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Research Article

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The research of array holdup tools response characteristic for oil-water two-phase in near horizontal well

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ABSTRACT

Stratified flow can be observed in typical flow pattern of oil-water two-phase in near horizontal well, which results in measure response using a conventional single probe centered measurement instruments cannot truly reflect the state of the fluid flow, inaccurate information taken from holdup measurements. Therefore, it is necessary to do the research on measuring holdup effect of Capacitance Array Tool (CAT) and Resistance Array Tool (RAT) in entire covering cross section of wellbore. In this paper, based on simulation experiment of multi-probe measurement instruments (CAT, RAT) in the large diameter flow loop, firstly, we have obtained the flow pattern characteristics in case of different proportion, made the charts of instrument response, for example, water holdup – flow rate (water cut) relationship, slip velocity – flow rate (water cut) relationship and inclination - water holdup (water cut) relationship, and so on. Secondly, using compiled data processing module, Surfer software and radial basis function, we have achieved fluid flow simulation for multi-probe measurement instruments (CAT, RAT), compared CAT with RAT measurement result, and obtained the assignment principle for holdup calculation with the weight optimization. Finally, the results can be used to judge oil-water two-phase flow conditions in near horizontal well and calculate each phase's holdup under different conditions.

Key words: Near horizontal well, Flow pattern, Simulation experiment, Multi-probe measurement tool, Holdup, Optimization calculation, Response characteristic

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INTRODUCTION

The multiphase flow pattern are usually bubble flow and slug flow for production profile in vertical well production logging, and the logging tools are usually single probe centered measured [1-3]. When the well's inclination changes that become highly deviated wells or horizontal wells，the distribution of fluid flow in the wellbore change significantly. Single probe centered measuring instrument using in vertical wells are not applicable to deal with the situation when it comes to stratified flow occurs [4-7]. In recent years, Schlumberger, Atlas, Sondex and other companies have developed multi-probe measuring instruments covering the whole wellbore for horizontal wells' multiphase flow under complex conditions, such as FloScan Imager, MCFM, CAT, RAT and SAT [8-13]. Capacitance Array Tool (CAT) and Resistance Array Tool (RAT) from Sondex are chosen in this study to conduct simulation experiments in large-diameter flow loop, both of response law in different well conditions and the assignment principle for holdup calculation with the weight optimization are given through the analysis of experimental data, which contribute to provide technical support for the accurate interpretation of production profile logging data in near horizontal well.

EXPERIMENTAL SECTION

The test data are from simulation laboratory of multiphase flow，taking tap-water and diesel as formation water and crude oil, using CAT and RAT as main test equipment. The total flowrate (water and oil) is set in 10, 30, 50, 100, 300, 500 m^3/d respectively and matching water cut is 0%，20%、40%、60%、80%、100%. Inclination (PD) is divided into uphill flow (5^o , 3^o , 1^o), horizontal flow (0^o) and downhill flow (-1^o , -3^o , -5^o).

ANALYSIS OF TEST DATA

1. Flow Pattern Classification

By analyzing 112 sets of experimental data, including oil-water injection flowrate, water cut, inclination degree, camera, photographic record and so on, there are six kinds of flow patterns are found based on the classification criteria from Trallero about two-phase flow pattern in horizontal well, such as stratified flow(ST), stratified flow with mixing at the interface(ST&MI), dispersion of oil in water and water(Do/w & w), oil in water emulsion(O/W), water in oil emulsion(W/O) and dispersions of water in oil and oil in water(Dw/o & Do/w) [14]. According to three main flow parameters (total flow, water holdup, inclination degree) with relationship of downhole flow patterns in experiment, researchers draw the distribution chart of three-dimensional flow pattern with superficial velocity of oil (Vso), superficial velocity of water (Vsw) and inclination degree (PD) as axis in view of sorting out the different inclination(5^o，3^o，1^o，0^o，-1^o，-3^o，-5^o) with corresponding speed of oil-water mixed fluid (Vm) (5787.037cm/s, 3472.222cm/s, 1157.4074cm/, 347.2222cm/s) and water cut(30%,50%,70%,90%). As shown in Figure 1, when the value of Vso and Vsw is relatively small, flow pattern is stratified flow (ST). As the value of Vso or Vsw increases, smooth interface appears corrugated and begins to blur, mixed stratified flow can be observed in interface (ST&MI). Then, changing the value of Vso much more, flow pattern will become mutually dispersed flow of oil - water (Dw/o & Do/w) or water in oil emulsion (W/O). However, during the time of stratified flow of promiscuous interface, if the value of Vso increases again, flow pattern will become dispersion of oil in water and water (Do/w & w). Continuing to increase the value of Vsw, oil appears oil in water emulsion (O/W).

