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The development and application of an intelligent detection and evaluation system for drilling fluid

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Abstract

Real-time detection of drilling fluid performance during drilling, data cloud storage, intelligent diagnosis and automatic optimization suggestions are the prerequisites for the oil and gas industry to achieve intelligent and Digital transformation. To this end, a drilling fluid intelligent detection system based on industry standards, on-site construction requirements, combined with the Internet of things and big data platforms has been developed. This system can perform 24 * 365 h full time, fully automatic, and uninterrupted detection of different drilling fluid system performance parameters under normal temperature ~ 200 °C and normal pressure ~ 8 Mpa conditions. The testing scope includes changes in drilling fluid temperature, density, rheological parameters, medium-pressure, high-temperature and high-pressure filtration parameters, and filtrate ion parameters. In addition, based on the intelligent analysis module, real-time parameters and design parameters of the drilling fluid are compared and analyzed, and optimization suggestions for the drilling fluid are provided in a timely manner to ensure the safety of underground construction. Through long-term indoor testing and thousands of sets of experimental comparison data from multiple test wells on site, the accuracy of the rheological module and filtration module is 97.3%; the accuracy of the ion testing module is 96.2%. The research results of this article provide accurate and stable data guarantee for safe, efficient, and intelligent oil and gas exploration and development prospects.

Keywords Digital oilfield construction · Intelligent detection and evaluation of drilling fluid · Ion concentration detection · Fully automatic real-time detection · Big data

Introduction

In petroleum drilling, drilling fluid has various functions such as lubricating the wellbore [1–4], balancing formation pressure, reducing bit temperature, and maintaining wellbore stability [5–7]. At the same time, drilling fluid can also carry the rock cuttings and oil and gas information released by the reservoir during the drilling process and circulate back to the surface [8, 9]. Therefore, in the petroleum industry, detecting the oil and gas information carried by drilling fluids is the most economical, direct, and commonly used method for discovering and locating oil and gas reservoirs [10]. The practice of oil and gas exploration and development has proven that quantitative detection of oil and gas content in drilling fluids can help describe reservoir oil and gas properties and evaluate reservoir oil and gas productivity [11–14]. At present, the main method for detecting underground oil and gas information carried by drilling fluid is conventional gas logging technology [15]. The principle is to use the stirring of a conventional degasser to separate the dissolved light hydrocarbon gases in the drilling fluid. Then, gas chromatography is used to detect C1–C5 hydrocarbon gases as well as non-hydrocarbon gases such as CO_2 and H_2S. Discovering abnormal gas displays to determine the location of oil and gas reservoirs [16]. With the development of quantitative gas measurement technology, oil companies have gradually developed quantitative extraction of drilling fluid samples. Then, equipment is used to heat and stir the drilling fluid to separate more gas components, and then advanced gas chromatography or mass spectrometry is used to quantitatively detect light and heavy hydrocarbon gas components such as C1–C10 [17, 18]. Due to the quantitative detection of drilling fluid, more accurate quantitative interpretation of reservoir gas components can be achieved.

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More accurate quantitative interpretation technology for reservoir oil and gas properties and characteristics is realized [19, 20].

At present, surface oil and gas detection technology also faces some problems [21]. One is that the vast majority of underground oil and gas reservoirs are composed of liquid oil and gaseous hydrocarbons. But there has always been no effective method to continuously detect the liquid oil content information in drilling fluid online. Therefore, when describing and interpreting oil and gas reservoirs and evaluating their productivity, important oil-bearing information is missing, leading to the limitation of accurate evaluation of reservoirs in surface oil and gas interpretation techniques. Secondly, with the increasing number of oil and gas drilling targets. Some reservoirs containing only heavy oil components have also entered the exploration target [22]. These reservoirs may only contain a small amount of gaseous hydrocarbons. Therefore, in on-site oil and gas exploration and detection, weak or no gas display may occur, making it difficult to detect abnormal displays of oil and gas reservoirs using conventional gas logging techniques. Therefore, there is also a need for a quantitative detection method for the oil quality information carried by drilling fluid in the formation, in order to comprehensively detect oil and gas reservoirs to the greatest extent possible. Thirdly, advances in drilling technology have made the structure of the drilled well more complex, therefore facing more severe drilling safety guarantees [23]. When drilling complex wells such as deep wells, ultra deep wells, and large horizontal wells, in order to ensure drilling safety, it is often necessary to add fluorescent organic additives to the drilling fluid, such as mixing crude oil, diesel, fluorescent lubricants, sulfonated asphalt, and other organic additives in the drilling fluid. This results in a strong fluorescence display of the drilling fluid. The intensity of these fluorescence displays has exceeded the fluorescence intensity of the real oil-bearing strata carried by the rock debris. Therefore, it is difficult to use the fluorescence intensity of rock debris to describe and discover oil-bearing reservoirs. At this point, it is necessary to stop drilling and treat the drilling fluid to reduce the fluorescence intensity of the drilling fluid additive. Stopping drilling to treat drilling fluid significantly increases drilling costs and prolongs the well construction cycle [24].

