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# Variation of interfacial tension of the steam-foam drive in heavy oil reservoirs

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**Abstract:** The reservoir could be divided into three zones: steam zone with saturated steam temperature, condensate zone and reservoir temperature zone. Experiments were conducted to investigate influence of mass fraction of foaming agent and temperature on interfacial tension at reservoir pressure and temperature, by means of high temperature and high pressure interfacial tension instrument. The results showed that increasing mass fraction of foaming agent and temperature would result in decreasing minimum dynamic interfacial tension and steady interfacial tension. As temperature increased, it would take less time for the system to reach minimum dynamic interfacial tension. In steam zone and condensate zone, the interfacial tensions between water and heavy oil all keep magnitude of 10-2mN/m, but it keeps magnitude of 10-1mN/m in reservoir temperature zone. So the foaming agent has better displacement efficiency for heavy oil in steam zone and condensate zone.

## 1. Introduction

Thermal recovery by steam flooding was the best support technique for heavy oil recover at present[1,2,3]. A mass of laboratory studies and field runs were carried out both domestically and overseas to solve the problem of gravity sinking and gas breakthrough during the steam injection. The results showed that high temperature bubble could improve the sweep efficiency of steam and displacement efficiency [4,5]. Foam formation in porous channel could prevent the gas breakthrough of steam effectively and improve swept volume of steam flooding and hot water flooding by adding high temperature foam agent and steam[6,7]. Foam agent not only could improve disadvantage mobility ratio, but also enhance displacement efficiency[8,9].

After the vapor was injected into the reservoir, there would form steam zone with saturated steam temperature, condensate zone and reservoir temperature zone. The fluids in those zones were foam agent and heavy oil system, hot water and heavy oil system, and cold water and heavy oil system, respectively. Experiments were conducted to investigate influence of mass fraction of foaming agent and system temperature on interfacial tension at reservoir pressure and temperature.

## 2. Experimental

### *2.1 Materials*

IOP Conf. Series: Earth and Environmental Science **186** (2018) 012011 doi:10.1088/1755-1315/186/4/012011

The simulated heavy oil was composed of kerosene and crude oil, which was dehydrated at 150ºC for 5 h by electric dehydrator, and its viscosity was 2000 mPa·s at 65ºC. High temperature foaming agent was composed of alkyl sulfonate(HR-1), alkylbenzene sulfonic acid(GMS), additive and water with the mass ratio of 2:3:1:4.

*2.2 Principle and apparatus*

In this experiment, oil droplet was formed in the needle by oil injection pump. Its profile photo was obtained by amplification camera system, and then input into computer image processing system. In the software, the image magnification of oil droplet was corrected by comparing with the diameter of needle. After the densities of the light and the heavy phases were inputted, the interfacial tension was gained by calculating the Laplace equation.

Figure 1 showed the experimental device. In experiment, the high temperature and high pressure interfacial tension instrument was used, with working temperature of 20℃～200℃ and maximum working pressure of 69MPa.

