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Research on the Error Calibration Method of Rheological Parameters of Rectangular Tubular Viscometer

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Abstract: In order to solve the problem of high error in the process of measuring the rheology of drilling fluids by the common pipe flow method, an online measurement device for the rheology of drilling fluids with rectangular tubular drilling fluids was fabricated, and a calibration method for the measurement error of rheological parameters was proposed and corresponding experiments were carried out. By measuring the differential pressure value and flow, flow rate and other parameters when the drilling fluid flows through the measuring tube, upload them to the host computer for processing, use VMD to decompose the measured differential pressure data, remove the residual term, and then perform Hibert transform on each modal component to obtain its analytical signal, modulate the amplitude and phase of each analytical signal, and then reconstruct the signal to obtain the optimized differential data, and finally bring it into the constructed calibration model of the rheological parameter measurement error of drilling fluid to obtain the rheological parameters. The experimental results show that the proposed method can obtain more accurate rheological parameters of drilling fluid, improve the measurement accuracy of drilling fluid rheology parameters, so as to judge the downhole situation more accurately and ensure the personal safety of on-site staff.

Keywords: Rheology; Rectangular tubes; In-line measurement; VMD; Viscosity.

1. Introduction

In petroleum engineering, the properties of the drilling fluid determine the success of the drilling of an oil and gas well. Drilling fluids has the function of transporting cuttings, transmitting signals and stabilizing the wellbore, and has an irreplaceable role in drilling. The rheology of drilling fluid refers to the flow and deformation of drilling fluid under the action of external force, which is usually described by the rheological curve of drilling fluid and rheological parameters such as plastic viscosity, apparent viscosity, and dynamic shear force. The control of rheological parameters of drilling fluid is of great significance for drilling hydraulic optimization and rock breaking, accurate control of downhole pressure and wellbore stability, and wellbore cleaning [1]. In recent years, the measurement of drilling fluid performance parameters has been highly valued by engineers, especially with the development of the oil drilling industry, drilling fluid to meet more and more functional requirements, how to accurately measure the rheology of drilling fluid is an important problem in practical engineering [2].

At present, the instruments widely used for rheological measurement of drilling fluids mainly include martensitic viscometer and rotational viscometer. The marsh funnel can easily obtain results, is widely used in the drilling site, and is easy to operate. However, the marsh funnel can only measure the funnel viscosity value of the drilling fluid, and the measurement time is long, the measurement error is large, and the accuracy and timeliness are insufficient. The rotational viscometer is the most commonly used instrument to measure the viscosity of drilling fluid at the drilling site, but it cannot be measured in real time, there are manual operation errors, and there are no automatic conditions [3]. Huang YR proposed the principle and structure of a capillary slit rheometer that can be measured automatically and continuously, and realized high-precision automatic measurement [4]. Liu BS, Wang ZJ et al. proposed a double-tube capillary measuring instrument, which realized the real-time continuous measurement of drilling fluid under the action of multiple shear stresses [5]. Wu Z proposed a drilling fluid rheology measuring instrument based on capillary method, which realized the change of different flow rates of drilling fluid under the same flow rate, and effectively reduced the experimental labor intensity of field personnel [6]. Sun Haoyu, Zhou YJ et al. proposed an online monitoring device for the rheology of variable diameter special-shaped tubular drilling fluid, and proposed a three-temperature cubic function temperature pressure difference correction compensation model for the influence of temperature on the pressure difference, which improved the measurement accuracy [7], but this paper only considers the influence of temperature on the differential pressure measurement results, and ignores other influencing factors under actual conditions.

For the existing on-line measurement device of drilling fluid rheology parameters, the measurement accuracy of the differential pressure data and flow velocity data at both ends of the measuring tube is very important for the calculation accuracy of the rheological parameters of water-based drilling fluid. Since the device needs to use pumping equipment to pump drilling fluid from the main line to the measuring line, the diaphragm pump is generally selected as the pumping equipment. Diaphragm pumps are reciprocating positive displacement pumps, and their reciprocating motion will cause the flow of water-based drilling fluid in the pipeline to change, that is, the fluid pulsation effect. The fluid pulsation effect will bring strong interference to the measurement of differential pressure signal, and seriously reduce the accuracy of the measurement of rheological parameters of water-based drilling fluids. Therefore, in this paper, the measurement error correction method of special-shaped tubular viscometer is studied to improve the calculation accuracy of the rheological parameters of water-based drilling fluids.

