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RESEARCH PAPER

Viscosity prediction model optimization for Saraline-based super lightweight completion fluid at high pressure and temperature

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Abstract: Investigation and analysis of the viscosity variation of Saraline-based super lightweight completion fluid (SLWCF) at high pressure and temperature were reported, and the viscosity prediction model was optimized. Viscosity measurements were carried out at temperature and pressure ranging from 298.15 K to 373.15 K, and 0.10 MPa to 4.48 MPa respectively. The data analysis reveals that the reduction of viscosity as a function of temperature may be divided into two regions, i.e. significant viscosity reduction at low temperature and fairly slow viscosity reduction at high temperature; the viscosity of Saraline-based SLWCF is less affected by the changes of pressure. The experimental data were fitted to four different viscosity-temperature-pressure models. The results show that, the modified Mehrotra and Svrcek's and Ghaderi's models are able to satisfactorily predict the viscosity value and measured value and describe the viscosity property at high pressure and temperature. The comparison with the Sarapar-based SLWCF reveals that the viscosity of Sarapar-based SLWCF is more affected by temperature than the Saraline-based SLWCF; pressure seems to have negligible effect on Saraline-based SLWCF viscosity; the modified Mehrotra and Svrcek's and Ghaderi's models are able to give more reliable viscosity predictions for Saraline-based SLWCF than for Sarapar-based SLWCF.

Key words: high pressure and temperature; viscosity prediction; super lightweight completion fluid; Saraline synthetic oil; underbalanced perforation

Introduction

In the case of cased oil wells, perforation tunnels created during perforation job are the only passages that allow hydrocarbon to flow towards the wellbore. However, the formation damage induced by perforation is one of the reasons for production decline[1−3]. The underbalanced perforation can minimize the perforation induced formation damage. And it refers to perforation job conducted when wellbore pressure is maintained lower than reservoir pressure prior to gun detonation[4−6]. And in order to meet underbalanced requirement, it is necessary to use low-extra low density completion fluid[7−9].

Based on previous researches, we have successfully developed a new type of completion fluid for underbalanced perforation application, i.e., Saraline-based Super Lightweight Completion Fluid (SLWCF) with density value of approximately 0.60 g/cm^3. This completion fluid has been successfully applied to Well BKC-18 by cleaning perforation tunnels effectively to increase oil production significantly. Well BKC-18 is a well of Bunga Raya field located at a joint-development area between Malaysia and Vietnam[6]. Given such promising potential application, further studies on SLWCF's physical properties (such as density and viscosity) are highly recommended, especially at reservoir conditions. It is shown that Saraline-based SLWCF flow behavior can be satisfactorily described by using two types of models, namely Sisko and Mizrahi-Berk models. However, these predictions are only limited at considerably low temperature and ambient pressure[10]. In its real application, however, SLWCF is always

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subjected to extreme reservoir conditions, which may alter the fluid behavior.

The investigation on the fluid properties of Saraline-based SLWCF at reservoir conditions, i.e. high pressure and high temperature (HPHT) is presented in this paper. Viscosities of Saraline-based SLWCF were measured at various temperature and pressure. The experimental data obtained from these measurements were then fitted to four different types of viscosity-temperature-pressure models. And then, the prediction model suitable for HPHT viscosity of Saraline based SLWCF was optimized by means of statistical analysis approach.

1. Research method

Fig. 1 summarizes the research idea and method.

1.1. Material preparation

To formulate Saraline-based SLWCF, Shell Saraline 185V synthetic oil (Shell Middle Distillate Synthesis, Kuala Lumpur) was used as the continuous phase. Saraline oil is derived from natural gas; hence it does not contain aromatic hydrocarbons, sulfur compounds, or amines. The density of Saraline oil is 0.778 g/cm^3 (6.49 lbm/gal). 3M glass bubbles (HGS4000) (3M, St. Paul, Minnesota, USA) were used as a density-reducing agent. Bentonite clay and suitable emulsifier were used to improve fluid stability.

