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Research article

Study on dual-frequency ultrasounds assisted surfactant extraction of oil sands

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ABSTRACT

The environmental impact of the energy industry is diverse. In view of the significantly large amount of energy consumption and following environmental problems in the oil sands separation process, this study proposed a dual-frequency ultrasounds assisted surfactant extraction of oil sands technology. Comparative experiments were performed in order to investigate the effects on the oil production rate by the application of ultrasound and their combination modes of the two ultrasounds with the different frequencies. Based on these experimental results, the improvement in the treatment conditions for surfactant extraction of oil sands, which is contributed by adding of dual-frequency ultrasounds, was researched. The results indicated that compared to the mechanical agitation, the surfactant extraction of oil sands under the effect of ultrasound with the frequency of 28 kHz resulted in an increase in the oil production rate by 13%. Further, the oil production rate of surfactant extraction assisted by dual-frequency ultrasounds, with the frequency of 28 kHz and 68 kHz separately, was found to be up to 95%, significantly higher than that of single-frequency ultrasound and alternated ultrasounds with the frequencies of 28 kHz and 68 kHz. When the maximum oil production rate treated by dual-frequency ultrasounds was acquired, the processing time was shortened from 45 to 15 min; the concentration of sodium dodecyl benzene sulfonate in washing liquid decreased from 5 to 2 g L^{-1}; the mass ratio of surfactant solution to oil sands reduced from 2.6 to 2 g L^{-1}; and the treating temperature decreased from 70 to 30 °C. Therefore, the dual-frequency ultrasounds assisted surfactant extraction of oil sands technology provides an environmentally friendly development method for high efficiency and low resource consumption exploitation of oil sands resources.

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1. Introduction

The oil sand, also known as asphalt sand, is a mixture of asphalt, sand, clay, and water; and it belongs to non-conventional energy resources [1–2]. Commonly, Oil sands contain about 3–20% of asphalt, 80–87% of sand and clay minerals, and 3–6% of water. In the world crude oil reserves, the asphalt and heavy oil resources are estimated at about 8.9×10^{11} m^3; however, the conventional oil reserves are estimated only at about 1.62×10^{11} m^3. More than 80% of the world's heavy oil and oil sands resources are distributed in Venezuela, Canada and the United States, and 70% of the oil sands resources are located in Alberta, Canada [3–4]. With the increasing demand for oil and gas in the world economic development, conventional resources cannot meet the rapid growth of energy demand, therefore, people have turned their attention to unconventional oil and gas resources. Oil sands and other alternative oil and gas resources with their large reserves, the concentrated distribution, and the fast-growing development technology, are increasingly important in the energy industry. Therefore, study of oil sands mine is extremely important to ease the energy crisis, and new technology is needed to enable profitable extraction [5–6].

Different from the method of conventional oil exploitation, currently there are two main types of mature methods for oil recovery from oil sands production. For deeper deposits of oil sands (greater than 75 m), in-situ separation method is used [7–8]. However, for the oil sands mine buried shallower (less than 75 m), opencast mining method is adopted. The techniques for separation and extraction involved in opencast mining of oil sands mainly employ the water-based extraction techniques, such as hot alkali water washing method, surfactant solution washing method, and organic solvent extraction method [9–14]. At present, the opencast mining method contributes to 55–60% of the total oil sands development in China [15]. Moreover, ultrasound-aided oil sand separation technology has been widely used because of its high separation speed and no secondary pollution to the environment.

Zhao et al. treated oil sands using YSFL aided by ultrasound with the frequency of 28 kHz. They pointed out that the introduction of ultrasound could increase the oil production rate from 80.2 to 93.4%. Moreover, the optimum separation temperature reduced from 80 to 60 °C

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[16]. Feng employed ultrasound with the frequency of 53 kHz to improve the oil recovery from Daqing oil sands, and the action mechanism of ultrasonic onto the separation process was explained by analyzing the surface of the solid particle after the treatment [17]. Abramov et al. studied the separation kinetics of asphalt molecule from oil sands in the presence of ultrasound. Based on the study, the effects of temperature, ultrasound power, concentration of alkali solution, and composition of oil sands on the oil production rate were determined [18]. Zou et al. investigated the changes in the residual oil rate of the oil sands and the surface morphology of the sands when ultrasound was introduced to oil sands separation with SDBS (sodium dodecyl benzene sulfonate) solution [19]. With progressive development, ultrasound-assisted water-base extraction technology has also been adopted in the industrial application.

Dual-frequency ultrasounds refer to the two ultrasounds with different frequencies play the role at the same time. Dual-frequency ultrasounds can produce a significant increase in cavitation activity compared with single frequency irradiation, and the cavitation production is much larger than the algebraic sum of that under individual irradiation. The mechanism of the cavitation enhancement effect of the dual-frequency ultrasounds mainly includes the following three aspects: (1) The dual-frequency ultrasounds accelerate the mechanical vibration, which helps more air enter into the liquid through its interface and thus cavitation nuclei increase [20]; (2) Each ultrasound generates individual cavitation when the dual-frequency ultrasounds irradiate. With the collapse of the individual cavitation bubbles, many new cavitation nuclei are generated, among which some cavitation nuclei are approaching the resonant frequency of the other frequency cavitation, so the whole cavitation effect is increased by their mutual influence [21]; (3) The threshold of the cavitation effect decreases, because the quasi-static pressure decreases in the negative pressure amplitude. The quantity of ultrasound cavitation activity is enhanced, because the inner burst intensity of bubbles increases in the positive phase [22–23].