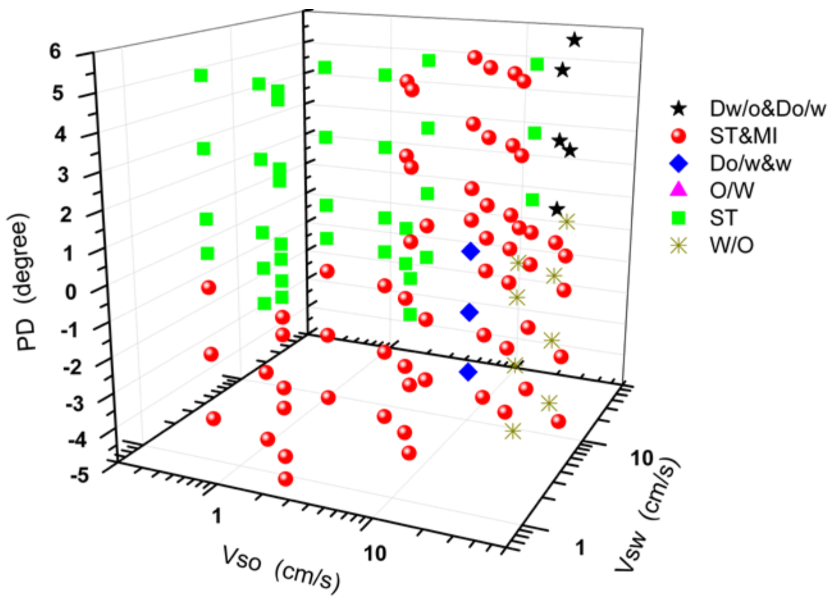
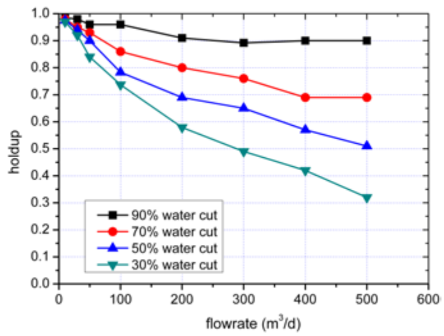
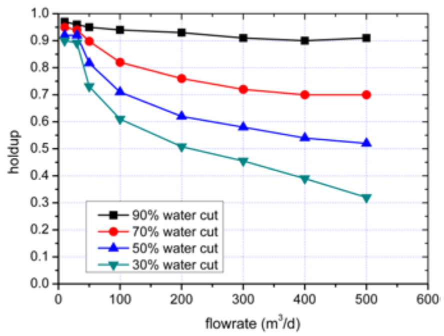


Figure 1: Three-dimensional flow pattern chart of oil-water two-phase in near horizontal well



