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Value and Practical Aspects of Accurate and Reliable Kick Detection during Connection and Steady Condition

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Abstract— *Kick detection has a growing importance in the drilling industry, as it bothers safety of rig and rig personnel as well as the environment with huge financial loss. How early this well control incidence is being detected will be significant to preventing damages as such enables earlier control of the situation.*

In this paper, focus is on kick detection using simulations of events at the surface circulation system with special emphasis on kicks taken during connection. An overview of kicks during connection is been presented. Discussed also were rig circulation system and how each component of the circulation system impacts on kick detection.

The simulation in this research paper was carried out with MatLab to study the dynamics of a changing pump rate in relationship to change in the surface measured volumes. A comparison to data gotten from the work of (D.P. McCann 1991) was made as well as using drilling data obtained from a well drilled in the Niger Delta. In order to make adjustments to the compared data the Adaptive Observer Program was used and also data smoothening was carried out on the data.

The simulation indicated the possibility of describing the volumetric changes of the circulatory system of a rig using basic programming. Thus, enabling elimination of such rig related volume changes.

Keywords— *Adaptive observer program, data smoothening, kick detection, matlab, rig circulating system and surface circulating system.*

I. INTRODUCTION

While drilling a well, one of the common challenges encountered is an influx from the formation, known as kick, which if not controlled on time can lead to a very risky event known as blow-out usually accompanied with severe negative consequence on safety and economic viability of the well being drilled. This highlights the reason why it became imperative for accurate and reliable techniques for detecting kicks.

Detection of these kick events are typically done by observation of the well for changes on certain parameters. Alarms are set on most of the monitored parameters in order to notify the rig crew of an anomaly from the well that might be indicative of a kicking well. It is common with these alarm systems to rely on human decision, for where the alarms should be installed and what threshold of the monitored change in the parameter should trigger the alarms. A disadvantage to this technique is its lack of understanding of the dynamics of the rig circulation system, hence necessitating for regular adjustments to be made. As such making it liable to human error.

Designing and implementing a technology that comprehends the dynamics of the rig system, with “learning” Capabilities just as used in “Artificial Intelligence”, to enable it positively notify drilling crew of actual kick situations will be of great significance. This will potentially decrease or completely eliminate false alarms, since chances of error due to human intervention will be eliminated

An uncertainty associated with kick detection during connection is the flowback of mud. Flowback volume of mud returning to surface tanks when circulation is stopped. A small loss of drilling fluid as a result of increased Equivalent Circulating Density (ECD) can lead to flowbacks when pumps are turned off during connection. This is an early sign of a ballooning/breathing wellbore. In order to avoid misinterpretation of wellbore breathing for a kick, accurate measurement are needed for fingerprinting flowback volume for setting a threshold of tracking normal and abnormal flowback volumes.

The ability to have full control over these transient conditions is significant as it will enable reduction of false alarms. Hence reducing Non Productive Time (NPT), making drilling of wells faster and reduced cost associated with NPT.

This work, centers on kick detection during connection. By focusing on understanding the dynamics of a changing pump rate in relationship to change in the surface measured volumes. As it is more challenging, detecting of kicks during these transient condition than for steady or static well conditions.

A. *Overview of Kicks During Connection*

During drilling to deepen the well, at a time it is necessary to stop the pumps and lift the Kelly in order to add a new stand of pipe, this process is known as connection.

When pumps are on during circulation, the bottom hole pressure for a conventional drilling system is thus:

$$BHP_{conv.,dyn.} = HP + AFP \quad (1.1)$$

When making connections, during pumps off condition, in the absence of annular friction losses, BHP becomes same as mud hydrostatic pressure

$$BHP_{conv.,static} = HP \quad (1.2)$$

For a closed loop drilling system, in order to maintain constant BHP, back pressure is available during both dynamic and static conditions.

$BHP_{closed,\ dyn.} = HP + AFP + BP$ (1.3)

$BHP_{closed.static} = HP + BP$ (1.4)

As seen in equations 1.3 and 1.4, the presence of the back pressure supplied by chokes eliminates fluctuations of the downhole pressure, which is the major causative agent of wellbore instability during connection in conventional open circulation systems.