In the early drilling process, oil and gas displays were discovered, and the determination of whether to drill into oil layers was mainly monitored through manual monitoring methods [25]. The main method is to observe whether there are oil splashes or bubbles on the groove surface of the mud tank when the drilling fluid returns to the wellhead and to check the sedimentary rock debris and other substances at the bottom of the buffer tank to determine the depth of the oil and gas bearing layer and locate the oil and gas [26]. Hayward combines the oil and gas detection value of drilling fluid with drilling speed and displays the corresponding curve between the detection value and well depth, thus forming the important detection technology of "gas logging" for discovering reservoir oil and gas information [27]. In 1952, gas chromatography began to mature and widely applied in the market. This greatly enhances the analysis ability of oil and gas components in drilling fluid, effectively promoting the development of oil and gas detection technology in drilling fluid [28–31].

Since the discovery of nuclear magnetic resonance (NMR) in 1946, it has been widely and rapidly applied in various fields due to its advantages of accurate and nondestructive detection of internal characteristics of samples. The research on nuclear magnetic resonance detection technology is accelerating and has quickly become a widely used and diversified analysis and detection technology [32, 33]. Nuclear magnetic resonance, as a molecular level nondestructive testing and analysis method, has been studied in various application fields. Various detection instruments have been developed and applied such as different nuclear magnetic resonance field strengths and measurement sensors. Nuclear magnetic resonance is a measurement method and means with a wide range of research fields, directions, and applications [34–36]. Nuclear magnetic resonance analysis technology has a long history of research in detecting oil–water mixtures or emulsifiers [37]. At present, nuclear magnetic resonance technology is the most effective analysis method for hydrogen containing fluids and the only reliable method for determining the oil or water content of such fluids. Among them, it is relatively mature to use one-dimensional T_1, T_2, and D measurement results of low-field nuclear magnetic resonance for oil–water differentiation and quantitative evaluation [38]. As long as the signals of different fluid components can be distinguished by cutoff values on the one-dimensional T_1, T_2 spectral distribution of the sample, the content of each fluid can be calculated by signal ratio (oil–water corresponds to T_1, T_2 spectral area) [39–42]. The research on nuclear resonance detection technology of drilling fluid was mainly carried out by Sinopec petroleum engineering Technology Research Institute in 2011, and the nuclear resonance detection instrument of drilling fluid for laboratory application was produced jointly with Suzhou Newman Technology Co., Ltd. This instrument is mainly used in laboratories at room temperature and has a heavy mass. The magnet adopts a permanent magnet with a magnetic field strength of 0.53 T and a nuclear magnetic resonance frequency of 22.621 MHz. The detection probe adopts a new type of coil with a diameter of 15 mm. The middle is the sample testing area. Using CPMG pulse train as the sampling sequence, it has an echo time of 0.1 ms, a waiting time of 500 ms, and a recovery time of 1000 ms. The instrument has constant temperature control. The temperature range is 31.99–32.00 °C, keeping the magnet in a constant temperature environment to ensure stable resonance frequency and detection accuracy. The instrument has the detection function of two-dimensional nuclear magnetic resonance, with a resonance frequency of 22.601 MHz, and uses a pulse sequence of PGSE-CPMG (D-T_2). Wang et al. [43] studied the effect of barite grading on the performance of drilling fluids and found that graded barite can effectively improve the overall performance of drilling fluids. Li et al. [44] studied the influence of microorganisms on drilling fluids and elucidated the effect of temperature on the maximum specific growth rate of Pasteurella in solid-free drilling fluids.

