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Optimization of pipeline scheme for measuring rheological parameters of drilling fluid by pipe flow method

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ABSTRACT

Drilling fluid is known as the blood of drilling engineering, which plays an important role in drilling engineering. The real-time measurement of drilling fluid rheological parameters is crucial to the optimization and adjustment of drilling scheme. Pipe flow method is a common method of measuring drilling fluid rheology parameters, pipe flow method monitoring equipment is an important reason of the pipe flow method monitoring principle, the analysis of the reason, put forward the spiral development section optimization scheme, using F LUENT numerical simulation software for simulation, the optimization platform and verify the reliability of the optimization of numerical simulation results, greatly reduce the pipe flow, method monitoring equipment volume. It also provides a theoretical basis for other pipeline measurement fields.

KEYWORDS

Drilling fluid; Rheological parameters; Pipe flow method; Spiral development segment; FLUENT.

1. INTRODUCTION

The real-time monitoring of drilling rheological parameters can ensure timely and correct decisions on downhole conditions[1-5]. Many monitoring methods of drilling fluid rheological parameters, the central tube flow method has the advantages of high degree of automation, not easy to plug, and easy to achieve real-time monitoring of drilling fluid rheological parameters[6-8]. When measuring the pipe flow method, it is necessary to measure the flow rate of drilling fluid under the inner laminar flow fully to obtain accurate and reliable differential pressure data, and a long pipeline length is needed, resulting in the limitations of large volume, high cost, and inconvenient disassembly and transportation. One of the ways to improve the monitoring efficiency and reduce the volume of the tubular monitoring equipment is to use the spiral tube instead of the traditional straight pipe, but the theoretical basis of the spiral pipe measurement[9]Is still under study.

The pressure measurement data at the inlet section of the pipeline is not stable. In order to obtain accurate and reliable differential pressure data, it is necessary to measure the drilling fluid flow rate full development section in the pipe, which often needs a long distance, which is the main reason for the large size of the straight pipe viscometer equipment. This paper proposes a method to reduce the length of the straight pipe development section and reduce the volume of the measuring equipment. First use the simulation software F luent to explore the feasibility of the spiral tube instead of the straight pipe development section theory, and then analyzed the influence of the structural parameters, according to the size of the parameters, then the design of the research results, the experimental results and six-speed measurement results, compare the accuracy of the spiral development segment simulation and the reliability of the ultimate size of the pipeline.

2. STRUCTURAL ANALYSIS OF PIPE FLOW METHOD

2.1. Monitoring principle of pipe flow method

Pipe flow method is the current drilling fluid rheological parameters real-time monitoring equipment commonly used a monitoring method, its principle is hagen, moisson law, namely a certain volume of fluid under a certain pressure gradient by given pipe time and laminar liquid viscosity, as shown in figure 1, the pipe flow method through flow meter monitoring flow through the pipeline, the pressure sensor monitoring pipeline pressure difference between a certain length, establish a mathematical model including flow, pressure difference, calculate the rheological parameters.

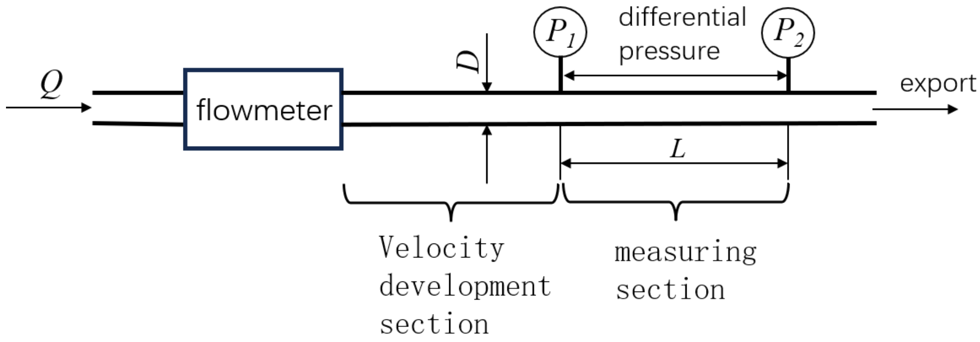

Figure 1. Principle of the pipe flow method

Drilling fluid is a viscous fluid. When it first enters the pipeline, the drilling fluid will form a sticky bottom layer near the pipe wall, namely the attached surface layer (Figure 1 velocity development section). As the drilling fluid continuously enters the pipeline, the surface layer will gradually expand to the axis of the pipeline along the flow direction of the drilling fluid until the flow state is stable. According to the investigation and analysis of the pressure in the flow rate development stage is not stable, namely the pipe flow method pressure measurement only in the flow rate development area (figure 1 measuring section) to obtain accurate differential pressure data, the flow rate development section usually need a short distance, and with the parameters of the pipe, the flow rate development section length will change, leading to the increase of the monitoring equipment volume.

