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Characterization of Dynamic Pressure Response in Vertical Two Phase Flow

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Abstract

One of the problems encountered in drilling, especially in offshore environments is "kicks". Kick is a sudden pressure imbalance in the wellbore during drilling operation. When this imbalances in pressure occurs the reservoir pressure has the ability to push the reservoir fluid into the wellbore. This may create a catastrophic event such as blow-out of the drilling rig. Thus, prior detection of the kick situation is critical to prevent any such catastrophic event. Currently, a kick situation is predicted or detected observing the properties of returned drilling mud from the wellbore. This method is not reliable as well as time consuming. The objective of this study is to develop a tool that will enable the prediction and detection of kick situations in managed pressure drilling (MPD). To achieve this goal, a two-phase experiment is conducted in 7.62 cm and 5 m long vertical pipe section. Instead of periodic sampling for kick situations, the newly developed tool enables the continuous monitoring of kick situations.

Keywords: Kicks; Wavelet transform; Two phase flow; Signal processing; Managed pressure drilling

Introduction

Managed Pressure Drilling (MPD) is a new drilling technique, which is developed for reducing the various drilling problems like kick, drilling fluid circulation loss, wellbore instability and formation damage. These drilling problems generally grow up during the conventional drilling process Managed Pressure Drilling is used to precisely manage the wellbore pressure when drilling with a narrow window between 1.38×10^6 and 2.068×10^6 Pa of the pore pressure and fracture pressure [1,2]. It is very useful for mature field because it can be revisited with better well control. Managed Pressure Drilling also reduces the Non Productive Time (NPT), which is time spent without drilling operations. It is believed that about 40% of the drilling problems happen as a result of pressure issues, lost return or kicks and stuck pipes. So MPD helps to reduce the drilling cost and stop the pressure related drilling hazards.

According to International Association of Drilling Contractors (IADC), Managed Pressure Drilling is an adaptive drilling process used to control precisely the wellbore pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. MPD is intended to avoid continuous influx of formation fluids to the surface. MPD categories contain three variations namely: Constant Bottom Hole Pressure (CBHP), Pressurized Mud Cap Drilling (PMCD) and Dual Gradient Drilling (DG). The CBHP method of managed pressure drilling uses annular frictional pressure and choke pressure in addition to mud hydrostatic pressure to achieve precise wellbore pressure control. This is the most common type of MPD being used.

The aim of MPD is to drill as close the pore pressure as possible and thereby reduce the dynamic overbalance. A reduction in dynamic overbalance often help to increase the rate of penetration (ROP), decrease surge and swab effect, reduce influx, and enhance well control (lost circulation, kicks). Lowering dynamic overbalance reduces the differential pressure in the well. As differential pressure is lowered, the force needed to break rock is lowered increasing ROP [3].

As defined, MPD controls the Bottom Hole Pressure (BHP) by applying surface back – pressure. This means that it can be chosen to drill with either a static underbalanced mud or a static balanced mud. Drilling with underbalanced mud yields a lager operating window, meaning if something unexpected happens in the well the operating margins are larger. However, if dynamic overbalance is not maintained at all times the sudden overbalance may cause severe damage to the unprotected formation. Government regulations are also strict regarding unbalanced drilling.

Conventional Methods of Detecting Kicks

A kick is an unwanted influx of gas or liquid into the wellbore, as a result of higher fluid pressure in the formation than in the wellbore. Conventionally, drilling mud of higher density than that of the formation fluid is used to prevent kicks. There are two basic conventional approaches of detecting kick – using pit gain (volumetric comparison), and using flow-out versus flow-in (rate comparison).

Pit gain (Volumetric comparison)

Pit gain is the variance in the amount of drilling fluid pumped into the well and the volume of drilling fluid pumped out of the well [4]. Under a no-kick situation i.e., stable situation, the two volumes should be equal i.e., zero gain. Whereas in a kick situation the amount pumped out is higher than the amount pumped in i.e., positive gain.

