to heavy crude oil, the influences of ultrasonic wave on paraffin crystals were clearly different for different time intervals. As illustrated in Figure 7a, for heavy crude oil irradiated by ultrasonic wave at the water-cut of 20%, paraffin crystals still presented with a small quantity, a big size in the shape of ellipsoid, assembled densely in certain areas and they were distributed at a poor rate of divergence, some of them were in the shape of sliver which should be intermediate transient state from ellipsoid to globular shape. When oil samples at the water-cut of 60% were irradiated by ultrasound, paraffin crystals no longer assembled densely in certain areas, and there were more evenly distributed in heavy oil, they presented with a big quantity, a small size in globular shape, the shape of ellipsoid vanishes and that of sliver also decreased to a large extent. When the water-cut increased from 20% to 60%, Figure 7 shows that the size of paraffin crystals at water-cut of 20% was higher than the one irradiated by ultrasound at water-cut of 60%. The viscosity decreased greatly and this improved flow ability of heavy crude oil.

4. MECHANISM ANALYSIS OF REDUCTION OF REVERSE PHASE POINT BY ULTRASONIC IRRADIATION

In summary, on the basis of analysis of the effect of ultrasound on the reduction of reverse phase point, its mechanism can be attributed to cavitation, mechanical vibration and heat effect.

As illustrated by Figure 5, the presence of ultrasonic irradiation on heavy crude oil can develop apparent thermal effect, which in turn results in viscosity reduction due to temperature increase. The oil and water blends sufficiently and this promotes revolution of water-oil system. However, the boiling effect due to generated heat and cavitation can also accelerate the evaporation of light component which has undesirable effect on viscosity, the viscosity reduction due to temperature increase exceeds that of boiling effect, because of finite effect (the maximum increase of temperature is 15°C), thermal effect is not the key factor in this process but the temperature increment indeed enhances the effect of cavitation and mechanical vibration.

The cavitation effect and mechanical vibration have an apparent influence on heavy crude oil. The cavitation effect accelerates the cracking of heavy components and lightening of the examined heavy fuel oil, the increase of power output enhances cavitation effect, moreover, the mechanical vibration effect results in strenuous vibration between oil molecules and gradually causes changes of long carbon chains into shorter ones. The combination of cavitation and mechanical vibration finally increases the content of light components and decreases that of heavy ones at the same time. With the increase of power output, the bubbles generated at the surface of heavy crude oil become more and more and sizes gets smaller and smaller and the color changes from black to light brown and all those indicate the occurrence of component differentiations. In the reduction of reverse phase point, cavitation effect, mechanical vibration and heat effect all play roles in the process, cavitation effect and mechanical vibration predominate while the heat effect only presents as subsidiary. The heat effect can reduce the viscosity but to a much lesser extent compared with the influence of combination of cavitation effect and mechanical vibration.

5. CONCLUSION

The presence of ultrasonic irradiation made the reverse phase point reduce from initial 50 - 60% to 20 - 30%. After ultrasonic irradiation, the water volume in the transportation of heavy crude oil can decrease by 50 - 60%. Ultrasonic action can significantly reduce the amount of water in heavy oil transportation.

Ultrasonic irradiation has an apparent influence on components of heavy crude oil. The peak value of heavy crude oil gradually decreases and the cavitation effect gets saturated, resulting in stability of oil components with the increase of the ultrasonic irradiation and the bubbles generated at the surface of heavy crude oil become more and more and sizes gets smaller and smaller and the color changes from black to light brown.

Ultrasonic irradiation finally increases the content of light components and decreases that of heavy ones at the same time. In the reduction of reverse phase point, cavitation effect, mechanical vibration and heat effect all play roles in the process, the cavitation effect accelerates the cracking of heavy components and lightening of the examined heavy fuel oil, the increase of power output enhances cavitation effect, cavitation effect and mechanical vibration predominate while the heat effect only presents as subsidiary.

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