The Research on Flow Imaging and Flow Profile Interpretation Method in Shale Gas Horizontal Well Multiphase Flow

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Multiphase flow state is complex in shale gas horizontal well. Using foreign array probe tools to accurately monitor fluid production location and flowrate is very important, but at present domestic flow imaging and flow profile interpretation technology is still immature. In this paper, based on analysis the structure and characteristics of Schlumberger FSI (Flow Scanning Imager), firstly, the multiphase flow in shale gas horizontal wells was numerically simulated by Fluent software, and the velocity and pressure distributions were obtained. Compared with the typical horizontal well gas-water two-phase flow pattern classification, the two methods are in good agreement. Secondly, using the methods of gridding and simple inverse distance interpolation, the calculation of holdup and average velocity are carried out. After that, considering the deviation and flow pattern, the calculation method of key parameters was deduced such as the apparent velocity, phase distribution coefficient and drift velocity. What's more, Flow profile interpretation model is established in horizontal air-water two-phase. In the end, the field test data show that three-dimensional flow imaging effect and interpretation precision is good for stratified flow.

1. Introduction

After about thirty years of technical preparation and experiment, the United States has developed and utilized of shale gas widely (Zhang et al, 2013). In domestic, there are three types of rich-organic shale, including marine shale, transitional shale, and continental shale. What's more, marine shale gas has realized industrial development which has the best prospects. According to China shale gas resources survey report issued by the Ministry of Land and Resources in 2015, Currently Fuling of Chongqing, Changning-Weiyuan of Sichuan province and other area have achieved a major breakthrough in shale gas exploration. Seven hundred and eighty shale gas wells has drilled by the end of 2014, and 1,300,000,000 m^3 shale gas has been mined. In case of Fuling shale gas field which is first large-scale development in China. Shale gas filed is mainly produced by horizontal well, and the production of single well is about 1,000,000m^3. For instance, Jiaoye-1HF well produced 203,000 m^3 gas every day with a small amount of water. However, water yield will be gradually increased with development of the perforated layer. So accurate monitoring of fluid distribution and flow phase in wellbore is an urgent problem to be solved (Li et al., 2016; Lei et al., 2017; Sun, 2013; Wang et al, 2015). At present, the dynamic monitoring of shale gas production process is mainly carried out by means of a mature array probe logging instrument abroad, for example, Flow Scan Imaging (FSI) from Schlumberger (Baldauff et al., 2004), Multi Capacitance Flowmeter (MCFM) from Atlas (Chace et al., 1999; Chace et al., 2000), MAPS (including Capacitance Array Tool, Resistance Array Tool and Spinner Array Tool) from Sondex (Gary et al., 2009). However, the corresponding methods of flow imaging and flow profile interpretation also need to be studied. Based on this background, firstly, the authors analyzed the characteristics of FSI. Secondly, shale gas horizontal well multi-phase flow conditions were simulated. Thirdly, shale gas multiphase flow two-dimensional flow imaging in horizontal well was achieved using the interpolation algorithm and programming.

And then, flow profile interpretation model in horizontal well gas-water two-phase was established. Finally, the example shows that flow imaging effect is good in stratified flow.

2. Array Probes Tool

As shown in Figure 1, FSI is triangular in shape and consists of five micro-turbine flowmeters, six FlowView electronic probes and six GHOST optical probes (Ahmad et al., 2013). Micro-turbine flowmeter can measure the local velocity of fluid, and then get the velocity profile imaging. The FlowView electronic probe and the GHOST optical probe array measure the electrical impedance and optical properties of the fluid, respectively, to determine the local water holdup and gas holdup that leads to holdup profile imaging.