2. Measurement Principle of Drilling Fluid Rheology Tube Flow Method Section Headings

2.1. Rheological model of drilling fluid

The fluids mainly include Newtonian fluids and non-Newtonian fluids, and the water-based drilling fluids used in the field are all non-Newtonian fluids, and the variation relationship between the shear stress and the shear rate calculated by the measurement of the drilling fluid can accurately describe the rheological properties of the drilling fluid [8], which can be represented by the rheological curve as shown in Figure 1:

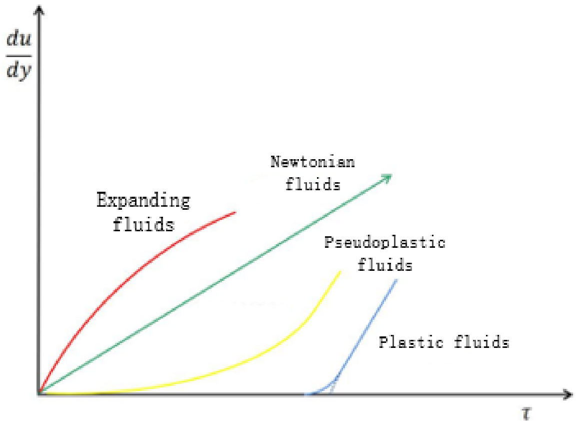

Figure 1. Fluid rheology curves

Several rheological modes are commonly used in the drilling industry: Bingham mode, power law mode, Carson mode and H-B mode.

1.Bingham mode

The Bingham mode is primarily used to describe the flow state of a plastic fluid. In Bingham mode, there is a static shear force in the fluid, which can only change the fluid from rest to flow when the externally applied shear stress τ is greater than the limit of the static shear force. The Bingham model rheological equation is shown in the following equation (1):

$$\tau = \tau_0 + \eta\gamma \tag{1}$$

where τ_0 is the dynamic shear force, Pα; γ is the shear rate, s^{-1}; η is plastic viscosity, Pα·s.

2.Power-law mode

The power-law mode is mainly used to describe the rheology of fluids at low shear rates. In power-law mode, there is no static shear force on the fluid, and any amount of shear stress will move the fluid in motion. In general, both pseudoplastic fluids and expansive fluids are suitable for power-law rheological modes, defined as pseudoplastic fluids when the fluidity index n is less than 1 and expansive when the fluidity index n is greater than 1. The power-law mode rheological equation (2) shows:

$$\tau = K\gamma^n \tag{2}$$

where K is the consistency coefficient, $P\alpha \cdot s$; n is the flow index.

3.Carson mode

The advantage of the Carson mode is that it can better describe the dynamic shear force and shear dilution behavior of the fluid, and compared with the Bingham rheological mode, the Carson mode has more advantages in low shear rates and medium shear rates, and is more commonly used in low shear rates and medium shear rates. The rheological equation for the Carson mode is shown in the following equation (3):

$$\tau^{\frac{1}{2}} = \tau_c^{\frac{1}{2}} + \eta_\infty^{\frac{1}{2}}\gamma^{\frac{1}{2}} \tag{3}$$

where τ_c is the Carson yield value, $P\alpha$;η_∞ is the plastic viscosity of Carson, $P\alpha$.