Flow-out vs. Flow-in (Rate comparison)

The flow-out rate is a measurement of the rate of fluid return from the well [4]. It is typically achieved by placing sensors in the flow line coming out of the wellbore. While flow-in rate is a measurement of the rate of fluid pumped into the well i.e., pump rate X volume per pump stroke. In a stable well, both flow rates should be approximately the same. An unexplained increased in the flow-out rate could be an indicator of a kick situation. This approach is normally used when the rig is not pumping fluid [4-6].

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Challenges with the conventional method

Although the conventional methods have shown some benefits overtime, there are still some challenges with them. Some of the key challenges are:

1. In both approaches, it takes some time for the return fluid to get back to surface (pit or flow-out sensor) in order to detect a kick situation. This time delay could be very costly, especially in deep water environment. Hence, early detection is critical to mitigating the impact of kicks.

2. Certain kinds of operations can make it impossible to use pit gain as a kick indicator. For example, this happens when return flow from the well goes overboard instead of into a pit. Rig personnel generally cannot measure the volume of flow overboard, so they cannot make volume-in/volume-out comparison during such operations.

3. There is also the issue of false alarms. For example, even with the pump closed, there could still fluid out flow due to thermal expansion of the drilling fluid, rig heave or ballooning [4]. If not properly diagnose, this could be misinterpreted as a kick situation, which will subsequently lead to unnecessary costly non-productive time (i.e., time spent without drilling operations).

4. Due to the volume of the pit tanks, the sensitivity of an in-/out-flux is very small [7]. Hence, an in pit volume can be in the range of 0.5 – 1.0 m^3 before the drilling crew responds [8].

Kick detection approach

In managed pressure drilling, the annulus is sealed while drilling. This closed loop system provides the additional advantage of making it easier to detect net flow rate and pressure anomalies within the wellbore. A detailed discussion of this advantage is documented by Grayson and Gans [9]. Reitsma has proposed a solution to detect kick by monitoring the time-trends of stand pipe pressure and annular discharge pressure in MPD [10]. Hauge described the modeling of kick detection and prevent using Ordinary Differential Equation (ODE) and Partial Differential Equation (PDE) models. Sonic measurement of the annular fluid, described by Hage and Avest has also been used to determine the phase shift induced by gas in the wellbore [7,11]. The proposed solution utilizes pressure anomalies in wellbore to detect kicks. By monitoring the time-trends of the down-hole pressure (with the aid of pressure sensors as shown in Error! Reference source not found), unwanted event such as kick can be detected. Downhole pressure measurements in time domain can be converted to frequency domain using Fast Fourier Transform (FFT) to detect unwanted signals. The proposed solution addresses the following key challenges faced by the conventional methods

Earlier detection of kick: By locating the pressure sensor(s) close to the source of the kick, the delay experienced with conventional methods is reduced. There is no need to wait for the flow to get to the surface.

Reduced false alarm: This method will eliminate false alarms due to out-flow drilling fluid expansion. This approach is more sensitive to kick situation as compared to the conventional methods. Hence, reduction is risk and subsequently improvement in safety.

Applications of proposed solution

The proposed solution can be applied in:

1. Managed Pressure Drilling (MPD) to detect pressure anomalies.

Pressure 1	Pressure 2	Pressure 3	Pressure 4	Pressure 5	3 Fluid Flow
54.320457	50.19384	14.580179	5.586773	11.627607	544.83972
54.320457	50.19384	14.580179	5.586773	11.246124	541.0752
54.320457	50.19384	14.924051	5.94955	11.627607	550.486501
54.320457	50.562089	15.207923	5.586773	11.627607	544.83972
54.320457	50.19384	14.236307	5.586773	11.627607	544.83972
54.686498	50.19384	14.580179	5.223995	11.627607	544.83972
54.320457	50.19384	14.580179	5.94955	11.246124	546.721981
54.686498	50.562089	14.580179	5.94955	11.627607	546.721981
54.320457	50.19384	14.580179	5.94955	11.627607	542.95746
54.320457	50.19384	14.924051	5.94955	11.246124	546.721981
54.320457	50.19384	15.955008	5.586773	12.00909	546.721981
54.320457	49.82559	15.267923	5.586773	12.00909	546.721981
54.320457	50.19384	14.024051	5.04055	12.390573	544.83972
54.320457	50.19384	13.20469	5.94955	11.627607	542.95746
54.320457	49.82559	14.580179	5.586773	11.246124	548.604241
57.248783	49.82559	14.580179	5.586773	12.00909	546.721981
54.320457	50.19384	14.924051	5.223995	11.627607	537.31068
54.320457	50.19384	15.267923	4.49844	11.627607	544.83972
54.320457	50.19384	14.580179	5.586773	11.246124	546.721981
54.320457	49.82559	14.580179	5.586773	11.627607	550.486501
54.320457	49.457341	14.580179	5.94955	11.627607	546.721981
54.320457	50.19384	14.580179	5.94955	10.483157	544.83972
54.320457	49.82559	14.580179	5.94955	11.627607	546.721981
54.320457	50.19384	15.267923	3.047331	11.246124	546.721981
54.320457	49.82559	14.580179	5.586773	10.86464	548.604241
54.320457	50.19384	15.267923	5.94955	12.00909	542.95746
53.054416	50.19384	14.024051	5.223995	11.246124	544.83972
54.320457	50.19384	14.580179	5.223995	12.00909	544.83972
54.686498	49.457341	14.580179	5.94955	11.627607	550.486501

Table 1: Experimental result showing the constant liquid rate (540 L/min) without air.

2. Conventional drilling where the operational mode does not allow the use of pit-gain or flow-out/flow-in methods to detect kicks.

3. Flow assurance to detect pressure anomalies. This study will focus on the application in MPD for detecting gas kick.

Laboratory Experiments

This section deals with the laboratory set-up and experiments performed. The experiment is to obtain good pressure readings by observing how two fluids (water and air) interact with each other to create abnormalities that might lead to kick situations in simulated wellbore.

Experimental set-up

The multiphase loop is consisted of two major sections, the horizontal and the vertical parts of the loop. Table 1 show the schematic diagram of the loop.

We focused majored only on the vertical section of the flow test section on our set of experiments. Installed along the loop, are pressure sensors, temperature sensors, air flow valve, liquid flow valve, air flow meters and liquid flow meter. Table 2 shows an image of the multiphase vertical flow loop with temperature and pressure sensors inserted in the pipe.

Design of experiments

Different flow phenomena and fluid interaction in the simulated wellbore have been studied. We obtained pressure reading by varying the flow rates of both liquid and air in two phase vertical pipe. We also

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Date and Time	Pressure 1	Pressure 2	Pressure 3	Pressure 4	Pressure 5	3 Fluid Flow
18-07-2014, 11:58	72.320457	53.508082	12.516946	20.460648	26.123967	697.3028
18-07-2014, 11:58	71.890416	53.508082	12.173074	20.097871	25.742484	701.06732
18-07-2014, 11:58	72.622498	53.139833	12.516946	20.823426	25.742484	702.94958
18-07-2014, 11:58	71.890416	53.139833	12.516946	20.460648	25.742484	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.516946	20.823426	25.742484	697.3028
18-07-2014, 11:58	71.890416	53.139833	12.860818	20.823426	26.123967	697.3028
18-07-2014, 11:58	71.890416	53.139833	12.516946	20.823426	26.886933	699.18506
18-07-2014, 11:58	72.320457	54.01283	12.20469	20.460648	26.50545	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.204469	20.823426	26.123967	695.42054
18-07-2014, 11:58	71.890416	53.139833	13.204469	20.823426	26.50545	699.18506
18-07-2014, 11:58	72.320457	53.139833	13.204469	21.186203	26.123967	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.516946	20.460648	26.886933	701.06732
18-07-2014, 11:58	72.320457	53.139833	12.860818	20.460648	26.123967	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.173074	21.186203	26.886933	701.06732
18-07-2014, 11:58	72.320457	52.103335	12.860818	20.097871	25.742484	701.06732
18-07-2014, 11:58	71.890416	53.139833	13.892435	20.460648	26.123967	699.18506
18-07-2014, 11:58	72.320457	53.139833	13.2.469	21.186203	26.886933	701.06732
18-07-2014, 11:58	71.890416	53.508082	12.860818	20.823426	24.216551	695.42054
18-07-2014, 11:58	72.320457	53.139833	13.20469	20.460648	25.742484	697.3028
18-07-2014, 11:58	72.320457	53.139833	12.516946	20.460648	26.50545	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.173074	20.460648	26.123967	699.18506
18-07-2014, 11:58	72.320457	53.508082	12.860818	20.823426	26.50545	701.06732
18-07-2014, 11:58	72.320457	53.508082	12.516946	20.823426	26.886933	699.18506
18-07-2014, 11:58	72.320457	53.139833	12.516946	20.460648	26.50545	701.06732
18-07-2014, 11:58	72.320457	53.508082	12.860818	21.186203	26.886933	701.06732
18-07-2014, 11:58	72.320457	53.139833	12.516946	20.460648	26.886933	701.06732
18-07-2014, 11:58	71.890416	53.139833	12.860818	21.186203	26.50545	701.06732
18-07-2014, 11:58	72.320457	53.508082	12.860818	20.460648	26.886933	693.538279
18-07-2014, 11:58	72.320457	53.139833	12.516946	20.460648	26.886933	697.3028

