

# Ultrasonic Batch Processing Of Ultra Heavy Oil For Viscosity Reduction On The Industrial Scale

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**Abstract**—Due to the shortage of the fossil fuel and with the increasing demand for it, heavy crude oil and ultra heavy crude oil whose density is less than 10API and 20API respectively are getting more attentions in the world. But their properties of heavier density, higher viscosity, and worse fluidity make it very difficult to produce and transport them. Ultrasonic wave technique is investigated to improve their rheological properties in lab and in the field in this paper. In lab, the viscosity of the emulsion of ultra heavy crude oil, water and viscosity reducer processed by ultrasonic wave has a more than 25% decrease of viscosity reduction and 20% less quantity of active macromolecule viscosity reducer is needed. When the initial temperature is not lower than 40°C, the uniformly-distributed emulsion can form when it is subjected to 10-30s ultrasonic irradiation. The mechanisms of effects of high intensity ultrasonic wave on the viscosity reduction are emphatically investigated. According to the experiments, an ultrasonic batch processing system with 4 ultrasonic horns whose basic frequency is 17 kHz is designed and installed in the Xinjiang oil field in the northwest of China. The pilots show that this system can be used to reduce the viscosity of ultra heavy crude oil for the practical production and transportation on the industrial scale.

**Keywords**—ultrasonic batch processing; ultra heavy oil; viscosity reduction; industrial prototype; on the industrial scale

## I. INTRODUCTION

Due to the shortage of the fossil fuel and with the increasing demand for it, the global demand for crude oil had a remarkable yearly growth rate from 1% to 1.8% (International Energy Agency, 2009) in the first decade of the 21st century. Therefore, heavy crude oil (HCO) and ultra heavy crude oil (UHCO) whose density is less than 10API and 20API respectively are considered as one of the most crucial sources to meet future energy demand[1-2]. But it is very difficult for them to be produced and transported because of their properties of heavier density, higher viscosity, and worse fluidity. To solve the problem of their production and transportation which are still very difficult technically in the world, the economical and effective methods which can be used to reduce their viscosities must be developed.

Blending of HCO or UHCO with a limited amount of lighter crude oil, hydrocarbon gases or alcohols et al. is one of the oldest and preferred methods. It can trace back to 1930s. It

is an effective method, especially in pipeline transportation. But Blending or diluting may cause certain operations such as dehydration and desalting etc. which request substantial investments in pumping and pipelines due to the increase of transport volume and need to separate the solvent, processes it and subsequently returns it to reservoirs at some point. And the composition of oil may affect the required oil/solvent ration. Special attention also has to be accorded to stability of asphaltene and paraffin in crude oil since addition of lighter oil may cause precipitation and clogging which is attributed to the crystallization and deposition of paraffin waxes [3-4].

In oil field, the recovery of HCO or UHCO is now predominantly achieved by chemical methods and thermal methods. The formation of oil in water emulsion with the help of surfactant is one of effective chemical methods. But the stability and formation of the oil in water emulsions depend on the physical properties of HCO, surface active molecules, surfactants and so on. As the oil in water mixture passes over chokes and valves, mechanical input leads to the formation of water in oil emulsion[5]. Furthermore, when the diameter of the emulsion is less than 10  $\mu\text{m}$ , the emulsion inversion to water in oil emulsion may happen and the viscosity will have a sharp increase[6]. Besides, the long-term use of chemicals can cause the oil reservoir pollution problems.

Conventional thermal methods such as steam injection, fire flooding, hot water injection and steam assisted gravity drainage (SAGD) may not fulfill the economic and environmental criteria[7]. Electromagnetic(EM) heating which includes ohmic heating or resistive heating, EM induction heating and microwave heating may overcome some problems of conventional thermal methods, but it still suffers from the environmental issues, low penetration depth, corrosion problem and so on[7-8].

Ultrasonic wave technique which is economical and environmentally friendly in theory is one of the most promising physical methods which can be used to improve rheological properties of crude oil either in reservoirs or pipelines[9-10]. In wells, the ultrasonic treatment can increase oil production by up to 50%[11]. The combination of ultrasonic treatment with the addition of active macromolecule viscosity reducer for a few minutes can cause the viscosity of HCO/UHCO to decrease at least 25% and 20% less quantity of viscosity reducer is needed[12]. Furthermore, the viscosity of HCO/UHCO will never return to the pre-treatment

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condition. Compared with other methods, the advantages of ultrasonic technique are simple operation, low cost, easy feasibility, and no environmental pollution.

