Experimental Study on Wax Deposition of Gas Emulsion during Intermittent Flow

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Abstract. Wax deposition of the gas-emulsion in intermittent flow with different water cuts and gas/emulsion superficial velocity in a flow-loop was investigated by crude oil, simulated oil, gas, and water as the experimental medium. In both the crude oil and simulated oil systems, the deposit was distributed around the pipe wall, and the deposit thickness decreased initially and then increased. These changes were induced by the increasing water cut resulting from the increasing viscosity and gelation point of the emulsions. The experimental results revealed that increasing gas and emulsion superficial velocity both have a negative effect on deposit formation.

1. Introduction
Research on wax deposition has focused mainly on oil-water emulsion/oil-gas two-phase flow, but studies on wax deposition under oil/gas/water (i.e., three-phase) flow have yet to be reported[1]. Therefore, in this work, gas and water with crude oil and simulated oil, respectively, was used to investigate the effect of water cut and gas/emulsion superficial velocity on the deposit thickness.

2. Materials
The crude oil (wax content: 22.50%, density: 872.4 kg/m³ at 20°C, wax appearance temperature: 50.0°C, and gelation temperature[2]: 38°C) was obtained from Da Qing oil field. The simulated oil has the following characteristics: wax content: 5.0%, density: 845.3 kg/m³ at 15°C, wax appearance temperature: 26.64°C, and gelation temperature: 15°C.

3. Experimental Process and Equipment
The flow loop has a sampler to ensure the stability of the emulsion and determine the water cut at the end of the test section[2]. An emulsifier-Span80 is corresponding to ~0.5% of water volume is added to the simulated oil system.
The crude oil is heated and kept at 80°C for 6 h (the simulated oil is kept at 50°C for 6 h). The temperature of the emulsion phase and test section for the crude oil (simulated oil) system are set to 50°C and 35°C (40°C and 15°C), respectively. When the oil temperature is stable, an appropriate amount of water (at the oil temperature) is added to the oil and mixed for 2 h. The pump is then started (at a suitable speed) and the compressor is also started. The valve for gas injection is opened when the gas temperature is same as the oil temperature. The data acquisition program is started when a stable flow pattern through the sampler is obtained. After 24 h (simulated oil system 120 min), the pump and compressor are turned off, and the air purge process is started. Afterward, the test section is removed from the flow loop, the deposit is photographed and the deposit thickness is measured using the volumetric displacement method[3]. Deposit samples (only simulated oil system, for easy dehydration) are obtained after the experiment. The components present in these samples are determined via high temperature gas chromatography and the wax crystal structure is observed with a Motic BA300Pol polarizing microscope. Each experiment is performed three times to minimize the man-made errors.

4. Results and Discussion

4.1 Effect of water cut on deposit

Table 1 shows the changes in the deposit thickness with variations in the water cut under gas-emulsion during intermittent flow. Table 1 indicates that the introduction of a water phase leads to a decrease in the deposit thickness. The thickness decreases initially with increasing water cut and increases thereafter, in both the simulated oil and crude oil systems. Moreover, a minimum thickness occurs when the water cut increases to 15% under simulated gas-emulsion in intermittent flows. Under the crude oil system, however, the minimum deposit thickness occurs at a water cut of 25%. This difference depends mainly on the viscosity and shear resistance of emulsion, which are significantly higher in the crude oil system than in the simulated oil system. The experimental observations are further investigated by considering the radial distribution of deposit around the pipe wall.

| Water cut (%) | Deposit thickness (mm) |
|---------------|------------------------|
|               | Simulated oil          | Crude oil            |
| 0             | 1.1952                 | 2.2197               |
| 5             | 1.1655                 | 2.1058               |
| 10            | 1.1075                 | 2.0575               |
| 15            | 1.0798                 | 1.9658               |
| 20            | 1.1061                 | 1.9471               |
| 25            | 1.1620                 | 1.879                |
| 30            | 1.2350                 | 1.9643               |
| 35            | 1.3379                 | 2.034                |
| 40            | 1.3798                 | 2.1099               |
| 45            | 1.4326                 | 2.2045               |

The viscosity and the pour point of the emulsion phase both increase with the water cut increase[3]. For one thing, when the water cut increases, the number of water droplets in the oil phase increases,
thereby hindering wax-molecule diffusion in the oil phase. This leads to a decrease in the diffusion coefficient of the wax molecules and the deposit thickness. For another thing, an increase in the emulsion pour point results in enhanced encapsulation capacity of the condensate oil, i.e., the anti-shear ability of the deposit layer is reduced, and the deposit thickness increases. The deposit thickness is affected by these two factors and, hence, the thickness decreases initially with increasing water cut, and increases thereafter.