Table 2: Showing constant liquid (693 L/min) flow rate with a sudden injection of short air.

observed the various flow patterns in the vertical test section of the pipe. Our experimental procedures are summarized as follows:

1. The flow was started with liquid first, and then pressure measured as air was gradually injected.

2. Different flow rates were obtained by adjusting both the air and liquid flow valves (producing bubble or slug flow patterns).

3. Pressure measurements are taken on the simulated wellbore.

4. The pressure-time result is saved for further analysis.

5. Keeping air flow rate constant and varying the liquid rates. (max liquid rate achievable was 718 L/min and the min rate was 540 L/min).

6. Keeping liquid rate constant and sudden release of air for a very short period (1 sec) into the system (the busty effect).

7. Tables 1 and 2 show an experimental data at 540 L/min without air and at 693 L/min with a sudden injection of air at a very short time (1 sec).

8. We also monitored the behaviour pattern of pressure from pressure probe 2 (#2 as shown in Figure 1) and pressure probe 4 (#4).

9. Our main area of focus is on the pressure #2 and #4 of the test section of the vertical pipe.

10. From the pressure difference between pressure #2 and #4, we predicted kick situation.

Result Analysis

This section deals the analysis performed for this study. It presents the underlying principles and performance of the kick detection tool used.

Underlying principle and detection algorithm

The foundation or main underlying principles used in the kick detection tool is wavelet transformation. A wavelet is a function of zero average [12]. Its amplitude starts at zero, increases, and then decreases back to zero. There are various type of wavelets based on the algorithm used in generating the wavelets [13]. The most common types are Daubechy, Coiflet, Meyer, Symmlet. Wavelet applications can be found in several applications such as image recognition applications, seismograph, blood-pressure, heart-rate and ECG analyses, music editing, finger print verification, DNA analysis, speech recognition, and several other signal processing applications [14] (Figure 2).

In summary wavelet transformation is the use of wavelets to remove or filter noise (unwanted signals) in order identify a pattern or target [14].

Kick detection algorithm

The algorithm used in detecting kicks is summarized in the flow steps below:

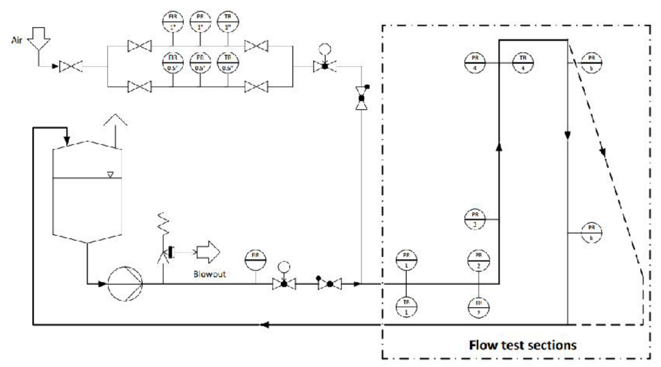

Figure 1: Full graphic image of the multiphase loop.