2.2. Proposal of the optimization scheme

Real-time monitoring of drilling rheological parameter data is crucial to drilling engineering, and oil drilling site space is relatively narrow, so the development of a small volume monitoring equipment can save a lot of trouble, for pipe flow method monitoring equipment, mainly divided into supply system, measuring system and transmission module, the measuring system occupies the volume of the whole equipment, the main reason is the flow velocity development in figure 1 is too long. In this paper, we propose a method of spiral pipe instead of straight pipe development section, which reduces the overall equipment size and achieves the purpose of portable and accurate measurement.

According to the measurement principle of spiral development segment and tube flow method, the following three structures are proposed (V-L, V-L, L-L from left to right):

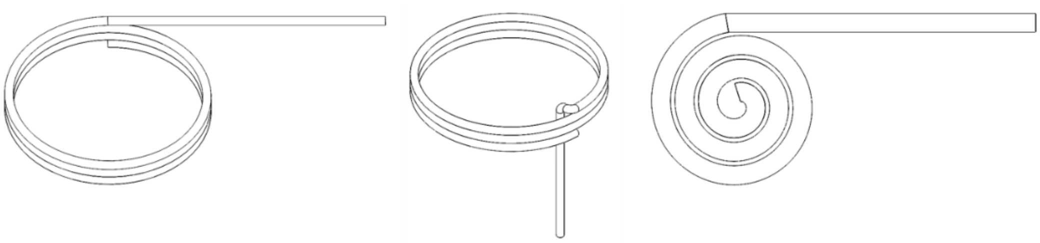

Figure 2. Optimization scheme of the spiral development segment

3. FEASIBILITY DISCUSSION

The obvious phenomenon that the flow rate does not reach the full development stage is the instability of the flow rate, including the speed of the flow rate in the direction of the cross section of the circular tube; and the pressure gradient along the flow direction. In order to better determine which structure can develop the drilling fluid faster, this section simulates the flow of the drilling fluid in several structures under the same conditions. The change of development segment length under different structures was studied from the flow rate cloud map of straight pipe section, the flow rate along the axis of pipe, the pressure gradient of pipe section and the unidirectional point speed and point pressure of different position sections.

3.1. Boundary conditions and parameter setting

In order to more clearly judge the flow behavior of drilling fluid in several structures, the dimensions of several development segment structures are unified, and the dimensions and other parameters of the spiral development segment are set as shown in Table 1 Parameter and base value setting.

Table 1. Setting parameters and reference values

Variable name	The initial value	unit
Drilling fluid density	2.2×103	kg/m^3
Drilling fluid flow rate	2.5545	m/s
Pipe diameter	20	m m
Number of turns in the spiral development segments	3	--
Helical development segment pitch	27	mm
Length of straight pipe section	2000	mm

$RNG\ k-\varepsilon$The flow of drilling fluid in the spiral pipe will produce secondary flow due to the action of centrifugal force and friction force. The model in F luent considers the influence of the rotation and cyclone flow by correcting the turbulent viscosity, so the turbulence model in this paper uses the model for steady state calculation. To better simulate the flow within the spiral tube, the turbulent model boundary conditions use the velocity inlet and the pressure outlet boundary, the wall is set as the stationary wall, the coupling of the pressure field and the velocity field is calculated by the Simple algorithm, and the pressure and velocity discretization adopt the second-order windwind scheme.$RNG\ k-\varepsilon$ Initialization was done using the Hybrid Initialization mode.

3.2. Analysis of the feasibility simulation results

3.2.1. Flow rate cloud chart

Several helical development structures were analyzed using the simulation software F LUENT, and Figure 3,4 and 5 show the flow velocity clouds of the three structures, respectively.

