ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

Classification and Advantages and Disadvantages of Early Overflow Monitoring Methods

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Abstract

There are three main types of surge monitoring in foreign countries. One is to judge the kick by measuring the difference between the inlet and outlet flow; the other is to monitor the well by logging parameters or the measured parameters at the bottom; the third is to monitor the propagation of pressure waves or sound waves in the drilling fluid. Speed detection detects the presence of free gas in the annulus; each method has its own characteristics. This paper investigates four types of inlet and outlet flow meters, namely baffle flow meter, sonic flow meter, electromagnetic flow meter and Coriolis mass flow meter. Four overflow detection systems using inlet and outlet flow measurements and their field applications were studied, namely Anadrill/Schlumberger overflow monitoring system, Coriolis mass flow sensor, IDAPS flow monitoring system and the early days of Statoil. Overflow monitoring system. The measurement principle and field application of different early overflow monitoring methods are summarized.

Keywords

Early overflow; flow meter; overflow detection system.

1. Flow Measurement Principle

1.1. Baffle Flow Mete

When the measured medium passes through the baffle flow meter, the baffle is opened. The opening of the baffle varies with the flow rate. At a certain flow rate, the torque acting on the baffle is balanced with the torque of the torsion spring in the flow meter, so that the baffle has a certain degree of opening, and the different opening corresponds to the corresponding flow. This opening is converted and transmitted to the meter by a series of mechanical and magnetic drive systems, and the pointer indicates the instantaneous flow through the flow meter fluid on the dial.

The baffle flow meter has an accuracy of ±2.5% and a maximum operating pressure of 0.6MPa. The baffle flow meter has the advantages of low cost and convenient installation, but its disadvantage is that the precision is low, and the high solid phase content will affect the measurement accuracy [1].

1.2. Acoustic Flow Meter

Acoustic flow meters are divided into two categories, one is the time difference method to measure flow, and the other is the Doppler method to measure flow.

1.2.1. Principle of Time Difference Measurement

The propagation characteristics of ultrasonic waves in stationary fluids and flowing fluids are different. Similarly, the propagation characteristics of downstream and countercurrent are also fundamentally different in flowing fluids. Obviously, due to the velocity of the fluid flow, compared with the velocity of the ultrasonic wave propagating in the stationary fluid, the velocity of the acoustic wave in the countercurrent direction and the velocity of the acoustic wave in the countercurrent direction are opposite. The former speed decreases and the latter

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

speed increases. Therefore, in the case of the same propagation distance, there is a difference in the propagation time of ultrasonic waves of the same frequency. By establishing a mathematical relationship between the measured fluid velocity and the propagation time, the flow velocity of the fluid can be obtained based on the known difference in propagation time. The method of obtaining the fluid velocity by this method is generally referred to as a propagation time difference method, which is simply referred to as a time difference method. That is, by measuring the time difference, the flow rate of the fluid can be obtained and then converted into a flow rate. Figure 1 is a schematic diagram of sound wave propagation and sensor arrangement in the flow rate of a circular tube by ultrasonic time difference method [2].

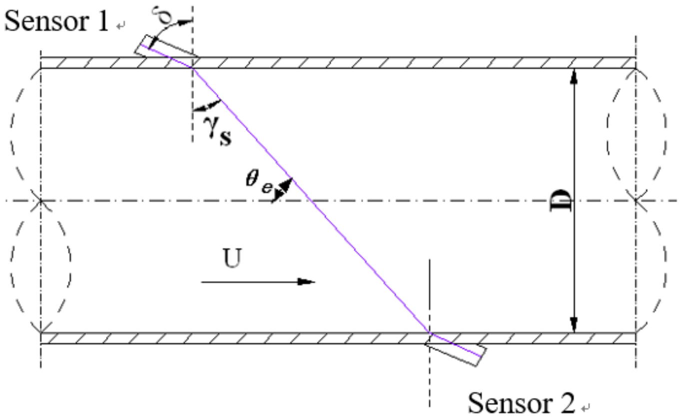

Figure 1. Acoustic wave propagation and sensor arrangement in the flow of a circular tube by ultrasonic time difference method

As can be seen from Fig. 1, the ultrasonic sensors 1, 2 are used for alternately transmitting or receiving ultrasonic pulses, and are mounted in an off-tube type. Two sensors are fixed on both sides of the circular tube, and sound waves are emitted from the sensor 1, and transmitted through the inner wall of the circular tube and the intermediate liquid, and transmitted to the other side of the round tube 2 for receiving. Due to the filling material in the sensor, the material of the pipe, and the material of the fluid in the pipe, their speed of sound is also different. In the case of liquid flow in the tube, the propagation time of the acoustic wave from sensor 1 to sensor 2 (downstream) and from sensor 2 to sensor 1 (countercurrent) is not the same. The flow rate and flow rate of the liquid in the round pipe can be measured by measuring the difference between the two propagation times of the forward flow and the reverse flow.

1.2.2. Doppler Frequency Difference Measurement Principle

The phenomenon that the observation frequency is different from the wave source frequency due to the motion of the wave source itself and the motion of the observer is called the Doppler Effect. As long as the wave source and the observer have relative motion, the wave received by the observer will deviate from the original frequency of the wave source, move in the opposite direction, and increase the frequency. When the wave moves back, the frequency decreases. The Doppler Effect consists of two cases: one is sound source motion, the observer is relatively stationary, and the other is observer motion, and the sound source is relatively stationary.

