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Research Article

# DEVELOPMENT OF OIL WELL MONITORING AND CONTROL SYSTEM

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A B S T R A C T

Kick is an unplanned and undesirable influx of formation fluid into the borehole which if not curtailed, may develop into a blowout. It may arise if the formation fluid flows into the wellbore in an unplanned fashion when the drilling mud hydrostatic head is insufficient to hold. A kick may escalate into a potentially catastrophic uncontrollable flow of reservoir fluids termed as blowout. If a blowout breaches surface containment, the fluid may ignite, resulting in inferno with loss of life and damage to the oil well facilities. This paper presents the development of an oil well monitoring and control system that is capable of preventing kick and its effects. The system comprises of a simulator, data acquisition and control and monitoring modules. The simulator comprises of sensors for the hook-load, stand pipe pressure, rotary per minute, major depth, mud weight, mud temperature, stroke per minute and other related parameters. The data acquisition module is required for data gathering, analysis and real time decision making for quick and effective service in oil well monitoring and control. It receives pulses or voltage signals from the sensors for storage or transmission. The control and monitoring module comprises of sub-modules for depth, drilling, flow and kick monitoring. The implementation of the proposed system was carried out in an environment characterized by Microsoft Access Database Management System and Microsoft Excel as backend, Visual Basic.Net served as the frontend while Microsoft Windows Operating System is the operational platform. The simulation of Nigeria's Etim oil well monitoring and controlling operations was carried out and obtained results confirmed the suitability and practicality of the proposed system



## INTRODUCTION

Oil well control is a precautionary method of ensuring a smooth drilling of hydrocarbon. It is a multifaceted phenomenal that guarantees economically viable and ecologically responsible drilling. Oil well control is required for averting inimical effects arising from un-envisaged discharge of formation fluid, maintenance of pressure on accessible formations as well as direction or prevention of the flow of formation fluids into the wellbore. It is also required for obstructing formation fluid (usually referred to as kick) from advancing into the wellbore during drilling. If the exerted pressure of drilling is not sufficient to overcome the pressure in the formation, there may be fluid penetration into the wellbore and failure to effectively manage or control this anomaly may lead to massive explosion (blowout). Excessive blowout may result in outbreak of fire (Aldred *et al*., 1999; ERDSG, 2005; API, 1999; Lyons and Plisga., 2005; Schlumberger Oilfield Glossary, 2011).

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Incorrect interpretation of well condition, poor fluid control, imprecise interpretation of trip tank data and inadequate problem prevention strategies have been reported as largely responsible for blowout. In some cases, field personnel lack the basic understanding of early kick detection and how rapidly things can deteriorate if the wrong action is taken. Several countries of the world had suffered terrible losses in terms of human capital and environmental degradation caused by incidences of blowout.

The need to keep drilling pressure under control and avert blowout as well as sporadic oil spillage which often precipitates into conflagration of inclination has motivated the development of several oil well control systems. The authors in [Iversen *et al,* 2006] developed a monitoring and optimization system for drilling operations, based on real time data measurements. The system observes the Weight on Bit (WOB), Rotary Per Minute (RPM) modulation and Rate of Penetration (ROP) within critical limits with a view to increasing safety and reducing operational downtime. The work in (Michael and Collin, 1999) focused on oil well drilling control practices and equipment consideration for deepwater operations plan. The research addressed the high cost and technical challenges associated with drilling in deeper waters as well as identified the magnitudes and type of events that may occur during an oil well drilling operation. Risk Analyses of oil well control practices and equipment utilization as well as hazards probability and consequences were carried out. The research is limited by its failure to give consideration to processing of risks associated with deepwater operations. A system for the analysis of alternative well control methods for dual density deepwater drilling was presented in (Mikolaj, 2005). The research addressed the issue of enormous uncertainties and huge capital investment acquired in most oil well control methods and proffered solution to difficulties associated with reaching the target depth for deepwater oil wells while retaining a useable borehole size. It also provided a system with acceptable pressure profiling in deepwater wells with narrow pores and fracture pressure margins. However, the system does not support significant riser surface pressure while drilling. The authors in (Byee, 2005) formulated a Risk Evaluation Model (REM) and Probabilistic Risk Assessment (PRA)-based technique for assessing and reducing the probability of kick occurrence in oil well drilling. The major challenges faced by the technique include inadequacy on the part of REM for real-life demonstration and lack of support for drawing inference and decision making. The authors in (Per and Pal, 2001) presented an overview of deep water kick frequencies and the important contributing parameters. Data on BOP failures and kicks were collected from relevant sources and used for the computation of the mean time between kicks (MTBK) and High Pressure Temperature (HPHT).

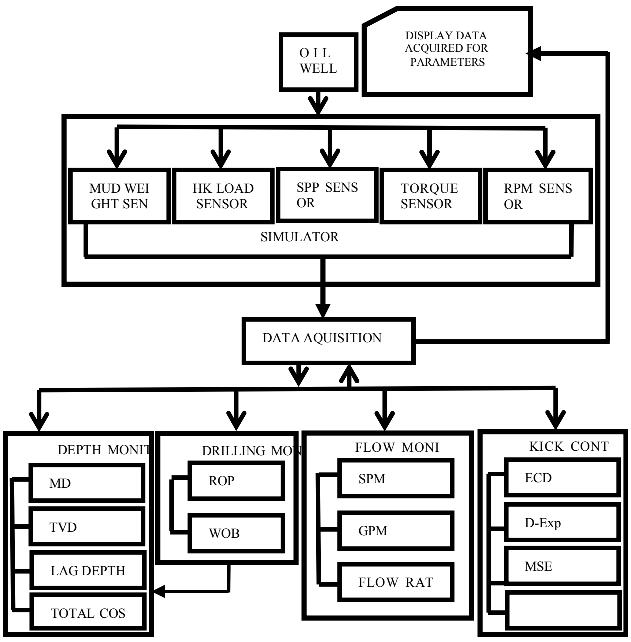


Figure 1: Architecture for Oil Well Control

The results of the computation encouraged the development of a system for the reduction of deep water kicks and the associated BOP problems. The system is however limited by failure to optimize the time required for kick control. In (Velavan *et al.,* 2015; Qingjie and Wang, 2011), wireless sensor network-based systems for effective and real-time control of oil exploration, drilling and pumping units spread over barren hills, mountain and deserts were presented. The systems provide power and time saving strategies for control and monitoring of oil well operations but susceptible to problems arising from network failure or loss of signal. (Presanta, 2001) addressed the problems of negative environmental impact, cost, time delay among others that are associated with the management of project on the pipeline operations and presented a Decision Support System (DSS) model for petroleum pipeline project risk management. The research is limited in scope and environment and therefore, its results are not suitable for global consideration.