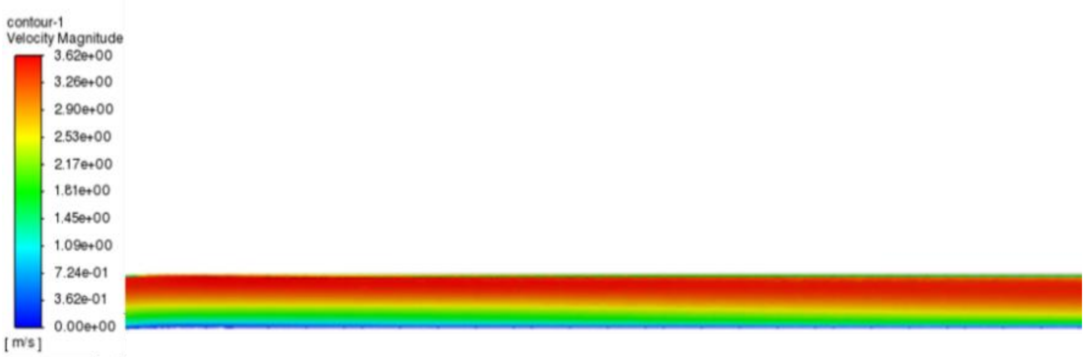

Figure 3. Cloud diagram of velocity distribution of V-L straight pipe section

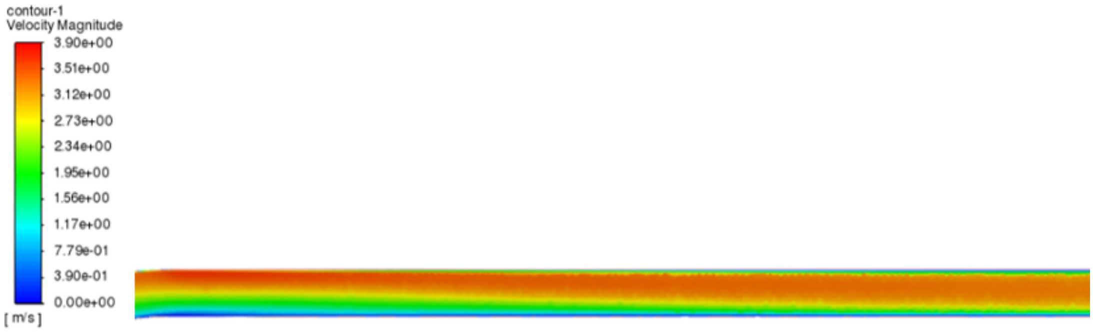

Figure 4. Cloud diagram of velocity distribution of L-L straight pipe section

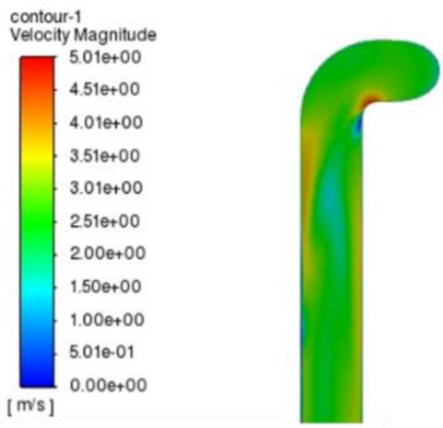

Figure 5. Cloud diagram of velocity distribution of V-V straight pipe section

In the V-V helix development structure, the V flow rate, As shown in Figure Figure 55, When the drilling fluid just enters the straight pipe section, The flow rate of the central part of the pipe is lower than on the sides, Its maximum flow rate reached 5.01 m/s, This is because the drilling fluid moves from the spiral development segment in the V-V structure to the straight pipe section after two rapid changes, Causes the internal flow rate of drilling fluid disorder; Figure 3 and Figure 4 show that because of the effect of the centrifugal force of the spiral development segment on the drilling fluid, During the straight tube stage, The maximum flow rate of the L-L type is greater than the V-L type. From the velocity cloud map of the three structures, V-L and L-L structures are superior to V-V structures, but they cannot clearly distinguish between L-L and V-L structures.

3.2.2. Pressure gradient judgment

After simulate the horizontal straight pipe under the same conditions, the pressure monitoring surface was established at every 100mm of the straight pipe segment of each structure, and the pressure gradient data of the resulting straight pipe segment was drawn as shown below.