When the water cut increases from 0% to 15%, the pour point also increases, while the inadequate increase amplitude (compared with the shear stress in the pipe wall) allows unopposed stripping of the shear stress. The inadequate increase amplitude leads to shearing and continual erosion of the emulsion packaged in the initial deposit. When the water cut increases from 15% to 45%, the viscosity of the emulsion and the ability of the initial deposit to package the emulsion increase further, and can thereby oppose the shear stress of the pipe wall. This increase in the water cut yields a further increase in the deposit thickness. In addition, when the water cut increases from 15%, the ability for wax-molecule diffusion is reduced and, hence, the wax crystal and deposit package a significant amount of emulsion. This emulsion is continuously sheared by the shear stress of the pipe wall, leading to a decrease in the thickness of the deposit (see table 1).

The dependence of the deposit thickness on the water cut is determined and the experimental analysis is simplified by considering the deposit radial distribution. Micrographs of the deposit on the bottom, side, and top of the pipe wall are shown in figure 1. As the figure shows, at the bottom of the pipe and the top of the pipe the, (i) water cut and number of wax crystals are greatest and smallest, respectively, and (ii) water drop and the structure of the crystals are least extensive and most extensive, respectively. This results mainly from the fact that the emulsion film zone and slug zone undergo rotation during intermittent flow and, hence, the ability for diffusion and oil packaging in the bottom is enhanced. The water drop is small, owing to the prolonged emulsion contact and considerable shear stress generated, compared with those at the top of the pipe.

4.2 The effect of gas/emulsion superficial velocity on the deposit

Figure 2 shows the experimental conditions (20% water cut) and the dependence of the deposit thickness on the gas and emulsion superficial velocity.
Figure 2. Dependence of deposit thickness on the gas/liquid superficial velocity.

For constant experimental temperature and water cut, the deposit thickness under both the crude oil system and simulated oil system decreases with increasing gas and emulsion superficial velocity. This decrease is attributed mainly to: (1) the emulsion and gas-phase rotation flow under intermittent flow, i.e., the periodic flow of the slug body through the deposit surface leads to strong washing action on the deposit surface. The intensity of this action is proportional to the gas and emulsion superficial velocity. Therefore, the increase in velocity is unfavorable for growth of the deposit thickness, thereby leading to a reduction in the thickness; (2) the slug frequency increases with increasing gas and emulsion superficial velocity, resulting in accelerated washing of the slug body to the deposit surface, leading to a reduction in the deposit thickness; (3) the turbulence and mixed flow between the gas and emulsion phase increases with increasing gas and emulsion superficial velocity.

These three events occur simultaneously during the process of deposit formation and, hence, the deposit thickness decreases with increasing gas and emulsion superficial velocity.

5. Conclusions
1. When the water cut of the crude oil and simulated oil system is increased, the deposit thickness decreases initially and then increases.
2. The deposit on the bottom of the pipe contains the smallest wax crystals, while the deposit on the top of the pipe contains the largest wax crystals.
3. The deposit thickness will decrease with increasing gas superficial velocity and emulsion superficial velocity.

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References
[1] Sarica, C., Panacharoensawad, E. (2012) Review of Paraffin Deposition Research under Multiphase Flow Conditions. Energy & Fuels, 26: 3968–3978.
[2] Qing, Q., Wei, W., Pengyu, W., Yuanxin, Z., Jing, G. (2015) Wax Deposition of Water-in-crude Oil Emulsion in a Flow-loop Apparatus. Petroleum Science & Technology, 33(5): 520-526.
[3] Jing, G., Yu, Z., Lulu, L., Jimiao, D., Pengyu, W., Jun, Z. (2011) Wax deposition in the oil/gas two-phase flow for a horizontal pipe. Energy Fuels, 25:1624–1632.