1.2. Formulation of Saraline-based SLWCF

In this study, Saraline-based SLWCF was prepared based on our previous works[10–11]. The fluid was prepared by mixing 60% of Saraline synthetic oil and 40% of glass bubbles. To improve the stability of the fluid, 3% of clay and 9% of emulsifier were added. The mixture was then agitated by using IKA T25 digital high-speed disperser at 6 000 r/min for one hour. The readily prepared fluids were then placed in a sealed-cap container for further tests.

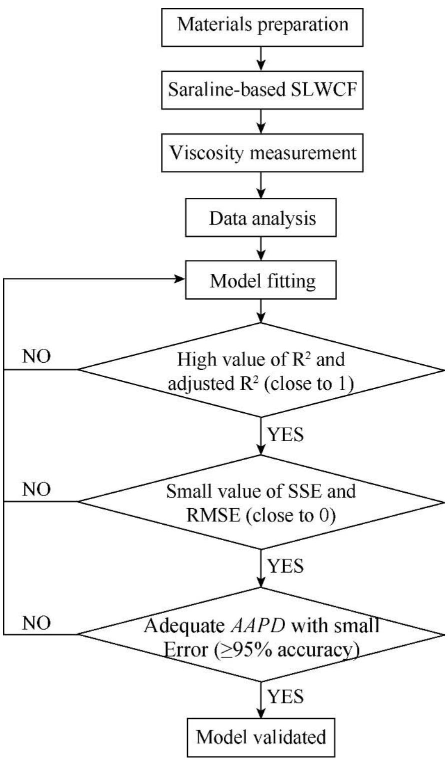

Fig. 1. Flowchart of the methodology.

1.3. Viscosity measurement

Saraline-based SLWCF viscosity at high pressure and high temperature (HPHT) conditions was measured by using an HPHT NI Rheometer FANN 75 (Nordman Instruments, Inc., Houston, Texas, USA). After the equipment was set up, approximately 100 ml of the sample were injected through the sample port. The experiment was carried out at temperature and pressure ranging from 298.15 K to 373.15 K and 0.1 to 4.48 MPa (14.5 to 650 psi) respectively. Test sample pressures and temperatures were varied by fluid pressurization and electric heater, respectively. Measurements were carried out at two different speeds, specifically 600 r/min and 300 r/min for each pressure and temperature. Measurements were conducted at least 3 times for each speed, before an average value was obtained. To obtain the viscosity, the reading angle at 600 r/min was subtracted from the reading angle at 300 r/min and the result was divided by 1 000 for unit conversion from cP to Pa·s.

1.4. Data analysis and model fitting

The measured viscosity data of Saraline-based SLWCF were fitted to four different viscosity-temperature-pressure models. The four models are the Mehrotra and Svrcek's equation[12] (Equation (1)), modified Mehrotra and Svrcek's equation[13] (Equation (2)), Ghaderi's equation[14] (Equation (3)) and Gold et al.'s modulus equation[15] (Equation (4)).

$$\ln\mu = \exp\left(A_1 + A_2 \ln T\right) + A_3 p \tag{1}$$

$$\ln\mu = A + B\ln T + Cp \tag{2}$$

$$\mu = \exp\left(B_1 + \frac{B_2 p}{\ln p} + \frac{B_3}{T} + \frac{B_4}{T^2}\right) \tag{3}$$

$$\mu = \mu_0 \exp\left[\frac{p}{a_1 + a_2 T + \left(b_1 + b_2 T\right) p}\right] \tag{4}$$

Data analysis and model fitting were carried out by using the software Matlab. Based on the data fitting, each of the calculated equation's parameters is generated and its ability to describe the relationship of viscosity function of pressure and temperature was statistically evaluated with Matlab. Several statistical parameters such as Sum of Square Error (SSE), and Root Mean Square Error (RMSE), R-squared and adjusted R-squared are calculated for model optimization.

1.5. Validation

To validate the prediction of SLWCF viscosity, the fitting results were evaluated by measuring the average absolute percentage deviation (*AAPD*), standard error (σ) and deviation (D) between the experimental values measured in the laboratory and the predicted values calculated by using the equa-