Research on electrostatic coalescence of water-in-crude-oil emulsions under high frequency/high voltage AC electric field based on electro-rheological method

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HIGHLIGHTS

- Chord Length Distribution (CLD) of dispersed water droplets within water-in-crude-oil emulsions is measured online.
- Relative viscosity reduction is taken as the main evaluation means to study the electric-field and flow-field parameters.
- Threshold shear rate, optimum electric field strength, frequency and the most efficient voltage waveform for electrocoalescence are discussed.
- Great application potential of high frequency/high voltage AC electric field in treating the highly conductive crude oil emulsions is confirmed.

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ABSTRACT

The viscosity–temperature characteristics and phase inversion point as well as the chord lengths distribution of dispersed droplets have been investigated. The relative viscosity reduction is then effectively taken as the evaluation means to investigate the effects of shear rate, electric field strength, frequency, voltage waveform, and initial water cut on the electrocoalescence efficiency experimentally systematically. It is determined that the phase inversion point is located between 35%–45%. The chord lengths of dispersed droplets are concentrated in range of 10–150 μm and the average value is 61.3 μm for the water-in-crude-oil emulsions sample. We found that the coalescence efficiency can be improved by increasing shear rate to some extent while keeping other parameters unchanged, but decreased instead with the shear rate exceeding 50 s⁻¹, which suggests that only the appropriate flow shear condition can help to promote the electrostatic coalescence. Meanwhile, the present work has demonstrated that there exists optimum electric field strength (8 kV/cm) and frequency (2 kHz) for the given water-in-crude-oil emulsions, and the ranking of three voltage waveforms in decreasing order of coalescence efficiency is AC...
square, triangular and sinusoidal waveform. In addition, with the three kinds of voltage waveforms, the coalescence efficiency are all significantly improved as the water cut increases from 10% to 40%, which demonstrates the good performance of high frequency/high voltage electric field for treating crude oil emulsions with high water cut.

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1. Introduction

When extracted from oil wells, crude oil are always accompanied by water, sand, wax and other substances which tends to produce stable water-in-crude-oil (W/O) emulsions. Normally, it is difficult to separate such emulsions completely just by gravitation settlement in conventional horizontal separator. However, when subjected to electric field, the collision and coalescence between emulsified water droplets will be greatly enhanced, thus promoting the separation of dispersed water-phase from continuous oil-phase [1]. Related technologies and industrial equipment such as electric dehydrator and desalter have been extensively used within oilfield and refinery worldwide since the early 60’s of last century. However, as the main oilfields around the world enter into the middle or late period of exploitation, the water cut of well stream is getting higher and higher. Furthermore, the implementation of acid fracturing and Enhanced Oil Recovery (EOR) technology has led to several problems such as greater stability and higher electrical conductivity of crude oil emulsions. In such conditions, it becomes more and more difficult to meet the requirements for conventional electric dehydrator owing to the frequent collapse of electric field, as well as the low efficiency of demulsification. In recent years, the high efficiency (>1000 Hz)/high voltage AC electric field has attracted wide attention for its higher demulsification efficiency, lower electric power consumption and better stability of working performance in processing the above challenged W/O emulsions.

According to Taylor et al. [2], the two main coalescence forms under AC electric field, i.e., dipole coalescence and oscillation coalescence, are respectively caused by electric field polarization and its periodic alternation, which jointly promote the electro-coalescence process both by enlarging inter-attraction force and accelerating oscillation deformation of dispersed water droplets simultaneously. Field strength mainly affects the polarization and stretching deformation of water droplets, while the electric filed frequency and waveform work together to affect the droplets’ oscillation frequency and amplitude. Therefore, when keeping other parameters such as water cut and dynamic stability of W/O emulsions unchanged, electric field strength, frequency and voltage waveform are three key factors affecting the electro-coalescence efficiency of dispersed water droplets in crude oil emulsions.

In recent years, many researches have been carried out on the electrostatic coalescence process of W/O emulsions from macro-, meso- and micro-scale theoretically and experimentally. Research at macro-scale is mainly conducted for dehydration performance test of industrial electric dehydrator. Study at meso-scale mainly investigates kinetic stability, rheological and dehydration properties of emulsions. And research at micro-scale concerns about the motion, deformation and collision mechanism of a single droplet or a few droplets subjected to electric field [3]. Currently, it has been widely accepted that the excessive electric field strength will cause the electro-dispersion of water droplets, because the excessive deformation amplitude will make the larger water droplets stretched excessively and then produce many smaller ones, which reversely increase the stability of W/O emulsions. Therefore, the optimum or threshold value of field strength is naturally determined according to this phenomenon [4]. However, most of those investigations were carried out based on commercial frequency (50 Hz)/high voltage AC or pulsed DC electric field. Up to now only a few researches have been conducted on electrostatic coalescence by utilizing the high frequency (> 1000 Hz)/high voltage AC electric field, and there still exist great debates about the effects of electric frequency, waveform and flow shear conditions on the electrostatic coalescence of water-in-oil emulsions.

Brown et al. [5] observed the threshold of electric field frequency for specific W/O emulsions, and suggested that the threshold frequency is determined by the electric conductivity of continuous phase. Bailes et al. [6,7] explicitly proposed the concept of optimum electric field frequency for the first time, and suggested that it is mainly related to the dielectric properties of the electrode coating and the continuous oil phase. Friedemann et al. [8] experimentally investigated the demulsification characteristics of W/O emulsions under high frequency/high voltage AC electric field, and found that the optimum frequency varies with the flow rate of emulsions. Chiesa et al. [9] studied the effects of AC square waveform and sinusoidal waveform on the electro-coalescence efficiency with W/O emulsions. It is declared that changing the voltage waveform between sinusoidal and square shows little significance on the coalescence efficiency. However, Lundgaard et al. [10,11] have found that AC square waveform could improve the electric dehydration efficiency by about 40% compared with AC sinusoidal waveform of the same peak value. But they also suggested that the most efficient coalescence can be achieved by using a voltage with a high RMS value, and declared that a capacitive voltage distribution will be generated when the applied frequency of AC electric field is higher than a certain value. Jin et al. [12–15] also investigated the dehydration characteristics with simulated W/O emulsions under high frequency/high voltage AC electric field. By taking the dehydration rate, electric current and average power consumption of electric energy as the evaluation criteria, they found 4 kHz is the optimum electric field frequency for given emulsions. Lesaint et al. [16] studied the effects of temperature, electric field strength, electric field frequency, voltage waveform and duration of applying electric field on the electrocoalescence efficiency. The three waveforms were ranked in decreasing order of coalescence efficiency as square, sinusoidal and triangular. And it is reported the viscosity reduction increases with the rise of electric field strength and frequency. Berg et al. [17] investigated the interfacial rheological behaviors and dynamic deformation behaviors of water-droplets in hydrocarbon liquids at micro-scale. Three waveforms have been applied to the W/O emulsions and they suggested that AC square waveform is the most effective waveform for electrostatic coalescence. Mohammadi et al. [18] used numerical simulation method to study the effects of field strength, frequency and waveform on the electrocoalescence efficiency. They suggested that square AC waveform is the most efficient, sinusoidal and pulsed DC voltages give lower efficiencies, while triangle and sawtooth waveforms are the least efficient waveforms. But it is also declared that no significant differences were observed in the approaching time of two water droplets by different electric field frequencies. Rodionova et al. [19] experimentally investigated the effects of different parameters including strength, frequency and waveform of electric field on the destabilization of North Sea acidic crude oil emulsions with also
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