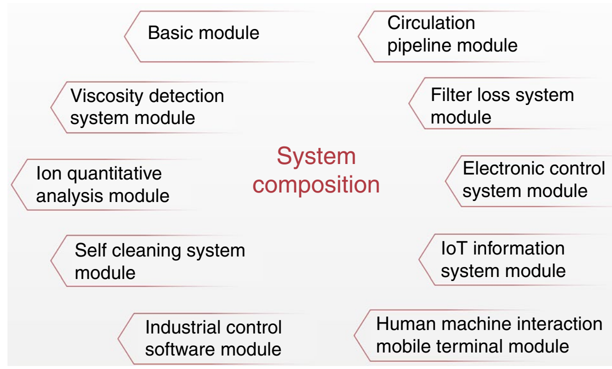

Fig. 1 Composition modules of the system

Novelties of this paper

At present, there is a lack of systematic research on the intelligent detection system for drilling fluid that is based on industry standards and meets the requirements of on-site construction, in conjunction with the Internet of things and big data platforms. In this paper, a drilling fluid intelligent detection system is developed on the basis on industry standards, on-site construction requirements, combined with the Internet of things and big data platforms. This system can perform 24 * 365 h full time, fully automatic, and uninterrupted detection of different drilling fluid system performance parameters under normal temperature ~ 200 °C and normal pressure ~ 8 Mpa conditions. The testing scope includes changes in drilling fluid temperature, density, rheological parameters, medium-pressure, high-temperature and high-pressure filtration parameters, and filtrate ion parameters. Based on the intelligent analysis module, compare and analyze the real-time parameters and design parameters of drilling fluid, and provide timely optimization suggestions for drilling fluid to ensure the safety of underground construction. Through long-term indoor testing and thousands of sets of experimental data comparison from multiple on-site test wells, the accuracy of the rheological module and filtration module is 97.3%, and the accuracy of the ion testing module is 96.2%. The research results of this article provide accurate and stable data guarantee for safe, efficient, and intelligent oil and gas exploration and development prospects.

System introduction

System composition

The instrument totally has ten modules, which mainly consists of four mechanical modules and two electronic analysis modules, as shown in Fig. 1.

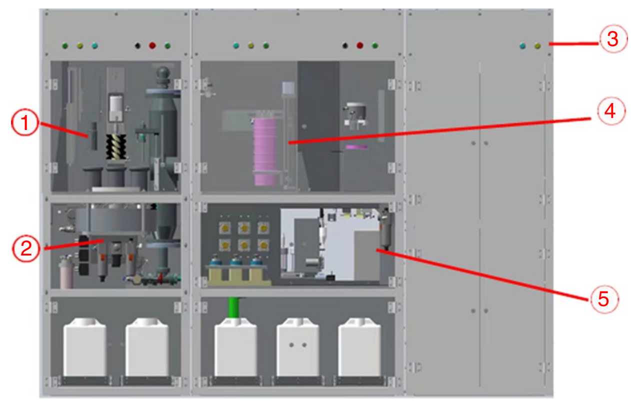

Fig. 2 System schematic diagram (① Drilling fluid rheological testing module; ② Drilling fluid circulation heating module; ③ Remote monitoring and intelligent diagnosis module for drilling fluid performance; ④ Drilling fluid medium-pressure and high-temperature high-pressure filtration testing module; ⑤ Drilling fluid ion concentration measurement module) and three-dimensional diagram

The mechanical module includes a drilling fluid circulation heating sampling module, a drilling fluid rheological testing module, a drilling fluid medium-pressure and high-temperature high-pressure filtration testing module, and a drilling fluid ion concentration measurement module, as shown in Fig. 2. The electronic analysis module includes a remote monitoring module for drilling fluid performance and an intelligent analysis module. The drilling fluid circulation heating system relies on a high-power adjustable constant temperature water bath heating device to maintain constant performance of the test sample within the set temperature range, ensuring a stable testing environment. The medium-pressure and high-temperature high-pressure testing module ensures that the drilling fluid can be freely adjusted within the pressure difference range of 0–7.2 MPa and can conduct fully automatic testing of filtration loss under room temperature ~ 200 °C temperature conditions. The ion titration module relies on different types of ionization test probes to measure the pH value, CL^-, and potential changes during the titration process, and obtain accurate ion concentration data. The remote monitoring and intelligent analysis module mainly relies on the electronic well history system and the well design input system to analyze the measured drilling fluid performance. Cloud storage data remote clients can access on-site test conditions and parameters at any time. The intelligent analysis module extracts the measured parameters of drilling fluid and automatically compares the electronic well history and well design. Abnormal horn alarm occurs to achieve the goal of safety production.

System function

The intelligent detection and analysis system for drilling fluid is a real-time automated service system for oil drilling production that integrates advanced automation equipment and IoT architecture and integrates artificial intelligence big data information management. According to this definition, the intelligent detection and analysis system for drilling fluid mainly achieves the following two functions, as shown in Fig. 3.

Data detection function

This system is mainly used in industries such as oil and natural gas and used for intelligent detection of over 20 parameters such as viscosity, density, temperature, medium-pressure filtration loss, pH, and ion concentration for drilling fluid performance. The system has implemented actions such as automatic slurry extraction, automatic grouting, automatic detection, automatic drug addition, automatic titration, and automatic cleaning.

IoT architecture features

This system communicates with remote servers through the Internet and can be connected to the EISS platform, becoming a monitoring center for drilling fluid performance on the production site. Real-time display of detection data to remote mobile devices (computers, mobile phones) and store the data in the server database for future data management and application, the system can achieve wired or wireless remote control.