***Proposed Oil Well Monitoring and Control System***

The architecture of the proposed oil well monitoring and control system which addressed some of the limitations of the existing works is presented in Figure 1 showing the core procedures involved in the effective monitoring and control in oil well operations. It consists of the simulator, data acquisition and monitoring modules.

***The Simulators***

The simulator is a computer model that mimics a real-life production or logistics process in oil well. It requires input voltage of between 220v to 230v and output voltage of zero to five volts to operate with various channels. The simulator is fitted with electrically powered sensors that acquire and send pulses or current signals on Hookload, Stand Pipe Pressure (SPP), Rotary Per Minute (RPM), Major Depth (MD), Mud Weight (MW), Mud Temperature (MT), Stroke Per Minute (SPM) and other related parameters to the Data Acquisition System (DAS) which in turn transmits the signals to a computer software. The circuit diagram of the Simulator is present in Figure 2. The Simulator requires 6-channel signal buffered by the AD op amplifier, an RC networks to provide high frequency noise filtering and isolate the buffer from the multiplexer switching transistor as well as a multiplexer IC to minimize the feed-back charge.

***Data Acquisition (DAS)***

The DAS is required for data gathering, analysis and real-time decision making for quick and effective service in oil well monitoring and control. It receives pulses or voltage signals from the sensors and vary the received signals before storage or transmission. It monitors sixteen analog and two digital channels for depth control with rugged enclosure that consists of the Central Processing Unit (CPU) and other hardware units that monitors data on mud weight, hook-load, stand pipe pressure, torque and rotary per minute, the drilling depth, flow pattern and kick occurrence. It does not require complicated equipment or procedures to deploy once the work string is in place as it uses acoustic energy to transmit real-time data to the surface where nonintrusive receiver forwards the data to the computer software for decoding, display and evaluation purposes.

***Depth Monitoring***

Depth in an oil well is the distance between the reference and target points. Oil wells are not always drilled vertically, hence leading to two depths for a given reference point, namely Measured Depth (MD) which is measured along the path of the borehole and True Vertical Depth (TVD) which is the absolute vertical distance between the datum and the point in the wellbore. In perfectly vertical oil wells, the TVD equals the MD; otherwise, the TVD is less than the MD measured from the same Ground Level (GL), Drilling Floor (DF), Rotary Table (RT), Kelly Bushing (KB) and Mean Sea Level (MSL). The mathematical expression for the true vertical depth, $d_t$ of survey of oil well is defined as follows:

$$d_t = \Psi\cos\theta + \rho \quad (1)$$

$$\Psi = M_2 - M_1 \quad (2)$$

$$d_n = \cos\theta * \Psi + d_t \quad (3)$$

$d_n$ is the new true vertical depth, ρ is the referential difference, θ is angle of inclination, $M_1$ and $M_2$ are the initial and final length from the last survey respectively.

### *Rate of Penetration (ROP)*

ROP in an oil well drilling is the speed at which the drilling bit breaks the formation rock to deepen the borehole. It increases in fast drilling formation such as sandstone (positive drill break) and decreases in slow drilling formations such as shale (reverse break). The monitoring of ROP requires conversion of the individual distance-per-time intervals to relative percentages of the total time being averaged. Similarly, each time-per-distance segment must be seen as a relative percentage of the distance being averaged. ROP, *r* is obtained as follows:

$$r = \frac{D_d}{D_t} \quad (4)$$

$D_d$, $D_t$ are the drilling depth and time respectively.

### *Cost of Drilling*

Cost of drilling in oil well operation comprises of drilling, tubing, casing and wellhead cost (Mitchell, 1974). The drilling cost per footage drilled represented as $C_k$ is computed as follows (Lapeyrouse, 2002):

$$C_k = \frac{B_k + G(R_k + T_r)}{P} \quad (5)$$

k= 1, 2, …, n, n is the number of footage, $B_k$ and $R_k$ are the cost and the rotating time for footage k respectively, G is the Rig cost, P is the bit footage and $T_r$ is the round trip time. The total drilling cost, for the total depth D and the cost per meter, $P_m$ of hole drilled are computed as [Nguyen, 1996]:

$$C_T = C_k \times D \quad (6)$$

$$P_m = P_b + H_c + M_c \times \frac{P_h(T_t+T_r)}{M} \quad (7)$$

$P_b$ is net cost of the bit, $H_c$ and $M_c$ are the cost of settling the host community and drilling the mud respectively, $P_h$ is rig rental price per hour, $T_t$ is tripping time and M is number of meters drilled.