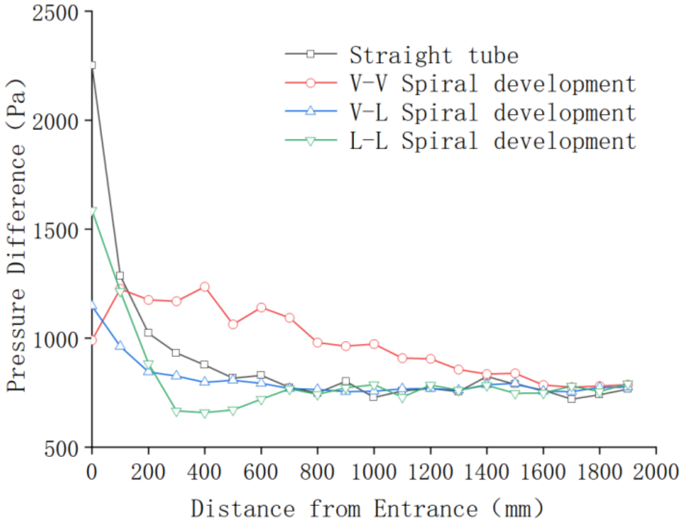

Figure 6. Change pattern of the pressure gradient in the straight pipe section

As can be seen from the figure,based on the evaluation of the pressure gradient of the straight tube segment,the V-L structure is better than the horizontal spiral tube and the other two spiral development structures;the pressure difference of the V-V structure is the longest;the balance at 1600mm from the inlet,while the L-L structure is the same,which is balanced at 700mm from the inlet.

3.2.3. Axis flow rate judgment

The horizontal straight pipe under the same conditions was simulated, and the flow rate at the axis of the straight pipe section of each structure was extracted, and the resulting flow rate data of the straight pipe segment was drawn as shown in Figure 7.

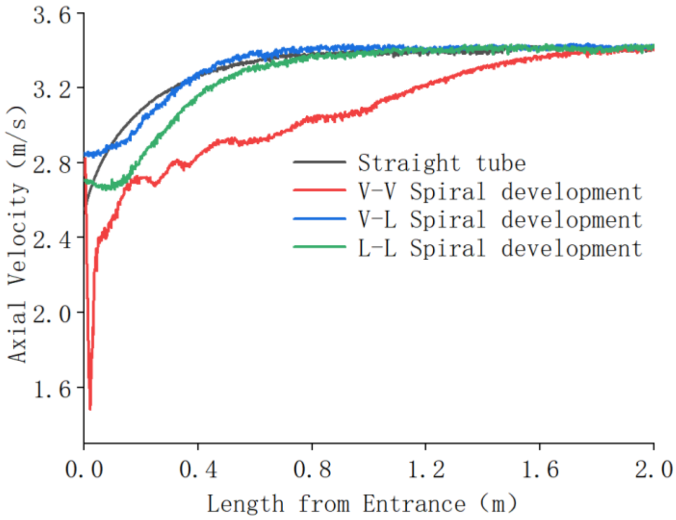

Figure 7. Change pattern of axis flow rate of straight pipe section

It can be seen from the figure, the drilling fluid in the straight pipe structure and V-L structure reaches the full development stage faster than the other two structures. The data show that under these conditions, the drilling fluid in the straight pipe starts to stabilize at 826.47mm; the development structure of V-L starts to stabilize at 585.426; the flow rate of V-V begins to stabilize at 1529.92mm, and the development rate of L-L begins to stabilize at 826.47mm.

4. SIMULATION AND CALCULATION RESULTS OF THE SPIRAL DEVELOPMENT SEGMENT

The factors that may affect the development length of the straight pipe segment were analyzed, and the factors of the bottom diameter, spiral development segment, turns (length) and shear rate (inlet velocity) were studied.

4.1. Pipe diameter

The pipe diameter is 15 mm, 20 mm, 25 mm, 30 mm and 35 mm respectively. Figure 8 shows the numerical simulation results of flow velocity at the axis of straight pipe section of spiral development structure under different pipe diameter.

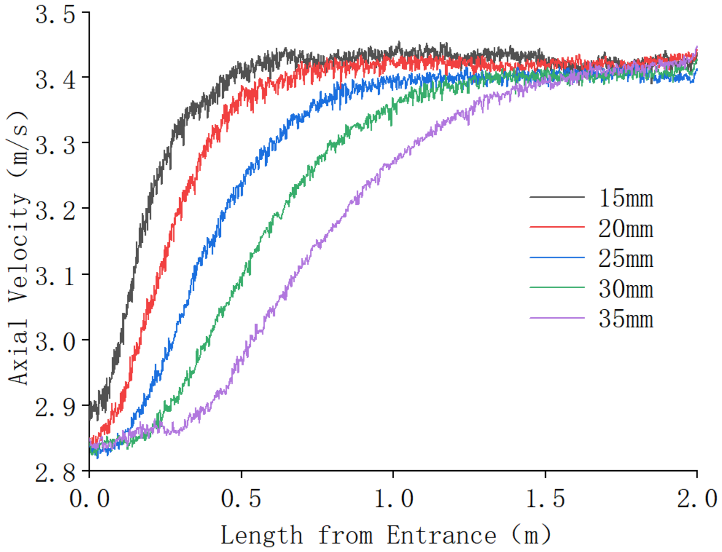

Figure 8. Effect of different pipe diameter on the length of the developing segment

As can be seen from the figure, when the pipe diameter changes at 10-35mm, the length of the straight pipe development section increases with the increase of the pipe diameter. This is mainly because when the pipe diameter increases, the larger the Reynolds number of drilling fluid flow inside the pipeline is, the more disordered the flow behavior is, and it is difficult to reach the full flow state.