（1）PD3



（2）PD1

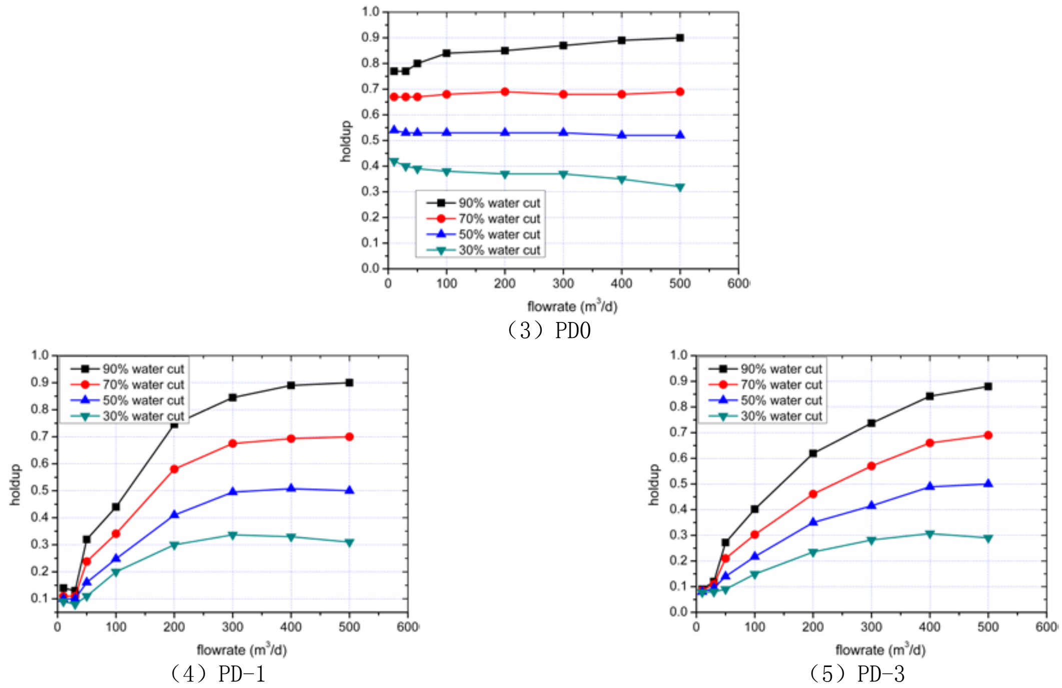


Figure 2: Relational charts of holdup - flowrate (water cut) under different inclination degree

2. Analysis of Instrument Response

2.1Relationship among holdup, flowrate and water cut under different inclination degree

When the value of inclination degree changes, holdup will be different because of gravity influence even if other conditions are the same in near horizontal well.

As shown in figure 2, when the value of inclination degree is positive and water cut is 30%, 50%, 70% and 90% respectively, holdup decreases with the increase of flowrate. When the value of inclination degree is negative and water cut is 30%, 50%, 70% and 90% respectively, holdup increases with the increase of flowrate. When the value of inclination degree is zero, less affected by changes in the slip velocity - flowrate can be observed.