4.H-B mode

The H-B mode mainly describes a pseudoplastic fluid that requires a certain dynamic shear force to be applied to the flow of the fluid [9]. The H-B mode is a composite of the above modes: when the hydrostatic shear force τ_0 is 0 and the fluidity index n is 1, the H-B mode is the same as the Newtonian model; When the hydrostatic shear force τ_0 is 0 and the fluidity index n is not 1, the H-B mode is the same as the power-law mode. Compared with the appeal mode, the H-B model can better describe the rheological properties of the drilling fluid, especially at low shear rate, and the accuracy is higher than that of the above three rheological modes. The rheological equation for the H-B mode is shown in the following equation (4):

$$\tau = \tau_0 + K\gamma^n \tag{4}$$

where τ is the shear stress, $P\alpha$; τ_0 is the yield value, $P\alpha$; γ is the shear rate, s^{-1}; K is the consistency coefficient, $P\alpha \cdot s$.

2.2. Pipe flow pressure loss analysis

When the incompressible homogeneous fluid passes through the thin tube with equal inner diameter placed horizontally at a constant velocity, the fluid is subjected to two forces: one is the force $F_1 = \pi r^2 \Delta p$ acting on the pressure difference between the two ends of the thin tube on the cylindrical end face, and the other is the resistance $F_2 = \pi\tau_w dL$ on the cylindrical wall during the fluid flow. Due to the constant velocity of the fluid, the shear stress of the pipe wall can be obtained:

$$\tau_w = \frac{\Delta pr}{2L} \tag{5}$$

where r is the radius of the pipe, Δp is the pressure difference between the two ends of the measuring pipe, and L is the length of the measuring tube.

2.3. The principle of Poiseuille

If the differential pressure of a measuring tube of length L is ΔP, the flow velocity at the distance from the center is:

$$\mathrm{v(r)} = \Delta\mathrm{P}/4\mu\mathrm{L} \cdot (\mathrm{R}^2 - \mathrm{r}^2) \tag{6}$$

where μ is dynamic viscosity;

As can be seen from Figure 2:

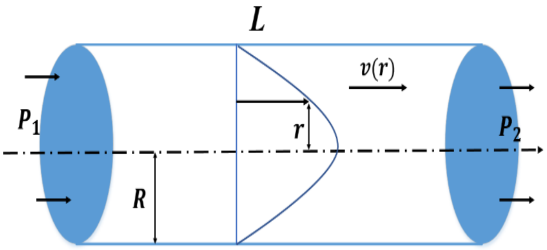

Figure 2. Schematic diagram of fluid pipeline flow

At $r = R$, the flow velocity is the smallest, and at $r = 0$, the flow velocity is maximum [10]:

$$\tau_B = \frac{D}{4} \cdot \frac{\Delta P}{L} \tag{7}$$

$$\frac{\tau}{\tau_B} = \frac{r}{R} \tag{8}$$

Assuming that the no-slip condition at the pipe wall is valid, the following formula can be written:

$$Q = \int_0^R v \cdot 2\pi r dr \tag{9}$$

Bringing the above equation v(r) into it, we get:

$$Q = \frac{\Delta P \cdot \pi \cdot R^4}{8\mu L} \tag{10}$$

According to the flow calculation formula, $Q = \frac{\pi r^2}{4} \cdot V$, then we can obtain:

$$\Delta P = \frac{32\mu v L}{D^2} \tag{11}$$

Substituting equation (11) into equation (8) yields:

$$\tau_B = \mu \frac{8v}{D} \tag{12}$$

According to Newton's equations, since $\tau_R = \mu(-\frac{dv}{dr})$, therefore, $\left(-\frac{dv}{dr}\right) = \frac{8v}{D}$.

For the non-Newtonian fluid of drilling fluid, it is assumed that $y = v$, $z = \pi r^2$; Points are sorted out:

$$\int_a^b ydz = yz|_a^b - \int_a^b zdy \tag{13}$$

When $r = R$, flow velocity=0, the arrangement is as follows:

$$Q = \int_0^R \pi r^2 \left(-\frac{dv}{dr}\right) dr \tag{14}$$

For pipes, the shear stress at the pipe wall is

$$\left(-\frac{dv}{dr}\right) = \gamma_\omega = \frac{3}{4}\left(\frac{8v}{R}\right) + \frac{dln\frac{8V}{R}}{dln\tau_B} \cdot \frac{8v}{R} \tag{15}$$

Introducing a generalized fluidity index, $\frac{dln\frac{8v}{R}}{dln\tau_B} = \frac{1}{N}$. Finishing the above formula, you get:

$$\gamma_\omega = \frac{8v}{R}(\frac{3N+1}{4N}) \tag{16}$$

where: γ_ω is the shear rate of the pipe wall; v is the velocity of the drilling fluid flowing through the measuring tube; R is the inner diameter of the measuring tube, and N is the generalized fluidity index, which can be obtained according to the $\ln\tau_\omega - \ln\frac{8v}{R}$ curve.