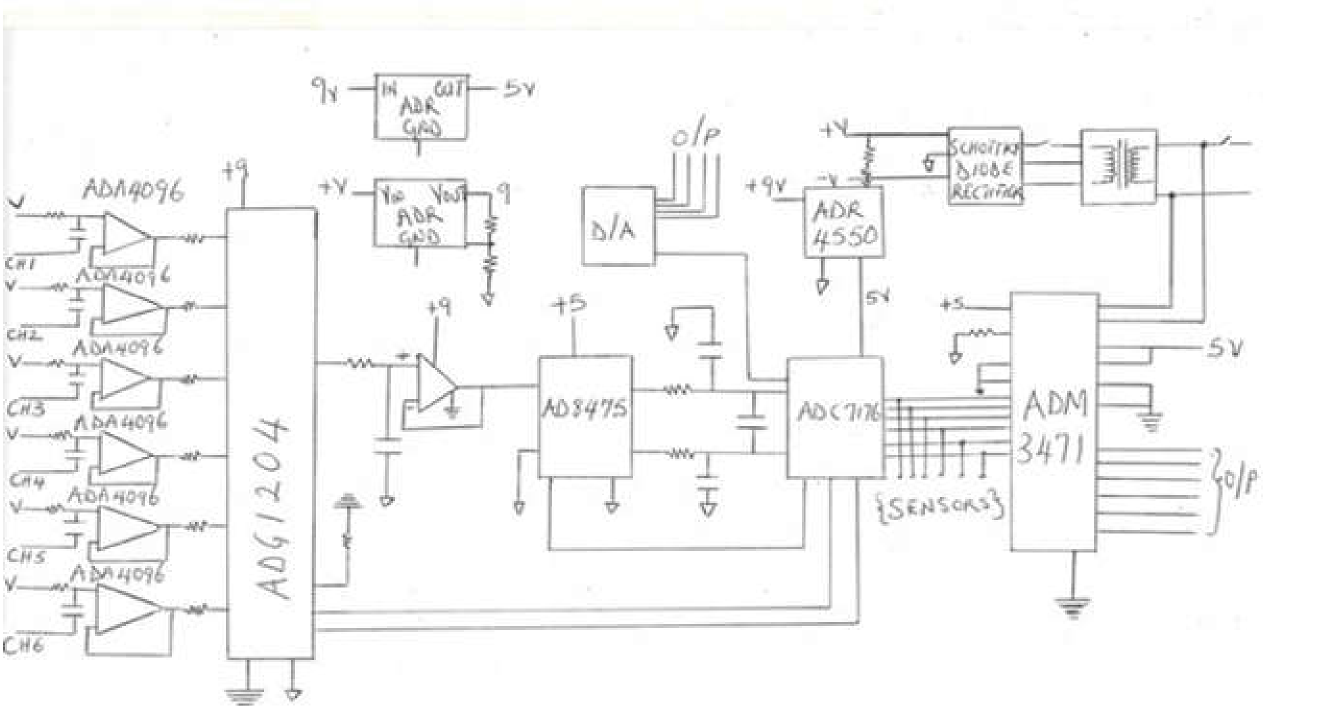


**Figure 2** Circuit Diagram of the Simulator

### *Weight on Bit (WOB)*

WOB is measured in thousands of pounds as the amount of downward force exerted on the drill bit provided by drill collars, which are thick-walled tubular pieces machine of solid bars of nonmagnetic nickel-copper alloy or carbon steel. It acts on the large mass of the collars to provide the downward force needed for the bits to efficiently break rock [Lyons and Plisga, 2005]. The drill string (and the drill bit), is slowly and carefully lowered until it touches the bottom and as the top of the drill string is lowered, more and more weight is applied, and correspondingly, less weight is measured as hanging at the surface. If the surface measurement shows 20,000 pounds or 9080 kg less weight than with the bit off bottom, then 20,000 pounds force on the bit (in a vertical hole) is presumed.

### *Flow Monitor*

The well pumping rate invariably determines its flow rate and is limited by the horsepower of the well pump, pump type, pump location, and other factors. The maximum well pumping rate set by the pump is normally a number stamped on the data tag attached to the well pump itself. The well pumping rate defines how fast in Gallons per Minute (GPM) the pump can deliver water if it has an infinite quantity available. The pump capacity $p_c$ is defined as follows:

$$p_c = v \times \frac{V_a \times C_a}{O_p} \quad (8)$$

$v$ represents the pump discharged in gpm, $V_a$ is annular velocity, $C_a$ is annular capacity and $O_p$ is output from the pump.

The flow rate, $f$ which is the volume of fluid that passes through a given surface per unit time, is obtained as follows:

$$f = \frac{1}{2} \times \pi r^2 \times v_f \quad (9)$$

r is radius of the pipe and $V_f$ is velocity of the flow of the fluid in the pipe.

***Pressure***

The pressure at the bottom of the borehole must be accurately determined if the leak off or fracture pressure of the formation is not to be exceeded. When the drilling fluid is circulating through the drill string, the borehole pressure at the bottom of the annulus exceeds the hydrostatic pressure of the mud. The extra pressure is as a result of the frictional pressure required to pump the fluid up the annulus. This frictional pressure must be added to the hydrostatic pressure to get a true representation of the pressure acting against the formation at the bottom of the well. An equivalent circulating density $d_c$ is then calculated as follows:

$$d_c = W_m * h + \frac{P_f}{0.052} \quad (10)$$

$W_m$ is the mud weight, $P_f$ is annulus frictional pressure drop at a given circulation rate and $h$ is depth in feet. The equivalent circulating density is continuously monitored to ensure that the pressure at the formation below the shoe, due to the ECD of the fluid and system, does not exceed the leak off test pressure.

***Implementation and Results***

The proposed system was implemented on a Pentium 4 with a Processor Speed of 400MHZ on a Hard Disk Space of 40GB and RAM of 4GB. The data acquisition system is a 32 bit MCC DAC Model, which interconnects a Simulator that comprises of 6 analog and 4 digital Sensors. The operational environment is characterized by the Windows XP, Microsoft Visual Basic.Net as the frontend engine and Microsoft Access Database Management System and Microsoft Excel as backend engines