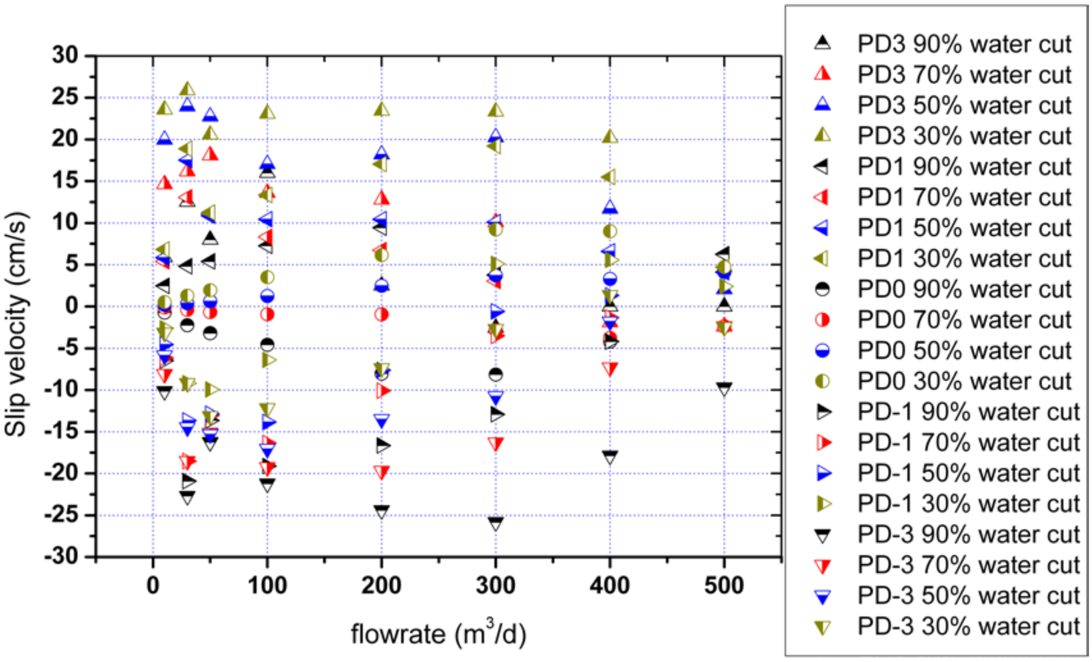


Figure 3: Relational chart of slip velocity - flowrate (inclination degree and water cut)

2.2Relationship between slip velocity - flowrate (water cut) under different inclination degree

As shown in figure 3, when the value of inclination degree is zero and water cut is less than 50 percent of total flowrate, the value of slip velocity is positive. And the value of slip velocity become negative as the water cut is more than 50 percent of total flowrate at zero degree. When the value of inclination degree is positive, the value of slip velocity increases compared to it at zero degree and is positive in most cases. And the value of slip velocity decreases compared to it at zero degree and is negative in most cases as the value of inclination degree is negative.

3. Simulation of flow regime

Using the interpolation algorithm to simulate the state of fluid distribution in the wellbore based on the response of experimental measurement with 12 array probes.

3.1Data pre-processing

In order to facilitate the simulation data preprocessing, the authors use Visual C++ to compile the data processing module named AHTDP (Array Holdup Tool Data Process Software), shown in Figure 4. After entering each array probe's response value and setting related parameters, the AHTDP can output interpolation data, the value of inner boundary conditions and outer boundary conditions, shown in Table1-3.

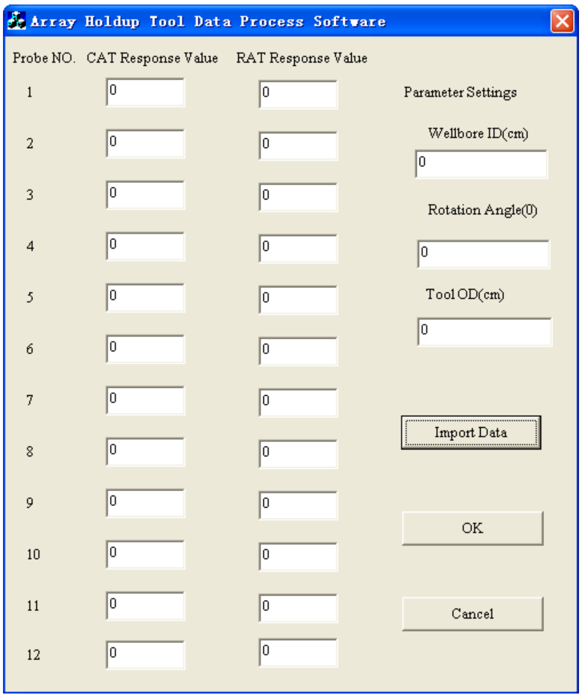


Figure 4: CAT & RAT Data pre-processing module

Table 1.Interpolation data of calculation

x1	y1	z
0.011489	-124	1.0331
-61.9884	-107.394	1
-107.379	-62.0133	1
-124	-0.0172336	0.9765
-107.397	61.9834	1
-62.0182	107.377	0.1576
-0.0229781	124	0.3241
61.9784	107.4	0.2954
107.374	62.0232	1.1083
124	0.0287226	0.9928
107.402	-61.9735	0.9513
62.0282	-107.371	1.0889

