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Rheological behavior and temperature dependency study of Saraline-based super lightweight completion fluid

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ABSTRACT

This article presents a rheological and statistical evaluation of Saraline-based super lightweight completion fluid (SLWCF) and its effect on operating temperature. In this work, eight rheological models, namely the Bingham plastic, Ostwald–de Waele, Herschel–Bulkley, Casson, Sisko, Robertson–Stiff, Heinz–Casson, and Mizrahi–Berk, were used to describe the rheological behavior of the fluid, and the results were compared with Sarapar-based SLWCF. The results showed that the fluid was best described by both the Sisko and the Mizrahi–Berk models. These two models seem to be able not only to describe the relationship between shear rate and shear stress accurately but also able to accommodate the physical characteristics of the fluids. In the study of fluid viscosity dependency on temperature, the experimental data showed that the viscosity of Sarapar-based SLWCF almost doubled the viscosity of Saraline-based SLWCF. Furthermore, the activation energy seemed to decrease dramatically for both fluids at low shear and tended to remain constant at a higher shear rate. However, Saraline-based SLWCF seemed to be less dependent on temperature, and its behavior could be described by the power equation. Results also showed that the viscosity of the Saraline-based SLWCF was more sensitive to temperature changes at low shear rates.

1. Introduction

In cased wells, perforation tunnels are the only passages that allow formation fluid flowing toward the wellbore. To create these tunnels, a jet perforation gun is commonly used (Papamichos et al., 1993). However, the pressure impact from a perforating gun impairs and shatters the rock properties (Ibrahim et al., 2009). This often creates a low permeability zone along the perforation tunnels, which leads to reduction of flow potential and well productivity (Bartusiak et al., 1997; Karacan and Halleck, 2003). This rock property impairment is referred to as “perforation-induced formation damage” (Walton, 2000). One of the effective means to minimize this damage is through the application of underbalanced perforation. Underbalanced perforation refers to perforation conducted in a condition in which the wellbore pressure is kept lower than the reservoir pressure (King et al., 1986; Karacan and Halleck, 2003).

Other underbalanced techniques with the use of air, gas, mist, or foam have also been developed to maintain an underbalanced condition before or during detonation of a perforation gun (Al-Riyamy, 2000). The Perforating Ultimate Reservoir Exploitation (PURE) perforating system optimizes the transient underbalance of the well, which occurs instantaneously after the creation of the perforation cavity (Behrmann et al., 2002). The advantages of using these techniques either in the drilling application or completion process include good hole-cleaning capability, the high penetration rate, and the ability to handle considerable formation water (Lorenz, 1980). However, these techniques are not always desirable because they may require additional work, time, special equipment, costs, and safety concerns (Khalil et al., 2010a,b).

In response to the above, an innovative Sarapar-based super lightweight completion fluid (SLWCF) has been successfully formulated to

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Nomenclature

Latin letters

E_a	activation energy ($ML^2T^{-2}M^{-1}$)
K_{HB}	Herschel–Bulkley fluid consistency index (M/LT^{2-n})
K_{HC}	Heinz–Casson fluid consistency index (M/LT^{2-n})
K_M	Mizrahi–Berk fluid consistency index (M/LT^{2-n})
K_{pl}	power law fluid consistency index (M/LT^{2-n})
K_{RS}	Robertson–Stiff fluid consistency index (M/LT^{2-n})
R	gas constant ($ML^2T^{-2}\Theta^{-1}M^{-1}$)$=1.987\times10^{-3}$ kcal/K/mol
T	temperature (Θ)

Greek letters

$\dot{\gamma}$	shear rate (T^{-1})
$\dot{\gamma}_0$	shear rate correction factor (T^{-1})
η	Heinz–Casson fluid flow behavior index (–)
η_{HB}	Herschel–Bulkley fluid flow behavior index (–)
η_M	Mizrahi–Berk fluid flow behavior index (–)
η_{pl}	power law fluid flow behavior index (–)
η_{RS}	Robertson–Stiff fluid flow behavior index (–)
η_S	Sisko fluid flow behavior index (–)
k_{0C}	square root of Casson fluid yield stress ($M^{1/2}/L^{1/2}T$)
k_{0M}	square root of Mizrahi–Berk fluid yield stress ($M^{1/2}/L^{1/2}T$)
τ	shear stress (M/LT^2)
τ_B	Bingham plastic fluid yield stress (M/LT^2)
τ_C	Casson fluid yield stress (M/LT^2)
τ_{HB}	Herschel–Bulkley fluid yield stress (M/LT^2)
τ_{HC}	Heinz–Casson fluid yield stress (M/LT^2)
μ	viscosity (M/LT)
μ_0	viscosity under reference condition (M/LT)
μ_B	Bingham plastic fluid plastic viscosity (M/LT)
μ_C	Casson fluid plastic viscosity (M/LT)

achieve the desired well pressure for underbalanced application (Badrul et al., 2009; Khalil et al., 2010a,b, 2011, 2012, 2013). It was expected that the formulated SLWCF is able to create a cleaner perforation tunnel during gun detonation. It is also believed that the formation damage and rock debris from a perforation job were minimized by the surge of fluid flow from the reservoir to the wellbore due to the pressure differential (Bartusiak et al., 1997). Hence, postperforation wellbore treatment, such as acidizing and skin fracturing, may not be necessary (Al-Riyamy, 2000).