B. Kick Indicators during Connection

A good understanding of the events occurring while an influx is in the wellbore will aid in making the right model of the situation.

When making connections, the rig pumps are shut off stopping circulation, the effective mud weight is reduced from ECD to static mud weight.

These events will usually be consolidated with what the return flow sensors or changes in the active system or the combination of both will indicate. Ideally since the pumps are off, the sensors should show complete no flow. But certain times, on some rigs, due to surface pipe draining, flowback of mud can continue but only a change in the usual flowback should be indicative of an anomaly.

The flowback volumes are affected by certain factors as mud compressibility, thermal expansion, components of rig circulation system and downhole events.

C. Rig Circulation System

For an ideal situation, volume of pumped-out-mud from the active pits should be same as what is returned via the flowline back to the pits, with any anomaly in the balance to be noted as either a gain/loss situation. however, passage of these mud volumes throughout the circulatory system does not go as expected, certain flowrates and passage pathway component determine the outcome at the surface which are signatory feature of a particular rig.

Proper interpretation of surface data requires an understanding of how components of the rig circulation systems influences the flowback volumes needed for fingerprinting and flow rates needed for estimating delta flow measurements for kick/loss detection.

D. Downhole Events

A phenomenon known as wellbore ballooning/breathing occurring downhole as a result of fluctuations from the starting and stopping of mud pumps during connection also mystifies what is read at the surface. As this can easily be misdiagnosed as an influx, with serious consequence for such misinterpretation. Especially if it involves opening and closing of micro-fractures, by simply taking well control measures, adding the mud weight, this can degenerate to total losses.

Other variations of these mechanisms occuring downhole can be in the form of changing temperature in deeper section of the wellbore, whereby significant increase in temperature leads to expansion of mud volumes, while a decrease in temperature leads to contraction of mud volume seen as gain/loss respectively.

Similar events can occur with an elastic deformation of wellbore, whereby significant increase in pressure leads to increase in wellbore volume, while a decrease in wellbore pressure leads to reduction in wellbore volume, hence seen as loss/gain respectively at the surface.

II. METHODOLOGY

A. Automation of Data Analysis and Data Smoothening

For kick detection technique to give accurate cautioning for signs of impending influx, the technique must be able to "some extent" comprehend the happenings around. Since disturbances and noise-effects if not properly sieved by the technique in a trendy manner will result to falsification of warning signals.

(Tarab H. Ali 2013) developed a system based on statistical analysis of trends, with an average threshold value set by looking at flowback data points of the Nth flowback curves at a given elapsed time from the start of the flowbacks. Using standard deviation it excludes any unusual event such as kicks, flowchecks or SCR.

(Gusrud T.O 2009), also using a statistical approach proffered a way of detecting stuck pipe. Demonstrating how false alarms due to spikes or noisy data can be avoided. This is achieved by setting a required number of samples for which to be positive within a dynamic time frame in order for an alarm to be triggered. In this work, a similar approach for exclusion of spiky data is utilized with the application of pass filters.For the purpose of this work high and low pass filters are deployed in the data smoothening.

Data smoothening involves creating an approximating function while adopting only significantly relevant patterns in the data and avoiding noise. This is done by reducing individual points of the data points of a signal. While points that are lower than the adjacent points are increased in order to get a smoother signal (Wikipedia 2016)

A range of algorithms are available for smoothening data points. Example of which are Kalman filter, additive smoothing, Butterworth filter, digital filter and exponential smoothing, low pass filter (LPF) and High Pass Filter (HPF).

(a) Low Pass Filter (LPF)

According to Wikipedia a low pass filter is used for passing signals with frequencies lower than a specified threshold frequency and attenuates signals with frequencies above the given threshold value. This is achievable using the following equation

$y[i] = y[i-1] + \alpha \cdot (x[i]-y[i-1])$ (2.1)

Thus, the filter recurrence relation gives a way to determine the output data in terms of the input data and the preceding output. As seen in the equation 2.1 above, the change from one filtered output $y[i]$ to the subsequent output $y[i-1]$ is proportional to the difference between the previous data output and the subsequent data input $(x[i]-y[i-1])$. While α is a filter factor which determines how the previous data output changes with the input data. Below is a figure depicting how a filtered signal from a paddle sensor behaved.