Instrument structural characteristics

The structural layout of this equipment refers to the default sampling and testing process during manual drilling fluid testing. From the perspective of humanization, rationalization, and security, the process of testing, data acquisition, cloud storage, data comparison, remote detection, intelligent diagnosis, and report export of the performance of the whole set of drilling fluid has been completed. The circulating heating slurry extraction system is directly connected to multiple points on the circulating tank guide groove and the water tank of the mud pump through pipelines. According to the changes in working conditions, the slurry can be recycled and insulated, and the drilling fluid density can be calculated through a flow density meter. The rheological testing module measures six-speed viscosity through a modified electronic torque meter and displays it for analysis on a 55-inch touchscreen display. At the same time, the dynamic and static shear, n value, K value, dynamic plastic ratio, and other related parameters of the drilling fluid can be calculated. The filtration module adopts medium-pressure and high-temperature high-pressure tank body pressurization heating mode. By using a robotic arm to automatically transfer the sample to be tested into a high-temperature and high-pressure heating tank with a power of 2 kW for heating, 300 mL of drilling fluid can be heated to 200 °C within 20 min. The volume measurement of the filtrate is taken through high-precision metering pumps, achieving visual, efficient, accurate, and fast experimental processes. The ion concentration titration module uses a high-precision injection pump to perform titration experiments at a rate of 0.03–0.05 mL/time, at the same time, complete pH and ion concentration detection with the

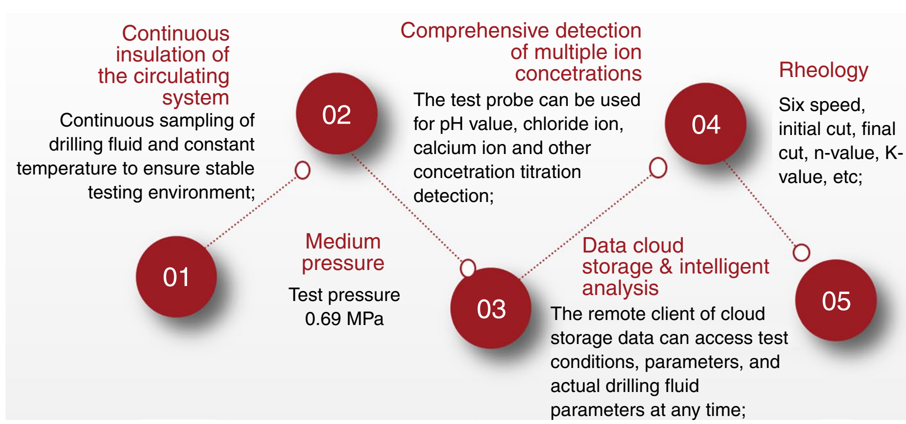

Fig. 3 Functions of the system

collaboration of different detectors. The remote module and intelligent analysis module detect and benchmark various drilling fluid parameters through internal servers and independently developed drilling fluid performance analysis software. After an abnormality occurs, the intelligent system will alarm, achieving an integrated and automated mode of data detection, collection, analysis, alarm, and suggestion.

Main technical indicators

Table 1 provides a reference for the main technical indicators of the drilling fluid intelligent detection system, as shown below.

Customized solution

According to different needs, it can be customized as a rheological miniaturization system and a water analysis miniaturization system. Due to its small overall volume, it can be directly installed on the mud circulation tank, no drilling fluid circulation pipeline, easy to install and handle.

Rheological miniaturization system

The three-dimensional and physical diagrams of the rheological miniaturization system are shown in Fig. 4.

Test function

Intelligent detection of funnel viscosity, temperature, density, and rheological properties (R600, R300, R200, R100, R6, R3, R3 relaxation time, initial cut, and final cut) of drilling fluid performance. The intelligent analysis system calculates and benchmarks the design parameters of drilling fluid to determine whether the drilling fluid adhesion meets the requirements of downhole rock carrying, suspended cuttings and flow pattern parameters, and provides a test report. The single testing time for drilling fluid performance is about 20 min, and it can be set for timed testing or 24-h continuous testing, as shown in Fig. 5.

Characteristics of rheological miniaturization system

This system has the following five characteristics:

(1) Compact equipment (detection body size 500 mm) × 500 mm × 1200 mm, control body at size 800 mm × 1400 mm × 400 mm), easy to install and handle.
(2) Accurate detection data, stable equipment, and high reliability; its data accuracy is over 98%.