4.2. Flow rate

With the flow rate corresponding to the six shear rates of the six-speed viscosity meter, the pipe drilling fluid flow rate is 0.01275 m/s, 0.0255 m/s, 0.42575 m/s, 0.8515 m/s, 1.27725 m/s and 2.5545 m/s respectively. Figure 9 shows the numerical simulation results of the flow rate at the axis of the straight pipe section at different flow rates.

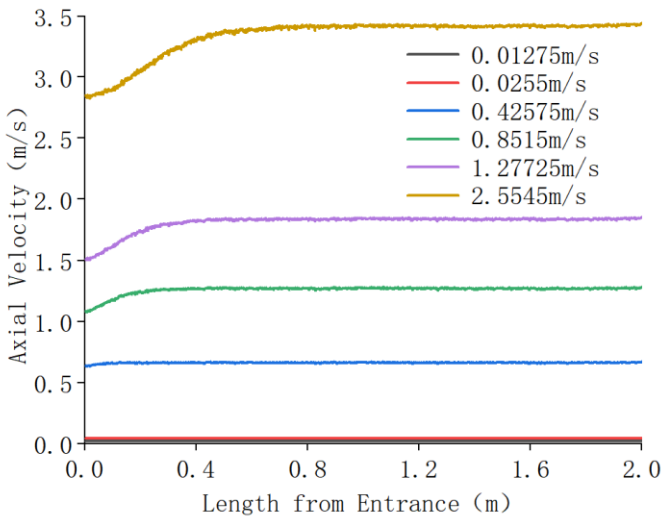

Figure 9. Effect of different flow rates on the length of the developing segment

It can be seen from the figure under low shear rate development is stable, with the increase of the flow rate, the length of the development section also increases, this is because when the flow rate increases, shear rate increases, the increase of drilling fluid flow more disorder, drilling fluid to reach the development section length is longer. Fitting of the simulation results resulted in:

$$y = 184.84e^{x/1.81} - 126.82 \tag{1}$$

Fitting Equation R^2=0.99

4.3. Number of turns of spiral development

The model of spiral development segments with different numbers of spiral turns was established respectively. Figure 10 shows the change of flow rate at the axis of the straight pipe segment under the numbers of turns of different spiral development segments.

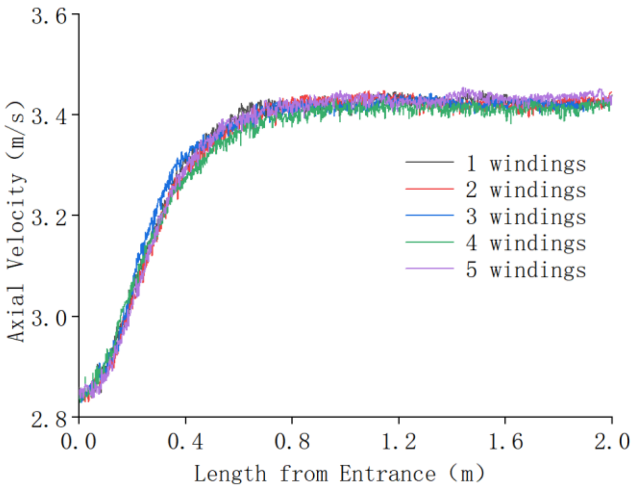

Figure 10. Effect of different turns on developmental segment length

The figure shows that the length of the straight tube developing segment does not change with the number of turns or the length of the spiral developing segment. This is because regardless of the length of the spiral development segment, the drilling fluid flows under the influence of centrifugal force. Therefore, the length of the straight tube developing segment is not affected by the length of the spiral developing segment. However, it is clearly wrong to assume that the length of the straight tube developing segment is not affected by the length of the spiral developing segment. Therefore, we need to investigate the critical value for the length of the helical developing segment. When the number of turns and pitch of the helical development segment are unchanged, it needs to be studied according to the spiral tube length, so as to further study the influence of the bottom diameter circle of the segment.

