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Full Length Article

Controlled delivery and release of surfactant for enhanced oil recovery by nanodroplets

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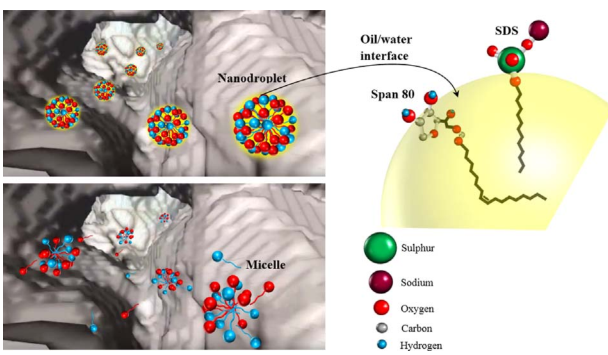
GRAPHICAL ABSTRACT



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ABSTRACT

Chemical-based oil recovery method has promising applications but suffers the problem of large quantity of chemical loss inside the reservoir. This work proposes an innovative concept of using nanodroplets as carriers for surfactants/polymers and control their release inside porous media to increase oil recovery in water-wet reservoirs. Comparing to conventional surfactant flooding, the proposed concept could not only reduce the adsorption of surfactant on rock surface, but also ease the problem of unstable surfactant slug injection and release surfactant slowly inside a reservoir. The oil recovery efficiency was evaluated for micelles and nanodroplet forms of surfactants blend in a customized core flooding system and differential pressures were monitored to evaluate the injection stability of flooding fluids. The retention of surfactants was analyzed by high-performance liquid chromatography after the core flooding tests. The experiments confirm the advantages of nanodroplets as surfactant carriers. The results show that the new approach promoted tertiary oil recovery around ~8%, while reducing the adsorption of surfactants almost half on the surface of sandstone rock comparing to the micelle form.

1. Introduction

In recent years surfactant flooding have attracted a great deal of attention due to the progress in surfactant technology and its high efficiency in enhanced oil recovery (EOR). Surfactant flooding or surfactant/polymer flooding has been commercially used in pilot scale for EOR after the primary and secondary recovery, particularly in USA and China [1]. For example, the required 2–12 wt% concentration of

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sensitive surfactant to high temperatures and high salinity (HT-HS) in initial development (1970–1980) has been dramatically decreased to the range of 0.5–2 wt% of surfactant that resist over HT-HS. Surfactant flooding is becoming increasingly attractive for EOR applications [2–4]. Some recent studies have some the potential of cationic microemulsions for mobilization and displacement of heavy oils inside conventional Berea sandstones, artificially fractured and heterogeneous cores [5,6]. At low surfactant concentrations, the performance of surfactant solution and microemulsion was found to be similar for Berea sandstone and limestone cores, but increased oil recovery rate was observed by microemulsions at high surfactant concentrations.

Surfactant and/or polymers increase the oil recovery rate by targeting the capillary-trapped and un-swept oil. The capillary and relative permeability depends on the wetting behavior of the rock, which significantly affects the oil recovery efficiency. In strong water-wet rocks or at the end of water flooding stage in moderate water-wet rocks, a great proportion of oil droplets remains permanently trapped by capillary effects at the pore scale, which increases the residual oil saturation [7,8]. This is because water formed a film on the rock surface, which ultimately leads to water bridging at the pore throats trapping oil droplets within the pores (Fig. 1a).

The process of surfactant flooding could be generally divided into three main stages: i) the surfactant solution is injected in the form of micelles to the reservoir; ii) the micelles flows through the pores of reservoir rock to reach the oil bank, where surfactant micelles contact with crude oil to form a bi-continues microemulsion phase formation at optimum conditions (e.g. salinity); and iii) bi-continues microemulsion phase pushes the oil bank to the production well after water post-flooding, which is schematically shown in Fig. 1b [9,10].