Table 1 Main technical indicators reference for the intelligent detection system of drilling fluid

No	Test items	Test scope and accuracy	Testing standards
1	Working temperature	Room temperature ~ 200 °C, accuracy range ≤ 1 °C	–
2	Density testing	0–4 g cm^{-3}, accuracy range ≤ 0.01 g cm^{-3}	GB/T 16783.1-2014
3	Rheological testing	Static shear force, dynamic shear force, plastic viscosity, dynamic plastic ratio, *n*-value, *K*-value ≤ 5%	GB/T 16783.1-2014
4	Filtration pressure	0–7.2 MPa (≤ 0.01 MPa)	GB/T 16783.1-2014
5	pH value and ion concentration test	pH value, CL^-, Ca^{2+}, K^+, Mg^{2+} ≤ 5%	GB/T 16783.1-2014
6	Medium-pressure and high-temperature high-pressure filtration loss test	API filtration ≤ 0.2 mL, HTHP filtration ≤ 0.1 mL	GB/T 16783.1-2014
7	Remote monitoring system	Relying on internal network servers and mobile apps to retrieve on-site data, view reports, and debug experimental conditions	
8	Cloud storage	The experimental data collected on site is centrally stored in the cloud for parameter retrieval and comparison anytime and anywhere	
9	Intelligent analysis system	Import the design parameters of the block where the well is located, complex data of adjacent wells, and on-site measured data from the cloud database for parameter comparison and provide optimization suggestions	
10	Expand functionality	Audit tracking function: record detailed equipment operation information, trace information such as startup time, login name, and test items; Electronic signature function: it can prevent non-relevant executors from misoperating the device and ensure the safety of equipment personnel	

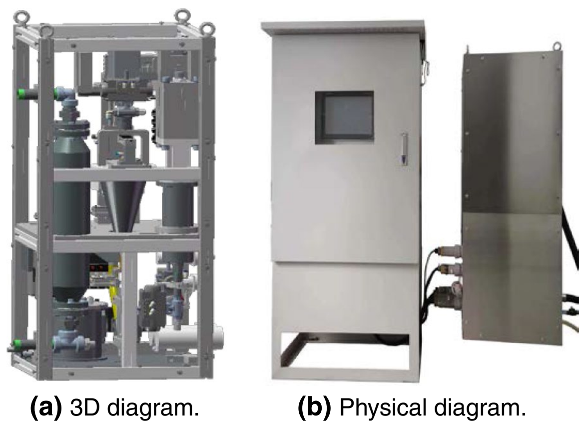

Fig. 4 The three-dimensional and physical diagrams of the rheological miniaturization system

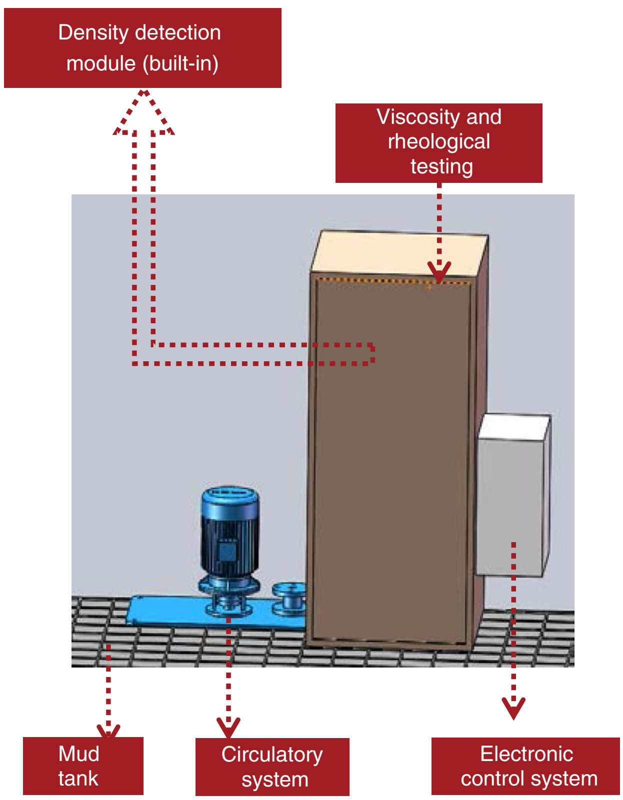

Fig. 5 Composition of rheological miniaturization system

(3) Mud can be heated to simulate the downhole temperature environment (≤ 90 °C) for testing.
(4) This device can achieve 24-h continuous automatic testing without the need for staff on duty.
(5) It can monitor the working status of various parts in real time. When a fault occurs, the PLC will transmit the collected information to the upper computer and display it in real time to inform the user of the fault point and reason.

Water analysis miniaturization system

Test function: medium-pressure water loss test; Extract filtrate; Calculate the filtration loss; Determination of pH value; Ion concentration measurement (chloride ions, calcium ions, etc.).

The system composition is shown in Fig. 6. This plan is a miniaturized design for the water analysis part of the intelligent detection and analysis system for drilling fluid, with an overall size of approximately 600 mm (length) × 400 mm (width) × 600 mm high. This plan mainly includes a medium-pressure dehydration module, a chemical storage module, a filtrate addition module, and a titration analysis module.