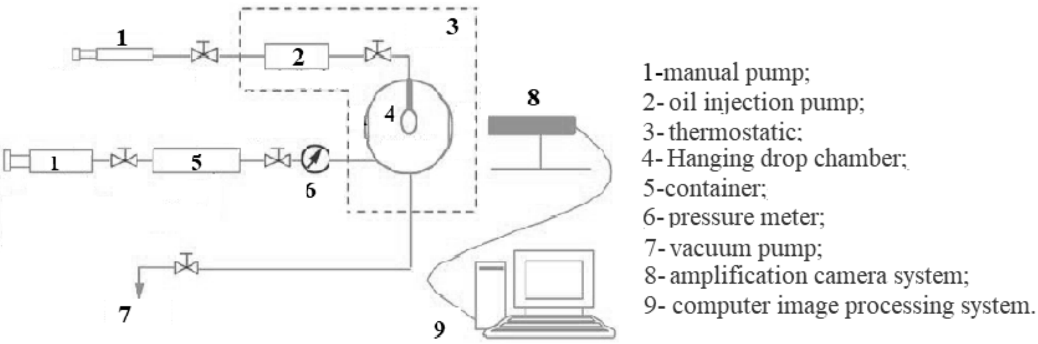


Fig.1. Schematic diagram of experimental set-up

*2.3 Procedure*

The variations of interfacial tension in foam/oil system, hot water/oil system and cold water/oil system by the interfacial tensiometer were measured. The influences of foam agent concentration and temperature on the interfacial tension were investigated. The experimental procedures were as follows: (1) The whole experiment system was cleaned using petroleum ether, and then the remaining petroleum ether was purged using hot nitrogen. Finally, the system was vacuumized; (2) After hanging-drop ventricle and crude oil injection pump were up to design temperature, the research system was put into hanging-drop ventricle. The pressure was added to 7.6MPa by using hand pump, and the valve was fasten up until pressure was stabled; (3) Oil was injected into the ventricle by crude oil injection pump, and a small oil-drop was formed at probe section. After keeping a period, the small oil drop photo was taken using the amplification photography system. According to the shape of oil drop, the interfacial tension was calculated using the Laplace equation.

## 3. Results and discussion

*3.1 Variation of interfacial tension between foam agent and heavy oil*

Figure 2 showed the dynamic interfacial tension between foam agent and heavy oil at different foam agent concentrations. At the mass fraction of foam agent ranging from 0.5% to 2.0%, the interfacial tension decreased with increasing time, then increased, and finally remained unchanged. This is because that in the initial stage the adsorption rate of foam agent is more than the desorption rate on oil/water interface, and surfactant aggregated on the interface leading to the decreasing dynamic interfacial tension. The content of surfactant in interface increased with an increase of time, resulting in the increasing desorption rate. As a result, the surfactant decrease with the increase of desorption rate, leading to an increase of the interfacial tension. When the quality of active material on the interface was identical with that in the liquor, the interfacial tension achieved at the stable level. The interfacial tension would be the lowest when adsorption rate was equal to desorption rate.

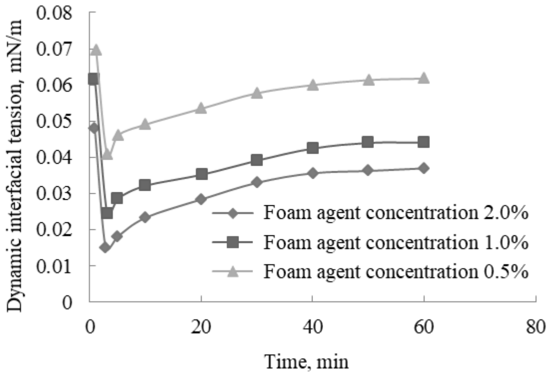


Fig. 2. The influence of foam agent concentration interfacial tension between foam agent and heavy oil

Figure 2 also showed that with the increase of foam agent mass fraction, the lowest interfacial tension and final steady interfacial tension decreased. The interfacial tensions reached the lowest interfacial tensions after the experiments were carried out for 3min, and the values were 4.1×10-2mN/m, 2.4×10-2mN/m and 1.5×10-2mN/m successively. After 50min, the interfacial tension remained stable, and the values were 6.2×10-2mN/m, 4.4×10-2mN/m and 3.6×10-2mN/m respectively. That was because the ionic strength of solution affected adsorption rate and desorption rate of foam agent on the oil/water interface. The higher the mass fraction of foam agent was, the more surfactant was adsorbed on the oil/water interface. As a result, the interfacial tension decreased greatly.

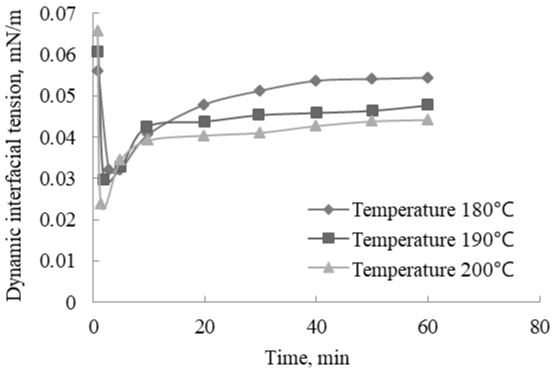


Fig.3. The influence of temperature on on interfacial tension between foam agent and heavy oil

The influence of temperature on the interfacial tension was similar to that of foam agent concentration. Figure 3 showed that in oil/water system the interfacial tension also decreased with the increasing time, then increased, and finally remained unchanged. With the increase of temperature, the lowest interfacial tension and steady interfacial tension decreased, and it needed shorter time to reach the lowest interfacial tension. At the temperature ranging from 180℃ to 200℃, the times were 3, 2 and 1.5min, the lowest interfacial tensions were 3.2×10-2mN/m, 2.9×10-2mN/m and 2.4×10-2mN/m, and the final steady interfacial tensions were 4×10-2mN/m, 4.7×10-2mN/m and 4.0×10-2mN/m respectively. It was concluded that the adsorption rate of active substances would increase with the increasing time. Theses active substances gathered quickly to the oil/water interface, which leaded to the interfacial tension achieving the lowest quickly.