As shown in Figure 2, the ultrasonic wave emitted by the ultrasonic transmitter propagates in the drilling fluid at a speed c. The angle between the direction and the flow direction is α. For the speed of the suspended particles in the fluid, the problem is relatively simplified. , assuming that its velocity is the same as the fluid flow rate, both are u. In this case, the relationship between the Doppler shift and the fluid flow rate can be derived. On the tube axis, if the ultrasonic beam meets the solid particles, the particles will move along the tube axis at a velocity u along with the fluid in the tube [3].

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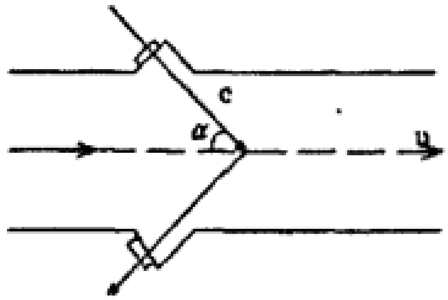

Figure 2. Schematic diagram of Doppler effect

For an ultrasonic transmitter, the particle moves at a speed ucosα and is further away from the transducer. The ultrasonic frequency f2 received by the particle should be lower than the transmitted ultrasonic frequency f1, in which case, according to The Puller effect and the frequency changes emitted and received can be used to calculate the flow rate in the tube to obtain the flow rate.

The monitoring accuracy of the sound wave measurement flow rate is ±1%~±5%. The main influencing factors affecting the accuracy of sound wave measurement are the propagation speed of sound wave in the measuring medium and the attenuation of the sound wave intensity by the solid phase content in the medium. In addition, according to the principle of sound reflection, the change in liquid level can be measured.

1.3. Electromagnetic Flow Meter

The electromagnetic flow meter is developed according to Faraday's law of electromagnetic induction and is used to measure the volumetric flow of conductive fluid. Faraday's law of electromagnetic induction means that a conductor generates an induced electromotive force at both ends of a magnetic field when it is cut in a magnetic field. The conductive liquid flows in a non-magnetic measuring tube perpendicular to the magnetic field, and is proportional to the flow rate in a direction perpendicular to the flow direction. Induced potential. The measuring tube of the flow meter is a non-magnetic alloy short tube lined with an insulating material. The two electrodes pass through the tube wall in the direction of the tube diameter and are fixed on the measuring tube. The electrode tip is substantially flush with the inner surface of the liner. When the excitation coil is pulsed, a working magnetic field having a magnetic flux density of B is generated, and the direction is perpendicular to the axis of the measuring tube. At this time, the fluid having a certain conductivity flows through the measuring tube, and the cutting magnetic field lines induce the electromotive force E. The electromotive force E is proportional to the magnetic flux density B, the product of the inner diameter D of the measuring tube and the average flow velocity V. The electromotive force E (flow signal) is detected by the electrode and sent to the converter through the cable. The converter amplifies the flow signal to display the fluid flow. Since the electromagnetic flow meter is mainly used for the measurement of the round pipe, if the electromagnetic flow meter is to be used for the measurement of the return flow of the drilling well, it is necessary to improve the flow path of the returning drilling fluid.

The measurement accuracy of the electromagnetic flow meter: ±0.1%~±2.5%, the advantage is high precision, the disadvantage is that the cost is high, and the signal is easily interfered by the external magnetic field [4].

1.4. Coriolis Mass Flow Meter

The Coriolis mass flow meter uses Coriolis force to measure the flow in the tube. Coriolis force refers to the force exerted on the pipe wall when the fluid flows in a rotating pipe. It was discovered by Coriolis when the turbine was studied in 1832, referred to as Coriolis force. The Coriolis mass flow meter is based on Coriolis force. There are two parallel U-shaped vibration

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

tubes inside the sensor, the drive coil is installed in the middle, the detection coil is installed at both ends, and the excitation voltage provided by the transmitter is added to the drive. When the coil is on, the vibrating tube vibrates in a reciprocating cycle. When the fluid medium flows through the vibrating tube of the sensor, a Coriolis force effect is generated on the vibrating tube, and the two vibrating tubes are twisted and flowed in the tube, and the detection is installed at both ends of the vibrating tube. The coil will produce two sets of signals with different phases, which are proportional to the mass flow of the fluid flowing through the sensor. The computer calculates the mass flow through the vibrating tube.

The Coriolis mass flow meter has high measurement accuracy with a maximum monitoring flow of 54.4 t/min, a minimum monitoring flow of 0.05 t/min, flow measurement accuracy: +/- 0.35 %, drilling fluid temperature, mud temperature: -50 °C ~ +200 ° C [5].

The Coriolis mass flow meter has high measurement accuracy and can theoretically measure the mass flow of different components. The disadvantage is that it needs to reconstruct the flow channel from which the drilling fluid returns. The entire measurement system is large.