From the above formula, the shear stress and shear rate can be obtained respectively, the rheological curve can be plotted, and the rheological parameter values of the drilling fluid can be obtained.

2.4. Rectangular tubes

In the process of using the conventional tubular viscometer, it is found that due to the characteristics of the round tube itself, the measurement error caused by the change of inlet and outlet kinetic energy often occurs in the measurement process, resulting in the problem of low measurement accuracy.

For the conventional round pipe, assuming that a pressure transmitter is horizontally installed at both ends of the straight pipe section of a measuring pipe with a diameter of D, and the distance between the two pressure transmitters is L, when the fluid with a volume flow rate of Q flows through the straight pipe section, a pressure loss will be generated between the two pressure transmitters, and its magnitude is Δp, and its value can be known from Poiseuille law:

$$\Delta p = \frac{128LQ\mu}{\pi D^4} \tag{17}$$

where μ is the dynamic viscosity.

For Bingham fluid, the formula for pressure loss in Bingham fluid tube flow can be obtained:

$$\Delta p = \frac{128LQ\mu}{\pi D^4} + \frac{16\tau_0}{3D} \tag{18}$$

where τ_0 is the yield point.

The dynamic viscosity μ obtained from the above equation (18) is:

$$\mu = \frac{\Delta p \pi D^4}{128LQ} - \frac{\pi D^3 \tau_0}{24Q} \tag{19}$$

For the rectangular measuring tube, assuming that the width of the rectangular measuring tube is α, the height is h, and the α is much greater than h, a pressure transmitter is installed horizontally at both ends of the straight pipe section of the measuring tube, and the distance between the two is L, assuming that the fluid flow velocity is v and the pressure loss between the two pressure transmitters is Δp, then the flow pressure consumption formula of the Bingham fluid rectangular pipe is as follows:

$$\Delta P = \frac{12Lv\mu}{\alpha^2} + \frac{8\tau_0 L}{3\alpha} \tag{20}$$

$$Q = \alpha h v \tag{21}$$

The dynamic viscosity μ obtained from the above equation (20) is:

$$\mu = \frac{\Delta p \alpha^3 h}{12LQ} - \frac{2\tau_0 \alpha^2 h}{9Q} \tag{22}$$

3. Rectangular Tubular Viscometer Rheological Parameter Error Calibration Model

3.1. Fluid pulsation

In order to shorten the overall measurement cycle and realize the rapid measurement of the performance parameters of the drilling fluid, the diaphragm pump is generally used to pump the water-based drilling fluid into the measurement pipeline for measurement. If the diaphragm pump discharges the same fluid each time it does reciprocating work, it can be considered that the average flow rate of the pump is constant. However, in practice, due to the working principle of the diaphragm pump, its instantaneous flow rate is changing, and its flow state is mainly pulsating flow, which will bring strong interference to the measurement of differential pressure signal and seriously reduce the accuracy of the measurement of rheological parameters of water-based drilling fluid [11].

3.2. VMD

The VMD algorithm is an adaptive and non-recursive signal decomposition mode, which can decompose a non-stationary signal into k modal components with different bandwidths, and the algorithm is especially suitable for dealing with nonlinear non-stationary signals [12]. The VMD algorithm mainly includes the following steps:

To decompose the initial signal into modal functions, it is necessary to ensure that the sum of the estimated bandwidths of each modal function is minimal, and the VMD-constrained variational model is as follows:

$$\min_{\{u_+,\omega_1\}} \left\{ \sum_k \left\| \partial_t [(\delta(t) + \frac{j}{\pi t}) * u_k(t)] e^{-j\omega_k t} \right\|_2^2 \right\} \tag{23}$$
$$s.t. \sum_k u_k = f$$

where $u_k = \{u_1, u_2, \dots, u_k\}$ is the function of each modality, and $\omega_k = \{\omega_1, \omega_2, \dots, \omega_k\}$ is the center frequency of each mode.