The formulated nontraditional SLWCF consists of Sarapar 147 synthetic oil, glass bubbles as a density-reducing agent, with an appropriate stabilizing and homogenizing agent. From laboratory tests, a density value as low as 0.60 g/cm^3 (5.0 lbm/gal) could be achieved. A field test was also conducted by preparing 11,448 L (72 bbl) of similar SLWCF. The mixture was then used in perforation operations of the BKC-18 well of the Bunga Raya field. This real field test reported that the well, completed by using SLWCF, significantly improved the daily oil production rate. The well perforated by using SLWCF showed an additional daily oil production of approximately 1000 barrels compared with a well perforated with conventional completion fluid (Badrul et al., 2009). The use of SLWCF has been considered as one the most attractive ways to achieve an underbalance condition because it does not require additional work, equipment, or special treatment. SLWCF is able to provide an underbalanced condition in the wellbore. SLWCF is also applicable in various reservoirs, including a pressure-depleted reservoir or matured well, in which the wellbore is always in an overbalance or balance condition.

Teow et al. (2001) reported that Saraline and Sarapar are suitable to be used as base oils for Oil Base Mud (OBM) in deep-water exploration activities. They also analyzed the physical properties of Sarapar and Saraline and found that Saraline has a flash point higher than 29.4 °C (85 °F), whereas the flash point of Sarapar is 50 °C (122 °F). Furthermore, Saraline also has a pour point that is lower than −16 °C (3 °F), whereas the pour point of Sarapar is higher than −11 °C (12 °F). It also shows that the benzene content for both Saraline and Sarapar is less than 1 ppm. Aromatics contents of Saraline and Sarapar are less than 0.05 wt% and 0.01 wt%, respectively. The physical and chemical properties of the Saraline and Sarapar base oil are shown in Table 1.

Table 1
Physical and chemical properties of Saraline and Sarapar oil (Teow et al., 2001).

	Units	Saraline	Sarapar
Density	g/cm^3	0.778	0.774
Flash point	°C (°F)	> 29 (> 85)	50 (122)
Pour point	°C (°F)	−16 (3)	> −11 (> 12)
Benzene	PPM	< 1	< 1
Aromatics	wt%	< 0.05	< 0.01
Aniline point	°C (°F)	74 (165)	76 (165)
Specific gravity	60/60 °C (°F)	−17 (0.79)	−17 (0.76)
Plastic viscosity	cP	9	6
Yield point	kg/m^2 (lb/100 sqft)	0.98 (20)	1.22 (25)
Gel strength	(10 s/10 m)	5/15	6/15
Electric stability	V	850	850

Table 2
The optimized conditions for both Saraline- and Sarapar-based SLWCF (Khalil et al., 2011; Muhammad and Raman, 2011).

SLWCF	Saraline	Sarapar
Base oil (%)	60	65
Glass bubbles (%)	40	35
Clay (%)	3	4
Emulsifier (%)	9	10
Density (g/cm^3)	0.50	0.60

In the upstream oil and gas industry, an accurate understanding of the fluid rheological behavior as a function of formation transient temperature and pressure during, before, and after the operations is important (Davison et al., 1999; Santoyo et al., 2001; Tehrani, 2007; Khalil and Mohamed Jan, 2012). Information on fluid rheology could be used not only to ensure that the fluid meets the requirement of the operation but also to select the correct operational practice. A pioneer study on the formulation of Saraline-based SLWCF was conducted by Muhammad and Raman, 2011. Based on the results, SLWCF with a density value of 0.50 g/cm^3 (4.17 lbm/gal) was formulated with a Saraline to glass bubbles ratio of 60:40, and homogenizing and stabilizing agent content of 3 and 9% w/w, respectively (Muhammad and Raman, 2011). However, no work has been carried out on the investigation of flow behavior of Saraline-based SLWCF. Therefore, as a continuation of previous work, the rheological behavior of Saraline-based SLWCF is presented in this study. The summary of optimized conditions for both Sarapar- and Saraline-based SLWCF are shown in Table 2 (Khalil et al., 2011; Muhammad and Raman, 2011).

Rheological behavior can be described as the relationship between an applied shear stress and the resultant shear rate in a laminar flow condition. This usually can be obtained by curve fitting of experimental