*3.2 Variation of interfacial tension between hot water and heavy oil*

Figure 4 showed the variation of interfacial tension between hot water and heavy oil at different foam agent concentrations at 150℃. In oil/water system the interfacial tension decreased with the increasing time, then increased, and finally remained unchanged. With tan increase of foam agent concentration, both the lowest interfacial tension and final steady interfacial tension decreased. For foam agents with mass fraction of 0.5%, 1.0%, 2.0%, the interfacial tension reached the lowest interfacial tension after the experiment began 5 min, which were 7.5×10-2mN/m, 5.8×10-2mN/m, and 5.6×10-2mN/m, successively. In addition, the final steady interfacial tension were 9.33×10-2mN/m, 7.48×10-2mN/m and 7.13×10-2mN/m, successively.

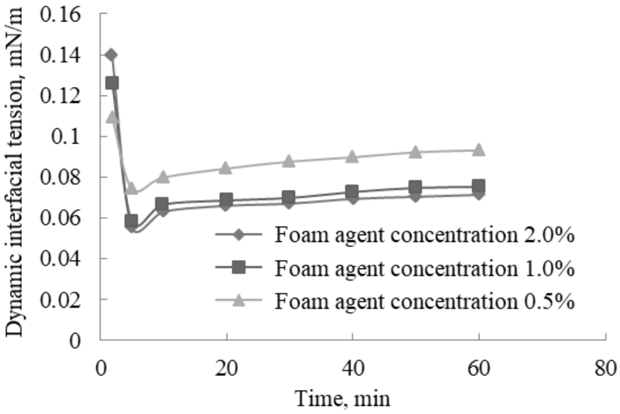


Fig.4. The influence of foam agent concentration on interfacial tension between hot water and heavy oil

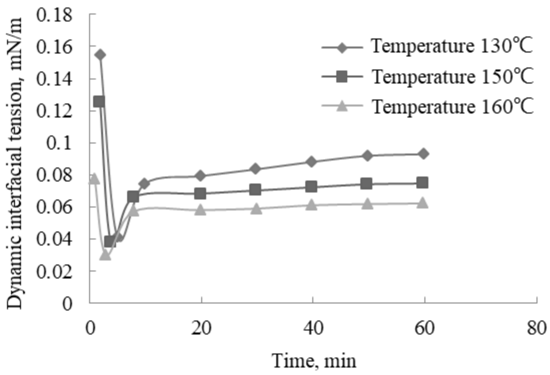


Fig. 5. The influence of temperature on interfacial tension between Hot water and heavy oil

Figure 5 showed the variation of interfacial tension between hot water and heavy oil at different temperatures with foam agent mass fraction of 1.0%. In oil/water system the interfacial tension decreased with the increasing time, then increased, and finally remained unchanged. With the increase of temperature, both the lowest interfacial tension and final steady interfacial tension decreased, and it needed shorter time to reach the lowest interfacial tension. At the temperature ranging from 130℃ to 160℃, the times were 8, 5 and 4min, the lowest interfacial tensions were 6.2×10-2mN/m, 5.8×10-2mN/m and 3.1×10-2mN/m, and the final steady interfacial tensions were 9.4×10-2mN/m, 7.48×10-2mN/m and 6.32×10-2mN/m respectively. The influences of foam agent concentration and temperature on interfacial tension were basically identical with foam/oil system in steam flooding area. Compared with the foam/oil system, the interfacial tension in hot water/oil system decreased gradually with the decrease of temperature, and it needed longer time to reach the lowest interfacial tension.