2. Overflow Monitoring System Using Inlet and Outlet Flow Measurement

2.1. Anadrill/Schlumberger Overflow Monitoring System

2.1.1. Measurement Principle

A ground overflow detection system developed by Anadrill/Schlumberger in 1987, which monitors the overflow by inlet and outlet flow differentials with a monitoring accuracy of 1.5 L/s. The system inlet flow is calculated by pumping, and the system mainly monitors the outlet flow [6].

Figures 3 and 4 show the flow rate of the drilling fluid outlet of the return line through a level sensor and an ultrasonic speed sensor mounted on the overhead trough.

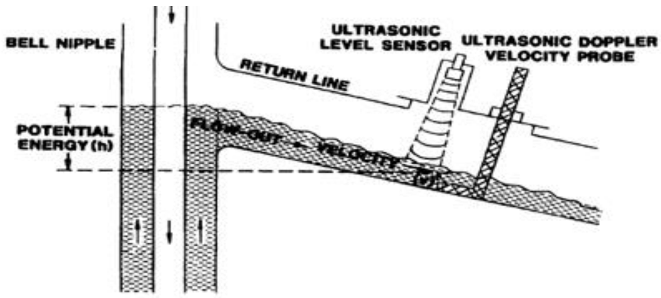

Figure 3. Installation diagram of the outlet flow meter

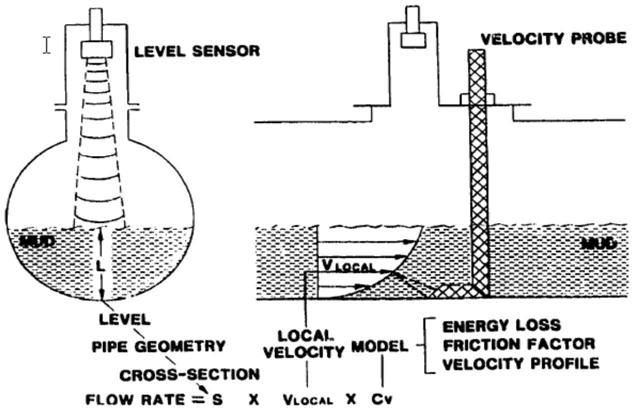

Figure 4. Schematic diagram of the outlet flow meter detection

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

The overhead trough can be round or can be an open trough at the top. The system monitors the height of the drilling fluid in the return line through the liquid level sensor, and monitors the flow rate of the drilling fluid through the Doppler sensor. The two sensors are welded to the upper end of the return line by the upper two flange means. According to the liquid level sensor, the flow cross-sectional area of the liquid in the tube is determined, combined with the speed measured by the ultrasonic sensor, and then the velocity distribution of the flow area is simulated according to the fluid mechanics, thereby determining the average flow velocity of the drilling fluid in the flow cross section, and finally determining the return flow. Traffic.

The return flow meter can not only measure water-based drilling fluid, but also oil-based drilling fluid. The maximum return flow rate can reach 75L/s, the measurement accuracy is 1.5L/s~3L/s, and the drilling fluid viscosity is 1~200cp. The density ranges from 1.0 g/cm^3 to 2.16 g/cm^3 [7].

2.1.2. Field Application

The experimental well Φ339.7mm casing down to 300m, Φ244.5mm casing down to 1000m, and the well drill string is 3 column Φ152.4mm drill pipe connected to Φ127mm drill pipe, simulating gas intrusion at the bottom of the well. The outlet flow was measured by an ultrasonic flow meter, the inlet displacement was calculated by pumping, and the drilling fluid volume was measured by a mud tank level gauge.

Allow at least one hour of circulation to ensure that the wellbore contains no gas before testing. Figure 5 shows a simulated overflow that simulates the entry of bubbles into the wellbore, and the expansion of the bubbles during the ascent causes the pressure in the well to decrease. The inlet displacement of the test was 1500 L/min, and the gas was stopped after 8 minutes of injecting. In 20 minutes, the volume of the mud pool was increased by 20 barrels. Once the gas injection starts, the outlet displacement increases exponentially. After 5 minutes, the difference between the outlet and the inlet is 120L/min, and the alarm device starts to alarm. If a conventional level gauge is used, the warning time for issuing a kick is 3 minutes. If a high-precision ultrasonic flow meter is used, the warning time can be increased to 9 minutes or even 16 minutes.

Figure 6 shows the test results of the simulated contact gas intrusion. When the gas injection is started at the bottom of the well for 6 minutes, the difference between the inlet and outlet reaches 120L/min, and an overflow alarm is issued. The traditional mud pool level gauge takes 17 minutes to measure. In order to determine the kick, only 2 to 3 minutes to control the kick, and the flow difference measurement method can be 14 minutes ahead of time, which is 5 times that of the conventional method [8].