In this paper, the effects of ultrasonic batch processing (UBP) on improving rheological properties of UHCO are investigated on the industrial scale. Firstly, the effects of ultrasonic wave on viscosity reduction for Fengcheng (FC) UHCO in Xinjiang oil field are studied in lab. Secondly, according to the experiments, an ultrasonic horn which can be used for UBP on industrial scale is designed. Thirdly, based on the ultrasonic horn and the experiments done in lab, a prototype that its electrical power is 10kW and can process 10-20 tons of UHCO per day is designed and installed in the field and the batch processing experiments on industrial scale is made in the Xinjiang oil field. Meanwhile the mechanisms of effects of ultrasonic wave on the viscosity reduction of UHCO are emphatically investigated.

## II. MATERIALS AND EQUIPMENTS

### A. Materials

FC UHCO used in this paper is provided by Research Institute of Science and Technology, CNPC. Its properties are shown in Table I and its viscosity temperature curve is shown in Fig.1. It's not Newtonian fluid.

TABLE I. PROPERTIES OF FC UHCO

Density 20 °C, g/cm <sup>3</sup>	Saturate M%	Aromatic M%	Resin M%	Asphaltene M%	Wax M%
0.9634	51.63	22.02	25.60	0.75	<1

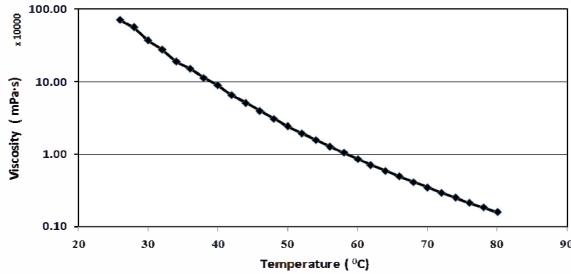


Fig. 1. Viscosity temperature curve of FC UHCO.

The oil in water (O/W) emulsion for FC UHCO viscosity is prepared by using of active macromolecule viscosity reducer and tap water. The optimal condition of the ratio of oil, water, viscosity reducer is 10:3:0.2% called as standard O/W emulsion (SOWE) and the initial agitating speed is no more than 400 rounds per minute [13]. For investigating the effects of ultrasonic wave on the reducing the viscosity of FC UHCO, 70%SOWE, 80%SOWE, and 90%SOWE are also prepared in which the ratio of oil, water, viscosity reducer is 10:2.1:0.14%, 10:2.4:0.16%, 10:2.7:0.18% respectively. The emulsion is made according to Q/SY118-2013 of CNPC.

### B. Equipments

The viscosity in this paper is measured by rheometer (Brookfield RVDVIII, USA) assembled with the accessories

of the TC550 constant temperature bath and a small sample adapter. The effects of measuring time, the torque, shear stress and shearing rate et al. on the viscosity value of measured UHCO are studied firstly. Then the suitable measuring situation is chosen. In the following measurement, the situation is sustained constant with cautions to reduce the errors caused by these factors.

As is shown in Fig.2, the ultrasonic processing (UP) equipment used in lab is ultrasonic horn (Institute of Acoustics, Chinese Academy of Sciences). The electrical power input for ultrasonic horn 150W and its frequencies are 18 kHz. Analytical balance (A & D, Japan), stirring apparatus, beakers, water tank, pump, measuring cylinders and so on are also used.

## III. EFFECTS OF ULTRASONIC WAVE ON OIL IN WATER EMULSION OF UHCO

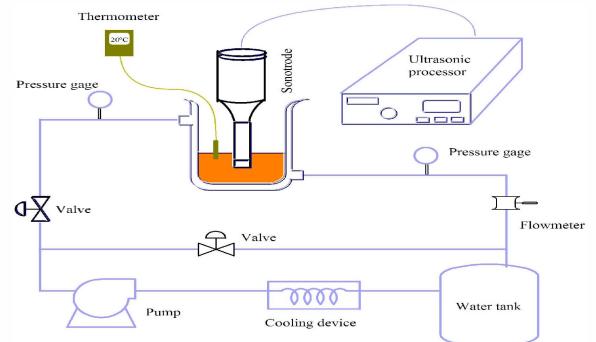


Fig. 2. Sketch of UP setups in lab.