IOP Conf. Series: Earth and Environmental Science **186** (2018) 012011 doi:10.1088/1755-1315/186/4/012011

*3.3 Variation of interfacial tension between cold water and heavy oil*

Figure 6 showed the variation of interfacial tension between cold water and heavy oil at different foam agent concentrations at 65℃. In oil/water system the interfacial tension decreased with the increasing time, then increased, and finally remained unchanged. The change law also appeared in no foam agent system, but interfacial tension increased significantly. With the increase of foam agent concentration, both the lowest interfacial tension and final steady interfacial tension decreased. For foam agents with mass fraction of 0.5%, 1.0%, 2.0%, the interfacial tension reached the lowest interfacial tension after the experiment began 30 min, which were 4.02×10-2mN/m, 2.67×10-2mN/m, and 1.01×10-2mN/m, successively. In addition, the final steady interfacial tension were 9.57×10-2mN/m, 7.93×10-2mN/m and 6.29×10-2mN/m, successively. For no foam agent system, it also reached the lowest interfacial tension at 20 min with the value of 8.3×10-2mN/m and the final steady interfacial tension of 1.80×10-1mN/m. This was because the reaction of acidic components with oil created surfactant at oil/water interface. That leaded to the decrease of interfacial tension in no foam agent system. However, in foam agent system the interfacial tension drops more rapidly.

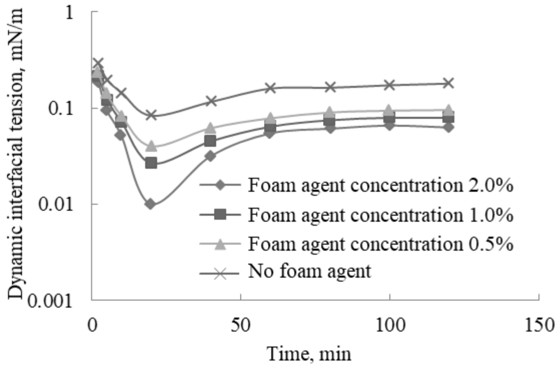


Fig.6. The influence of foam agent concentration on interfacial tension between cold water and heavy oil

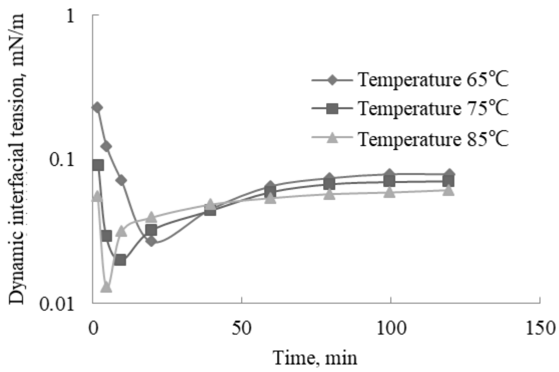


Fig.7. The influence of temperature on interfacial tension between cold water and heavy oil

Figure 7 showed that the variation of interfacial tension between cold water and heavy oil at different temperatures with foam agent mass fraction of 1.0%. In oil/water system the interfacial tension decreased with the increasing time, then increased, and finally remained unchanged. With the increase of temperature, both the lowest interfacial tension and final steady interfacial tension decreased, and it needed shorter time to reach the lowest interfacial tension. At the temperature ranging from 65℃ to 85℃, the times were 25, 10 and 6min, the lowest interfacial tensions were 2.68×10-2mN/m, 1.98×10-2mN/m and 1.29×10-2mN/m, and the final steady interfacial tensions were 7.87×10-2mN/m, 7.05×10-2mN/m and 6.12×10-2mN/m respectively. The influences of foam agent concentration and temperature on interfacial tension were basically identical with foam/oil system in steam flooding area and hot water/oil system in condensing zone. With the decrease of temperature, the interfacial tension decreased, but it still kept a low value at lower temperature.

## 4. Conclusions

(1) The influences of foam agent concentration and temperature on the interfacial tension were basically the same. In oil/water system the interfacial tension decreased with increasing time, then increased, and finally remained unchanged.

(2) With the increase of foam agent concentration, both the lowest interfacial tension and final steady interfacial tension decreased; with the increase of temperature, both the lowest interfacial tension and final steady interfacial tension decreased, and it needed shorter time to reach the lowest interfacial tension.

(3) It could produce low interfacial tension to meet oil displacement in foam/oil system, hot water/oil system and cold water/oil system. The interfacial tension could maintain a 10-2mN/m level. It was beneficial for to heavy oil reservoir to improve oil recovery.

## Acknowledgements

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