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Step 1: Measure the pressure difference between a reference location and the point of interest in the wellbore (higher than the reference location).

Step 2: Appropriate wavelet transform level is calculated based on this pressure difference.

Step 3: Pressure response from the interest location is passed through the wavelet scale tool.

Step 4: Spikes (Kicks) are detected by the tool. The current version of the wavelet tool developed is a pure nominal scale that detects a kick or non-kick situation. Currently, the severity/magnitude of kick not calculated by the tool.

i. Flat line = Non-kick situation.

ii. Spike = Kick situation.

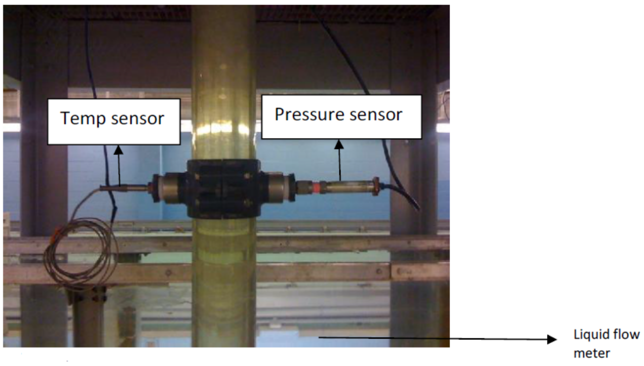

Figure 2: Temperature and pressure sensors.

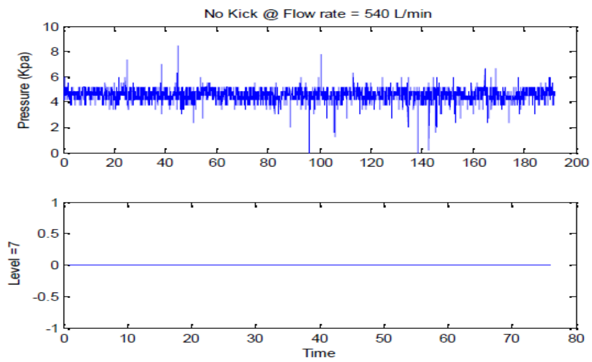

Figure 3a: No kick @ flow rate = 540 L/min.

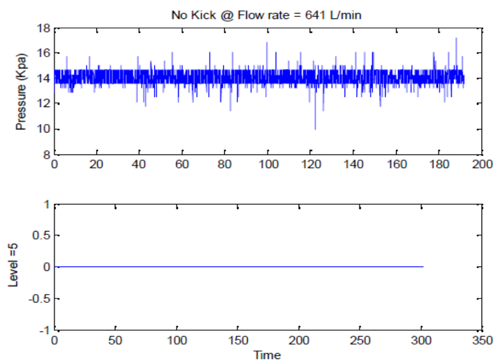

Figure 3b: No kick @ flow rate = 641 L/min.

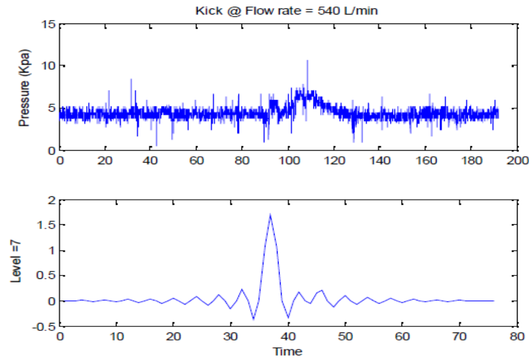

Figure 4a: Kick @ flow rate = 540 L/min.