The two-time penalty factor α and the pull operator λ are introduced to convert the constrained variational model of the above formula into an unconstrained variational model, which can ensure the accuracy of the reconstructed signal and ensure the strictness of the constraints, and the expression is as follows:

$$L((u_k), (\omega_k), \lambda) = \alpha \sum_k \left\| \partial_t \left[\left(\delta(t) + \frac{j}{\pi t} \right) * u_k(t) \right] e^{-j\omega_k t} \right\|_2^2 + \| x(t) - \sum_k u_k(t) \|_2^2 \tag{24}$$

The saddle point is found by iteratively updating $\hat{u}_k^{n+1}, \omega_k^{n+1}, \hat{\lambda}^{n+1}$ by using ADMM:

$$\hat{u}_k^{n+1}(\omega) = \frac{\hat{f}(\omega) - \sum_{I \neq k} \hat{u}_i(\omega) + \frac{\hat{\lambda}(\omega)}{2}}{1 + 2\alpha(\omega - \omega_k)^2} \tag{25}$$

In the same way, the iterative center frequency expression can be obtained:

$$\omega_k^{n+1} = \frac{\int_0^\infty \omega |u_k(\omega)|^2 d\omega}{\int_0^\infty |u_k(\omega)|^2 d\omega} \tag{26}$$

For the above iterative process, in order to obtain K modal component signals, the discriminant accuracy must meet the requirements.

$$\sum_k \frac{\|\hat{u}_k^{n+1} - \hat{u}_k^n\|_2^2}{\|\hat{u}_k^n\|_2^2} < \varepsilon \tag{27}$$

It is worth noting that the traditional VMD needs to artificially set the decomposition mode number k value, and a large k value will cause the VMD to over-decompose the original signal and interfere with the signal analysis. The small k value will cause some modal components with limited bandwidth to be unable to be completely decomposed, resulting in modal aliasing and excessive fluctuations of the decomposed low-frequency signal.

The specific implementation process of VMD is as follows:

1. Initialize the parameters $\hat{u}_k^1, \omega_k^1, \hat{\lambda}^1$, n=0;

2. Execute a loop so that $n = n+1$, for ω>0, according to the above formula, update the values of $\hat{u}_k^n$ and ω_k^n;

3. Update the value of the pull operator λ

$$\hat{\lambda}^{n+1}(\omega) \leftarrow \hat{\lambda}^n(\omega) + \tau\left(\hat{f}(\omega) - \sum_{i \neq k} \hat{u}_i^{n+1}(\omega)\right)$$

4.For the given accuracy convergence criterion ε, if the ε does not meet the above accuracy convergence requirements, go back to step 2; If the ε meets the above accuracy convergence requirements, the iteration is stopped.

3.3. Rheological parameter error calibration model

The measurement parameters of the differential pressure sensor on the measuring tube of the water-based drilling fluid rheology online monitoring device are affected by the fluid pulsation, and the α of the differential pressure sensor is a function of the error between the measured differential pressure value and the theoretical differential pressure value, and the error obeys the normal distribution of $\mu = 0$, that is, $N(0, \sigma^2)$, and i The probability density function is shown in the following equation (28):

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \mathrm{e}^{(-\frac{x^2}{2\sigma^2})} \tag{28}$$

In each sampling period T, the differential pressure sensor decomposes the collected data through VMD to obtain a set of target state estimates relative to the current measurement management theory differential pressure parameters, and the likelihood function can be obtained as follows equation (29):

$$L(\mu, \sigma^2) = (2\pi\sigma^2)^{-\frac{n}{2}} e^{-\frac{1}{2\sigma^2} \sum_{i=1}^n (\hat{x}_i - \mu)^2} \tag{29}$$

