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Tailoring of wormlike micelles as hydrodynamic drag reducers for gravel-pack in oil field operations

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ABSTRACT

This paper describes a systematic investigation to verify the potential of wormlike micelles (WLMs) as additives to improve gravel-pack operations. This is an important step of the completion operations, in which a sand core along of an oil well is created. WLMs have high potential to reduce the hydrodynamic drag of sand suspensions during the gravel-pack operation. The capability of WLMs to survive in aqueous solution with high salt content and at the temperature of the reservoir was investigated. The screening of the best formulation was carried out in a rheometer under turbulent conditions. Based on the rheological results the best formulations were used to investigate the levels of hydrodynamic drag reduction (HDR) in circuits. The more appropriated WLMs were formed by the combination of commercial surfactants Ethoquad O/12 with Arquad 12–50 and sodium salicylate (NaSal). We also checked the effect of the presence of WLMs on the transportation of sand grains in conditions close to the ones used in gravel-pack operations.

1. Introduction

Hydrocarbon production in deep and ultra-deep waters gained relevance after depletion of terrestrial reservoirs and off shore fields in shallow water occurred in the last forty years. The growing number of producing wells in deeper and deeper water has caused many challenges and the search for new technologies has been required. A frequent problem is the contention of unconsolidated or easily fragmentation mineralogical structures, when the wells are perforated. Some fields contain grains that are not sufficiently stuck to each other, i.e., there is no effective cementing agent (Martins et al., 2005). In these cases, when the production starts, the flow of oil can break down the reservoir, especially around the well, where the flow flux lines are concentrated. If it happens, the particulate material can be brought into the production column creating problems of erosion and deposition in pipes and other equipment (Magalhães et al., 2006). These problems can be avoided by using the operation known as open hole gravel-pack (OHGP). This operation consists of placing a set of screens tubes inside the open hole and pumping a fluid with suspended sand grains or ceramic spheres through the annular space between the screens and the producing formation (Salahudin et al., 2006). As schematically indicated in Fig. 1, when the annular gap between the well and the screen is filled, second porous medium is created, where the pores of the annular grains have diameters smaller than the reservoir grains diameters.

The packaged grains thus form a kind of selectively permeable filter that prevents migration of formation grains into the production column, allowing only the oil flow (Magalhães et al., 2006).

Drilling in deep and ultra-deep waters requires the displacement of the gravel-pack with high operational precision to avoid equipment damages or fracture of the formation. The HDR effect during the gravel-pack operation is very promising to improve this technique.

Hydrodynamic drag reduction, HDR, is promoted by small amounts (ppm) of certain additives (usually polymers with very high molar masses) capable to reduce the shear stress in turbulent flow (Bailey and Koleske, 1976; Toms, 1948). The physicochemical approach of the microscopic effect caused by the tiny amount of a dissolved polymer is interesting. However, one must consider that little about the phenomenon has been understood since the cause of the turbulence is still a challenge in physics (Bizotto et al., 2011). Fundamentally, the hypotheses suggest that molecules that act as drag reducers interfere with the production, development or transport of turbulence. The main models can be grouped by addressing issues related to length, time and energy scales (Morgan and McCormick, 1990). The oil industries use the benefit of HDR,

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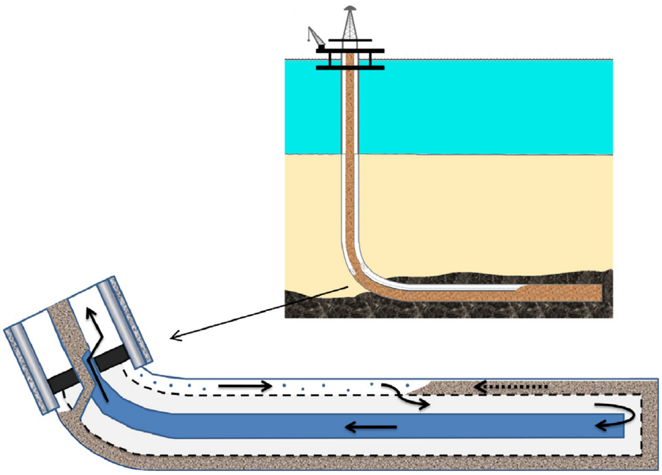

Fig. 1. Scheme of a gravel filling (adapted from Magalhães et al., 2006).

well exemplified in the pipeline that connects Prudhoe Bay to the Valdez (Alaska), in which the addition of polymers reduces in 30% the energy necessary to pump oil along of the 1287 km (Kulicke et al., 1989).

Currently, several classes of substances are known as drag reducers. Among these are: synthetic and natural polymers, fibers, solid particles and wormlike micelles, WLMs, (Morgan and McCormick, 1990). The problem of mechanical degradation (Bizotto and Sabadini, 2008) limits the use of polymers as HDR agents for gravel-pack, but the non-covalent nature of the "living polymers" based on WLMs arise as natural candidate. The long aggregates are naturally breaking and reforming and for this reason immune to undergo mechanical degradation under high shear (Candau et al., 1985).