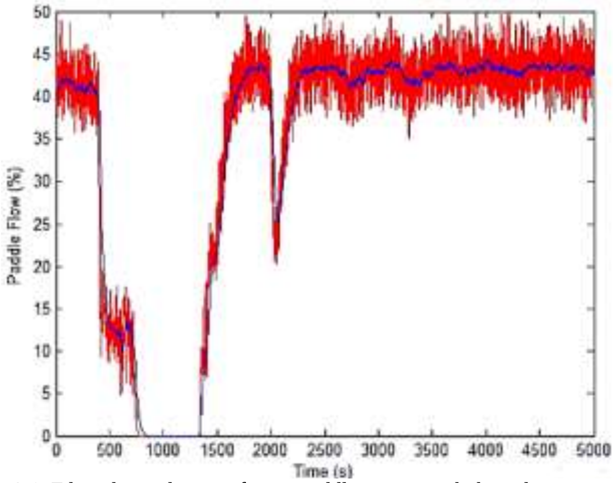

Fig. 2.1. Filtered signal output from a paddle sensor, with the red representing the unfiltered data while blue represents the smoothened data

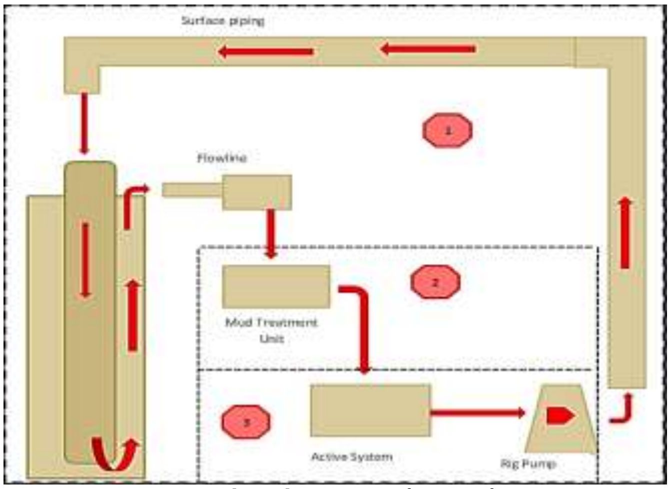

Fig. 2.2. Partitioned circulation system for ease of presentation in a MatLab model (1) Surface piping, Drill String and Wellbore (2) Mud Treatment Unit (3) Active system and Rig Pumping unit

As can be seen in the figure above, with a decreased noise-effect, warning-signal settings can be made to as low as 4% after smoothening which wouldn't have been possible without smoothening up till a 20% range. However, in order to avoid delayed response to changes, the strength of filtering applied should be prudently applied.

(b) High Pass Filter

High pass filters passes signals with a frequency above the set threshold and attenuates signals below the threshold values (Wikipedia 2016) This filter is needed for smoothing such errors that keep accruing. It is achievable via this equation (Wikipedia 2016):

$$y[i] = \alpha \square (y[i-1]+x[i]-x[i-1]) \quad (2.2)$$

Just like the case of low pass filter, the filter recurrence relation gives a way to compute the output data in terms of the input data and the previous data. Here the output data *y[i]* is related to the sum of the previous data output *y[i-1]* and change in input *x[i]-x[i-1]* with a direct proportionality. While α, which is the smoothing factor determines the impact of prior output *y[i-1]* and current changes in input *x[i]-x[i-1]* and is given thus.

$$\alpha = \frac{RC}{RC + \Delta t} \quad (2.3)$$

RC-time constant

Δ*t* –Sample time

The larger the value of α the slower the decay of the output value, however will be strongly influenced by small changes in input. Smaller value of will result to faster decay in the output value and as such will require large changes in the input in order to stimulate change in the output.

B. Design of a Circulation Model to Simulate Volumetric Changes

The proposed model needed for simulating volumetric changes is as seen in figure 8 above. The circulation system is being partitioned into three parts for ease of definition in MatLab. The model accounts for only volume and flow rate changes but none of pressure losses is being accounted for.

The governing equations for modeling flow and volumetric changes in the proposed modeled circulation system is thus;

$$dv = (q_{in} - q_{out})dt \quad (2.4)$$

Where dv is added volume in (m^3) for time difference of dt in seconds with respect to volumetric flowrate changes in (m^3s^{-1}).