4.4. bottom diameter circle diameter

The bottom diameter of 100 mm, 200 mm, 300 mm, 300 mm, 400 mm, 500 mm and 600 mm are selected for simulation. Figure 11 shows the axis flow rate of straight pipe section under different bottom diameter circle diameter as shown below.

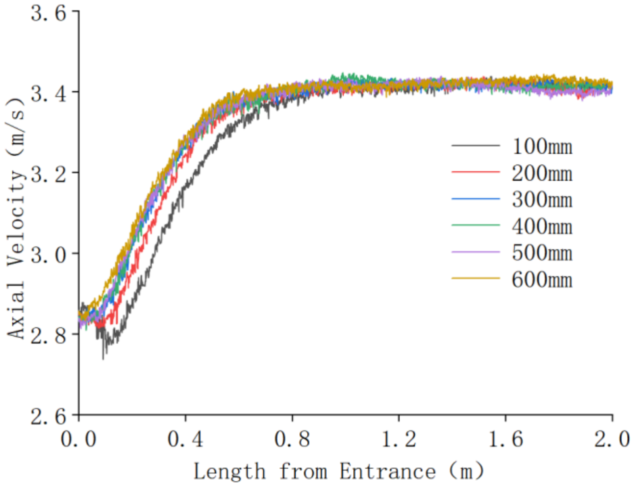

Figure 11. The effect of different bottom diameter circle diameter on the length of the developing segment

As can be seen from the figure, with the increase of the bottom diameter diameter of the spiral development section, the length required for the drilling fluid to achieve stable flow inside the straight pipe does not change significantly. Data show that the bottom diameter circle is within 200mm-600mm, and the length of the straight pipe development section fluctuates between 561mm-687mm. When the bottom diameter circle is 400mm, the longest development section is 687mm; 687 mm; 600mm, the shortest is 561mm.

4.5. Small bottom diameter circle

The bottom diameter circle of the spiral development segment has diameters of 60mm, 80mm, 100mm, 120mm, 140mm, 160mm and 180mm respectively to simulate the velocity development of straight pipe segments under several structures. Figure 12 shows the cloud diagram of straight pipe segment with a diameter of 60mm-160mm (from left to right, 60mm-10 mm-160mm).

As can be seen from Figure 12, when the bottom diameter of the spiral development section is small, the change of the internal flow rate of the straight pipe section is obvious. Because of the centrifugal force of the spiral development section, the deflection of the drilling fluid occurs, namely the drilling fluid on the side near the outer wall is higher than that of the wall on the other side. With the increase of the bottom diameter circle of the spiral development section, the maximum velocity inside the pipeline gradually decreases, and the velocity deviation caused by centrifugal force also gradually weakens. The flow rate at the axis of the straight pipe section of several structures is drawn as shown in Figure 13.