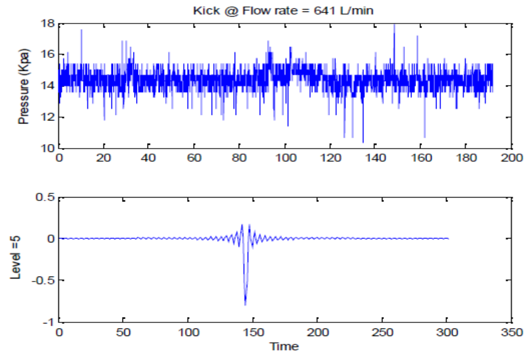

Figure 4b: Kick @ flow rate = 641 L/min

Results

This section presents the result and conclusion of the analysis performed in this study. The result is based on flow patterns of 540 L/min to 718 L/min and air burst durations of 0, 1, and 2 seconds. The reference point is taken as #P2 probe, while the point of interest is #P4 probe. Results from the wavelet tool are compared with results from pure gauge pressures at the location of interest.

No kick situation: Figures 3a, 3b is the response without kicks at the lower and upper ends of the achievable flow rates in the lab. The top charts are the gauge pressure response, while the bottom charts are the wavelet scale response. Observing the top charts exclusively could be misinterpreted for kick. By using the tool, no spike is observed, the line is flat, hence no kick

Bursty early kick situation: Figures 4a, 4b is the response with kicks at different flow rates. The top charts are the gauge pressure response, while the bottom charts are the wavelet scale response. By using the tool, a spike was clearly visible to indicate a potential kick situation.

Reliability test: Three runs (repeated measurements) where performed on sample size of 16 flow scenarios. Reliability tests were performed in SPSS and MedCalc using both coefficient of variation from duplicate measures test as well as Cronbach's Alpha test. As shown in Figures 5a, 5b, no variation was observed between duplicate runs and the Chronbach's alphas score is 1. For research purposes Chronbach's alpha should be more than 0.7 [15].

Validity test: The validity test performed using Kappa Agreement test. Twenty four flow scenarios were measured using the wavelet tool against actual physical observation (goal standard). As shown in Figures 6a, 6b, the Kappa score is 0.909 (90.09%) indicating very good

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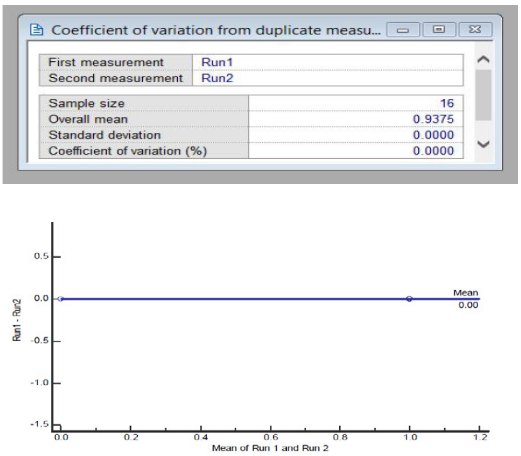
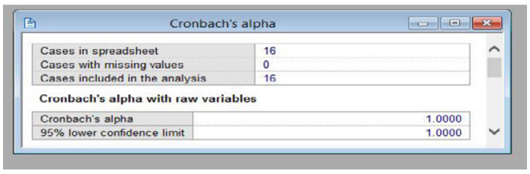
scale. The wavelet scale successfully detected 15 of 16 kick situations and 8 of 8 no kick situations.

Performance and liquid flow rate: Experiments were performed to determine the advantages of the wavelet tool (over pure gauge pressure method) at different flow rates. As shown in Figure 7, at lower flow rates (Figure 7a), both gauge pressure method and wavelet method can clearly show the kick. At higher flow rates (Figure 7b), the wavelet method out performs the pure gauge pressure method.



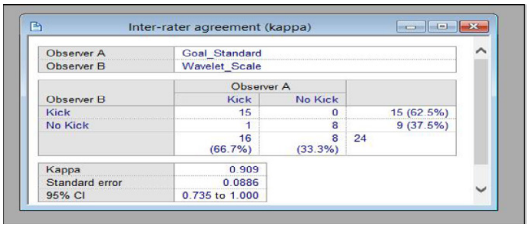
First measurement	Run1
Second measurement	Run2
Sample size	16
Overall mean	0.9375
Standard deviation	0.0000
Coefficient of variation (%)	0.0000

Figure 5a: Co-efficient of variation test results.