Considering that flow is guided by gravitational principles, given by the equation for volumetric discharge from a tank with varying head thus;

$$Q = CA\sqrt{2gh} \quad (2.5)$$

Where $\boldsymbol{C}$ is a dimensionless discharge coefficient, which is a function of flow orifice. A is the cross-sectional area of orifice, g is acceleration due to gravity and $\boldsymbol{h}$ is the height of fluid column.

Thus, we can deduce that the discharge equation equates with out-flow rate.

$$q_{out} = Q \quad (2.6)$$

Since $V = a \times h$ (2.7)

Where a is the cross sectional area of mud tank and not that of the orifice, h is the height of fluid column in the tank.

In-flow rate q_{in}, into a subsequent tank will be driven by q_{out} from a preceding tank in the system or can be from the rig pump as the case may be. Also into consideration is, inclusion of a time-delay for flow going into a tank from a preceding tank or the rig pump's flow rate.

Also in order to account for changes in level height we can put,

$$Q = k \times h \quad (2.8)$$

Where k is a representation of the factors in-play which permits modification of the model and a streamlined equation for usage as input for an adaptive observer Technique (AOT) model.

(a) Operational Principle of the Model

The model operates thus; the head in the tanks will be zero, during steady state conditions with no flow. While for a situation whereby the pumps are on, the tank level will be seen increasing, consequently with an increasing head. For a continuous stable flow, the tank level will be increasing with either of the following occurring;

1. A balance is attained between flow in and flow out, thus attaining a steady state for certain level until an external effect in terms of flow change occurs or.
2. A tank level attains its maximum capacity with the excess volume seen flowing into the next tank as illustrate in the figure below.

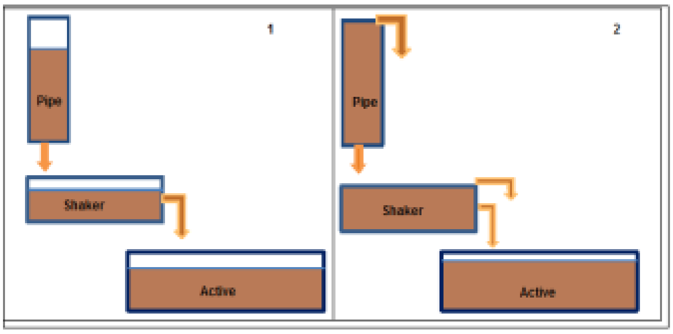

Fig. 2.3. Illustration of the Operating Principle of the Model

What drives the simulated circulatory system is the flow rate input as defined by the user, flow rate (ramp up and ramp down), Drainage area of tank and tank volumes are also inputted.

The calculation of volume change is done this way:

Flow from the active system via the pumps enters the pipe after a time step. Apparent change in volume is calculated from the flow out via the drain with the previous head. The calculated volume in comparison with the maximum volume used to determine the possibility of an overflow as well as the volume of the overflow. A time delay is introduced prior to entry of the flow out volume into the shaker system.

Similar procedure is followed in calculating for the shaker system with another time delay introduced to the flow into the active system from the shaker.

Simulation of the model was carried out using Matlab. To have a feel of its applicability in real situation, the model is ran continuously with calculations done at regular intervals. Thus it can give a simulated output for any observable change in the input values which is comparable to real data. An alarm can be included, which is triggered by the difference in simulated values from the actual values based on a threshold value defined by the user.

C. Assumptions

(a) Flowrate determines the volume in the piping

The volume of fluid retainable in the surface lines is a function of the flowrate. Higher flowrates means more fluid lost in piping while lower flowrates means lesser part of the piping is occupied by the fluid. Thus fewer losses incurred during such transient. This assumption is buttressed by the findings in the work of (D.P. McCann 1991) where it was observed that the change in surface volume while shutting pumps from 1700l/m is different from when shutting pump from a flow rate of 3700l/m. indicating that loss of fluids in the pipes is a function of flowrate from which the pumps were shut off.