By estimating the parameters of the probability density function, the corresponding likelihood value $\hat{\alpha}_i$ for each sample $\hat{x}_i$ as follows equation（30）:

$$\hat{\alpha}_i = \int_0^{\dot{x}_i} \frac{1}{\sqrt{2\pi}\sigma^*} \exp\left(-\frac{x^2}{2\sigma^{*2}}\right) \quad (30)$$

By using the likelihood value, the weight ω of any of the differential pressure parameters in this group of sample values for the estimated theoretical differential pressure state is ω_j as follows equation（31）:

$$\omega_j = \frac{\alpha_j}{\sum_{i=1}^{n} \alpha_i} \quad (31)$$

By analyzing the differential pressure parameters, the optimal differential pressure estimate of the measuring tube can be obtained $x_{op}(k)$ is as follows equation（32）:

$$x_{op}(k) = \sum_{i=1}^{n} \alpha_i \hat{x}_i(k) \quad (32)$$

where $\hat{x}_i(k)$ is the measured shear stress value at time k, and $x_{op}(k)$ is the optimal predicted output of the differential pressure signal.

Through the accurate estimation of the differential pressure parameters, the shear stress and shear rate of the data drilling fluid are accurately calculated, the flow curve of the water-based drilling fluid is accurately drawn, and the dynamic calibration of the rheological parameters of the drilling fluid is finally realized.

4. Experiments and Data Analysis

4.1. Protocol design

In order to verify the accuracy of the rheological parameter error calibration method of the rectangular tubular viscometer proposed in this paper, the rheological parameter acquisition scheme of the rectangular tubular viscometer was designed, the experimental bench was built, and the experimental data were obtained, and the experimental verification method proposed in this paper could effectively calibrate the error.

First of all, the electric diaphragm pump continuously pumps the drilling fluid from the mud storage tank to the experimental device, the drilling fluid passes through the damper, and then flows out through the mass flow meter, the mass flow meter measures the current drilling fluid temperature, density and mass flow data, and judges whether the current flow is stable through the measured data, and then the electric diaphragm pump is fed back to ensure that the current drilling fluid flow is constant. Then the drilling fluid passes through the rectangular measuring tube, and the flush membrane differential pressure sensor is installed on the measuring tube, and the differential pressure sensor is used to measure the differential pressure signal at both ends of the measuring tube, and the differential pressure signal is transmitted to the host computer, and the traditional six-speed measurement result is output, and the values of plastic viscosity, dynamic shear force, static shear force, consistency coefficient and fluidity index are obtained, and the drilling fluid returns to the drilling fluid tank at the same time to complete the cycle.

4.2. Experimental bench construction

The experimental measuring frame is mainly composed of a diaphragm pump, a damper, a mass flow meter, a rectangular measuring tube, a differential pressure sensor, and a slurry storage tank. The measuring tube is a rectangular tube of 10mm×30mm×2m and a wall thickness of 2mm. The diaphragm pump is used as a power source to continuously pump the drilling fluid from the mud storage tank to the experimental device; Dampers can physically reduce fluid pulsation [15]; The mass flow meter is responsible for the feedback control of the diaphragm pump to ensure that the current drilling fluid flow is constant; The differential pressure sensor uses a flush membrane differential pressure sensor to measure the differential pressure, and the measured raw differential pressure data is recorded in real time and transmitted to the host computer, and the working principle of the device is shown in the following figure 4:

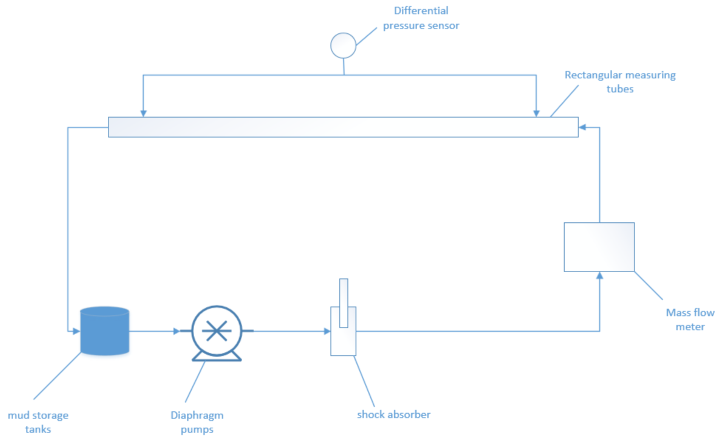

Figure 4. Diagram of the installation model

The specific experimental setup is shown in the figure 5:

1-Diaphragm pumps; 2-shock absorber; 3-Mass flow meter;

4-Differential pressure sensor; 5-Rectangular measuring tubes

Figure 5. Actual drawing of the installation

4.3. Rheological experiments and results analysis

In the process of rheology experiment using the experimental platform built, it should be noted that in the measurement process, the measurement of each flow rate needs to be maintained for 3 minutes, which is to carry out the differential pressure measurement after the flow reaches stability, so that the measured differential pressure data is more stable, the measurement time is 15s, the average value of multiple sampling is taken, when the data acquisition under the quantity is completed, the flow rate is changed by the program control pump, and the flow rate of 1.3m/s, 0.6m/s, and 0.2m/s is measured in turn, and the process flow chart is as follows:

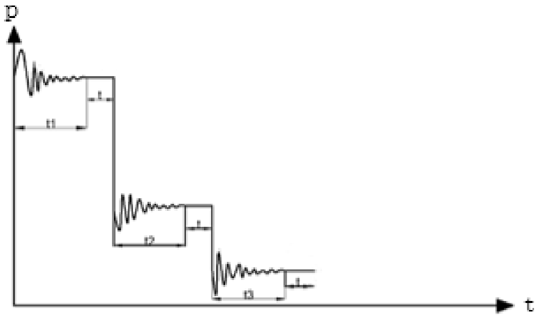

Figure 6. Process flow diagram

During the experiment, the flush membrane differential pressure sensor was used to collect the differential pressure data at both ends of the measuring tube, and the obtained differential pressure data was transmitted to the upper computer, and then the signal was decomposed and processed by VMD on the upper computer, and then the rheological parameters of the drilling fluid were calculated after reconstruction, and the decomposition process is as follows:

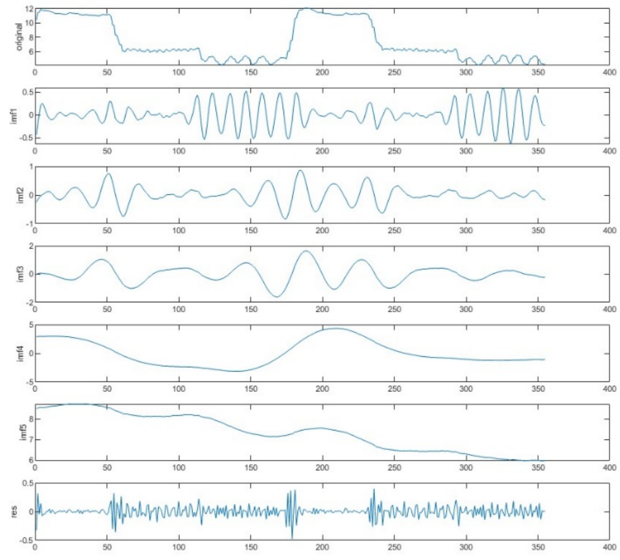

Figure 7. VMD decomposition process

The original and processed differential pressure signals are shown in the figure 8 below:

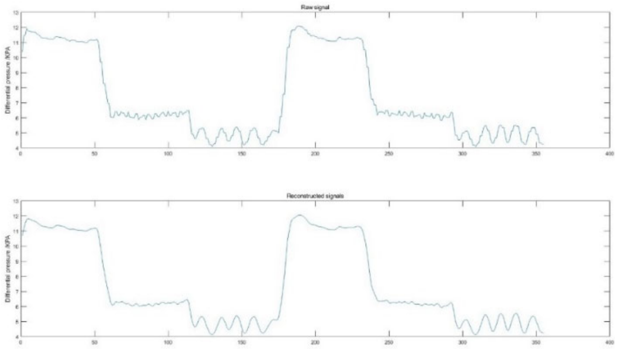

Figure 8. VMD effect comparison chart

As can be seen from Figure 8 above, the reconstructed signal is smoother than the original signal, which improves the quality of the signal. At the same time, the reconstructed signal is almost the same as the original signal, but the reconstructed signal is smoother, which indicates that the reconstructed signal does not affect the properties of the original signal, and almost all the characteristics of the original signal are retained.

The differential pressure signal after VMD decomposition and reconstruction was brought into the constructed rheological parameter measurement and correction model of drilling fluid, and the shear stress and shear rate of the data drilling fluid were accurately calculated through the accurate estimation of the differential pressure parameters, and the flow curve of the water-based drilling fluid was accurately drawn, and finally the dynamic calibration of the rheological parameters of the drilling fluid was realized.

4.4. Comparison of experimental results of 25mPa.s bentonite drilling fluid

25mPa.s bentonite drilling fluid was prepared, and the rheological parameters of the drilling fluid were measured by the developed drilling fluid rheology measurement device, the pressure difference signals at both ends of the measuring tube were collected, and the original data and the data calibrated by the error correction method were brought into the drilling fluid rheological parameter model, and the test results of the two methods were compared, and the comparison of the results before and after the correction is shown in Table 1.

Table 1. Comparison of results before and after correction

parameter	Apparent viscosity		Plastic viscosity	
	Before amendment	After the correction	Before amendment	After the correction
Standard value	25	25	23	23
average value	22.46	23.74	21.37	22.51
absolute error	2.54	1.26	1.63	0.49
relative error	10.16%	5.04%	7.08%	2.13%

As can be seen from Table 1 above, when the drilling fluid with a viscosity of 25mPa.s flows through the measuring device, the device can indeed determine the rheological parameters of the drilling fluid, and the correction method of the rheological parameters of the drilling fluid can indeed improve the accuracy of the measurement parameters.

4.5. Comparison of experimental results of 52mPa.s bentonite drilling fluid

52mPa.s bentonite drilling fluid was prepared, and the rheological parameters of the drilling fluid were measured by the developed drilling fluid rheology measurement device, the pressure difference signals at both ends of the measuring tube were collected, and the original data and the data calibrated by the error correction method were brought into the drilling fluid rheological parameter model, and the test results of the two methods were compared, and the comparison of the results before and after the correction is shown in Table 2.

Table 2. Comparison of results before and after correction

parameter	Apparent viscosity		Plastic viscosity	
	Before amendment	After the correction	Before amendment	After the correction
Standard value	52	52	39	39
average value	55.37	53.03	42.46	40.96
absolute error	3.37	1.30	3.46	1.96
relative error	6.48%	2.5%	8.87%	5.02%

As can be seen from Table 2 above, when the drilling fluid with a viscosity of 52mPa.s flows through the measuring device, the device can indeed determine the rheological parameters of the drilling fluid, and the correction method of the rheological parameters of the drilling fluid can indeed improve the accuracy of the measurement parameters.

5. Summary

Considering the problem of insufficient measurement accuracy of the rheological parameters of the drilling fluid in the field, the self-made on-line measurement device of the rheological parameters of the drilling fluid is used to measure the rheological parameters of the drilling fluid, and the problems of excessive error and insufficient accuracy caused by the influence of fluid pulsation of the measurement results of the device are studied, and the error calibration method of the rheological parameters is proposed. According to the measurement of the pressure difference value at both ends of the measuring tube, the original pressure difference signal is obtained, the signal is decomposed and reconstructed by VMD, and the optimized reconstruction signal is brought into the rheological parameter model, and finally the rheological parameters of drilling fluid are obtained. The experimental results show that the error correction method proposed in this paper can effectively improve the measurement accuracy of rheological parameters.

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