Research Article
Experimental Investigation of Non-Newtonian Fluid Flow in Horizontal Wells During ASP Flooding

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Abstract: In order to investigate the complex natures of non-Newtonian fluid flow in the horizontal wells during ASP (Alkaline/Surfactant/Polymer) flooding, a full-scale experimental facility has been designed and constructed, based on which a series of studies upon oil and ASP solution two-phase flow in a horizontal concentric annulus are conducted. The working fluids are self-made ASP solution and the mineral white oil. Results show that under the experimental conditions, the flow pattern is dominated by the dispersed flow while the alternative stratified flow is rarely seen. Similar to the single-phase flow, the pressure drop of oil and ASP two-phase flow has also an approximate exponential relationship with the mixture flow rate and first increases and then decreases with increasing the input oil volumetric fractions. The critical oil cut at which the phase inversion occurs is between approximately 30 and 40%. The achievements obtained in this study is a foundation for developing and validating the corresponding model with respect to the pressure drop of oil and ASP two-phase flow in an annuli.

Keywords: ASP solution, experiment, horizontal annulus, non-newtonian fluid, two-phase flow

INTRODUCTION

Tertiary recovery, an advanced technique developed in recent years in China, plays an important role in enhancing oil recovery and stabilizing the old oil field crude oil production. The core technology of the tertiary recovery is the chemical flooding, which mainly contains the polymer flooding, alkaline flooding, surfactant flooding and binary or ternary compound flooding through combining with two or three flooding (Yang, 2007). During the 10th Five-Year Plan, Daqing Oilfield has developed the ASP (Alkaline/Surfactant/Polymer) flooding, which the ABS (alkyl benzene sulfonate) is taken as the major agent, having been widely promoted and applied in China (Li, 2008).

While the horizontal well under the ASP flooding produces, the flow type in the wellbore usually shows as oil and ASP solution two-phase complex flow in an annulus which refers to the annular flow space between the sucker rod and the outer tube. Practical research demonstrates that the ASP solution often represents a special rheological behavior like pseudo-plastic power-law non-Newtonian fluid (Nasr-El-Din et al., 1991; Chen et al., 1998; Huang et al., 1999). At present, the research on annular flow pressure drop of single non-Newtonian fluids is relatively mature (Hanks and Larsen, 1979; Uner et al., 1989; Gupta and Chhabra, 1996), but the studies on Newtonian fluids and power-law non-Newtonian two-phase annular flow behavior are rarely seen.

Based on a self-developed multifunctional full-scale experimental facility, experiments are conducted on oil and ASP solution two-phase flow in a horizontal concentric annulus and high quality of data upon pressure drop are obtained. The achievements obtained in this study provide favorable data for developing and validating the pressure drop model of oil and ASP solution two-phase complex flow in an annulus.

EXPERIMENT DESCRIPTION

Experimental facility: The experimental facility is mainly composed of three parts including fluid supplying equipment, testing instruments and simulation section, as shown in Fig. 1.

Fluid supplying equipment mainly includes liquid storage tank 1, progressive cavity pump 3 and variable frequency drive 4 which can be used to regulate the output flow rate of the progressive cavity pump in the range of 0~50 Hz, corresponding to the real output flow rate in the range of 0~10 m^3/h. Testing instruments mainly contain vortex shedding flow meter 5 and differential pressure pick-up 7, both of which can output electrical signal in the range of 4~20 mA. It can realize real-time acquisition via being connected to the computer.

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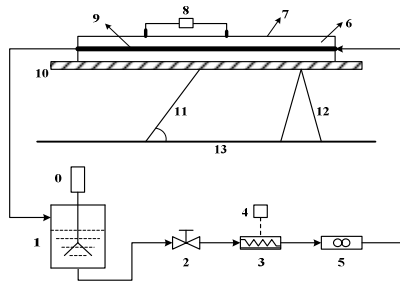
Fig. 1: Experiment flow diagram
Symbol description: 0 the electromagnetic stirrer; 1 liquid storage tank; 2 throttle valve; 3 progressive cavity pump; 4 variable frequency drive; 5 vortex shedding flow meter; 6 annulus; 7 simulated tube; 8 differential pressure pick-up; 9 simulated pump rod; 10 experiment table; 11 hydraulic lift; 12 support bracket; 13 floor

Table 1: Operating conditions

Parameters/Tube inclined angle		Values 0 (Horizontal)	Units °
The ratio of ASP	Alkaline	900	mg/L
	Polymer	500	
	Surfactant	100	
Flowing parameters	Flow rate	40, 80, 120, 160 200	m^3/d
	Oil volumetric fractions	10, 20, 30, 40, 50	%
Operating conditions	Temperature	20～25	°C
	Pressure	0.1	MPa

Simulation section is mainly composed of three parts, which are simulated tube 7, simulated pump rod 9 and experiment Table 1. The simulated tube is made of acrylic tube whose inner diameter is set at 62 mm and wall thickness is set at 11 mm. The length of testing section reaches 1m, the length of entrance and exit steady flow respectively reaches 4 and 2 m. The simulated pump rod is made of stainless steel pipe whose outer diameter is set at 22 mm. In addition, the experiment table can achieve an inclination in the range of 0~90° by controlling the differential pressure pick-up, which serves a convenience to conduct related experiments in various inclined angles.