(b) Time delay is not influenced by flowrate

Delay time is specified while inputting variables, that is the delay from entry into pipe from the pumps, exit from shakers to active systems are specified. For real field situations there is delay in time for fluid moving from desander to desilter and through degassing which timings are all influenced by flowrate. For the purpose of this model, the time delay is made invariable from the defined flowrates.

(c) Head level cannot be below zero

In order for the simulation to compute changes from one flow rate to another linearly, while defining input values a specified time is allocated to the time it takes for the flowrate to change from one value to another, thus distinguishing the flowrate change over the allocated time.

(d) Effects of Gas entry are assumed negligible

For a real situation, gas presence in the return mud can influence the volume calculation due to density change as a result of gas expansion. For the purpose of simplifying calculations in this simulation, it is assumed that the volume of pumped fluid from the active system will remain constant throughout the circulatory system except for fluid returning to the active system. Thus when an influx is being simulated, it is only depicted as an increment in flow and volume hence neglecting any calculation with respect to change in density due to gas expansion.

(e) Entry of invading fluid occurs at a constant flowrate

In the simulation for influx, values of the rate of influx and starting time for the influx is inputted, thus making it easier to simulate kicks during both transient and during circulation. The kick is added as an increase of flow out of the annulus (pipe). Thus, in the model the kick continues till the simulation is ended, irrespective of whether the rig pumps are on/off.

III. Results and Discussions

A. Case One-Background

In the background case, the simulation with the model was done to compare with the results gotten in the work of (D.P. McCann 1991). Though no data was available as input for rig and circulation, however high and low flowrates of 3700l/m and 1700l/m were used in the work. Also there wasn't information about the time for shut down and start of the pumps, neither was there any data on time for ramping up/down for either of the flowrates of 3700l/m and 1700l/m. However it was noticeable from figure 3. of the work of (D.P. McCann 1991) that the pumps were started even before the active system stabilizes, an indication that the pipings were not allowed to completely drain during connection. Though in the work of (D.P. McCann 1991) no detail information was available of the working principle of the software used in modeling, results gotten from the simulations of the model developed in this work and compared with their work indicates some similarity with their work.

In this research work, during the test of the model, alterations were carried out on input data in order to have a

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comparable graph with the results from the work of (D.P. McCann 1991). In the three simulated cases adjustment were made severally.

(a) 1st run: No Influx into the Active System

In this run, a simulation of the active system was carried out to visualize the response on shutting off and on of the pumps for the flowrates of 3700l/m and 1700l/m respectively. Before allowing the active system to stabilize. This was used for comparative reason for the subsequent two runs.

1. 3700l/m-flowrate

For the data gotten from the results of (D.P. McCann 1991) when the pump were shut down. Within a time span of 400 secs, a gain of 9m^3 was recorded due to draining surface piping (flowback) when the rig pumps were started the active system recorded a loss of 7.6m^3 within a time span of 521 secs. Below is a table of the input data used in simulating.

TABLE 3.1. Input data used in simulating 3700l/m flowrate

Triple Tank: 3700l/m flowrate			
Data	**Value**	**Data**	**Val ue**
Low flow-rate	0l/m	Reduce Start of flow	1040secs
High flow-rate	3700l/m	Increase start of flow	1430secs
Co-pipe	2	Ramp time	120secs
Co-shaker	8	Delay via pipes	20secs
Pipe Drainage Area	8.5x 10^{-4} m^2	Delay via shaker	35secs
Shaker Drain Area	2.8x 10^{-3} m^2	Base volume shaker	20m^3
Shaker Area	4m^2	Max Volume shaker	40m^3
Pipe Maximum Volume	8m^2	Active base-volume	100.3m^3