***System Simulation***

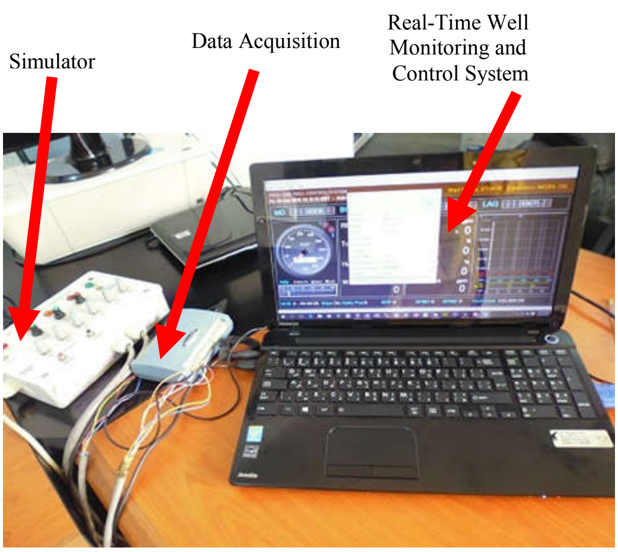


**Figure 3** Experimental Setup

The experimental setup for the simulation operations based on ETIM 36 Mobil Oil operations in Nigeria is presented in Figure 3. The simulator comprises of four (4) digital and eight (8) analogue sensors and configured to the required input and output voltages that range between 220-230v and 0-5v respectively with the aid of the 32 bit MCC DAC data acquisition tool. With distinguishable cables, the simulator was connected to the oil well and the data acquisition mechanism.

The first digital sensor was connected to channel 2 of the system and transmits at a signal and attenuation values of 2804 and 1 respectively while the second digital sensor transmits at attenuation of 1 but with no assigned channel and signal value. The third digital sensor actuates Pump 1 and feeds channel 2 at a signal strength of 2504 and attenuation of 1. Finally, the fourth sensor is connected to Pump 2 to transmit at signal strength of 2524 on channel 2 and an attenuation of 0.9.

Analogue sensor 1 monitors the hookload and is connected to channel 2 with low and high voltage of 0.04 and 2.47 respectively and maximum and minimum psi values of 300klb and 0klb respectively. Analogue sensor 2 monitors the SPP and it is connected to channel 2 at a low voltage of 0, high voltage of 2.76, maximum psi value of 3000klb and minimum psi value of 0klb. The third analogue sensor requires a minimum psi value of 0 and maximum psi value of 280klb to function and monitors the RPM via channel 3 at a low and high voltage of 0.04 and 2.42 respectively. While analogue sensor 4 monitors the outflow using channel 4 and a high voltage of 2.19 at maximum psi value of 12klb, analogue sensor 5 monitors the total gas using channel 5 and a high voltage of 0.77 with maximum psi value of 56klb. Sensors 6, 7 and 8 are all connected to channel 6 to monitor the torque, mud weight and ROP respectively. The three sensors operate at a high voltage of 1.8, 1.79 and 1.8 respectively and maximum psi values 12klbs, 8klb and 8klb respectively. Table 1 presents the standard (actual length of the bit) and the calculated (calibrated) lengths (in feet) as well as the total and footage pulse generated from the encoder for five (randomly) selected points in the oil well. The calibrated lengths were derived as the difference between the previous and present standard lengths.

**Table 1** Depth calibration of Experimental Setup

| ID | Points | Standard Length | Calibrated Length | Total Pulses | Pulses/Footage |
|---|---|---|---|---|---|
| 1 | Point #1 | 12.50 | 10.00 | 1221 | 122.10 |
| 2 | Point #2 | 22.90 | 10.40 | 1216 | 116.92 |
| 3 | Point #3 | 34.19 | 11.29 | 1293 | 114.53 |
| 4 | Point #4 | 44.80 | 10.61 | 1235 | 116.40 |
| 5 | Point #5 | 54.70 | 09.95 | 1110 | 111.56 |

For each point *i*, the calibrated length, $L_i$ was obtained and the total pulse, $T_i$ was recorded by the encoder. The pulse per footage is computed as the quotient of $T_i$ and $L_i$. The sensors were electrically powered to acquire well borehole distances, mud level and pipe vibrations as well as strings rotation. The kick simulator provides the kick tolerance calculation and stimulates quick influx into the well bore. With high accuracy and less conservative, it predicts the maximum pressures at any point of the annulus and how much time the rig crew has to shut-in the well before the influx exceed the kick tolerance limit. Based on these, the simulators provide direct indications in the level of risk involved under various scenarios. The simulator has sensors for monitoring the Hookload, SPP, RPM, MD, WOB, ECD, MSE, Mud Weight, Mud Temperature, SPM and other relevant signals for depth, drilling, flow and kick control. It used various channels that either increase or decrease pulses received from the sensors for onward transmission to DAS in a way similar to reading actual values of digital and analog sensors.

## ANALYSES OF RESULTS

The default parameter settings are presented in Table 2 and the results for the data acquisition mechanism based on synergy between the simulator and the computer software are presented in Table 3, Table 4, Table 5 and Table 6.

**Table 2** Parameters and their default values

| ID | Variable | Value |
|---|---|---|
| 1 | Minimum Hookload | 150 |
| 2 | Maximum Kelly Height | 100 |
| 3 | Bit Cost | 25000 |
| 4 | Maximum Hookload | 250 |
| 5 | Rotary Height | 4 |
| 6 | Maximum ROP Gauge | 500 |
| 7 | ROP Correction | 0 |
| 8 | Current MD | 350 |
| 9 | Current Bit | 368.7 |
| 10 | Pump Output | 0.125 |
| 11 | Mechanical Efficiency | 0.35 |
| 12 | Annular Pressure Loss | 0.5 |
| 13 | Normal Pore Pressure Gradient | 0.245 |
| 14 | Normal D-Exponent | 0.3 |

Figure 5 presents the characteristics curve of MD against WOB values. The curve reflects irregular and unsteady penetration rates for the measured depths and the bit weights. Between 365ft and 369.5ft, the bit weight only increased by 1ft/hr indicating a very slow penetration.