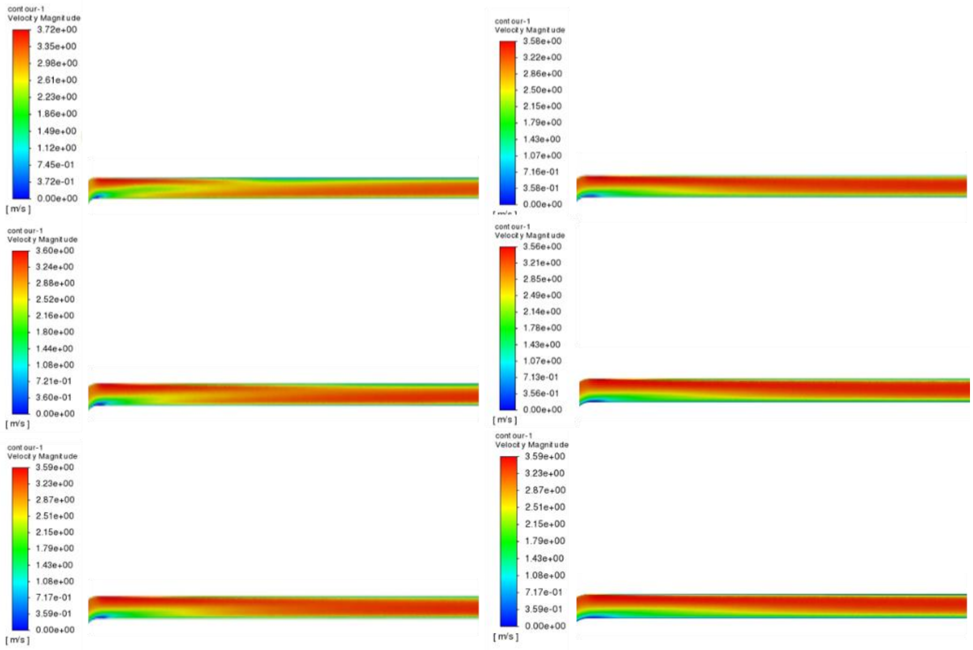

Figure 12. Cloud plot of flow velocity varying with bottom diameter

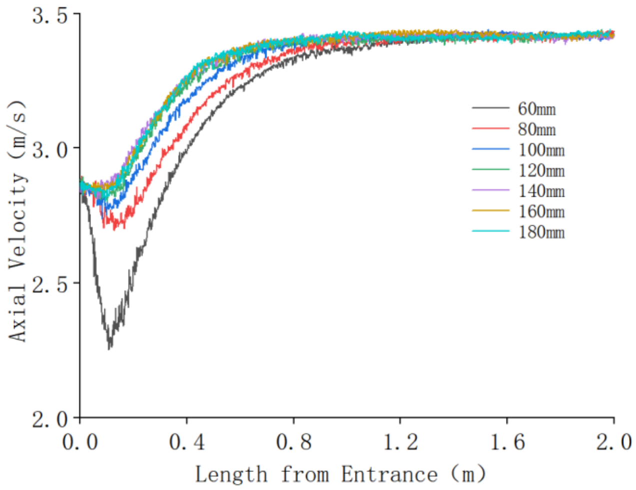

Figure 13. The effect of different bottom diameter circle diameter on the development segment length

As can be seen from Figure 13, the smaller the diameter of the spiral development segment, the shorter the length required for the drilling fluid to achieve full development in the straight pipe segment. This is because the smaller the centrifugal force of the drilling fluid inside the pipeline, the weaker the flow rate deviation in the straight pipe section, and the shorter the length of the pipeline required to overcome the residual centrifugal force. Fitting of the simulation results resulted in:

$$y = -397.546 + 52.0096x \tag{2}$$

Fitting Equation R^2=0.99068

5. EXPERIMENTAL ANALYSIS

5.1. Platform building

According to the analysis of simulation data, the experimental platform of tube flow method of spiral development section was designed, as shown in Figure 15, which includes the liquid supply system and measurement module. The models of each component of the experimental platform are shown in Table 2. The tested fluid is a self-configured water-based drilling fluid. The density is 1.22 g / cm³, the configuration scheme is: clay 4% + PAC-LV 2% + tablet base NaOH 0.2% + inhibitor ZNP 0.2% + lubricant 1%.

Table 2. Experimental equipment

Experimental equipment	act on	unit	accuracy
peristaltic pump	Pump the drilling fluid	[r/min]	0.10%
The Coriolis mass flowmeter	Measure the density and flow rate	[kg/h]	0.2%
pressure transmitter	Measure the pipe pressure	[K Pa]	0.5%
PVC pipeline	Deliver the measured medium	--	--

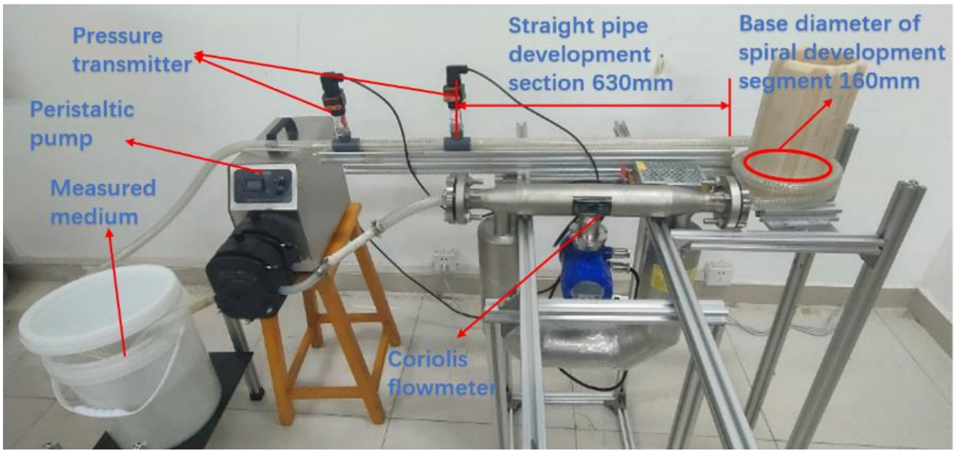

Figure 15. Experimental platform of the tube flow method in the spiral development section

To verify the accuracy of the experimental results, the rheology was measured again using a six-speed glutinometer conforming to the API standard, and the experimental instrument is shown in Figure 16.

