



Adsorption of Surfactant on Sandstone Under Vibro-Energy†

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AJC-15705

Elastic wave and surfactant flooding composite technology effectively reduces the adsorption of surfactants on strata and improves the utility of surfactants. This study investigates the mechanism for the influence of elastic wave vibration on the loss of surfactant during adsorption. Law of the adsorption of surfactants on core sands under elastic wave vibration is indirectly represented through the absorption shading value under the same condition of fluid/sand (fluid and sand ratio of 20:1 and 12 h of contact). This result reveals the sensitivity of elastic wave parameters to the adsorption law. Furthermore, elastic wave vibration remarkably reduces the loss of surfactants in strata. An optimal parameter combination is a frequency ranging from 15-25 Hz and an acceleration of 0.4 m/s². The elastic wave can change the mode of adsorption by causing the adsorption isotherm to increase first and to noticeably decrease thereafter.

Keywords: Vibro-energy, Core sands, Non-ionic surfactant, Adsorption, Adsorption isotherm.

INTRODUCTION

Surfactant flooding is one of the major technologies for water injection development, causes serious loss in adsorbing rock walls when employed in oil reservoirs with low permeability¹. Thus, this technology is a key factor in restricting the oil displacement effect and improving oil recovery efficiency. Current studies on decreasing surfactant adsorption are focused on developing new surfactants and testing adsorption performance²⁻⁷ or reducing major surfactant loss through preflush by low cost lignin surfactants⁸. These studies do not solve the problems of expensive surfactants and adsorption loss. Given these drawbacks, surfactant flooding cannot be applied extensively. Elastic wave has been applied in intensified mining in oil reservoirs with low permeability as an effective physical oil recovery technique that effectively improves stratum filtering flow⁹⁻¹⁴. Motivated by these advantages, this study proposes an elastic wave and surfactant flooding composite technology and discusses the mechanism of decreasing surfactant adsorption in core sands under elastic wave vibration. The results reveal the influence of elastic wave on the law and mode of surfactant adsorption in core sands, with elastic wave effectively reducing surfactant adsorption loss. The findings of this study can serve as a driving force of the development of applications for this new composite technology.

EXPERIMENTAL

The following are the experiment materials used: alkyl polyglucoside (APG); 80-100 core sands that were cleaned, dried and screened after oil washing; 5 % phenol solution, concentrated sulfuric acid and stratum water.

The following are the experiment apparatuses used: 723 visible spectrophotometer (JINGHUA Instruments, Shanghai), experimental setup of elastic wave vibration (self-made), 20 mL measuring flask, 50 mL conical flask, suction bulb, 5 mL dropper, measuring cylinder, beaker and glass bar.

Methods: A series of alkyl polyglucoside solutions with stratum are prepared and the standard curves of absorbance and concentration are drawn. A certain amount of core sands and a certain concentration of alkyl polyglucoside solution are proportionally drawn and then transferred to the conical flask for the two experiments, namely, adsorption with elastic wave and adsorption without elastic wave at 30 °C. The upper clean liquid is drawn to measure the absorbance of the alkyl polyglucoside solution. The concentration of the solution can be identified based on the standard curve and adsorption can be determined through eqn. 1.

$$\eta = V \frac{(c_0 - c)}{m} \quad (1)$$

†Presented at 2014 Global Conference on Polymer and Composite Materials (PCM2014) held on 27-29 May 2014, Ningbo, P.R. China

where η is the apparent amount adsorbed (mg/g); c_0 and c are the contents of surfactant before and after adsorption on the stratum (mg/mL), respectively; V is the volume of surfactant solution in the adsorption system (mL) and m is the sand mass (g).

Drawing of standard curve: The standard curve of alkyl polyglucoside content is drawn (Fig. 1) according to the method presented in the literature¹⁵.