The specific working principle is as follows: Firstly, after the turbine is started, the fluid in the pipe impinges on the turbine blades to push the turbine to rotate against the fluid resistance and friction force. For a specific flow of fluid, the turbine speed is directly proportional to the fluid velocity. Secondly, FlowView electronic probes differentiate water from hydrocarbon by differences in fluid conductivity. The water holdup is determined by the share of water in the fluid and the flow velocity is determined by the bubble count rate of the oil and gas. Thirdly, because of the difference between gas and water, the GHOST optical probe can distinguish the gas phase and the water phase by measuring the intensity of the reflected light, and calculate the gas holdup according to the ratio of the measured bubble count within the unit time.
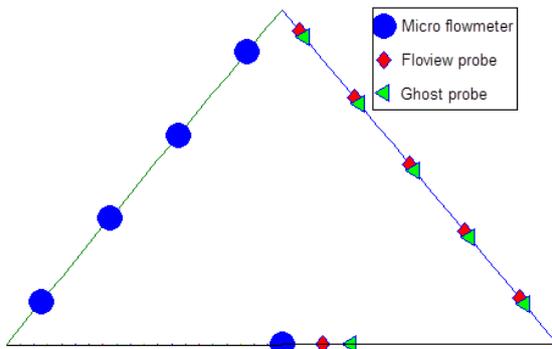

Figure 1: FSI instrument probe distribution diagram

3. Numerical Simulation of Flow State

At present, the domestic flow loop simulation laboratory is under normal temperature and pressure condition. And the highest gas flowrate in simulation is about $1,000 m^3/d$. Hence, in this paper, FLUENT software is used to simulate gas-water two-phase flow state in horizontal pipe under high temperature, high pressure and high flowrate (Zhu, 2014). the set of parameters are 6 m long horizontal pipe, 0.124 m inner diameter, "O" type grid meshing cross section of the wellbore, Euler VOF multiphase model, medium for air and water, volume factor B_g is 0.02017, inlet and outlet pressures of 30,603,784 Pa and 30,594,679 Pa, inlet and outlet temperatures of 357.1462 K and 357.0648 K. As shown in Figure 2, they are three groups gas phase distribution. The left side of the pipe is the entrance, and the right side is the outlet. At the same time, red and blue is gas and water respectively.

Table 1: Parameter variable and simulation results

No.	$Q_{gsurface}$ (m^3/d)	$Q_{gdownhole}$ (m^3/d)	$Q_{wdownhole}$ (m^3/d)	Flow Pattern of Simulation	Flow Pattern of Catala	Comparison Result
1	100,000	2,017	104	wavy stratified flow		Identical
2	350,000	7,060	104	wavy stratified flow		identical
3	500,000	10,085	104	dispersed flow		good agreement

As shown in Figure 2(a) and 2(b), when gas flowrate at surface is 100,000 m^3/d and 350,000m^3/d, stable flow pattern is wavy stratified flow. As shown in Figure 2(c), when gas flowrate at surface is 500,000m^3/d,