The packing of the surfactant molecules at the micelle surface (cpp), define the transition from spherical micelles to WLMs. The cpp is related with the head group area, the extended length and volume of the hydrophobic part of the surfactant molecule (Israelachvili, 1991). For ionic surfactants, the transition can be induced by increasing the ionic strength of the solution. The charge of the micellar surface is screened by the added ions of opposite charge, decreasing the effective area of the head group, thus leading to variations on cpp. WLMs can be formed in lower surfactant concentrations if certain aromatic ions are added to solutions of cationic surfactants. In this case, additionally to the charge neutralization, the threading of the aromatic group into the micelle palisade (driven by the hydrophobic effect) increases the stabilization of the WLMs (Olsson et al., 1986). WLMs containing cationic surfactants are formed even in a dilute regime (which is an important prerequisite for the gravel-pack process) in the presence of aromatic anions such as salicylate (Bijma and Engberts, 1997), tosylate (Bijma et al., 1998), chlorobenzoate (Bachofer and Turbitt, 1990) and naphthalene sulfonate (Brown et al., 1989).

In this paper several formulations of commercial surfactants and salicylate were investigated, in order to evaluate the potential of WLMs to produce HDR in harsh conditions of temperature and salt concentrations, such as the ones of the oil reservoir. A comparative sand transportation was also investigated in suspension without and with WLMs.

2. Experimental section

2.1. Materials

The cationic surfactants used were: Ethoquad O/12 (mainly oleyl-$N(CH_3)(C_2H_4OH)_2Cl$), Arquad 12–50 (mainly $C_{12}H_{25}N(CH_3)_3Cl$),

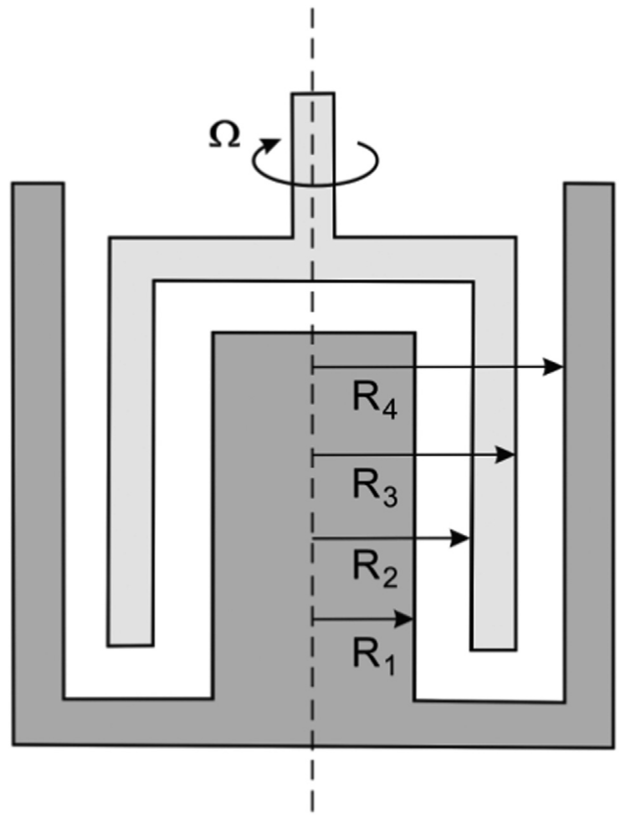

Fig. 2. Scheme of the double-gap cell used in the HDR experiments carried out in the rheometer, being: $R_1=8.88$ mm, $R_2=9.18$ mm, $R_3=10.50$ mm and $R_4=10.85$ mm. The length of the rotor is 55.00 mm.

Arquad 16–50 (mainly $C_{16}H_{33}N(CH_3)_3Cl$), Arquad SV 50 (mainly soya-alkyltrimethylammonium chloride) and Arquad T-50 (mainly tallow-alkyltrimethylammonium chloride). These commercial surfactants were donated by AkzoNobel which contained about 50% active cationic surfactant in water and isopropyl alcohol.

The sodium salt of 2-hydroxy benzoate (NaSal), was obtained from Merck. All reactants were used without any further treatment. Surfactant concentrations were varied from 2.0 mmol L^{-1} to 18.0 mmol L^{-1}, while the concentrations of NaSal were varied from 0.6 mmol L^{-1} to 12.4 mmol L^{-1}.

The samples were prepared in pure water and in completion fluid (whose composition is 54.9117 g of NaCl, 4.1864 g of Na_2SO_4, 24.9672 g of KCl, 0.2066 g of $NaHCO_3$, 1.395 g of $CaCl_2$ and 5.4463 g of $MgCl_2$ per kg of solution). The salts used to prepare the completion fluid were purchased from Synth-Brazil.

2.2. Methods

Rheological experiments with the surfactants and sodium salicylate were conducted in a Haake RheoStress 1 rheometer. In these experiments only 13 mL of samples are required and the results were used to screen the potential formulations of WLMs capable to survive to salt and high temperature. A schematic representation of the double-gap cell used in the experiments with the dimensions depicted is in Fig. 2. Temperature was controlled by an external water bath system with a precision better than 0.10 °C. Special care was taken to avoid the interference of foam. The temperature sweep experiments were measured over a temperature range of 25.0 °C to 75.0 °C at a fixed angular velocity of 900 rpm, in which levels of HDR is produced.

For pilot scale, two different flow circuits were necessary to be used (Fig. 3). In one loop (named as A) the experiments are limited