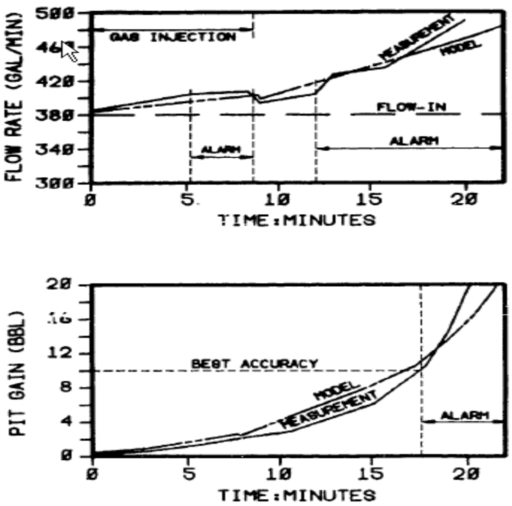

Figure 5. Testing the rig on the rig

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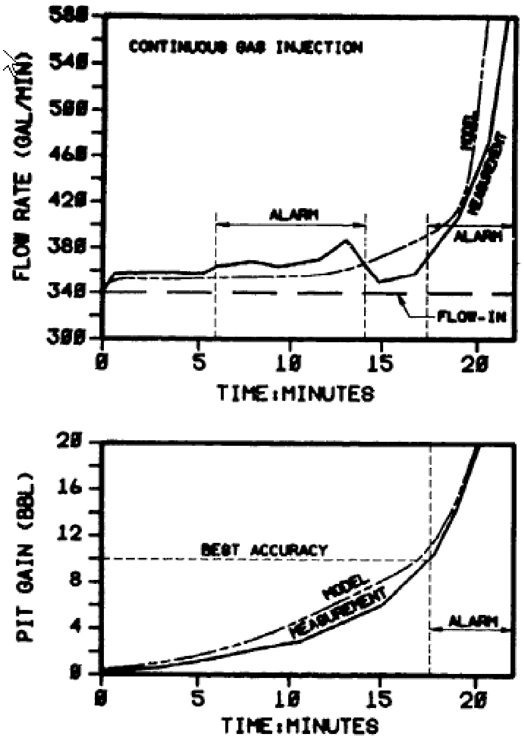

Figure 6. Continuous gas intrusion test on the test rig

2.2. Coriolis Mass Flow Sensor

2.2.1. Working Principle

When the fluid flows through a vibrating tube having a natural frequency, the fluid is forced to accept the vertical momentum of the tube. During the half cycle of the upward vibration of the tube, the fluid flowing into the meter is pressed downwards to resist the upward force of the tube, whereas the fluid flowing out of the meter has an upward force that resists the reduction of the vertical momentum of the tube and pushes the tube up. The Coriolis force generated on the vibrating tube causes the two vibrating tubes to twist and vibrate. The sensors installed at both ends of the vibrating tube will generate two sets of signals with different phases. The phase difference between the two signals and the fluid flowing through the sensor the mass flow is proportional.

Coriolis mass flow sensors are increasingly being used to measure drilling fluid density and real-time flow, collect real-time data on density and flow, help reduce drilling costs, and detect wells early and improve drilling Advance safety and avoid some serious well control accidents. The Coriolis used to measure the density and return flow of the outlet drilling fluid during the drilling process is shown in Figure 7.

Real-time data from Coriolis flow sensors can be aggregated into the rig control system and graphically displayed to provide drillers and drilling fluid engineers with timely changes in drilling parameters as early as possible. The general configuration is that the first flow meter is installed between the mud tank and the mud pump to measure the inlet fluid parameters, and the second flow meter is installed in the return line for detecting the outlet fluid parameters.

Coriolis flow sensors have been successfully applied to well detection, lost circulation detection and pressure controlled drilling, taking measurements of the density, volumetric flow and mass flow of the inlet and outlet fluids. Real-time, accurate, and reliable measurement of fluid volume is necessary to identify and mitigate fluid loss and kicks. The overflow is monitored by the pumping of the surface drilling pump and the change in the level of the mud tank, and monitoring the overflow through the level change of the mud tank has problems in terms of accuracy, reliability and timeliness. Comparing the return flow of the wellhead or the change in flow of another Coriolis flow meter at the suction end of the mud tank can provide an effective means to monitor formation loss or kick [9].

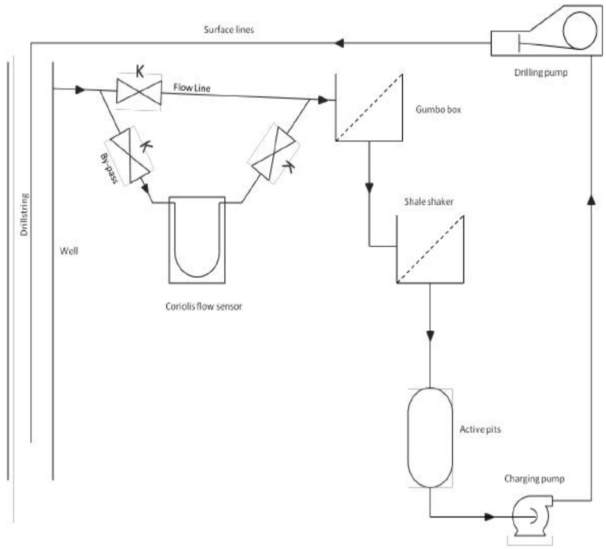

Figure 7. Schematic diagram of Coriolis flow sensor installation

The loss of formation can be obtained by real-time monitoring of the outgoing flow (Volume IN) minus the incoming flow (Volume OUT), as shown in Figure 8. Any volume of fluid that does not return to the ground can be considered to have occurred a lost circulation. A portion of the lost fluid forms a filter cake and the remainder is considered a normal leakage loss, which will contain a certain proportion of solids and liquids.