Equipment structure composition and working principle of each part

Testing of drilling fluid density and six-speed viscosity

The drilling fluid density detection module samples and detects drilling fluid through a mass flow density meter. Through the transfer pipeline, the drilling fluid is transferred to the drilling fluid viscosity testing cup for six-speed viscosity testing. The mass flow density detection method can detect and collect data at a rate of points per second, achieving uninterrupted monitoring of drilling fluid density. The six-speed viscosity data is calculated

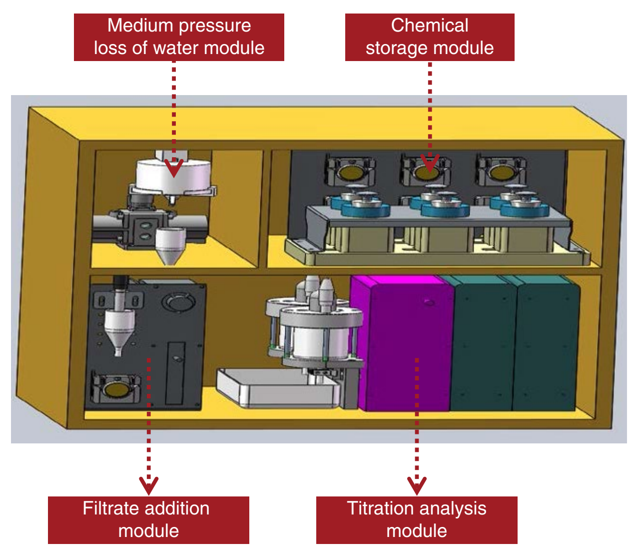

Fig. 6 Composition of miniaturized water analysis system

through an intelligent analysis system and the drilling fluid design parameters (GEL, τ, AV, PV, YP, n, K) meet the requirements of downhole rock carrying, suspended cuttings and flow pattern parameters.

Detection of medium-pressure and high-temperature and high-pressure filtration rate of drilling fluid

The drilling fluid filtration detection module consists of two parts: medium-pressure filtration and high-temperature and high-pressure filtration. Medium voltage standards refer to API standards, and HTHP testing is designed according to national standards, pressurized by connecting a three-body booster pump in series, with a working pressure of 0–8 Mpa. The high-temperature and high-pressure components are heated up through an electric heating sleeve, which can meet the temperature rise requirement of 300 mL drilling fluid at room temperature to 200 °C within 20 min. The operation of temperature and pressure settings for the experiment can be carried out on the remote control interface. The experimental process is completed by a fully automatic robotic arm inside the instrument protected by tempered glass. This ensures the safety and speed of the experiment, as well as the accurate measurement of the experimental results.

Detection of ion concentration in drilling fluid

The filtration test time can be set at 7.5 min–1 h to ensure the collection of sufficient filtrate samples for ion titration experiments. The pH detection electrode in the filtrate collection cup can be used for pH detection. After pH detection, the filtrate is fed into the titration cup with implanted chloride ion and calcium ion detection probes through a titration pump for a minimum flow rate of 0.001 mL/time titration and potential detection experiment. Subsequently, the potential change signal is converted into a digital signal. This ensures accurate calculation of the experimental results.

Remote monitoring and intelligent diagnosis

The intelligent analysis system integrates detection data of rheological parameters, filtration parameters, and ion concentration parameters. Comparing the drilling fluid design and adjacent well data that have been entered into the system, the system will automatically generate parameter change curves and data anomaly reports. Provide strong data guarantee for safe and efficient technical services of different drilling fluid systems on site. The remote monitoring system mainly uses the proxy APP to store data in cloud storage and transmits all the data collected on site to the laboratory for data integration. To achieve the purpose of visualizing and digitizing oilfield data detection, facilitate the analysis and processing of on-site conditions by rear technical personnel, and provide better technical services.

Field application examples

Overview of the application of intelligent drilling fluid detection system functions

At present, the intelligent detection and analysis system for drilling fluid has tested and analyzed over 3500 sets of drilling fluid samples, formed over 76,500 sets of data. Compared with manual detection, the coincidence rate reaches over 96.5%. The detection results have good repeatability and strong data stability. In addition, the equipment has conducted over 1800 sets of drilling fluid performance testing and data collection indoors, including the density, AV, PV, YP, GEL, API-FL, HTHP-FL, Cl^- concentration, and Ca^{2+} concentration of the drilling fluid. The test results accurately reflect the performance changes of the drilling fluid, with a test data accuracy rate of 95.34%.

Application in S Oil and Gas Field

Due to formation depletion, easy collapse, and leakage, the design of Well X in the S Oil and Gas Field adopts a polysulfonate system and a brine system. After applying the intelligent detection system, there were 6 alarms for abnormal fluctuations in drilling fluid density. The rheological parameters exceeded the limit 9 times, filter loss exceeding design alarm 12 times. The calcium ion concentration exceeded the limit twice, two times of pressure plugging, with a 50% reduction in accident rate compared to the big data statistics of adjacent wells. The cost of drilling fluid decreased by 31.7% year-on-year. Reduce labor costs by 16.6%.