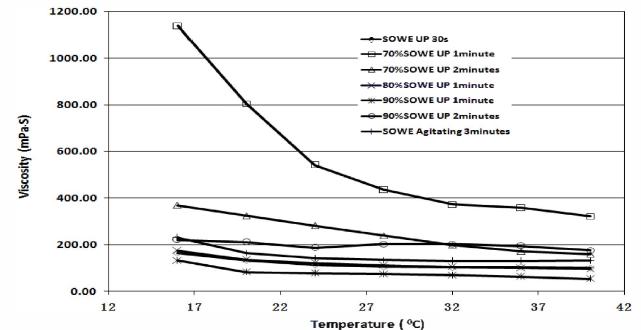


Fig. 3. Viscosity- temperature curve of different SOWEs .

In experiments, the mixture of crude oil, water and viscosity reducer is put in 100mL beaker according to the corresponding ratio firstly. Then it is put in the constant temperature bath in which the temperature is kept at 50 °C. It is agitating 3 for without UP. When it is processed by ultrasonic horn, it is not agitated. In the Ultrasonic Processing (UP), the temperature is kept almost constant.

In Fig.3, the curves from top to bottom are: SOWE with 30 seconds UP, 70%SOWE with 1 minute UP, 70%SOWE with 2 minutes UP, 90%SOWE with 2 minutes UP, SOWE with 30s

UP and 80%SOWE with 1minute UP which coincide with each other very well and hard to be distinguished in this figure, 90%SOWE with 1minute UP and SOWE with 3minutes agitating. It seems that there is optimal UP time for different percentage SOWE. For example, the viscosity of 90%SOWE with 1minute UP is lower than that with 2 minutes UP. Therefore when the ultrasonic processing is used to help reduce the viscosity of O/W viscosity reduction, the optimal such as UP time, electrical power input must be chosen by the experiment for the special situation.

The effects of ultrasonic wave on the emulsion viscosity reduction are active obviously, especially when the temperature is low. Compared with the viscosity stirred, that processed by ultrasonic wave has a more than 50% decrease of viscosity reduction at 20 °C. Due to the cavitations, vibrations, jet and shock wave effects, the emulsion with UP looks more uniform. The fluctuations of the viscosity value of the emulsion without UP during measurement are more violet, which means the emulsion is not stable and not uniform enough. Sometime the UHCO can be observed that separate with water and surround the measuring rotor. The phenomena can be observed in 80%SOWE, 90%SOWE and SOWE without UP. That's the reason that cause the violet fluctuations of viscosity value for emulsions without UP. For emulsions with UP, the phenomenon is little. The viscosity of the emulsion processed by ultrasonic wave has a more than 25% decrease of viscosity reduction at 20°C. A decrease of more than 25% viscosity for emulsion with UP can be achieved and 20% less quantity of active macromolecule viscosity reducer is needed.

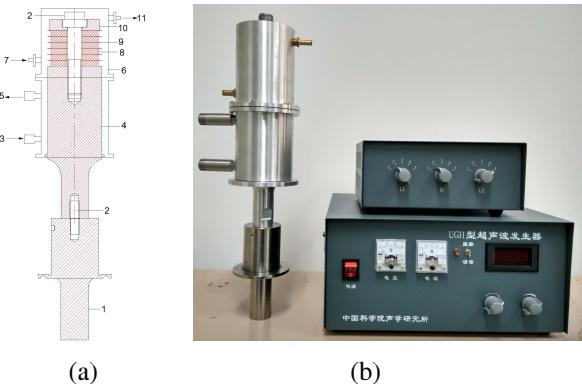


Fig. 4. Ultrasonic horn for industrial scale.

#### IV. INDUSTRIAL PROTOTYPE FOR VISCOSITY REDUCTION

According to the experiments in the lab, ultrasonic wave can reduce the viscosity of UHCO emulsions effectively and improve their properties. To meet the practical application needs in the oil field. Firstly, an ultrasonic horn for industrial scale is designed. Then, an industrial prototype is proposed and implemented than can be used on the wellhead.

##### A. Ultrasonic Horn for Industrial Scale

Fig.4 is the ultrasonic horn for industrial scale. Fig.4(a) is the structural sketch of the horn and Fig.4(b) is the apparatus. In Fig.4(a), 1 is radiation head (titanium), 2-screw bolt(steel),

3,5-water cooling inlet and outlet(stainless steel), 4-front end plate(aluminum), 6-overcoat(aluminum), 7,11-air cooling inlet and outlet(brass), 8-PZT ceramics, 9-electrode(copper), 10-back end plate(steel).