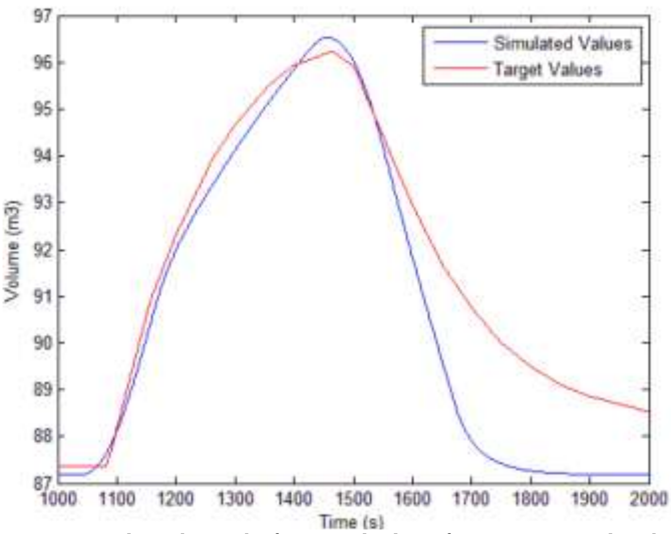

Fig. 3.1. Triple Tank: Graph of compared values of D.P. McCann et al. with that of tuned triple tank model being turned off from a flowrate of 3700l/m

An observable feature from the results of the simulation in the figure above is the abrupt drop from the curve of simulated result as compared to curve of the work of (D.P. McCann 1991). This is an indication that irrespective of the fact that the timing for start of flow from shakers to the active system was almost same. Flowrate has been set lower for the simulated model than the curve from the work of (D.P. McCann 1991). From the graph of the simulated model, it can be seen that the curves are stabilizing earlier than the compared data. For the curves of the simulated model an initial slow flowrate is seen into the active system at start-up. Followed by a sudden increment then it stabilizes. For the curves of the work of (D.P. McCann 1991) an initial high flowrate is seen into the active system at star-up, with no sudden increment as seen in the simulated curve and the curves are not seen stabilizing since it can be seen decreasing at the 1000th second time mark. Flowback levels out from an earlier time than the compared results of (D.P. McCann 1991).

Altering the co-constant values in the input gives a similar trend on the simulated curve as compared to the results of the work of (D.P. McCann 1991), where it was seen that the curves were not stabilizing at the 1000nth time mark. But this is not the case with the flowback as simulation curves does not fit well and large volumetric changes were observable.

A major challenge is the filling of the surface piping's which is seen as a drop in the active system when the pumps are restarted.

2. 1700l/m -flowrate

The data from the results of (D.P. McCann 1991) when the pumps were shut down within a time span of 340 seconds , a gain of 2.4m^3 was recorded while a drop of 2.1m^3 was recorded within a time of 390 seconds . Below is the input data for the simulation.

TABLE 3.2. Input data used in simulating 1700l/m flowrate

Triple Tank: 1700l/m flowrate			
Data	**Value**	**Data**	**Value**
Low flow- rate	0l/m	Reduce Start of flow	70secs
High flow-rate	1700l/m	Increase start of flow	42secs
Co-pipe	1.1	Ramp time	30secs
Co-shaker	2.7	Delay via pipes	10secs
Pipe Drainage Area	3.0x 10^{-4} m^2	Delay via shaker	20secs
Shaker Drain Area	8.0x 10^{-3} m^2	Base volume shaker	20m^3
Shaker Area	6m^2	Max Volume shaker	40m^3
Pipe Maximum Volume	8m^2	Active base-volume	50m^3

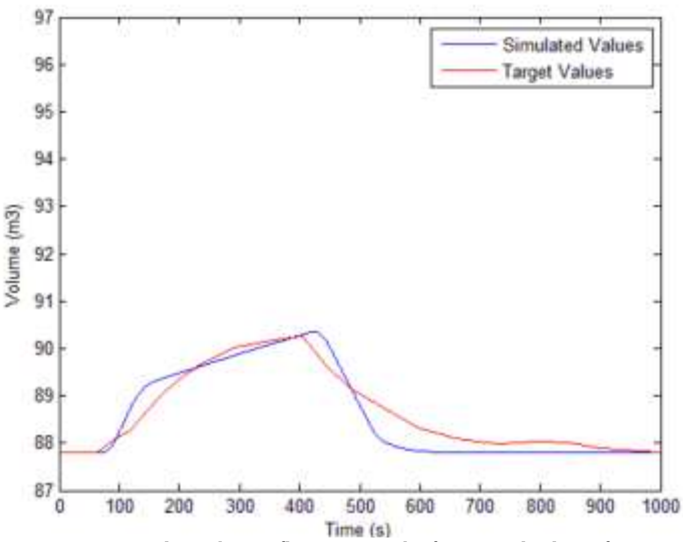

Fig. 3.2. Triple Tank Low flowrate: Graph of compared values of D.P. McCann et al. with that of tuned triple tank model being turned off from a flowrate of 1700l/m

Recreating a similar curve at the flow rate of 1700l/m was also faced with challenges. As seen in figure 3.2 above, the

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curves of the simulated active-system decreases more rapidly than the curve from (D.P. McCann 1991). Also the flowback trends in the two curves are dissimilar by adjusting the values of the co-pipe and co-shaker that influences the flowback curve trends.