stable flow pattern is dispersed flow. As shown in Table 1, compare the flow pattern from numerical simulation with horizontal gas-liquid flow pattern from Catala (Baldauff et al., 2004), which indicates that both alignments are good.
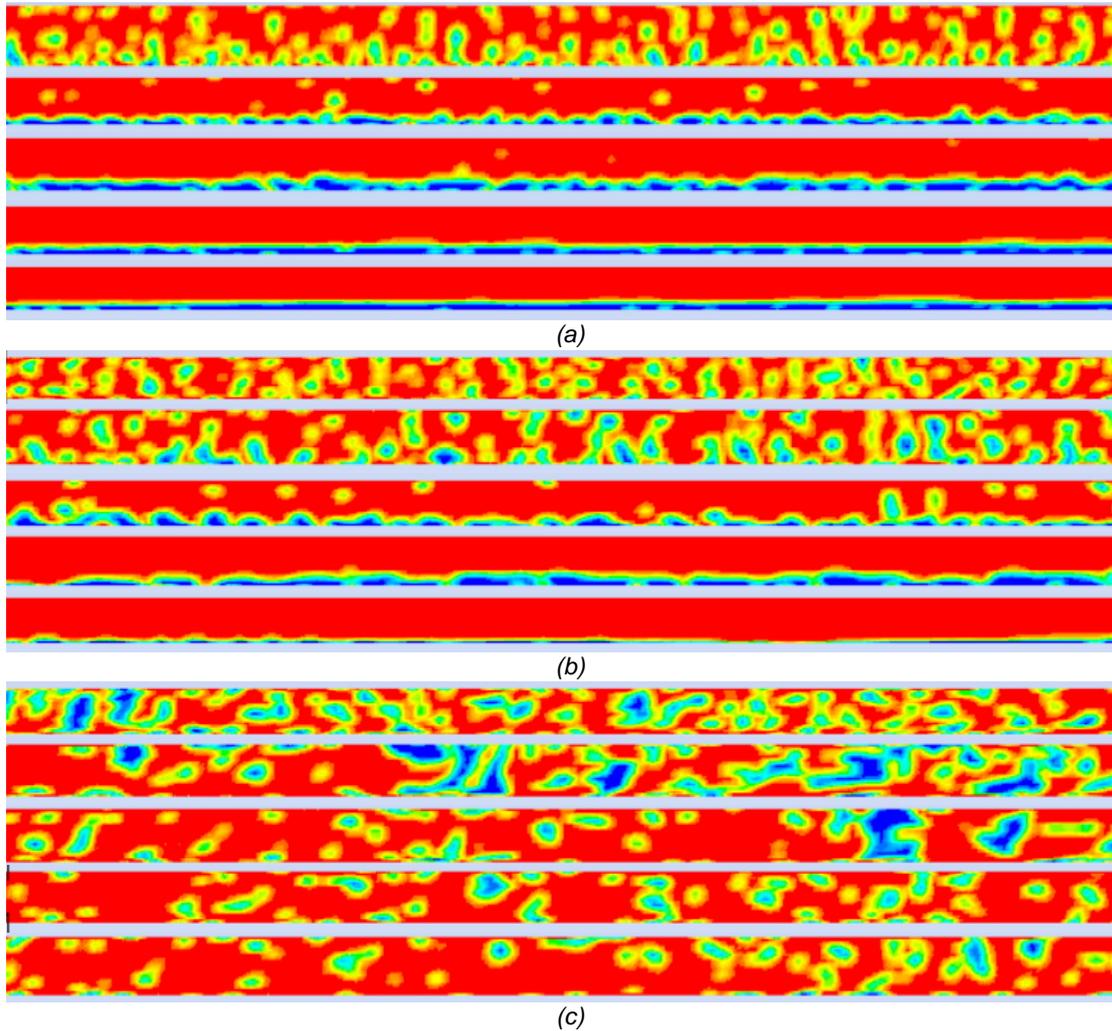

(a)

(b)

(c)

Figure 2: Gas phase distribution map: (a) 100,000 m^3/d (b) 350,000 m^3/d (c) 500,000 m^3/d

4. Flow Imaging Algorithm

Combined with the calibration values of FlowView electronic probe and GHOST optical probe in oil, gas and water, the local holdup in wellbore section can be calculated. Then, by using simple distance inverse, radial basis and other interpolation algorithms, the holdup of unmeasured points can be interpolated, and then the holdup imaging can be achieved and the average holdup can be obtained.
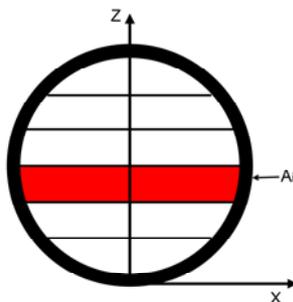

Figure 3: Fluid regional division

As shown in Figure 3, five micro-turbine flow meters are evenly distributed in the vertical direction. The wellbore section is divided into n zones. Each turbine works independently. And then, the flow rate measured by each turbine is considered as the velocity of this zone. Thus, the i-th region of the flow rate:

$$v_i = \frac{R_i}{k_i} - v_x - v_1 \tag{1}$$

The average flow velocity across the horizontal cross-section is:

$$v_m = (\textstyle\sum_n A_i \times v_i)/\sum_n A_i) \tag{2}$$

Where v_i is the fluid velocity in the i-th zone. R_i is the number of revolutions of the i-th turbine at logging speed. v_x is the turbine startup speed. v_1 is the logging speed. k_i is the slope of the i-th turbine after correction. v_m is the average flow velocity of the entire section. A_i is the area of i-th zone.

