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Research paper

Desalting and dewatering of crude oil in ultrasonic standing wave field

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ABSTRACT

A standing wave field of ultrasound was established in the designed standing wave tube. The enhancement of ultrasound irradiation on desalting and dewatering process of LU-NING pipeline oil was studied. The results showed that the best conditions of the oil pretreatment was: adding 30 mg/L demulsifier, injecting 5% (v.) wash water, irradiating the crude oil 5 min by 10 kHz ultrasound (intensity 0.38 W/cm^2, standing wave field), settling for 90 min. The final results of salt and water contents were 3.851 mg/L and 0.37%, respectively. The effect of standing wave field combined with demulsifier was better than that of the demulsifier only. High temperature (80 °C) in the process was better than low temperature. Salt balance study showed that the key of desalting was: the wash water and the oil should be mixed sufficiently to extract the salts into the water as more as possible, the water added in should be provided to be separated out. If one stage of desalting process could not achieve the norm, two stages of desalting process should be considered.

1. Introduction

Removal of corrosive water soluble salts, particularly chlorides of sodium and potassium from crude oil is an important processing operation in refining of crude oils. The process of desalting usually involves addition 1–20% (w.) of wash water to the crude oil, mixing to form a W/O emulsion and then subjecting the emulsion to electrostatic demulsification or hydrocyclone treatment (Goyal et al., 1993; Varadaraj, 2006). Under the influence of electrostatic or centrifugal fields the dispersed water droplets coalesce and the W/O emulsion is demulsified. Water and the water soluble salts are separated from the crude oil and removed. Most crude oils that contain asphaltenes and naphthenic acids tend to form stable W/O emulsions, which are complex scattered systems (Kumar et al., 2001).

Salts of chlorides in the oil may be hydrolyzed into HCl to erode the instruments, reduce the efficiency of energy exchanging, and increase the oil flow resistance and even obstruct the pipes. Moreover, over amount of salts and water in the crude oil would poison the catalysts in refining. In order to mitigate the corrosion, it is advantageous to reduce the salt concentration to under 5.0 mg/L and water content to under 0.3% (v.) of the crude oil before refining.

The crude oils are necessary to desalting and dewatering before distillation (Dantas et al., 2001). Key to the desalting of the crude oil is to demulsification and dewatering. The efficiency of these processes depend greatly on the degree of polydisperdity of the W/O emulsion that is formed. The highly efficiency is obtained if the emulsion is monodisperse (Shvetsov and Kabirov, 1992). Thus, chemical demulsifiers were used for desalting heavy crude oils (Elliott et al., 1995; Varadaraj et al., 2001). Pacifico V. Manalastas suggested that a chemical demulsifier added into the crude oil before adding the wash water could help desalting and save the amount of wash water (Manalastas et al., 2001). Paul Eaton reported the injection of a pretreatment mix of water and a special ethoxylated polyol demulsifier with water targeting a removal rate of more than 95% salts (Eaton, 2002).

With the quality deteriorating of the crude oils, methods such as cross-flow membrane (MeKechnie and Thompson, 1987), multiple stage desalting processes (Martin, 1980; Robinson, 1983; Hargreaves and Hensley, 1983) were developed. But nowadays, even three stages of electrostatic demulsification can't meet the norm of refining. New researches showed that, ultrasound irradiation is a good method to enhance the process of desalting and dewatering (Sun et al., 1999; Yu et al., 2001; Varadaraj et al., 2001; Combette et al., 2001; Han et al., 2004; Cai et al., 2005). Most of the studies concerned on the influences of reverberation ultrasonic field to desalting of the crude oils, few of them mentioned on applying the standing wave field of ultrasound to that.

When the standing wave of the ultrasound spreads in a fluent medium which contains scattered drops, the “displacement effect” happens, this phenomenon is named demulsification. When the drop's density differs from that of the medium, the ultrasound standing wave will push the drop moves to the wave nodes or antinodes. Then the drops collapse and settle down, thus to obtain the result of demulsification. When water droplets scattered in the oil, standing wave of the ultrasound will push the water particles to the wave nodes because the density of water is bigger than that of the crude oil.

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This thesis studied the standing wave field of ultrasound used for enhancement to the LU-NING Pipeline crude oil, Sinopec. The original salt content of the crude oil and other characters were listed in Table 1.

2. Establishment of the standing wave field

2.1. Theories and design of the standing wave tube

The crude oil was treated in a standing wave tube. One end of the standing wave tube was blinded, the other end of which was fixed with the ultrasound transducer (Fig. 1).

The tube provides a good condition to obtain plane wave. Plane wave spreading in a tube with "hard" blinded end must get a total reflection at the interface. The reflection wave which spreads at the opposite direction of the incident wave has the same amplitude and frequency as the incident one. These two waves will interfere to each other. Once the standing wave field is established, an ultrasound field with high standing wave ratio can be obtained by choosing a proper distance between the acoustic radiation surface and the reflection surface. The ultrasound intensity at wave nodes is very low and that at antinodes may be 4 times as high as the incident wave (Abe et al., 2002).

The standing wave tube was made of steel, 5.6 cm of inner diameter, 34.8 cm long and 0.2 cm of wall thickness. One end of the tube was blinded by a smooth steel circular flat-plate in order to get a reflecting wave. The thickness of the end plate was also 0.2 cm.