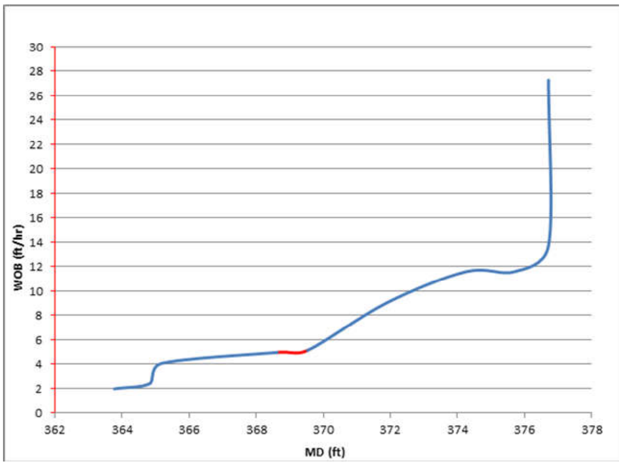


Figure 5: Characteristics Curve of MD against WOB

**Table 3** Sensor derived data for depth monitoring

| MD | TVD | ROP | HOOK-LOAD | TOQUE | LAG DEPTH | TOTAL COST/DEPTH (N) | MUD WEIGHT |
|---|---|---|---|---|---|---|---|
| 363.7683761 | 341 | 00 | 299.63 | 9.55 | 0 | 130000 | 6.40 |
| 364.8311226 | 348 | 10 | 298.73 | 9.54 | 0 | 132000 | 6.39 |
| 365.1577630 | 356 | 20 | 299.79 | 9.51 | 0 | 134000 | 6.38 |
| 368.6258157 | 364 | 30 | 296.62 | 9.52 | 0 | 136000 | 6.38 |
| 369.5246684 | 364 | 40 | 297.68 | 9.52 | 0 | 138000 | 6.38 |
| 371.8911080 | 364 | 50 | 296.47 | 9.52 | 0 | 140000 | 6.38 |
| 374.2575476 | 364 | 60 | 300.09 | 9.52 | 0 | 142000 | 6.38 |
| 375.7007173 | 364 | 60 | 300.84 | 9.47 | 0 | 144000 | 6.35 |
| 376.7136251 | 364 | 60 | 291.35 | 9.35 | 0 | 146000 | 6.27 |
| 376.7136251 | 364 | 60 | 302.95 | 9.46 | 0 | 148000 | 6.34 |

Figure 4 presents the graph of the plot of data on measured depth (MD) against rate of penetration (ROP). The graph depicts how the ROP fluctuates based on the nature of formation encountered at different depths. When a hard formation is encountered, ROP becomes low and vice-versa. As illustrated on the graph, at 371ft, soft formation is encountered and consequently, the rate of penetration was high (48ft/hr). Conversely, ROP decreased to 21.51ft/hr on getting to 374.25ft and to a further 10.76ft/hr when the bit encountered a harder formation at 378.713ft. The zigzag nature of the graph implies an irregular soil formation and consequently, a non definable rate of penetration. It also shows that the pattern of swag between the soft and hard formations in the oil well is undefined or unpredictable.

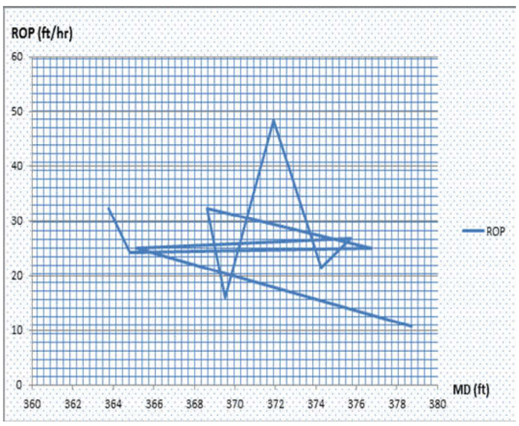


**Figure 4** Graph of MD Against Rop

For between 369.5ft and 375 ft, the penetration rate improves steadily as the bit weight increases to 6 ft/hr before assuming a near-constant rate for MD in the range 375ft and 376.5ft. A sharp and very high penetration rate is depicted for MD of about 377ft with a bit weight of 14*ibl*.

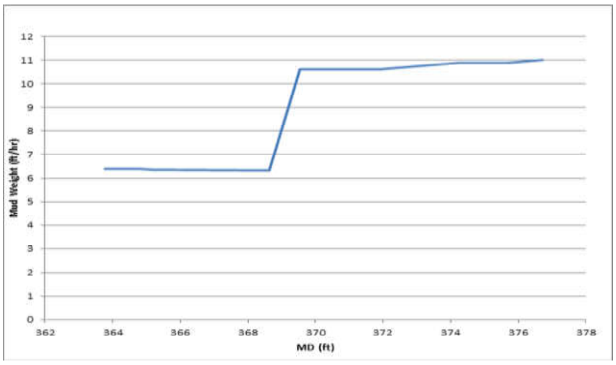


Figure 6: Graph of MD against Mud Weight

The plot of MD against the mud weight values is presented in Figure 6. The plot reveals a steady decrease of the mud weight from 6.4ppg to 6.32ppg at depth 363.7ft through 368.6ft before increasing from 6.32ppg to 10.6ppg at depth 368.6ft through 369.5 and from 10.6ppg to 11ppg at depth between 369.5ft and 376ft. Decreased mud weight is attributed to drilling of hard formation while increased mud weight is attributed to drilling of soft formation. The rate of increase or decrease of the mud weight signifies the degree of the softness or the hardness of the formation.