One of the main challenges during this process is the high loss of surfactants due to the surfactant adsorption on rock surfaces before reaching the trapped oil. Moreover, the highly concentrated micelles produce a cloudy and unstable surfactant slug, which is undesirable for the injection. All these increase the cost of tertiary flooding process and make it difficult for large scale application of surfactant-based flooding techniques [11,12]. There are lots of research on the formation of bi-continues microemulsions at optimum conditions and phase behavior evaluation of crude oil with surfactants solution [13–15], however few

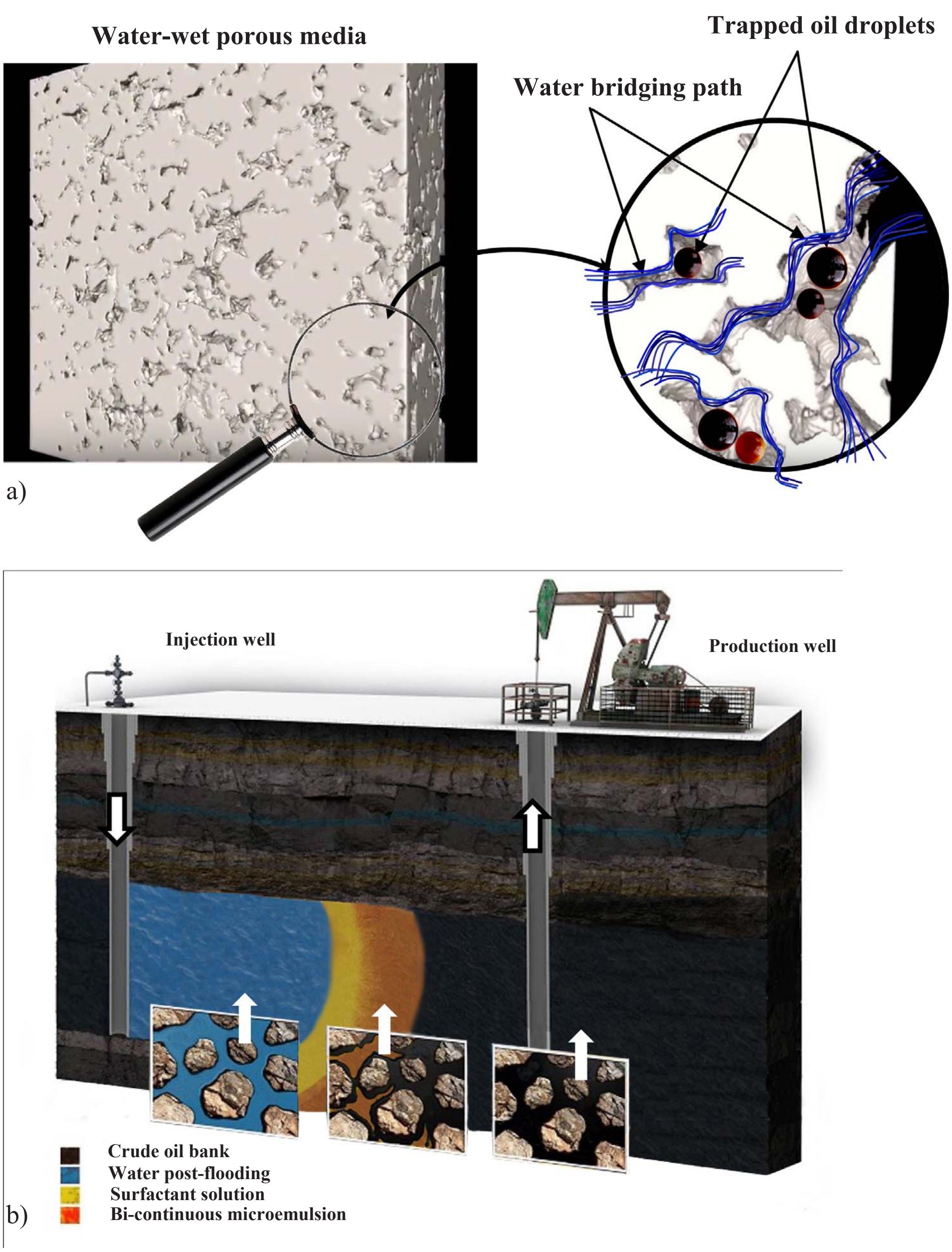

Fig. 1. (a) Oil droplets trapping in a water-wet rock, and (b) different stages of surfactant flooding.

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