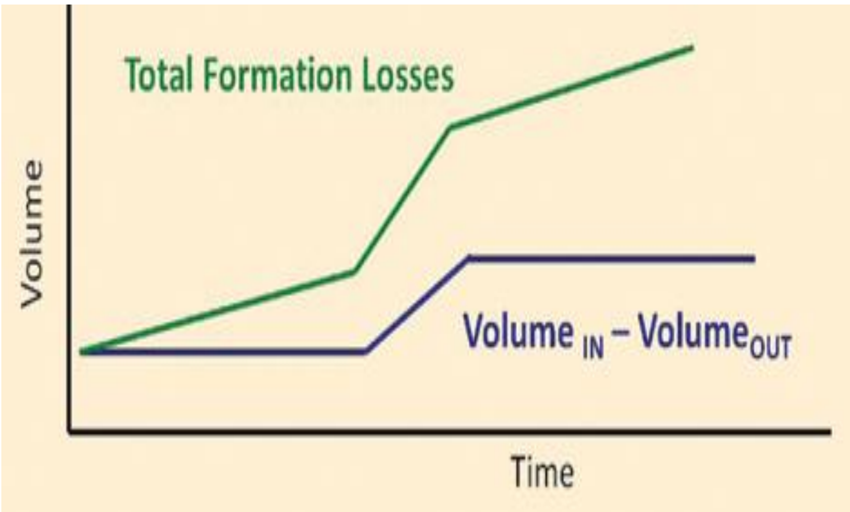

Figure 8. Well leakage monitoring

Real-time, accurate, and reliable fluid flow data is also essential for detecting abnormal leaks and reducing accidents, such as wellbore instability, stuck drilling, poor formation evaluation, and even blowout. The same Coriolis flow data can be used to enhance kick detection. Current practice involves comparing pump stroke based inlet flow and return flow and is used in controlled pressure drilling systems. The same application is applied to conventional drilling and pressure controlled drilling. Figure 9 shows the Coriolis flow sensor installed at the exit.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

Figure 9. Coriolis flow sensor installed at the entrance and exit

2.2.2. Field Application

The following case is based on data obtained during the drilling of ultra-high temperature and high pressure using the drilling vessel. The data comes from the Norwegian oil company. The drilling ship used is a sixth-generation drilling ship with a water depth of 2,500 m and a borehole size of 311.15 mm.

The commonly used overflow monitoring method mainly uses a baffle flow meter to measure the outlet flow rate or monitor the volume change of the mud tank. The baffle flow meter has the advantage of being easy to install, but has the disadvantage that the measurement results from the baffle flow meter are not very accurate, especially in the sloshing process on the drilling ship, it is impossible to obtain a relatively accurate outlet flow. This measurement can be done, but accuracy is not guaranteed. Moreover, when measuring with a baffle flow meter, it needs to assume the velocity distribution of the fluid, but no one can accurately predict the fluid velocity distribution. The fluid velocity has a great relationship with the fluid density and rheological parameters.

Figures 10 and 11 show real-time data on a single kick event. The graph has been plotted and shows in real time the entire process of the kick that occurred during the drilling operation. The well occurred at 7:00 pm and decided to stop the pump at 7:10. The final shut-in time was 7:20 and the shut-in pressure was recorded at 450 psi. Some operations in the well control operation are shown on the Coriolis sensor, which also explains the change in flow measured by the sensor after shutting down.

Figure 10 compares the outlet flow difference between a baffle flow meter and a Coriolis flow sensor. It is clear in Figures 1-10 that if the platform is only equipped with a baffle flow meter, it is unlikely to detect an overflow that occurs at 7:00 PM. Even when the pump was stopped, the flow measured by the baffle flow meter was not sufficient to infer the presence of an overflow, but observing the difference in inlet and outlet flow rates obtained by the Coriolis sensor, it was apparent that the fluid began to flow out of the wellbore at 7:00 pm.

Figure 11 represents the monitoring of the change in the level of the mud tank. The method for detecting the increase and decrease of the drilling fluid volume in the mud tank is accurate, and the liquid level change of the mud tank level is monitored to be 5 minutes later than the observed liquid flow in the inlet and outlet flow difference. Consider that the well outlet displacement is about 35 gallons per minute, and the 5 minute delay surge is above 4 barrels, especially if it is gas intrusion, which is not negligible [10].