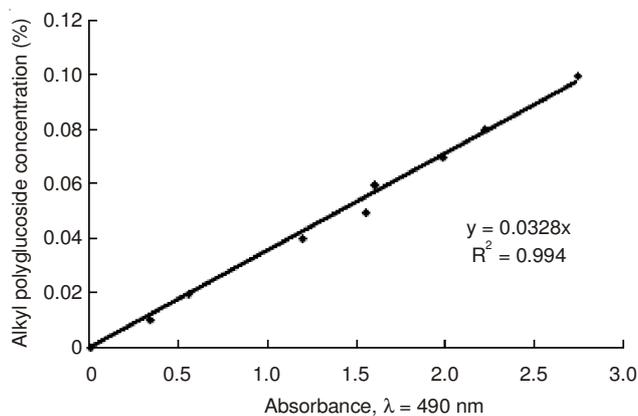


Fig. 1. Standard curve of alkyl polyglucoside content

The experimental results show a linear relation between absorbance and content ($y = 0.0328x$, $R^2 = 0.994$). This relation indicates that the method of measuring the content by the standard curve is feasible.

RESULTS AND DISCUSSION

Determination of adsorption time determination: The concentration of the alkyl polyglucoside solution is 0.5 mg/mL and the liquid/sand ratio is 20:1 (mL/g). Fig. 2 shows the influence of time on adsorbance. Without elastic wave vibration, the adsorption of surfactant on core sands is so slow that saturation is achieved after 10 h. With elastic wave vibration, adsorption is considerably fast, with saturation achieved after 6 h. Adsorbance obviously decreases with elastic wave vibration. A 12 h adsorption time is selected in the experiment to study the adsorbance with and without elastic wave vibration.

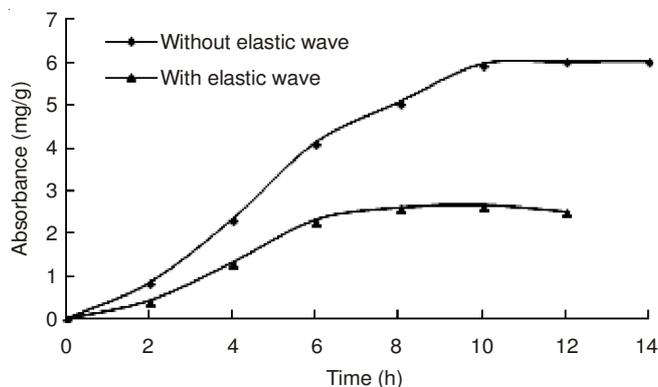


Fig. 2. Determination of adsorption time

Determination of liquid/sand ratio: Fig. 3 presents the effect of different liquid/sand ratios (mL/g) on the adsorbance of surfactant on core sands with an alkyl polyglucoside solution

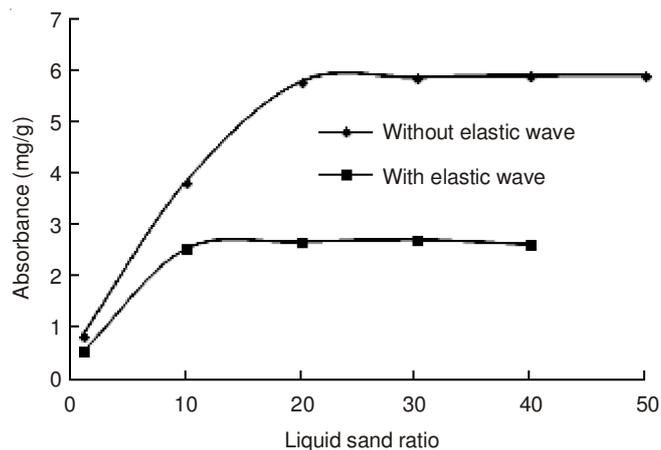


Fig 3. Determination of liquid/sand ratio

concentration of 0.5 mg/mL and an adsorption time of 12 h. Adsorbance reaches equilibrium without elastic wave resonance and when the liquid/sand ratio is 20:1. The same is achieved with elastic wave vibration and when the liquid/sand ratio is 10:1. To remove the influence of liquid/sand ratio on adsorbance, the ratio is set to 20:1 in the following experiments.

Changes in adsorption isotherm: An adsorption time of 12 h and a liquid/sand ratio of 20:1 are employed to compare the adsorption of surfactant on core sands with and without elastic wave vibration. Figs. 4 and 5 show the influence of different elastic wave parameters (*i.e.*, frequency and acceleration of the vibration). These two figures show that elastic wave vibration exerts great influence on adsorbance and that without vibration, adsorbance tends to increase gradually at first (similar to a linear rise) up to a point of low concentration. Thereafter, adsorbance increases to a high value with the increase in surfactant concentration. Adsorbance is maintained at this point. With elastic wave vibration, adsorbance also reaches a turning point at the point of low concentration, increases up to its peak and then decreases.