**Table 4** Sensor derived data for drill monitoring

| MD | TVD | ROP | WOB | LAG DEPTH | SPP |
|---|---|---|---|---|---|
| 363.76837610 | 341 | 0 | 4.969996 | 0 | 2681.57 |
| 364.83112260 | 348 | 10 | 5.129996 | 0 | 2673.61 |
| 365.15776300 | 356 | 20 | 1.959996 | 0 | 2682.89 |
| 368.62581570 | 364 | 30 | 11.59999 | 0 | 2655.03 |
| 369.52466840 | 364 | 40 | 13.72000 | 0 | 2664.32 |
| 371.89110800 | 364 | 50 | 2.410001 | 0 | 2653.7 |
| 374.25754760 | 364 | 60 | 27.28001 | 0 | 2685.55 |
| 375.70071730 | 364 | 60 | 9.040001 | 0 | 2692.18 |
| 376.71362510 | 364 | 60 | 11.59999 | 0 | 2608.59 |
| 376.71362510 | 364 | 60 | 4.070001 | 0 | 148000 |

**Table 5** Sensor derived data for flow monitoring

| SPM | GPM | FLOW IN | FLOW OUT |
|---|---|---|---|
| 80 | 420.0 | 10.00 | 10.250 |
| 80 | 420.0 | 10.00 | 10.270 |
| 82 | 420.0 | 10.25 | 10.240 |
| 82 | 430.5 | 10.25 | 10.250 |
| 82 | 430.5 | 10.25 | 10.230 |
| 82 | 430.5 | 10.25 | 10.210 |
| 82 | 430.5 | 10.25 | 10.230 |
| 82 | 430.5 | 10.25 | 10.024 |
| 82 | 430.5 | 10.50 | 10.460 |
| 82 | 430.5 | 10.25 | 10.25 |

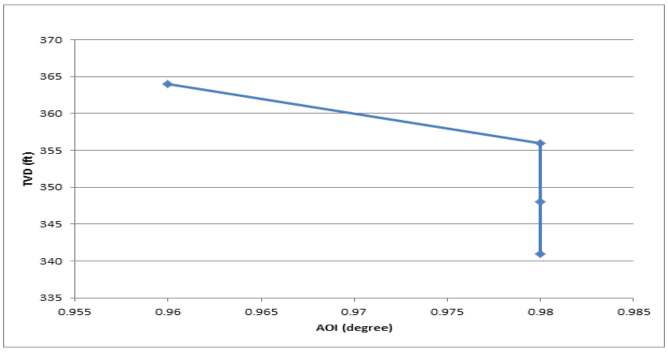


**Figure 8** A Graph of AOI against TVD

Figure 7 represents the relationship between MSE and WOB in the oil well at different formations in the transition zone. The zigzag shape of the curve implies that different hard and soft formations are drilled in no specific order. Visual inspection of this relationship reveals that MSE rises steadily from 190 to 280 for WOB between 4ft/hr and 11ft/hr and falls to 190 when WOB falls from 11ft/hr to 8ft/hr. MSE again rises steadily to 375 when WOB increases from 8ft/hr to 27.5ft/hr before attaining a maximum value of 400 and a minimum value of 370 as WOB decreases to 2.5ft/hr.

The line plot of the angle of inclination (AOI) against the TVD presented in Figure 8 shows a constant angular inclination of $12^{o}$ (0.98) for oil well drilling from 341ft through 356ft, before drilling deviates steadily to angular inclination of $15^{o}$ (0.96) from 356ft to 364ft.

**Table 6** Sensor derived data for kick control monitoring

| MD | ECD | D-Exponent | Pore Pressure | Flow In | Flow Out | SPP | ROP | MUD Weight | RPM |
|---|---|---|---|---|---|---|---|---|---|
| 363.7683761 | 11.28 | 1.49 | 0.0551 | 10.00 | 10.25 | 2681.57 | 10 | 6.40 | 276.20 |
| 364.8311226 | 11.05 | 1.50 | 0.0402 | 10.00 | 10.27 | 2673.61 | 10 | 6.38 | 276.63 |
| 365.1577630 | 10.80 | 1.40 | 0.0414 | 10.25 | 10.24 | 2682.89 | 20 | 6.37 | 275.91 |
| 368.6258157 | 10.57 | 1.53 | 0.0331 | 10.25 | 10.25 | 2655.03 | 30 | 6.32 | 276.06 |
| 369.5246684 | 10.57 | 1.52 | 0.0367 | 10.25 | 10.23 | 2664.32 | 40 | 10.6 | 275.91 |
| 371.8911080 | 10.57 | 1.02 | 0.0342 | 10.25 | 10.21 | 2653.70 | 50 | 10.6 | 275.77 |
| 374.2575476 | 10.57 | 1.73 | 0.0495 | 10.25 | 10.23 | 2685.55 | 60 | 11.9 | 275.77 |
| 375.7007173 | 10.57 | 1.30 | 0.0494 | 10.25 | 10.02 | 2692.18 | 60 | 10.9 | 271.89 |
| 376.7136251 | 10.57 | 1.36 | 0.0599 | 10.50 | 10.46 | 2608.59 | 60 | 11.0 | 275.34 |
| 376.7136251 | 10.57 | 1.10 | 302.95 | 10.25 | 10.25 | 148000 | 10 | 11.0 | 276.63 |

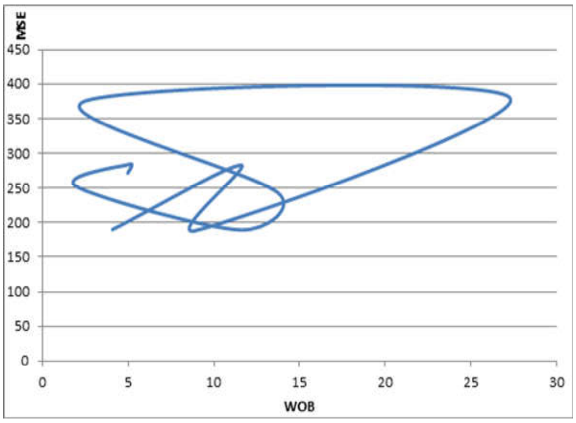


Figure 7: Graph of WOB against MSE

The constant angular inclination of oil well drilling is attributed to entry of oil well formations with uniform rock or soil structure while the steady deviation in angular inclination of oil well drilling is attributed to entry of oil well formations that experience steady increase in soil formations.