5. Flow Profile Interpretation Model

Based on flow loop simulation experiment, the main flow patterns of gas-water two-phase flow in horizontal pipe are stratified flow, wavy stratified flow and dispersed flow. As shown in Figure 4, the method to build drift-flux model can be used for shale gas horizontal well, so the flow profile interpretation model is:

$$\begin{cases} V_{sg} = C_0 V_m Y_g \\ V_{sw} = V_m - V_{sg} \end{cases} \tag{3}$$

Each phase flowrate is:

$$\begin{cases} Q_g = V_{sg} \times PC \\ Q_w = V_{sw} \times PC \end{cases} \tag{4}$$

Where V_{sg} and V_{sw} are apparent velocity of gas and water respectively. Y_g is gas holdup, which measured by the gas holdup tool or GHOST, or obtained by water holdup. V_m is gas-water mixing flowrate, which is measured by the flowmeter. C_0 is phase distribution coefficient, depends on the flow pattern, and C_0 from the experiment chart fitting is 1.49 for stratified flow in Figure 4. PC is the pipe constant, which is obtained by the inner diameter of the wellbore and the outer diameter of the instrument. Q_g and Q_w are flowrate of gas and water respectively.
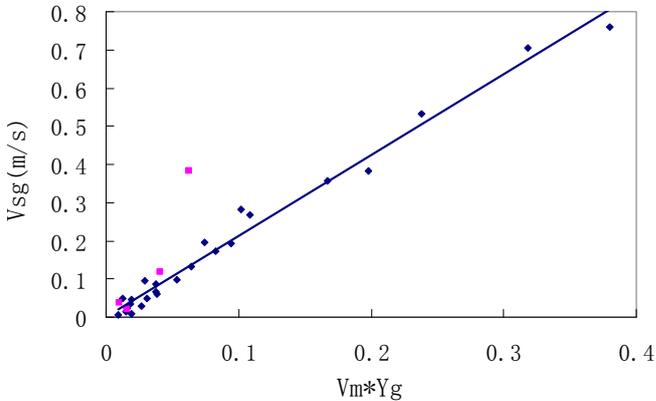