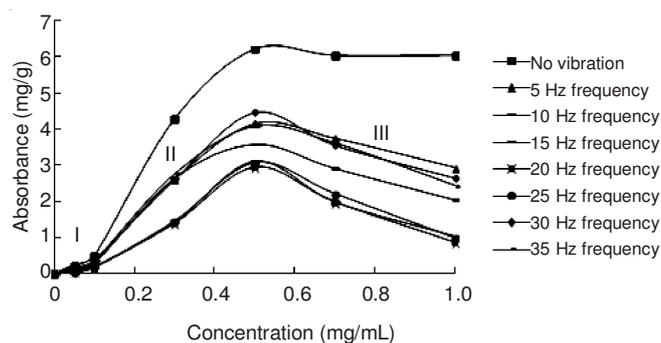


Fig. 4. Influence of elastic wave frequency on adsorption

Figs. 4 and 5 show that adsorption can be decreased through the elastic wave vibration of any parameter. Fig. 4 shows that when frequency increases, adsorbance increases first before decreasing. Adsorbance decreases to the lowest point when the frequency is between 15 and 25 Hz, which is the natural frequency of a narrow band of core sands. Fig. 5 demonstrates that when acceleration increases, adsorption decreases until it rises again to 0.4 m/s². In this case, adsorbance is immune to the influence of acceleration. Thus, proper

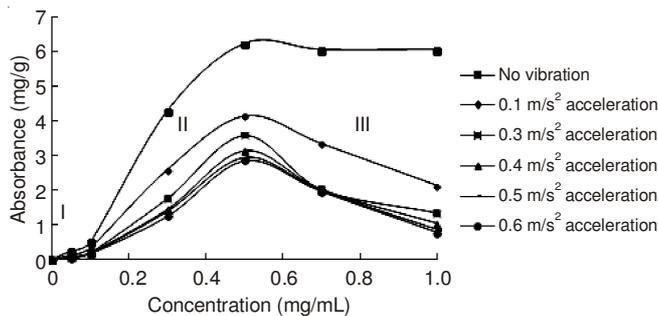


Fig. 5. Influence of elastic wave acceleration on adsorption

acceleration can compensate for the loss resulting from the loss in surfactant adsorption in oil mining to improve the economic benefit of surfactant flooding.

Adsorption isotherm without vibration: In Figs. 4 and 5, the adsorption isotherm curve of a single surfactant follows an “S” shape. The curve can be divided into three regions. In region I, the slope is small, which indicates non-ionic surfactant adsorption at low concentration. This condition is in accordance with Henry’s law. Adsorption on the surface of a solid is monolayer adsorption without aggregation. In region II, the slope moves upward and the transition from monolayer adsorption to multilayer adsorption occurs. When multilayer adsorption co-exists with monolayer adsorption to form a state of hemimicelles, which quickly gather and become adsorbed on the surface, adsorption transforms into multilayer adsorption. At the later stages of semimicelle adsorption, adsorption slightly slows down upon reaching a favorable point. When the retarding effect reaches the maximum, adsorbance reaches the peak and the critical micelle concentration (CMC) emerges. In region III, a large amount of micelles form in the solution after the CMC is reached. This formation occurs with the increase in solution concentration. As a result, a single surfactant molecule drops. To maintain equilibrium, a competition commences for a single surfactant molecule in the solution between the sand surface adsorption layer and the micelles in liquid phase. When the concentration exceeds the CMC, adsorbance decreases slightly. Nevertheless, a steady equilibrium between the speeds of adsorption and desorption is achieved thereafter. Thus, the adsorbance changes slightly with a continuous increase in solution concentration.

Adsorption isotherm with elastic wave: The adsorption isotherm curves in Figs. 4 and 5 both follow an “S” shape. The difference lies in the role of any parameter of elastic wave vibration. Alkyl polyglucoside adsorption rises up to the peak before decreasing remarkably.