Cases in spreadsheet	16
Cases with missing values	0
Cases included in the analysis	16
Cronbach's alpha	1.0000
95% lower confidence limit	1.0000

Figure 5b: Cronbach's alpha test result.



Observer A	Goal_Standard		
Observer B	Wavelet_Scale		
	Observer A		
Observer B	Kick	No Kick	
Kick	15	0	15 (62.5%)
No Kick	1	8	9 (37.5%)
	16 (66.7%)	8 (33.3%)	24
Kappa	0.909		
Standard error	0.0886		
95% CI	0.735 to 1.000		

Figure 6a: Kappa agreement test result.

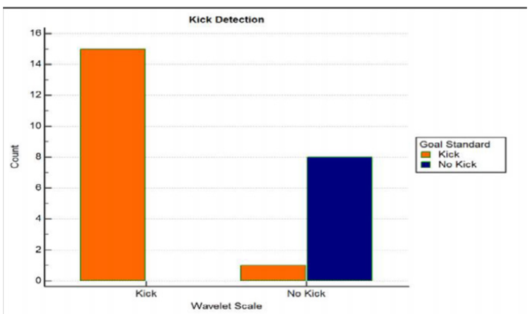


Figure 6b: Kick detection frequency chart.

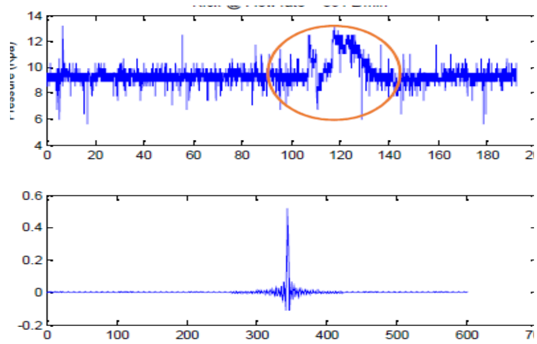


Figure 7a: Kick @ flow rate = 564 L/min.

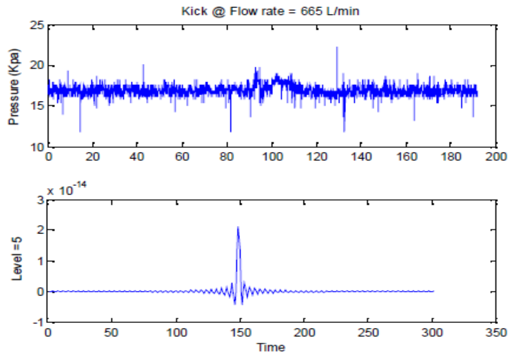


Figure 7b: Kick @ flow rate = 665 L/min.

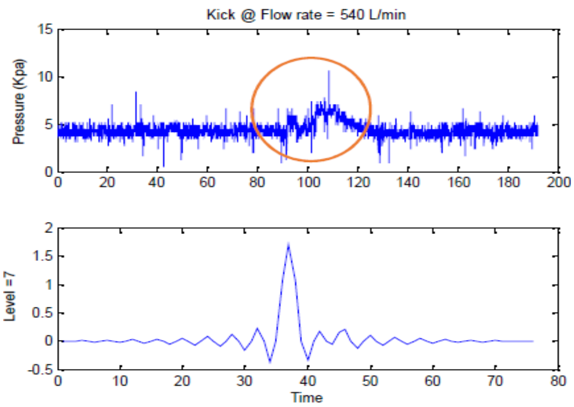


Figure 8a: Kick @ flow rate = 540 L/min at 2 seconds burst.