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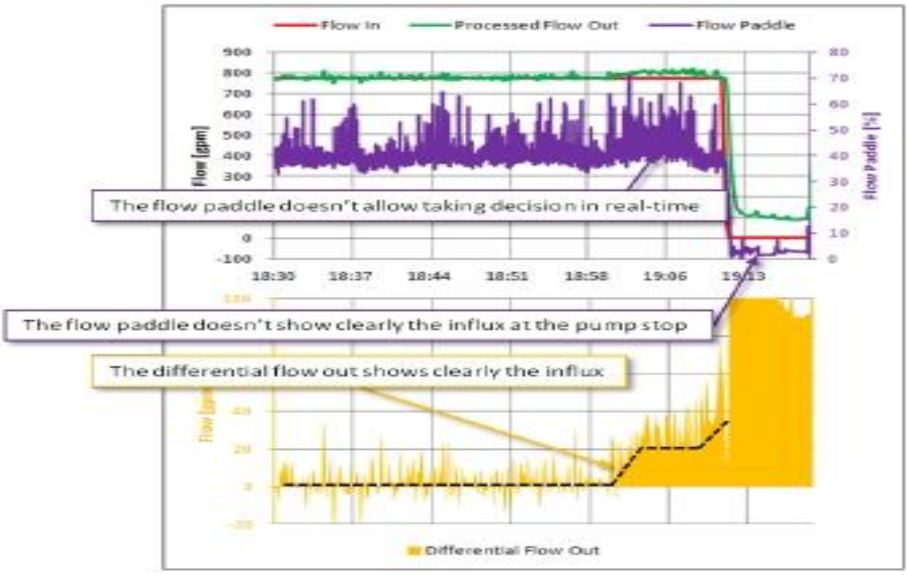

Figure 10. Comparing the inlet and outlet and the normal flow rate under normal conditions

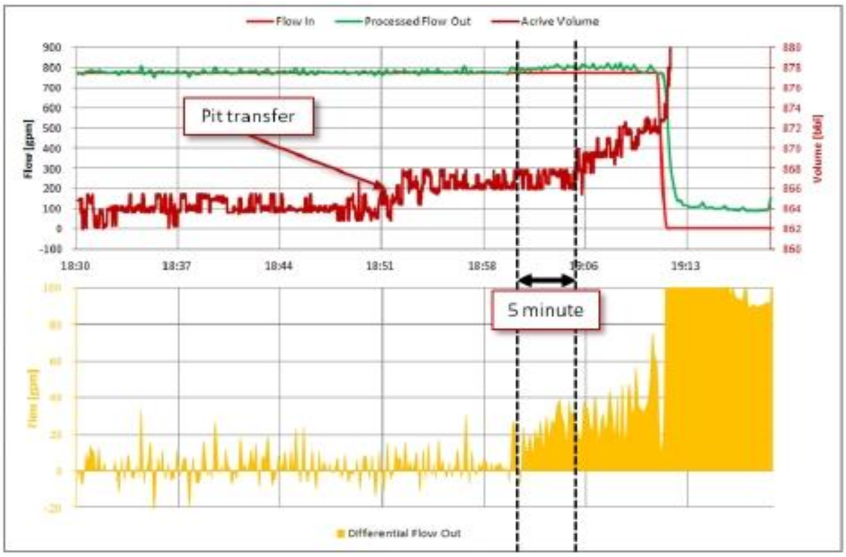

Figure 11. Comparing the volume change of mud tank and the change of inlet and outlet flow

2.3. IDAPS Flow Monitoring System

In 2016, B. A. Tarr et al. developed a set of Influx Detection at Pumps Stop (IDAPS). Real-time parameters such as inlet and outlet displacement, inlet and outlet density, mud pool volume change, drill bit depth and well depth are used as input parameters to achieve high probability monitoring with low false alarm rate.

2.3.1. Working Principle

The main principle of the software is to compare the drilling parameters detected when the current and previous single roots are taken. If the drilling parameters of the current single root are deviated from the drilling parameters of the conventional single root, there is a possibility of overflow. The software monitors and saves data at the maximum time interval as a special event; the most recent valid data is used to calculate acceptable thresholds for common events; the pattern recognition algorithm is used to monitor the validity of the data and remove Reliable data; when statistically or continuously deviating from normal values, it represents gas intrusion with different confidence levels; advanced signal processing and four-feature fusion ensure predictive results minimize false positives and maximization Successful monitoring;

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

finally, the decision variable is compared with four different thresholds, which usually correspond to higher and higher confidence levels. Using these confidence thresholds also reduces the false positive rate.

2.3.2. Monitoring Method

Figure 12 shows a comparison of the drilling parameters of the current single root with the drilling parameters of the previous single. Figure 13 reflects the IDAPS software's analysis of the current single drilling parameters and the previous single drilling parameters. Red indicates the current single drilling parameters and green indicates the previous drilling parameters. Among them, on the decision variable (LDF) map, the low, medium, high and determined thresholds are displayed as different color horizontal lines. If the calculated LDF value exceeds any given threshold, the corresponding alert is triggered. In this example, the high probability overflow alarm is triggered at 182s and the acknowledge overflow alarm is triggered at 263s.