In view of the cavitation effect caused by the dual-frequency ultrasounds under room temperature and pressure condition, being obviously stronger than that generated by the single-frequency ultrasound, the dual-frequency ultrasounds have been applied in numerous fields. For example, Zhang et al. applied the dual-frequency ultrasounds, with the frequencies of 20 and 25 kHz separately, for the disintegration of sludge aggregates [24]. Tan et al. applied the dual-frequency ultrasounds in the degradation of ammonia nitrogen in coked waste water, and the synergistic effect of the cavitation effect of the dual-frequency ultrasounds was studied [25]. Zheng et al. utilized the dual-frequency ultrasounds to enhance the degradation process of azo fuel waste water by H_2O_2 [26]. The ultrasound assisted oil sand separation technology is mainly dependent on the cavitation effect of the ultrasound, and the cavitation effect of dual-frequency ultrasounds has an obvious synergistic effect; therefore, the dual-frequency ultrasounds should have a better effect in oil sand separation. Based on this hypothesis, in this study comparative investigation of the oil production rates of surfactant extraction was conducted under the effect of dual-frequency ultrasounds, single-frequency ultrasound, and without ultrasound. Further, the treating conditions required for achieving the maximum oil production rate were optimized, and the improvement in the treating conditions in the presence of dual-frequency ultrasounds was analyzed. The adding of dual-frequency ultrasounds in surfactant extraction of oil sands can reduce energy consumption and reduce environmental pollution effectively. This study provides a new choice for the development of oil sands resources.

2. Experimental

2.1. Materials

The oil sands samples used in the experiment were obtained from West China, without any obvious congelation of crude oil. The wetting type of the samples from this area is water wetting. The median grain diameter and the specific surface area of the oil sands are 186.35 μm and 21.03 $m^2 \cdot kg^{-1}$. After sampling, the samples were evenly mixed and sealed for storage. The Dean–Stark method recommended by AOSTAR was employed to measure the mass fraction of each component in the samples as follows: 9.8% of oil, 5.1% of water, and 85.1% of sand and clay. SDBS solutions with different mass concentrations were used for oil sands extraction. The SDBS was analytical-grade and purchased from Sinopharm, China.

2.2. Methods

2.2.1. Experimental procedure

First, oil sands samples (200 g) were collected and mixed with the washing solution (the mass concentration of SDBS was 2 g L^{-1}) in a mass ratio of 1:2 in a beaker. The mixture was stirred and placed in the ultrasound generator, with the frequency of 28 kHz or 68 kHz, or bath oscillator (SHA-B, Shanghai Lichen Tech co., LTD, with the maximum oscillation frequency of 300 r min^{-1}) or overhead blender (OS40-S/OS20-S, Nanjing Huaao Instrument co, LTD, 300 r min^{-1}) for 30 mins' treatment. The intensity of the ultrasonic generator is 0.75 W/cm^2, and the tip surface area is 800 cm^2. The schematic of the experimental equipment of dual-frequency ultrasounds is shown in Fig. 1.

Then the mixture was poured into the flotation container. The air was inlet through the bottom of the container and the mixture was mixed using a blender. As a result, the micro-droplets of asphalt got separated from the sand body, and resulted in the formation of asphalt foam after encountering the air bubbles. The asphalt foam was observed to be floating on the surface of the solution attributed to the density difference. The asphalt droplets and asphalt foam could be recovered by using the decantation method. The operation was repeated until no black material was seen floating up on the surface of the solution in the flotation container.

Thirdly, the asphalt foam was transferred to another container and then the defoamer was added. The asphalt and water were separated after the disappearance of the bubbles.

Finally, the separated asphalt and petroleum ether were mixed in a mass ratio of 4:1, and placed in a centrifuge machine rotating at 2000 r min^{-1}. The micro fine sand mixed in the asphalt was separated and the pure asphalt was obtained. The oil production rate is defined as the ratio between the amount of the produced oil from unit mass of oil sands and the oil content of the unit mass of oil sands. In order to obtain more accurate results, each experiment was repeated three times, and the averages of the results were selected.

2.2.2. Definition of combination mode of ultrasounds

In order to study the effect of the combination modes of the two ultrasounds on the ultrasound-assisted separation of oil sands, following combinations of two sound waves were employed. Dual-frequency ultrasounds (DFUs) means that two ultrasound with different frequency of 28 and 68 kHz simultaneously treated on the oil sands mixed with the SDBS solution for 15 min; Alternated ultrasounds (AUs) refers to treating the mixture of SDBS solution and oil sands with the first ultrasound in a frequency of 28 kHz (or 68 kHz) for 5 min, and then changed to the ultrasound with a frequency of 68 kHz (or 28 kHz) for another 5 min; the cycle was repeated 3 times with the total treating time of 30 min, and the experiments were recorded as AUs-28 and AUs-68, respectively. Furthermore, for comparison, the single-frequency ultrasound experiments were also conducted, in which the ultrasound with a frequency of 28 kHz (or 68 kHz) was used alone to treat the mixture for 30 min, and the experiments were recorded as SU-28 and SU-68. The experiment without ultrasound was also carried out.

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