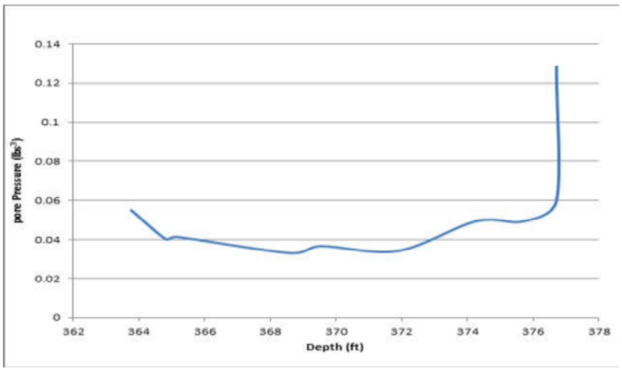


**Figure 9** **A** Graph of MD va;ies agaomst pore pressure

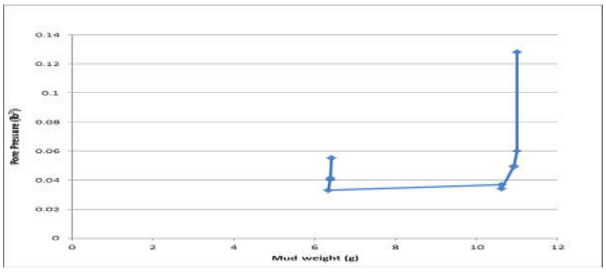


Figure 10: Plot of the MUD weight values against the Pore Pressure

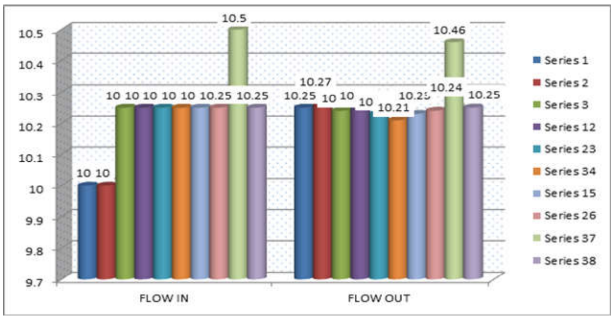


Figure 11: Bar Chart of FLOW-IN against FLOW-OUT

Figure 9 presents the plot of the MD against the pore pressure values. The plot shows the changes in pressure as the drill depth increases due to movement from one formation zone to the other. At 363.7ft, 364.8ft and 365.15ft, the pore pressures were 0.551lbs$^3$, 0.0402 lbs$^3$ and 0.0414 lbs$^3$ respectively. However, a near steady increase in pressure was noticed between 371.85ft and 376.51ft after which the pressure remains steady. The graph of the mud weight against the pore pressure presented in Figure 10 reveals that for mud weight between 0.0551Ppg and 0.0331Ppg, the pore pressures range between 6.4lbs$^3$ and 6.32 lbs$^3$ after which the pressure rises steadily for mud weights in the range 6.32lb$^3$ to 10.72lb$^3$. A very sharp rise in pressure is then noticed for mud weight in the neighborhood of 11lb$^3$, which indicated stability in pore pressure.

Figure 11 depicts the amount of inflow and outflow formation fluid in the well bore. When there is equal amount of inflow and outflow formation liquid, then there is stability in flow rate and no kick occurrence. In case of any external liquid inflow into the wellbore, the formation liquid outflow will exceed the formation liquid inflow but when the amount of formation liquid inflow exceeds the liquid outflow, then there is a possibility of kick occurrence.

Table 7 presents the Equivalent Circulating Density ($D_c$) and TVD ($D_v$) (extract from the oil well simulation with sensors generated data for kick control and monitoring. $D_c$ is 10±1 standard in drilling and production engineering while the annular pressure is 200psi.

**Table 7** Extract from Oil Well Simulation with Sensors Generated Data for Kick Control Monitoring

| S/No | $D_c$ | $D_v$ |
|---|---|---|
| 1 | 11.28 | 341 |
| 2 | 11.05 | 348 |
| 3 | 10.80 | 356 |
| 4 | 10.57 | 364 |
| 5 | 10.57 | 364 |
| 6 | 10.57 | 364 |
| 7 | 10.57 | 364 |

Based on the extracted oil well dataset, the annular pressure loss, $P_l$ during drilling for the various $D_c$ and $D_v$ values is computed based on the formula:

$$P_l = 0.052 \times D_c \times D_v \qquad (11)$$

Annular Pressure Loss (APL) of 200 psi is obtained for each row of Table 7 based on Equation 11. This is the standard and conforms to the rules for kick controlling and monitoring outlined in (Lapeyrouse, 2002). Tangible depend variables were computed to describe the functional relationship during drilling of the oil well. A regression model was developed for MD as the dependent variable with functional independent variables that are associated with data from monitoring and controlling of depth and drilling. The Model is based on the data presented in Table 3 and is stated as follows:

$$MD=\alpha_0 + \alpha_1\beta_1 + \alpha_2\beta_2 + \alpha_3\beta_3 + \alpha_4\beta_4 + \alpha_5\beta_5 + \alpha_6\beta_6 \qquad (12)$$

$\alpha_0$ is intercept of the dependent variable while $\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$, $\alpha_5$ and $\alpha_6$ are coefficient of independent variables and $\beta_1$, $\beta_2$, $\beta_3, \beta_4$, $\beta_5$, *and* $\beta_6$ are the TVD, ROP, hook load, torque, total cost and mud weight respectively.

As shown in Table 8, the R square is 0.9955 which indicates that the independent variables explained 99.55% of the variable in the dependent variable. Table 9 presents the analysis of variance (ANOVA) for the model with a significant factor (F) of 0.001301 for sum of square (SS) of 230.29 and regression and residual mean of square (ms) of 38.211 and 0.3432 respectively. These statistics confirm the suitability of the model for the prediction of the dependent variable. Based on the coefficient ratios of Table 10, MD is computed as follows:

$$D=625.97 + 0.02978\beta_1 + 0.1978\beta_2 + O.261\beta_3 + 156.145\beta_4 - 0.0008\beta_5 - 286.4\beta_6 \qquad (13)$$

**Table 8** Regression Statistics for measured depth

| Statistic | Value |
|---|---|
| Multiple R | 0.997762 |
| R Square | 0.995529 |
| Adjusted R Square | 0.986587 |
| Standard Error | 0.585847 |
| Observations | 10.000000 |

**Table 9** Analysis of Variance for measured depth

| *Statistic* | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 6 | 229.2675 | 38.21126 | 111.3327 | 0.001301 |
| Residual | 3 | 1.029651 | 0.343217 | | |
| Total | 9 | 230.2972 | | | |

This model reveals that for every unit of ROP, MD increased by 0.197969 fraction of ROP. It is therefore implied that the new model can be used to predict all the dependent variables.