Table 2.Inner boundary condition (part of the data)

x2	y2
361	1
0.0039841	-43
-0.746448	-42.9935
-1.49665	-42.9739
-2.2464	-42.9413
-2.99547	-42.8955
-3.74362	-42.8367
-4.49063	-42.7649
-5.23627	-42.68
-5.98032	-42.5821
-6.72255	-42.4713
-7.46273	-42.3475

Table 3.Outer boundary condition (part of the data)

x3	y3
361	0
0.011489	-124
-2.15255	-123.981
-4.31593	-123.925
-6.47799	-123.831
-8.63809	-123.699
-10.7955	-123.529
-12.9497	-123.322
-15.1	-123.077
-17.2456	-122.795
-19.386	-122.475
-21.5204	-122.118

In the data calculated of interpolation, the first column stands for probe abscissa x1, the second column stands for probe ordinate y1 and the third column stands for a response value z for each probe of CAT or RAT.

Where in, Probe abscissa:

$$x1 = R \cdot \sin\left(\phi + \left(n-1\right) \cdot 30\right) \tag{1}$$

Probe ordinate:

$$y1 = R \cdot \sin\left(\phi + \left(n-1\right) \cdot 30\right) \tag{2}$$

Where R is an inner diameter of the wellbore, ϕ is the instrument rotation angle, and n is the probe number.

There are 361 points evenly distributed surrounding wellbore in the calculated boundary condition, which are connected to a closed curve, including the outer boundary and inner boundary condition. In the data calculated of boundary condition, the first column indicates x2 or x3 and the second column indicates y2 or y3.

(1)Coordinates of each point of inner boundary condition

Abscissa:

$$x2 = r \cdot \sin\left(\phi + \left(n-1\right) \cdot 1\right) \tag{3}$$

Ordinate:

$$y2 = r \cdot \sin\left(\phi + \left(n-1\right) \cdot 1\right) \tag{4}$$

(2)Coordinates of each point of outer boundary condition

Abscissa:

$$x3 = R \cdot \sin\left(\phi + \left(n-1\right) \cdot 1\right) \tag{5}$$

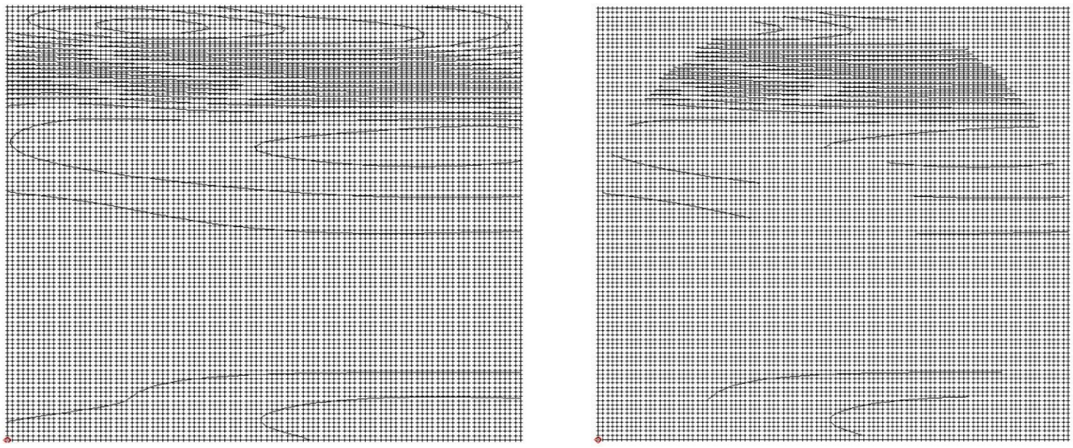
Ordinate:

$$y3 = R \cdot \sin\left(\phi + \left(n-1\right) \cdot 1\right) \tag{6}$$

Where, n is the point number taking integer value from 1 to 361, point No.1 and No.361 stands for the same point. r is an outer diameter of the instrument.