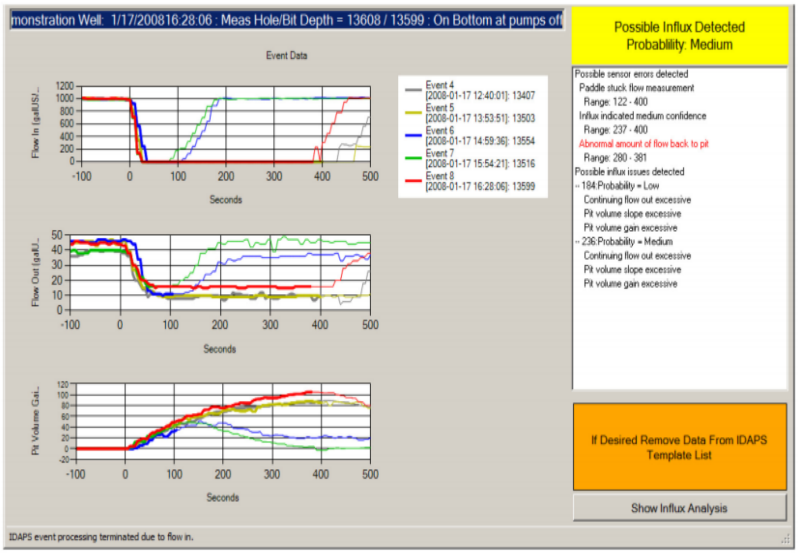

Figure 12. Comparison of the drilling parameters of the current single root and the drilling parameters of the previous single root

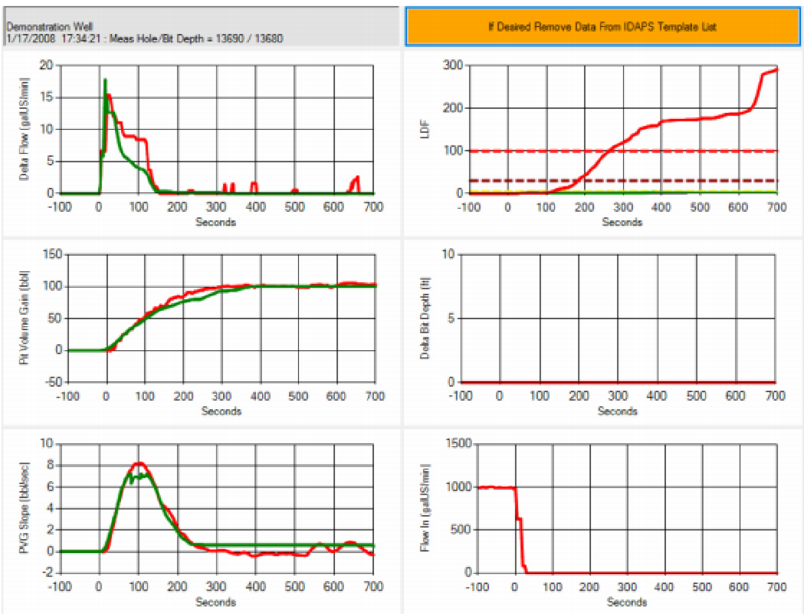

Figure 13. IDAPS software analysis of current single drilling parameters and previous drilling parameters

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

Based on data from 30 wells (more than 10,000 hours of real-time operational data), the IDAPS software has a mean false alarm rate (FAR) of 1/195 with a 100% overflow detection rate. By setting a series of alert levels, the user is made aware of the possibility of overflow occurring in real time.

2.4. Norwegian National Oil Company's Early Overflow Monitoring System

In 2013, Statoil developed an early overflow monitoring system based on mathematical statistics to monitor incremental changes in mud pools during pump shutdowns. The traditional method of judging overflow by monitoring mud pool changes depends mainly on the personal experience of field workers, engineers and drillers. Due to human factors, there is a misunderstanding of the measurement results and misjudgment (false alarms or false negatives flow). Moreover, the return flow during the pump stop process is not only caused by the pressure imbalance, the compressibility of the drilling fluid and the thermal expansion, the wellbore volume change caused by the plastic deformation of the formation, and the heave movement of the drilling ship may cause the return flow. Variety.

The overflow monitoring system uses the method of mathematical statistics to monitor the volume change of the mud pool in a period of time after the pump is stopped, and calculates the mean value and mean square error of the detected values, and plots the mean value of the normal return flow and the mean value of the normal return flow respectively. The return flow (for example, 1 or 2 times) of the multiple of the positive and negative deviation mean squares is monitored with time, and the monitoring curve is compared with the small overflow characteristic curve and the large overflow characteristic curve. If the measured return flow is positively deviated the intersection of the curve and the overflow characteristic curve indicates that an overflow may occur. Figure 14 is a comparison of the 1% mean square error and the overflow characteristic curve of the measured data. After about 40 seconds of monitoring, the characteristic curve of the small overflow intersects with the positive deviation curve of 1 times of the return flow. At this time, it means that the measured mud pool increment is only 3 barrels larger than the normal mud pool increment. The identification method, this overflow may be underreported, but according to the new intelligent reflow monitoring system, it can accurately identify the occurrence of small overflow in the wellbore.