Due to the development of large sections of shale in the MX Y well of S Oil and Gas Field, a polyamine strong inhibition drilling fluid system is designed. Alarm 5 times for abnormal fluctuations in drilling fluid density in the application intelligent detection system. The rheological parameters exceed the limit 10 times; filter loss exceeding design alarm 6 times; pressure sealing once. The accident rate is 75% lower than the statistical data of adjacent wells. The cost of drilling fluid materials decreased by 33% year-on-year. Reduce labor costs by 12%.

Application in L Oilfield

Through feedback and parameter correction from artificial intelligence systems, the stability and effectiveness of on-site construction drilling fluid performance parameters are effectively ensured, and the application effect is significant. At present, the system has provided on-site services for a total of 11 wells in L Oilfield and WY area. Among them, the dual platform well in L Oilfield is designed with a polysulfonate system and a brine drilling fluid system due to formation depletion, easy collapse, and leakage. Alarm 6 times for abnormal fluctuations in drilling fluid density after the application of intelligent detection system; the rheological parameters exceeded the limit 9 times; filter loss exceeding design alarm 12 times; calcium ion concentration exceeds the limit twice; pressure sealing twice. The accident rate is reduced by 50% compared to the big data statistics of neighboring wells. The application of intelligent drilling fluid detection equipment reduces labor costs by 19%. Due to the development of large sections of shale in the WY platform well in Sichuan, a polyamine strong inhibition drilling fluid system is designed. Alarm 5 times for abnormal fluctuations in drilling fluid density in the application intelligent detection system; the rheological parameters exceed the limit 10 times; filter loss exceeding design alarm 6 times; the potassium ion concentration is lower than the design 5 times; pressure sealing once. The accident rate is 75% lower than the statistical data of adjacent wells. The application of intelligent drilling fluid detection equipment reduces labor costs by 21%.

Taking L Oilfield as an example. The service cycle of this well is 124 days. During the drilling process, an intelligent detection system for drilling fluid is used to synergistically detect various parameters of the drilling fluid. A total of 422 sets of drilling fluid samples were tested through human–machine comparison, forming 2418 data items. The overall average accuracy of the data is as high as 95.7%. By comparing and analyzing the differences in some parameters of the drilling fluid tested by humans/machines, it was found that the maximum fluctuation of the six-speed viscosity parameter in the human–machine comparison test was not more than 9.86%, and the fluctuation of the rheological parameter in the human–machine comparison test was not more than 4.22%, as shown in Fig. 7, equipped with the ability to provide real-time monitoring of drilling fluid performance parameters and technical services for accident prevention.

The technical support effect of the intelligent detection system for high-temperature and high-pressure drilling fluid is significant. This provides new ideas and methods for identifying and solving problems during the drilling process of different drilling fluid systems on site. This device effectively reduces the number and workload of on-site service personnel while ensuring accurate and timely on-site data, built a solid technical platform for data collection, analysis, and sharing.

Application in PS block

Within the service cycle of PS M well, modules such as density, six-speed viscosity, medium-pressure filtration, ion titration, data analysis, and remote access will be verified. More than 500 sets of drilling fluid samples were tested, resulting in over 4000 data items.

(a) The density module has undergone on-site testing and manual comparison: the numerical difference is ≤ 0.02 g cm^{-3}, and the error rate is less than 1%.
(b) The system automatically calculates the dynamic shear force, plastic viscosity, apparent viscosity, dynamic

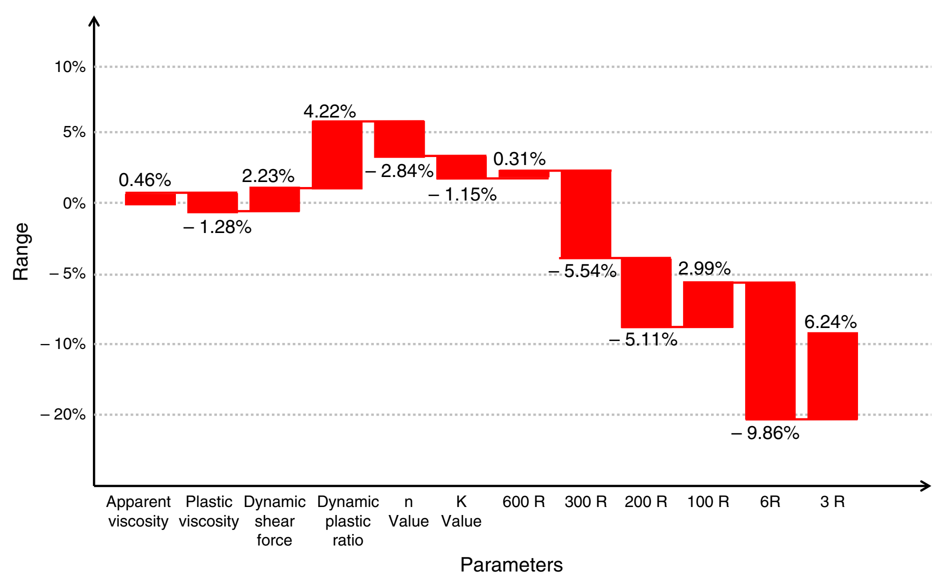

Fig. 7 Analysis of differences in human–machine testing parameters

plastic ratio, n value, and K value, with a fluctuation range of ≤ 10% compared to manual test values.