***Comparative Analysis***

For the purpose of validation, comparative analysis of the results of the proposed and existing systems was carried out. In Hakan (2010), a percentage flow-in of 45.7% at 160 GPM and a percentage flow-out of 48.6% at 170 GPM were recorded as against a flow-in percentage of 10.5% at 44.1 GPM and flow-out percentage of 10.6% at 45.0 GPM recorded for the proposed system. These results reveal similar GPM/flow ratios for the two studies and buttressed agreement. Any slight variation may be due to differences in environmental factors and locations. Dc (corrected exponent) values that range from

1.1 to 1.30 with normal mud weight of 9.0ppg were stated in Lapeyrouse (2002). For the proposed system, Dc is evaluated based on the value of D-exponent ($D_e$) which is 1.73 at a measured depth of 374.2575ft and normal mud weight of 10.9 PPg. Using the formula Dc = $D_e$ * ($\delta/\rho$) Table 6, Dc is obtained as follows:

$D_c$ = 1.73 *(9.0/11.9) = 1.30

Results of simulation demonstrated the applicability and practicality of the system in real-life scenarios as well as its suitability for generation of real time oil well monitoring and control data through a number of digital and analog sensors, enforcement and optimization of monitoring and control with a view to averting kick, conflagration and blowout and their lives and environmental endangering effects.

**Table 10** Co-efficient values of measured depth

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 625.877 | 192.1465 | 3.25729 | 0.047228 | 14.38096 | 1237.373 | 14.38096 | 1237.373 |
| TVD | 0.029799 | 0.077206 | 0.38597 | 0.725264 | -0.2159 | 0.275503 | -0.2159 | 0.275503 |
| ROP | 0.197969 | 0.063418 | 3.121648 | 0.052404 | -0.00386 | 0.399793 | -0.00386 | 0.399793 |
| HOOKLOAD | 0.261146 | 0.24044 | 1.086114 | 0.356904 | -0.50404 | 1.026334 | -0.50404 | 1.026334 |
| TORQUE | 156.1448 | 85.43598 | 1.827623 | 0.16506 | -115.751 | 428.0402 | -115.751 | 428.0402 |
| TOTAL COST/DEPTH (N) | -8.4E-05 | 0.000407 | -0.20599 | 0.849985 | -0.00138 | 0.001212 | -0.00138 | 0.001212 |
| MUD WEIGHT | -286.38 | 158.5198 | -1.80659 | 0.168565 | -790.861 | 218.1007 | -790.861 | 218.1007 |

$\delta$ and $\rho$ and are the standard and obtained mud weights respectively. In addition, from Table 6, substitutions for $D_e$ of 1.5 for measured depth of 364.8311ft and utilized mud weight of 10.9ppg produced a $D_c$ of 1.24. These results reveal that the $D_c$ values obtained from the simulation of the oil well using the proposed system conform to the standard in the field of Petroleum Engineering (PE) and oil well drilling as established in Lapeyrouse (2002). This also established that operations based on the new systems will be in tandem with general practice in petroleum engineering and allied disciplines. The computed annular pressure losses for the simulation of the Etim oil well drilling for the various Equivalent Circulatory Density (ECD) and TVD values yield the same annular pressure loss of 200psi. The TVD values range from 10.05 to 11.28 as presented in Table 7. This conforms to Lapeyrouse (2002) which states that ECD must be 10±1 standard in drilling and production engineering while the annular pressure loss is 200psi. Based on extracted data from oil well data set, the summation of all the ECD values produced 75.41 with average of 10.8 which agree with Lapeyrouse values of 10±1 as standard in petroleum Engineering and production. estimation of the depth, TVD, pore pressure, mud weight and cost of drilling as well as monitoring the rate of inflow and outflow of fluid in the well bore. Generally, the new software can be adopted to controlling and monitoring the drilling of oil well at different locations when configured to the formation and calibrated as the functional tools are embedded. The research did not capture the oil well lithology when drilling different formations at depths and its calibration did not consider the circulating mud density with temperature and its effect on the circulating pressure in the oil well. The research also overlooked the effect of

## CONCLUSION

The paper presents the design and implementation of an oil well monitoring and control system. The system is primarily embedded with sensors and data acquisition tools to monitors oil well depth, drilling, flow and kick status. The core procedures involved in the effective management of an oil well were strictly adhered to. The in-built sensors require accurate calibration and settings for such parameters as mud weight, hook-load, SPM, torque and RPM for effective transfer of data to the data acquisition component for further processing. The data acquisition component is equipped for calling of some predefined procedures in order to compute some relevant decision values.

It will also be suitable for dealing with the estimation of the depth, TVD, pore pressure, mud weight and cost of drilling as well as monitoring the rate of inflow and outflow of fluid in the well bore. Generally, the new software can be adopted to controlling and monitoring the drilling of oil well at different locations when configured to the formation and calibrated as the functional tools are embedded. The research did not capture the oil well lithology when drilling different formations at depths and its calibration did not consider the circulating mud density with temperature and its effect on the circulating pressure in the oil well. The research also overlooked the effect of temperature on the penetration rate of drillings in oil well and placed no consideration to the impact of pressure due to presence of gas on the drilling operation in the oil well. Further research therefore focuses on the investigation of the effect of soil lithology when drilling different formations, how temperature affects the circulating pressure and penetration rate in the oil well drilling and the impact of pressure due to presence of gas on the drilling operation.

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