Figure 16. Six-speed viscometer

5.2. Results analysis

5.2.1. Six-speed measurement results

After pre-shearing the drilling fluid, the six-speed viscosity meter speed was adjusted to 600 r, 300 r, 200 r, 100 r, 6 r and 3 r respectively. In order to ensure the accuracy of the six-speed experimental data, the above steps were repeated for three sets of experiments, and the reading of the six-speed viscosity gauge pointer was as shown in Table 3.

Table 3. Measurement results of the six-speed viscometer of the water-based drilling fluid

speed （r /min ）	Pointer reading for the first group	Shear Stress (Pa)	Pointer reading for the second group	Shear Stress (Pa)	Pointer reading for the third group	Shear Stress (Pa)
600	99	50.589	100	51.1	99	50.589
300	66	33.726	67	34.237	67	34.237
200	50	25.55	51	26.061	52	26.572
100	30	15.33	31	15.841	30	15.33
6	3	1.533	3	1.533	3	1.533
3	2	1.022	2	1.022	2	1.022

According to the measured six-speed viscosity gauge pointer reading, using the calculation formula to process it to obtain the rheological parameters related to the drilling fluid are shown in Table 4.

Table 4. Measurement results of the six-speed viscometer

Types of drilling fluid	Apparent viscosity AV (mPa · s)	Plasticity viscosity PV (mPa · s)	Dynamic shear force YP (Pa)	liquidity index n	Consistency coefficient K (mPa · s^n)
Density 1.22	49.275	32.21	17.44	0.5752	0.9448

5.2.2. Measurement results of the tube flow method experimental platform

The pipe flow method experimental platform was used to measure the drilling fluid, and the pressure transmitter data was recorded several times to ensure the reliability of the data source. Table 5 is the pressure transmitter data obtained from the experimental measurement.

Table 5. differential pressure data of pipe flow method

Mass flow rate (kg / h)	The first group of pressure difference	Pressure difference group 2	Pressure difference group 3	Pressure difference group 4	Pressure difference group 5
150	0.11	0.12	0.1	0.11	0.12
245	0.17	0.18	0.16	0.16	0.17
510	0.47	0.43	0.44	0.4	0.45
600	0.64	0.62	0.66	0.61	0.64
730	0.94	0.93	0.94	0.97	0.97
835	1.03	1.04	1.03	1.01	1.07

5.2.3. Comparison of the experimental results

The reading of the shear rate obtained by the tube flow method and the conversion of the six-speed viscosimeter is compared with the dial values measured by the real six-speed viscosimeter, and the calculation errors are shown in Table 6.

Table 6. Reading of the six-speed viscosity gauge dial

rate of shear (s^{-1})	Reads after a six-speed correction	Revised reading of the pipe flow method	bias
5.1	2.5	2.4	0.1
10.2	3.3	3	0.3
170.3	28.4	27.8	0.6
340.6	49.5	48.5	1
510.9	66.3	65.5	0.8
1021.8	98.6	96.9	1.7

The tube flow method is compared with the six-speed viscometer measurement results and the relative errors are shown in Table 7.

Table 7. Measurement results of drilling fluid

measuring method	Apparent viscosity AV (mPa · s)	Plasticity viscosity PV (mPa · s)	Dynamic shear force YP (Pa)	liquidity index n	Consistency coefficient K (mPa · s^n)
Six-speed viscosity meter	49.28	32.21	17.44	0.58	0.94
Tube flow method	485.4	31.43	16.38	0.56	0.93
fractional error	1.6%	2.4%	6.1%	1%	0.34%
bias	03.8	0.78	1.06	02.0	0.01

From Table 6 and Table 7, the maximum deviation between the pipe flow method and the six-speed viscosity gauge dial is 1.7, and the maximum deviation between the measurement of drilling fluid in the pipe flow method experimental platform of the spiral development section is 1.06, which basically meets the measurement requirements. The main cause of the error is the error caused by the data fitting, and the measurement error of the pipe seal and the six-speed viscometer.

6. CONCLUSION

1). Based on the F LUENT numerical simulation software, the feasibility of the spiral tube generation development segment is verified, and the results show that the V-L structure is better than the straight tube and the other structures.

2). The influence of different spiral development segment structures on the length of straight tube segment was studied. The numerical simulation results show that the larger the flow rate and pipe diameter, the longer the path required for the drilling fluid to reach the full development stage.

3). Build an experimental platform according to the numerical simulation results, verify the reliability of the numerical simulation results, and further verify the feasibility of measuring the drilling fluid rheology in the spiral development section.

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