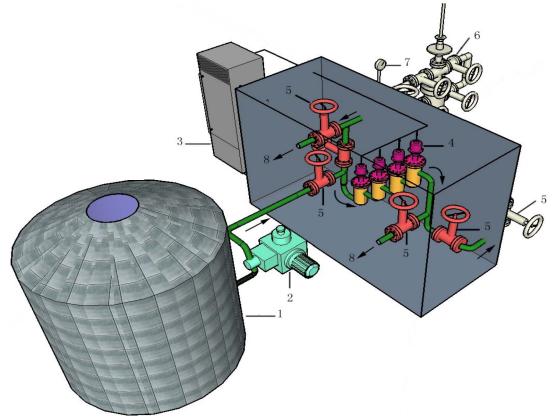


Fig. 5. Ultrasonic batch processing system for viscosity reduction.

The basic frequency of the horn is 17kHz and its input electric power is 2.5kW. It can work continuously at 150°C when the air cooling and water cooling system is operating both. The radiation titanium head can be changed easily also. The apparatus can be adjusted for different acoustic load to be fit for different HCO and UHCO. The effects of ultrasonic wave irradiated by the horn on the FC UHCO is shown in Table II. It shows that 10-30s irradiation of ultrasonic wave can make uniformly-distributed oil in water emulsion when the initial temperature is not lower than 40 °C. Once the uniformly-distributed emulsion forms, it can be produced and transported by the pipelines.

TABLE II. EFFECTS OF ULTRASONIC WAVE ON FC UHCO OIL IN WATER EMULSION DISTRIBUTION

Initial temperature °C	Irradiation time s	Viscosity mPa·s	Effects
>40	10	< 300	Uniformly distributed
	20	< 300	Uniformly distributed
	30	< 300	Uniformly distributed
40	10	—	Nonuniformly distributed
	20	< 300	Uniformly distributed
	30	< 300	Uniformly distributed

##### B. Ultrasonic Batch Processing System

According to the effects of ultrasonic wave on the UHCO in above mention, an ultrasonic batch processing system is designed for viscosity reduction in the oil field(see Fig.5). In Fig.5, 1 is a tank filled with 1m<sup>3</sup> miscible liquids of water and viscosity reducer whose volume ratio is 3:0.16%, 2-proportional pump which is used to pump the miscible liquid in the tank into the pipelines, 3-explosion proof box in which the electrical source and 4 ultrasonic generators are located, 4-ultrasonic horns shown in Fig.4, 5-valves, 6-production tree, 7-flowmeter, 8-sampling outlet. The industrial prototype is

composed of 3,4,5,8 in Fig.5. And it is installed in the Xinjiang oil field (See Fig.6). The system can work between 10°C-50°C. Its input power is 10kW and 10-20 tons UHCO production liquid can be processed per day.

When the UHCO production liquid is pumped on the ground and passes through the prototype, the miscible liquid of water and viscosity reducer is pumped into the pipelines according to its flux. Then they are processed by the four ultrasonic horns. After the procession, the emulsion of UHCO, water and viscosity reducer is pumped into the pipelines to the oil gathering station. Sampling can be taken before and after the ultrasonic procession through the sampling outlet.

HCO and UHCO account for higher proportion in Xinjiang oil field located in northwest of China. Some of the oil well can produce only when the air temperature is higher than 25°C and the UHCO cannot be transported by pipeline for its high viscosity.

The high viscosity of UHCO has restricted its production and transportation. The preliminary pilots of the industrial prototype in Xinjiang show that it can improve the fluidity of HCO and UHCO. Certainly, the challenge of working in winter still exists and some improvements need to be made for the further practical industrial production.



Fig. 6. Industrial prototype installed in Xinjiang oil field.

## V. CONCLUSIONS

The feasibility of ultrasonic batch processing of ultra heavy oil for viscosity reduction is investigated in this paper and the conclusions could be summarized as follows:

1. The obvious viscosity reduction effects of ultrasonic wave on HCO or UHCO can be observed for examples whose viscosity irradiated by ultrasonic wave is 25% lower than that un-irradiated at 20 centigrade and 20% less quantity of active macromolecule viscosity reducer is needed. And the reason of the phenomenon observed in this paper is analyzed qualitatively.
2. The uniformly-distributed oil in water emulsion can form when their miscible liquid is subjected to the 10-30s irradiation of ultrasonic wave emitted by the horn designed in this paper.
3. According to the results in the oil field, the prototype of ultrasonic batch processing for the UHCO can be used to reduce the viscosity of UHCO on the industrial scale. And some improvements need to be made for the further practical industrial production. The results obtained in this paper can

provide fundamental basis for the development of new ultrasonic technologies of reducing the viscosity of UHCO, which is helpful for improving and keeping good fluidity of HCO and UHCO during their extraction and pipe transportation.

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