The acoustic impedance Z_s of the medium can be calculated as $Z_s = \rho_0 \times c_0$. Where, ρ_0 and c_0 are the density and sound velocity of the medium. The acoustic impedance of the crude oil Z_{oil} under 80 °C was calculated by measurement of sound velocity and density of the crude oil, which was 1.045×10^6 kg/(cm^{2}s). And Z_{steel} could be estimated as $Z_{steel} = \rho_{steel} \times c_{steel} = 7.8 \times 10^3 \times 6.1 \times 10^3 = 47.58 \times 10^6$ kg/(cm^{2}s). The acoustic impedance of air could be estimated as $Z_{air} = \rho_{air} \times c_{air} = 1.29 \times 330 = 0.43 \times 10^3$ kg/(cm^{2}s). The calculations showed when the tube was filled with the crude oil, and a sound wave incidences from the empty end, the wave would all transmit from the oil to the steel, for Z_{steel} is 10 times bigger than Z_{oil}, and the thickness of the steel end (0.2 cm) was much smaller than the ultrasound wave length in steel (30.5 cm of 20 kHz ultrasound, 61.0 cm of 10 kHz ultrasound). However, at the surface between steel and air, the sound wave would be totally reflected into steel, for Z_{air} is far smaller than Z_{steel}. Thus, the wave was totally reflected back.

2.2. Checkup of the standing wave field

In order to check up the formation of standing wave field, an experiment was done using the degassed water.

The tube was filled with pure water, which was kept at 80 °C for 2 h to get rid of the air. This step could avoid the sound attenuation caused by gas bubbles. Then the water was cooled to 33 °C. Wave length of 10 kHz ultrasound at 33 °C in water was 15.15 cm. Thus, the distance from the acoustic radiation surface to the reflection surface should be adjusted as 30.3 cm (2 times as the wave length). The sound intensity in the tube was measured by hydrophone. The results were shown in Fig. 2. The vertical axis meant the length between measurement points to the reflection surface of the tube. The Y-axis meant the ultrasound intensity measured at different points.

Table 1
Characters of LU-NING Pipeline oil.[a]

Species	Value	Species	Value
API°	22	Salt content (mg NaCl/L)	31.93
Density (20 °C) (g/cm^2)	0.9199	Water content (% v.)	0.25
Kinematical viscosity (50 °C) (mm^2/s)	108.0	Carbon residue (% v.)	6.41
Pour point (°C)	19	Ash (% v.)	0.015
Acid value (mg KOH/g)	1.92	Characteristic factor (K value)	11.75

[a] Provided by Yangzi Petrochemical Company, Sinopec (YPC).

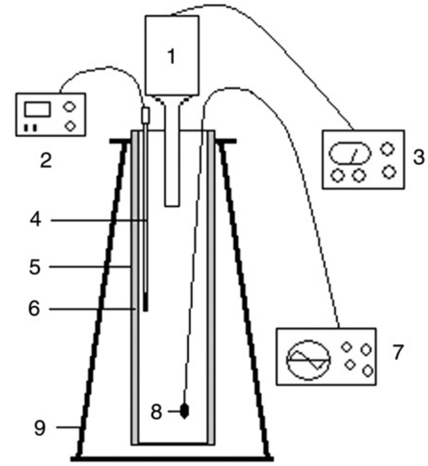

Fig. 1. Structure of the standing wave instrument. 1 ultrasound transducer, 2 thermo control instrument, 3 ultrasound generator, 4 thermometer, 5 insulation, 6 standing wave tube, 7 osciliograph, 8 hydrophone, 9 bracket.

The measured and the calculated wave node numbers were the same to each other, the sound intensity measured at the antinodes were also in consonant with the calculated value (Fig. 2). There was a little attenuation at the end of reflection surface. The result was satisfactory for the steady standing wave field established in the tube.

The standing wave field formed by 20 kHz ultrasound in the tube was also studied (Fig. 3). The results showed that there also formed steady wave nodes and antinodes in the tube. The wave shape of 20 kHz ultrasound was not as good as that of 10 kHz ultrasound. Because the standing wave tube was designed for 10 kHz ultrasound and 80 °C crude oil (inner diameter ≤ 8.8 cm). 20 kHz ultrasound needed a tube with an inner diameter less than 4.4 cm to form a good standing wave field. It could not form good plane wave and excellent standing wave in a tube with an inner diameter of 5.6 cm. Nevertheless, we had also got a wave in the tube by 20 kHz ultrasound, which was not very regular and had low standing wave ratio.

The experiments showed that low frequency ultrasound could form a better steady standing wave field in a suitable tube. It was hard to form a good standing wave field by experiments with high frequency ultrasound, for which needed more accuracy both in size of standing wave tube and in adjustment of distance between the acoustic radiation surface and the reflection surface. On the other hand, the small tubes which match high frequency ultrasounds were useless in industry application.

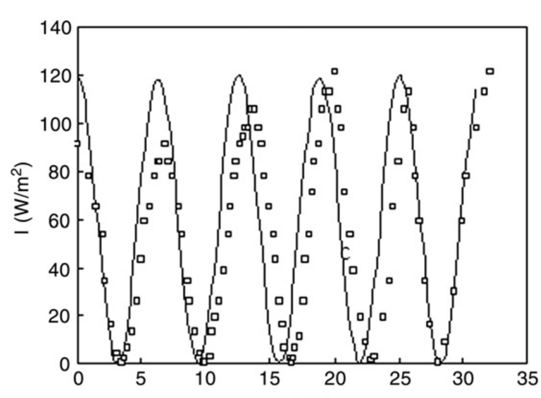

Fig. 2. Standing wave field measured by hydrophone. -□- measured value, — calculated value; ultrasound frequency: 10 kHz, ultrasound power 10 W.