In the process of experiment, pumping prepared oil and ASP solution two-phase fluids into the simulated section and the measurement and collection for some related experimental data can be performed after the flow displays a steady flow. In order to ensure the fluid regular circulation within the entire experimental loop, the output fluid from the simulated section is directly guided into the liquid storage tank. And not until the experiment is ended does the stirrer in the tank 1 mixed with oil and water cease to work, so as to maintain the oil and ASP solution two-phase to mix sufficiently.

Experimental conditions: The operating conditions of this experiment are shown in Table 1.

Experimental procedure: The main content of this experiment is to measure the pressure drop of oil and ASP solution two-phase flow in an annulus. The corresponding procedure is as follows:

- Preparing the ASP solution according to pre-given ratio and stirring approximate 30 min
- Determining the fluid rheological mode and the corresponding rheological parameters through measuring the rheological parameters of samples.
- Pouring the white oil designed with minimum oil volumetric fractions into the liquid storage tank and constantly stirring.
- Adjusting the inclined angle of experimental tube to horizontal state.
- Pumping the prepared flowing media with several pre-given flow rates into the experimental loop successively, respectively measuring the pressure drop after the flow tends to be stable.
- Increasing the oil volumetric fractions of the flowing system according to the designed ratios in sequence and repeating the operation (5).

RESULTS AND ANALYSIS

During the experiment, the flow pattern and pressure drop of simulated oil and ASP solution two-phase flow are observed and measured respectively under conditions of various oil volumetric fractions. Under the experimental conditions, the flow pattern of oil and ASP solution two-phase flow in a horizontal concentric annulus is dominated by the dispersed flow, which is similar to the emulsion, as shown in Fig. 2.

Oil and water two-phase flow in conventional tube usually appears oil and water stratified flow, lower density oil phase will flow on the top of tube, while higher density water will flow on the bottom of tube, a clear interface existing between the two phases (Trallero *et al*., 1997; Shi, 2001). Under experimental conditions in this study, however, no clear oil and water stratified flow has been found. Two aspects can be used to explain this phenomenon: one of which is that oil and ASP solution two-phase flow is more likely to be emulsified compared to ordinary water, making it easier for the flow system to display dispersed flow pattern not stratified flow pattern with clear interface. Considering oil and ASP solution is dominated by

Fig. 2: Oil and ASP solution dispersed flow system in the process of experiment
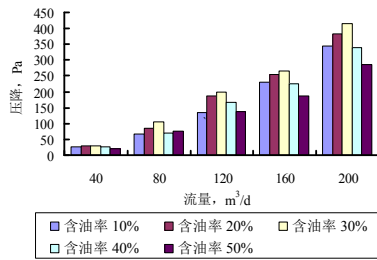
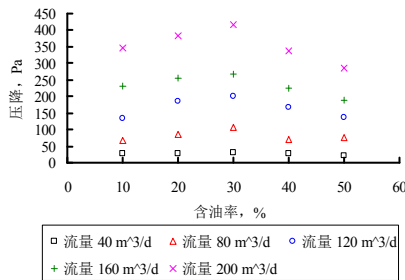Fig. 3: Relationship between measured pressure drop and flow rate

Fig. 4: Relationship between measured pressure drop and input oil volumetric fractions

dispersed flow pattern, the pressure drop of flowing system could be predicted by the homogeneous model with appropriate mixture's physical property relationship.

The pressure drops of oil and ASP solution two-phase flow in a horizontal concentric annulus are mainly measured under conditions of various mixture flow rates and input oil volumetric fractions, the results are shown respectively in Fig. 3 and 4.

Figure 3 and 4 show that under the experimental condition, the pressure drop of oil and ASP solution two-phase flow has an approximate exponential relationship with the mixture flow rate, which is similar to single-phase flow; the pressure drop first increases and then decreases with increasing the input oil volumetric fractions, demonstrating that the mixture of oil and ASP solution also exists obvious phase inversion, which is similar to the conventional oil and water two-phase flow (Arirachakaran *et al*., 1989; Angeli and Hewitt, 2000; Piela *et al*., 2008); the critical oil cut, at which the phase inversion occurs, is between 30 and 40%.

CONCLUSION AND RECOMMENDATIONS

A full scale experiment facility is designed and constructed to investigate the flow behaviors of oil and ASP solution two-phase flow in a horizontal concentric annulus. Several specific conclusions and suggestions as follows have been obtained:

- The mixture of oil and ASP solution is more likely to be emulsified while flowing compared to that of oil and water.

- While oil and ASP solution two-phase is dominated by dispersed flow, the pressure drop first increases and then decreases with increasing the input oil volumetric fractions.
- The critical oil cut of oil and ASP solution two-phase flow in a horizontal concentric annulus at which the phase inversion occurs is between approximately 30 and 40%.
- It is suggested that more experiments on inclined flow be conducted in order to better verify the results obtained in this study, so as to develop a comprehensive predicting model of the pressure drop.

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