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Yield stress behavior for crude oil–polymer emulsions

Mamdouh T. Ghannam[a,*], Nabil Esmail[b]

[a]Department of Chemical and Petroleum Engineering, College of Engineering, United Arab Emirates University, P.O. 17555, Al-Ain, United Arab Emirates

[b]Department of Mechanical Engineering, Concordia University, 1455 de Maisonneuve Boulevard W., Montreal, Quebec, Canada M3G 1M8

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Abstract

Since all industrial applications of crude oil–polymer emulsions demand emulsions transportation, it is important to study the flow characteristic in term of apparent yield stress. The yield stress measurements of crude oil–polymer emulsions were carried out using RheoStress RS100 under controlled stress mode. Controlled stress rheometers provide the most direct technique for the measurement of yield stress. The yield stress measurements were carried out for crude oil–Alcoflood polymer emulsion over the range of 0–75% by volume of crude oil concentration and 0–10^4 ppm of polymer concentration. Three different Alcoflood polymers were employed in this investigation. These are AF1235, AF1275, and AF1285. The yield stress measurements of polymer aqueous solutions and crude oil–polymer emulsions are extensively investigated. Casson Model can be used to predict the apparent yield stress for either Alcoflood polymer aqueous solutions or crude oil–Alcoflood polymer emulsions. The increase of polymer concentration improves the initial flow resistance for the three tested polymer materials. At a polymer concentration beyond 10^3 ppm, the apparent yield stress raises strongly with polymer concentration. For polymer concentration below 10^3 ppm, the three polymer materials show close values of the apparent yield stress. For polymer concentration higher than 10^3 ppm, the polymer material of AF1275 causes higher apparent yield stress than AF1285 and AF1235 in order. Non-linear three dimensional model is provided to predict the apparent yield stress of crude oil–Alcoflood polymer for a wide range of crude oil and Alcoflood polymer concentrations.

Keywords: Yield stress; Crude oil; Alcoflood polymer; Emulsion; Shear stress; Shear rate

1. Introduction

The emulsion term is generally utilized to describe the blending mixture of two or more immiscible liquids together. The dispersion of droplets of one liquid phase such as oil thoroughly into an immiscible

* Corresponding author. Fax: +9713 7624262.
E-mail address: mamdouh.ghannam@uaeu.ac.ae (M.T. Ghannam).

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continuous phase of another liquid such as water will lead to oil-in-water emulsion (O/W emulsion).

Emulsions of different applications are widely produced within numerous technologies including pharmaceuticals, food industries, and enhanced oil recovery. The emulsion system may only be stable if the dispersed droplets are covered with emulsifier. The addition of emulsifier during an emulsification process is necessary to achieve a short range repulsion mechanism between the droplets of the dispersed phase. Therefore, the emulsifier role is to avoid coalescence mechanism between droplets phase and thus stabilizes the emulsion for longer time.

It is well recognized that the mechanical properties of structured liquids modify significantly over a narrow low range of stress level. Below this stress level, the material deforms elastically with finite rigidity (i.e. to observe solid-like behavior). Above this stress level, the material shows continuous deformation (i.e. to observe viscous liquid-like behavior). The stress level at this transition stage is known as apparent yield stress. As the applied stress increases, the mechanical properties change significantly, i.e., the material shows continual steady deformation. For example, the flow properties of a 6% suspension of iron oxide in mineral oil change from a very viscous liquid around 10^5 Pa s at stress less than 0.7 Pa to a mobile liquid around 0.5 Pa s at slightly higher stress of 3 Pa (Macosko, 1994).

Yield stress is directly influence the initiation of an emulsion flow from a container, pumping an emulsion into a transportation pipeline, coating or spreading of an emulsion over a solid substrate. The utilization of controlled stress rheometer (CS-mode) has made the measurement of yield stress more accurate in comparison with controlled rate technique. It is possible to investigate extremely low shear rate for non-Newtonian behavior, and therefore, to measure yield stress using CS-mode measurements (Schramm, 1994).

Oil–water emulsion is a complex mixture of multi-component and multi-phase system. The emulsion characteristics have been investigated in several papers from different points of view. Literature survey on the rheological behavior of oil emulsions showed that many investigations have been studied on oil emulsions in which the continuous phase is Newtonian (Sherman, 1970; Princen, 1983, 1985; Princen and Kiss, 1986; Pal and Rhodes, 1989). The rheology of dispersed solid particles in liquid emulsion has been reported in many articles (Tanaka and White, 1980; Chan and Powell, 1984; Metzner, 1985; Gupta and Seshadri, 1986; Poslinski et al., 1988). Limited work is available on the rheological studies of oil emulsion in which the continuous phase is non-Newtonian polymeric solution (Han and King, 1980; Pal, 1992; Ghannam, 2003). The published studies given by Princen (1983, 1985) and Princen and Kiss (1986) showed the role of the dispersed phase concentration and reported that the rheological properties are characterized by elasticity at low shear stress and yielding behavior existence. The work published by Langenfield et al. (1999), which describes the viscoelastic behavior of highly concentrated water-in-oil emulsions, reported that such emulsions behave as elastic solids. When highly concentrated emulsions are subjected to small shear deformation, these emulsions show a strong elastic response and a yield stress (Pal, 1999). Most of the previous works that have been completed before on emulsion rheology were focused on dilute and medium concentrated emulsions (Sherman, 1983).

In a previous investigation of flow properties of crude oil–Alcoflood polymer emulsions (Ghannam, 2003), it shows a non-Newtonian behavior of shear thinning response. The viscosity of emulsion increases with Alcoflood concentration and decreases with shear rate. The type of Alcoflood polymer plays a significant role at lower shear rate (i.e. $<10\ s^{-1}$). AF1285 emulsion provides higher viscosity than AF1275, AF1235, and water emulsions in that order due to the intrinsic viscosity of the employed polymer. For shear rate $>10\ s^{-1}$, the measurement results show no difference between the three Alcoflood emulsions of AF1235, AF1275, and AF1285. The previous study (Ghannam, 2003) also shows that the well-known Casson (1959) model, Eq. (1), fits very adequately the flow behavior of the crude oil–Alcoflood polymers.

$$\tau = \left(\tau_o^{0.5} + (\dot{\gamma} + \eta_c)^{0.5}\right)^2 \quad (1)$$

where τ_o is the apparent yield stress parameter determined by Casson model in Pa, η_c is the Casson