(c) The difference in pH value is ≤ 0.66, and the error rate is less than 10%.

(d) Difference in drilling fluid filtration value ≤ 0.5 mL; the error rate is less than 10%.

(e) Chloride ion concentration error ≤ 5%; calcium ion concentration error ≤ 10%.

Main technical features and advantages

The system has the following four advantages:

(a) Customized monitoring of drilling fluid performance parameters.

The system can be customized for testing modules according to the needs of different regions, wells, and drilling fluid systems. More targeted and professional.

(b) Integrated construction of drilling fluid performance testing.

The system can simultaneously test parameters such as temperature, density, viscosity, rheology, filtration loss, and ion concentration on a single machine within 40 min.

(c) Intelligent analysis of drilling fluid performance parameters.

Relying on the electronic control system for data collection and uploading to the cloud, analyzing the collected parameters against the cloud based well history big data and drilling design standards. Promptly alarm in case of parameter abnormalities.

(d) Digital application of drilling fluid performance parameters.

After data transmission, the remote control module of the system can achieve functions such as remote access, testing condition correction, and analysis. Automatically generate drilling fluid performance parameter correction suggestions through the trend analysis chart and comparison chart generated by the intelligent control module.

Integrated construction of drilling fluid performance testing

The system can simultaneously test parameters such as temperature, density, rheology, filtration loss, and ion concentration within 30 min. After each data collection, it is immediately displayed on the main screen of the system. The integration of testing functions and the direct reading of testing parameters ensure the convenience, intelligence, and timeliness and accuracy of instrument operation and data, effectively reducing the occupancy rate of different experimental equipment space during manual operation; reduced the workload of cleaning and debugging equipment, and improved the accuracy and efficiency of data collection and application.

Customized monitoring of drilling fluid performance parameters

The intelligent detection system for drilling fluid can selectively customize testing modules based on the needs of different regions, wells, and drilling fluid systems. The pertinence and professionalism of testing are more prominent. On the premise of ensuring the stable operation of the basic modules, the system can be divided, combined, and installed in categories according to the different drilling fluid systems applied on site, including the setting of circulating sampling points, ion detection types, remote monitoring network selection, and intelligent component report types, to achieve the goal of fully meeting the requirements of on-site drilling fluid performance testing.

Intelligent analysis of drilling fluid performance parameters

The intelligent detection system for drilling fluid relies on an industrial PC that uses IPC527E as an industrial computer that integrates screen display, control, communication, and other functions. The distributed I/O module includes a bus module, a digital input module, a digital output module, an analog input module, and other modules to jointly complete data collection and upload to the cloud. Analyze the collected parameters based on the benchmark cloud-based well history big data and drilling design standards, and report any abnormal parameters in a timely manner.

Digital application of drilling fluid performance parameters

The digital module consists of a 5G network module and an industrial switch. The 5G module connects to the external network through a network card for remote access by clients. Industrial switches configure the functions of each module of the equipment in a reasonable manner and form a local area network. After data transmission, the remote control module can achieve remote access, test condition correction, and analysis. By comparing the trend analysis chart of drilling fluid data through the intelligent control module, optimization suggestions for drilling fluid performance parameters are automatically generated.

Conclusions

The platform construction of the drilling fluid intelligent detection system combines the drilling fluid testing technology of the traditional oil and gas industry with the Internet of things platform and big data platform, providing technical support for the digital transformation of the oil industry. The main research conclusions are as follows:

(a) Comprehensive functionality, real-time accuracy. This system can perform real-time detection and monitoring of 20 parameters such as drilling fluid temperature, density, rheology, filtration, and ion concentration for different regions, well conditions, and drilling fluid systems. Through statistical analysis of over 1800 sets of data, the average accuracy reached 95.3%.

(b) Intelligent analysis and digital cloud storage. The system can upload collected data to the cloud and compare adjacent well databases and drilling fluid design related parameters to timely alarm and correct abnormal parameters of on-site drilling fluid. This ensures the long-term stability of drilling fluid performance within the design range;

(c) Safety and environmental protection, cost reduction, and efficiency enhancement. The system adopts a one click, fully automatic detection mode, reducing the frequency of manual HTHP experiments, and hazardous chemical detection experiments, improved the safety level of drilling fluid testing.

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