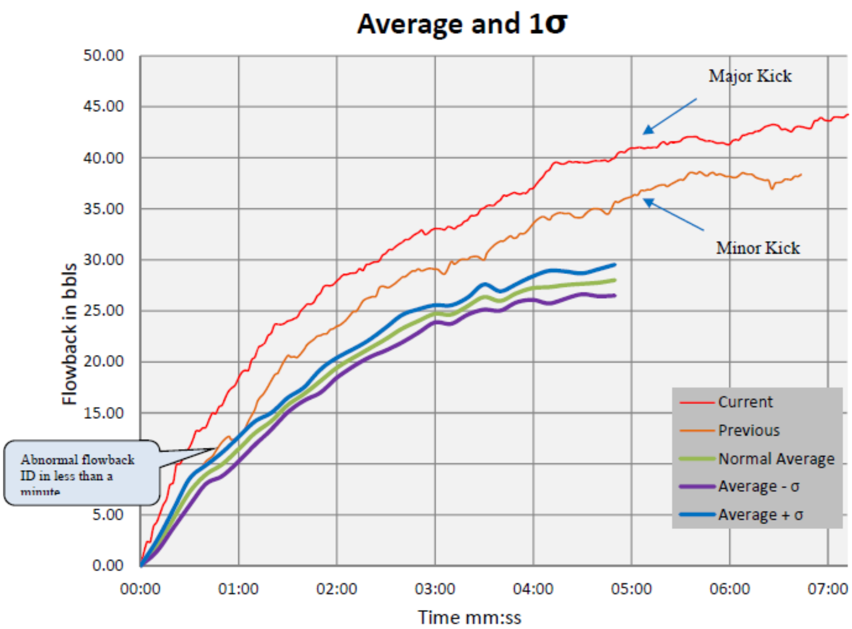

Figure 14. Intelligent reflux early overflow monitoring curve

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3. Classification and Advantages and Disadvantages of Early Overflow Monitoring Methods

There are three main types of surge monitoring in foreign countries. One is to judge the kick by measuring the difference between the inlet and outlet flow; the other is to monitor the well by logging parameters or the measured parameters at the bottom; the third is to monitor the propagation of pressure waves or sound waves in the drilling fluid. Speed detection detects the presence of free gas in the annulus; each method has its own characteristics.

3.1. Early Overflow Monitoring of Inlet and Outlet Displacement Methods

Measuring the difference between the inlet and outlet flow rates depends on accurately determining the inlet and outlet flow rates; the inlet flow rate is generally calculated by parameters such as the cylinder liner diameter of the pump, the pump stroke and stroke, and the pump efficiency, while the outlet flow rate is calculated. Measurements include baffle flow meters, ultrasonic flow meters, mass flow meters, electromagnetic flow meters, sonar flow meters, and the like. The accuracy of the baffle flow meter is not high. The ultrasonic flow meter is greatly affected by the solid phase content. The electromagnetic flow meter can only measure the conductive fluid. The sonar flow meter has better precision and compatibility, but the cost is higher. In addition, the inlet and outlet flow meters and the level gauge of the mud pool can be used together to improve the sensitivity of the well monitoring. The influence of the inflow and intrusion formation fluids by the inlet and outlet flow difference methods is greatly affected. If the invading fluid is a liquid, the well is effectively monitored; if the gas is invaded, since the gas is a compressible fluid, the gas will change in volume as the gas changes during pressure and temperature during the annulus rise. Changes, when the gas begins to invade, the flow of the wellhead will not change greatly due to the small expansion of the gas. However, as the gas rises, the gas expansion increases, the outlet flow rate increases, and the measured flow rate increases. As the gas approaches the wellhead, the expansion tendency becomes more pronounced. Theoretical studies have shown that gas expansion mainly occurs near the wellhead. Therefore, there is a hysteresis in monitoring the kick by using the inlet and outlet flow methods. That is, in the early stage of the well, the flow changes of the inlet and outlet are small, the actual gas intrusion is neglected, and the flow of the inlet and outlet is obviously changed, and the gas has already reached the vicinity of the wellhead. For oil and gas drilling fluids, this hysteresis is more obvious due to the influence of gas solubility. Therefore, there are certain limitations in using the inlet and outlet flow variation methods to monitor gas intrusion.

3.2. Early Flood Monitoring Using Logging, LWD, APWD Data and Wellbore Pressure Simulation

This method is the most common and practical early well monitoring method currently used. The logging data in deep water drilling is more comprehensive, although these measuring sensors still have such problems, especially the measurement accuracy is not too high, well Many of the characteristics of the ground surface display can be reflected by logging and LWD logging parameters, such as the flow rate, density, temperature, mud pool level change, mechanical drilling speed, various gas measurement parameters, pump pressure, Torque, ECD, gamma, neutron, density, comprehensive analysis of the above parameters, early monitoring of the kick.

3.3. Early Overflow Monitoring By Measuring the Free Air Content in the Annulus

In order to overcome the shortcomings of the method of monitoring the wellbore by the inlet and outlet flow change methods, foreign research and development directly measures the existence of free gas in the air. There are two ways to measure the presence of free gas in the

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.201910_2(7).0014

annulus. One is to generate and receive sound waves or pressure waves at the wellhead, and the other is to monitor the presence of free gas directly at the bottom of the well. The main problem in transmitting and receiving sound waves through the wellhead is that the attenuation of sound waves in the drilling fluid is relatively large. It is usually difficult to directly measure sound waves. Therefore, some studies have replaced sound waves with pressure waves, and pressure waves can propagate. Farther distance. The advantage of this method is that both the generating and receiving devices are on the ground and the presence of free gases in the drilling fluid can be monitored in time. Directly measuring the presence of free gas at the bottom of the well is feasible in both method and principle, but the measurement results can only be uploaded by the MWD tool to obtain real-time measurements.

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