(b) Simplifying the Model to a Dual-tank Model

The number of tanks were reduced to 2 from 3 in order to simplify the simulation so as to have a better curve-fitting, also without challenges associated with the flowback volumes, below in figure 3.3 is the model of the dual tank system model which will be compared with the triple tank system.

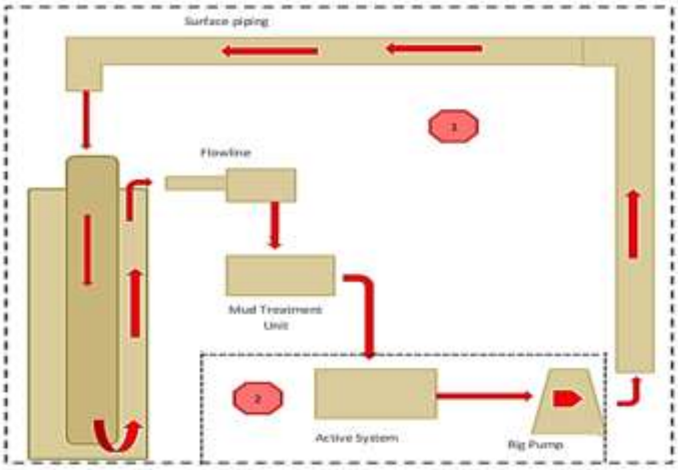

Fig. 3.3. Simplified Dual Tank system model: Pipe & Shaker combined to give a single set-up

1. 3700l/m –Dual Tank System

In the table below are the input values and results for the 3700l/m flowrate simulated using the dual-tank model using flowback volumes different from earlier volumes with the triple-tank model.

TABLE 3.3. Input data used in simulating 3700l/m flowrate (with difference in flowback volume)

Dual Tank: 3700l/m flowrate			
Data	**Value**	**Data**	**Val ue**
Low flow- rate	0l/m	Reduce Start of flow	2070secs
High flow-rate	3700l/m	Increase start of flow	2475secs
Co-shaker	5.7	Flow ramp timing	30secs
Shaker Drain Area	1.5x 10^{-3} m^2	Delay via shaker	20secs
Shaker Area	$4m^2$	Base volume shaker	$20m^3$
Active base Volume	$50m^3$	Maximum shaker volume	$45m^3$

After running simulations with the dual-tank model, it is observable that the curve does not still fit well to the compared values of (D.P. McCann 1991). Noticeable here is the change in volume where for this work it is $14.2m^3$ while that of the compared value is $8.9m^3$ in as seen in figure 3.4 above.

It is observable that an improvement in the curve fitting has been achieved during the flowback which is better than in 3700l/m flowrate earlier in the triple-tank model. Also during pipe fill ups after starting the pump again, it was observed that the curve fitting are giving a better fitting to the compared curves. However, it is noticeable that the simulated curves are appearing to be stabilizing while the compared curve-trends are not.

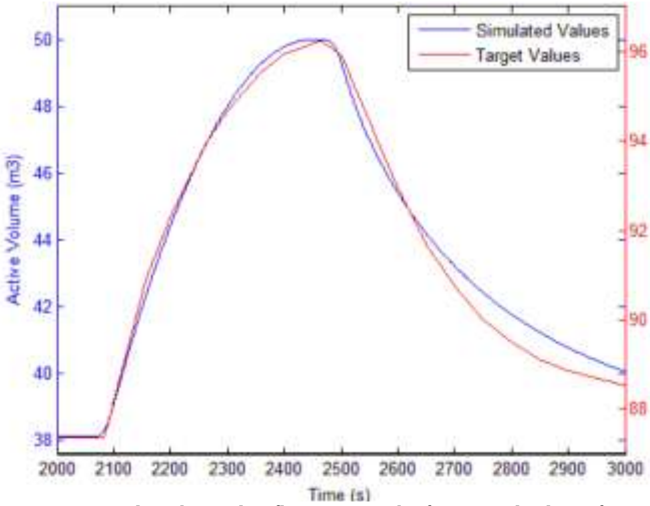

Fig. 3.4. Dual Tank 3700l/m flowrate: Graph of compared values of D.P. McCann et al. with that of tuned dual tank model with a difference in flowback volume. Initial flowrate from a value of 3700l/m