3.2 Flow simulation

Based on the data preprocessed above, using radial basis function of Surfer software to deal with the 12 probes with data gridding, shown in Figure 5(1). It is necessary to take "whitening" function with inner and outer boundary condition to handle the data above due to the oil - water flows in the annular space consisted of the wellbore and instruments, shown in Figure 5(2). Then, the authors draw the flow simulation distribution state of oil-water two-phase in the wellbore based on "contour map" function, combined with color code of oil and water, shown in Figure 6.



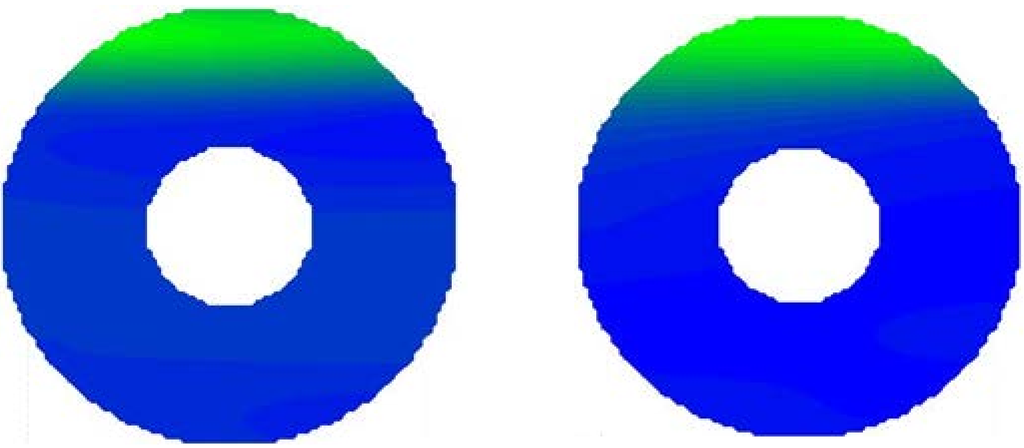
(1)Data gridding **(2)Join the boundary condition**

Figure 5: Data gridding

As shown in Figure 6, when the total flowrate of oil-water is 80 m^3/d with the water cut of 90%, the actual flow patterns from experimental observation are stratified flow, but the simulation results in CAT and RAT are stratified water. But the amount of water shown in CAT is more than RAT because of poor response effect of capacitive measuring probe with high percentage of water cut. Under the theoretical case, CAT is fit for identifying stratified flow with middle or low percentage of water cut where RAT for dispersed flow. Therefore, the authors will be taking weighted average calculation of processing results for both are feasible in the use of actual data.

$$\begin{cases} Y_w = a \cdot Y_{CAT} + b \cdot Y_{RAT} \\ a + b = 1 \end{cases} \tag{7}$$

Where, Y_{CAT} is water holdup values measured by CAT. Y_{RAT} is water holdup values measured by RAT. Y_w is water holdup values optimized through formula computing. a and b are different weight value.



(1)Simulation chart of CAT **(2)Simulation chart of RAT**

Figure 6: Simulation comparisons between CAT and RAT with high percentage of water cut

CONCLUSION

Based on the study of array holdup tools, main conclusions could be drawn as follows.

(1)When the fluid is uphill flow with the same water cut, holdup decreases with the increase of flowrate. For downhill flow with the same condition, holdup increases with the increase of flowrate. In horizontal flow, affected by changes in the flowrate of holdup is less.

(2)When the fluid is uphill flow, the value of slip velocity is positive in most cases. For downhill flow, it is positive in most cases. In horizontal flow, numerical value is around zero.

(3)When the fluid is stratified flow with low percentage of water cut, by CAT can truly reflect the distribution state of fluid flow. For dispersed flow, using RAT can obtain better measurement results. It is suggested to combine two measuring instruments in practical application.

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