Figure 4: Interpretation parameters of horizontal well gas-water two-phase flow

6. Example analysis

Jiaoye X well is a shale gas well of Fuling, Sichuan province. And the wellbore deviation is 85-89 degree, and gas flowrate at surface is $100,000 m^3/d$. FSI is used to measure X well in 2,796-4,188 m. Among them, six optical probes (GHOST) are used to distinguish gas and liquid, as well as calculating gas holdup. Six electronic probes (FloView) distinguish hydrocarbon and water, as well as calculating water holdup. Five mini flowmeters are used to measure fluid velocity at different location of the wellbore. Figure 5(a) is fluid flowing diagram from FSI, this part is in uphill section and the flow pattern is stratified flow. Compared with the Figure 5(a), which simulates fluid distribution, It indicates that both agree very well. Figure 5(b) shows flow profile of every perforation layer production and gas-water distribution along with the wellbore trajectory.
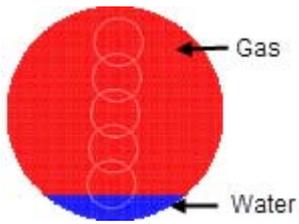
(a)
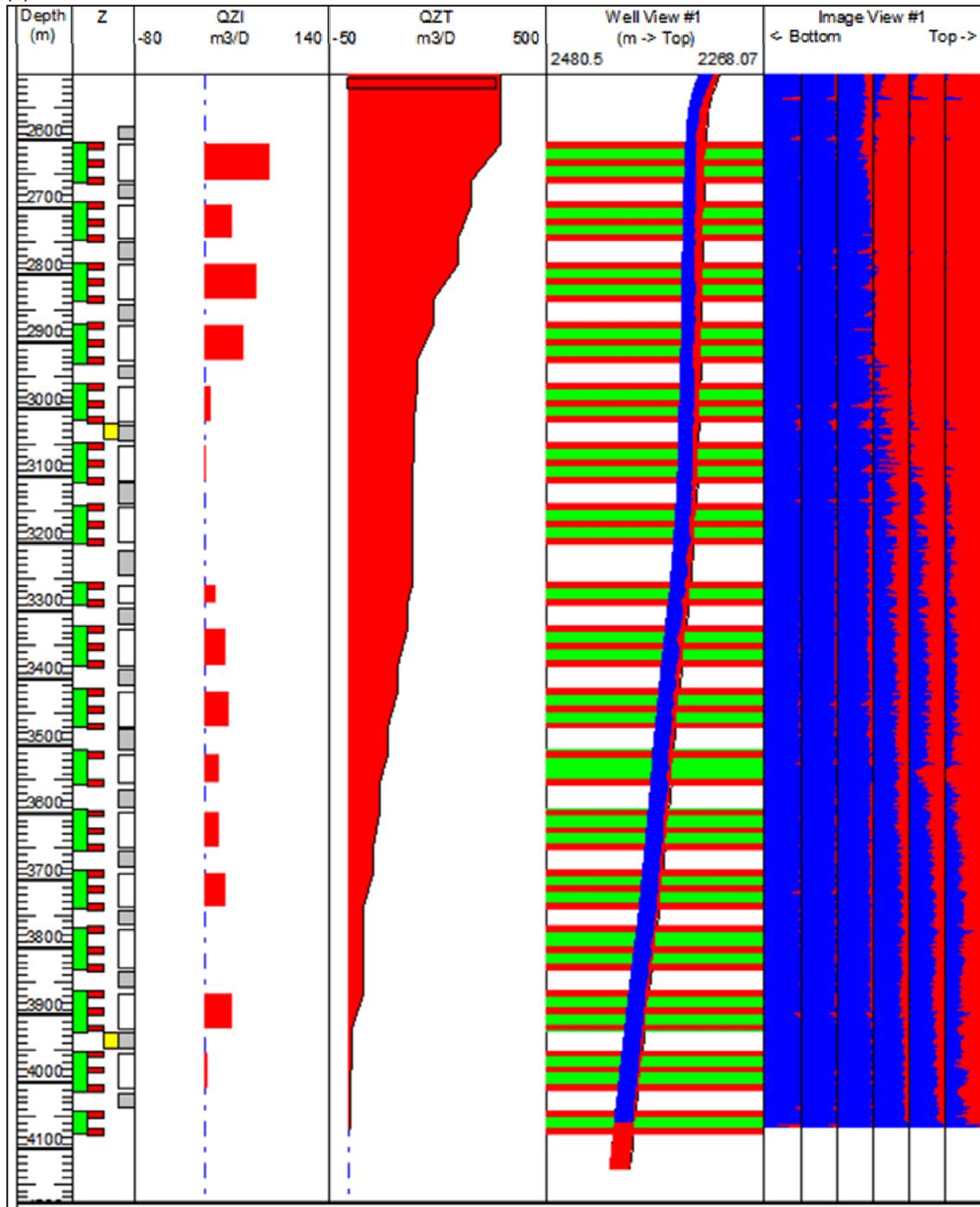
(b)

Figure 5: Interpretation results: (a) Fluid flow imaging (b) Flow profile and gas-water distribution

7. Conclusions

(1) The array probe tool which covering full-bore is used to measure multiphase flow in shale gas horizontal well. And it can accurately monitor stratified flow and measured parameters are mainly holdup and velocity.
(2) Using Fluent software to simulate gas-water two-phase flow in horizontal pipe under the condition of high temperature, high pressure and high flowrate, the flow pattern mainly is wavy stratified flow.
(3) For horizontal well gas-water two-phase stratified flow, the imaging performance of the flow imaging algorithm is good, basically in line with the actual situation.
(4) The flow profile interpretation model of gas-water two-phase flow in shale gas horizontal well has been established. And the example shows that FSI measured flow diagram and the numerical simulation results fit well. What's more, the flow profile interpretation result can indicate the production state of perforation layer and distribution of gas-water in the wellbore.

Acknowledgments

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