The forced vibration principle reveals that vibrostand causes acceleration on an object when the object is placed on the vibrostand. Therefore, every mass point of the object is under forced vibration. The equation of forced vibration is shown below.

$$m \frac{d^2x}{dt^2} = -kx - \gamma \frac{dx}{dt} + F_0 \cos \alpha x \tag{2}$$

Suppose that the damping of the object is small and that

the attenuation term can be neglected. Assume $\omega_0^2 = \frac{k}{m}$,

$2\beta = \frac{\gamma}{m}$ and the amplitude of $f_0 = \frac{F_0}{m}$. The amplitude of sand grains A in the forced movement is

$$A = \frac{f_0}{\sqrt{(\omega_0^2 - \omega^2)^2 + 4\beta^2 \omega^2}} \tag{3}$$

where m refers to the mass of the object, k is the elastic coefficient, γ is the damping coefficient, F_0 is the amplitude of the harmonic external force, x stands for the displacement, t denotes the time and ω is the angular frequency of the simple harmonic vibration external force.

Once core sands are exposed to the alkyl polyglucoside solution, the adsorption and desorption processes begin. The expression for amplitude (3) indicates that amplitude reaches the maximum when the frequency of elastic wave vibration equals the natural frequency of sands or when the amplitude of the relative motion of sand is large. These conditions indicate the great possibility of avoiding adhesion of the surfactant onto the sand surface. The D-value between adsorption speed and desorption speed is smaller with elastic wave vibration than without elastic wave vibration. The adsorbance of surfactant on core sands decreases with the vibration. Thus, the frequency selected is similar to the natural frequency of sands. The results are almost the same as those in Fig. 4. When the frequency of elastic wave vibration is the natural frequency and surfactant concentration is maintained at the same level, the increase of acceleration, f_0 increases the amplitude of vibration. Furthermore, chances of collision and adsorption increase, adsorption becomes quick, the amplitude of sand movement increases and surfactant adhesion is avoided. However, the difference between adsorption speed and desorption speed becomes small. The same can be observed in adsorbance. If it is raised increases further, then a steady equilibrium between adsorption speed and desorption speed can be reached. Therefore, the continuous increase in acceleration has little effect on adsorbance.

The adsorption isotherm of the surfactant with elastic wave vibration can also be divided into three regions. In region I, the slope is small and the adsorbance is low. The analysis on the vibration effect reduces the adhesion of the surfactant onto the sand surface. As a result, the D-value between the adsorption speed and the desorption speed is significantly large without elastic wave vibration. In region II, the slope is considerably large and monolayer adsorption co-exists with multilayer adsorption to form semimicelles. Elastic wave vibration reduces adhesion and improves desorption speed, thereby decreasing the adsorbance in this region. In region III, a large amount of micelles form beyond the set CMC. With the effect of elastic wave vibration, the structure becomes tense and thermodynamic stability is improved while increasing its capability of competing for surfactant molecules in the solution. After reaching the CMC, adsorbance drops with the increase in concentration.

Conclusion

- The adsorbance of surfactant on core sands was determined quantitatively with elastic wave vibration through an indoor simulation experiment setup for the artificial response

of elastic wave. Different vibration parameters can effectively decrease the adsorption of surfactant on rock surfaces.

- If other conditions are kept unchanged, then an optimal vibration frequency range can be reached between 15 and 25 Hz, at which point the capacity of reducing adsorption is at its strongest. When the vibration acceleration is 0.4 m/s^2 , the adsorption isotherm is at its lowest.

- As indicated by the experimental environment and according to the forced vibration principle and equation, the response of an object in the narrow band of the natural frequency is most active. This condition is consistent with the experiment results.

- Combined with related studies, the experiment on the adsorption of surfactant on rock surfaces with elastic wave vibration can provide references for determining the mechanism of wave conditions when improving surfactant flooding. The results of this work can support the establishment of a surfactant flooding mechanical model under wave conditions.

ACKNOWLEDGEMENTS

This study was sponsored by the National S & T Major Project for the Research on High-Power Resonance Wave Of Low Permeability Reservoirs and Chemical Flooding Composite Technology (Project No.: 2011ZX05009-004). Support was also received from the Natural Science Foundation of China, particularly for the "Research on Complex Oil Displacement Mechanism of Low-frequency Vibration and Surfactant for Low Permeability Reservoir" (Project No.: 51274229).

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