Performance and burst duration: Experiments were performed to determine the advantages of the wavelet tool (over pure gauge pressure method) at different air burst durations. To bursts durations – 1 second and 2 seconds were used for the analysis. At longer burst durations (Figure 8a), both pure pressure and wavelet methods can clearly show the kick. At shorter burst durations (Figure 8b), the wavelet method out performs the pure gauge pressure method.

Performance and burst rate: Experiments were performed to see how the tool reacts with burst rate. At low burst rates (Figure 9a) the tool is more accurate at detecting the number of bursts. At higher burst rated (Figure 9b), the performance diminishes. This is in agreement with the design of the tool. The tool is designed to detect early kick which is typically characterized with low rate bursts. High rated bursts signify late kick situations.

Conclusion and Future Work

From the results and analysis present above, it shows that the wavelet method appears to be more efficient than pure gauge pressure gauge method in detecting bursty early kicks situations. Its benefits over the pure gauge method is more pronounced with higher liquid flow rates, with shorter kick burst duration, and as well as with shorter kick burst durations. This type of scenario is similar to a potential kick environment in deep see drilling i.e., higher drilling mud flow rates with higher drilling depths, and lots of fractures zones that are potential sources of bursty kicks. This current version of the tool does not calculate the severity/magnitude of the kick. For future work, the returned wavelet coefficients could be utilized in developing an algorithm to determine the kick severity. In conclusion, wavelet transformation is a viable tool in early detection of kicks.

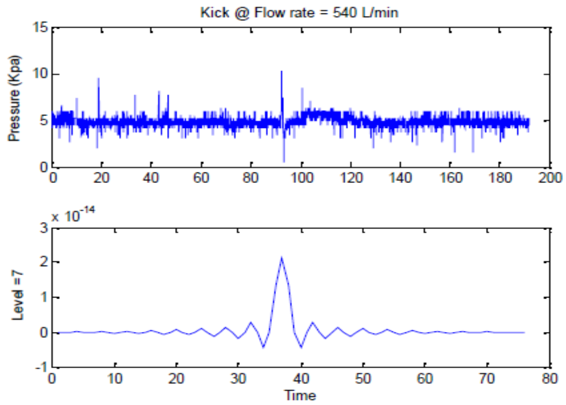


Figure 8b: Kick @ flow rate = 540 L/min at 1 second burst.

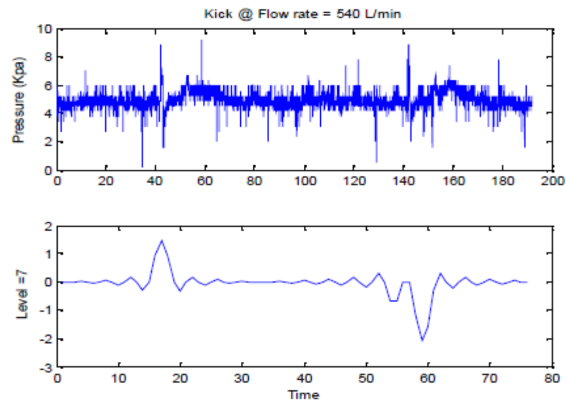


Figure 9a: Kick @ flow rate = 540 L/min; Bursts at 25% and 75% flow time.

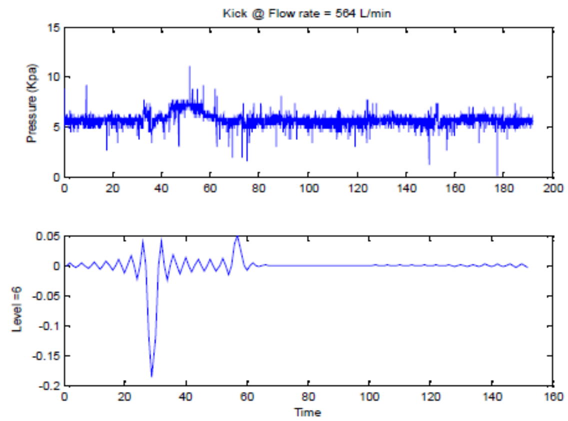


Figure 9b: Kick @ flow rate = 564 L/min; Bursts at 25%, 75% flow time.

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