It is now obvious that by reducing the number of tanks in the model, it becomes glaring the improvement in the curves fitting. Hence an effort to attain similar curve fitting with the flowback. Below is a data of the input data and a graph of the outcome in figure 3.5.

TABLE 3.4. Input data used in simulating 3700l/m flowrate

Dual Tank: 3700l/m flowrate			
Data	**Value**	**Data**	**Value**
Low flow- rate	0l/m	Reduce Start of flow	2030secs
High flow-rate	3700l/m	Increase start of flow	2435secs
Co-shaker	6.55	Flow ramp timing	180secs
Shaker Drain Area	1.5x 10^{-3} m^2	Delay via shaker	10secs
Shaker Area	$4m^2$	Base volume shaker	$20m^3$
Active base Volume	$96m^3$	Maximum shaker volume	$45m^3$

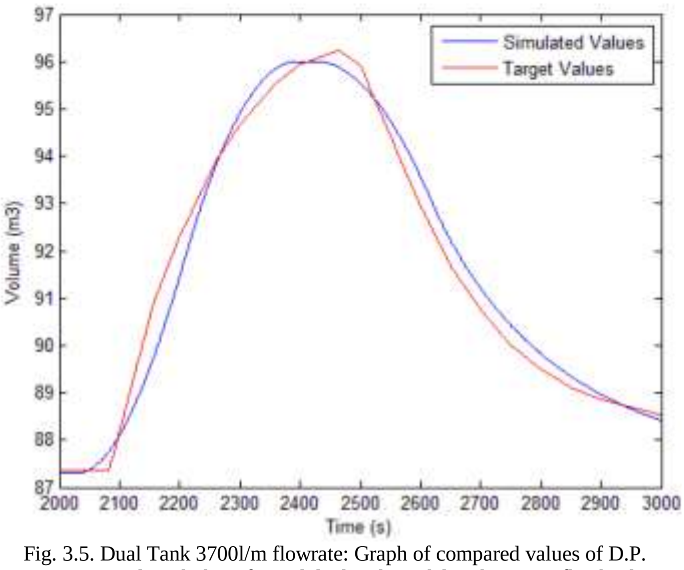

Fig. 3.5. Dual Tank 3700l/m flowrate: Graph of compared values of D.P. McCann et al. with that of tuned dual tank model with correct flowback volume. Initial flowrate from a value of 3700l/m

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As seen in the figure 3.5 above the simplified models are giving a closer fit to the compared curves. However it appears that improvement hasn't been achieved in terms of flowback since the simulated curve for the triple-tank model seems to be a better fit than the simplified model in terms of flowback. However the outcome with the filling up of pipes seems to be better.

2. 1700l/m –Dual Tank System

In order to attain better curve fitting using the simplified model, one requires utilizing lengthy times for ramp-up, sometimes as long as 4 minutes. In furtherance to see how much improvement in the curve fitting between the simulated curves and the compared curves using simplified dual-tank model, we utilize the model with the 1700l/m flow rate. Below is the table of the input variables and the graph of outcome in figure 3.6.

TABLE 3.5. Input data used in simulating 1700l/m flowrate

Dual Tank: 1700l/m flowrate			
Data	**Value**	**Data**	**Value**
Low flow- rate	0l/m	Reduce Start of flow	2040secs
High flow-rate	1700l/m	Increase start of flow	2330secs
Co-shaker	6.57	Flow ramp timing	200secs
Shaker Drain Area	1.5x 10^{-3} m^2	Delay via shaker	10secs
Shaker Area	$5m^2$	Base volume shaker	$20m^3$
Active base Volume	$90m^3$	Maximum shaker volume	$45m^3$

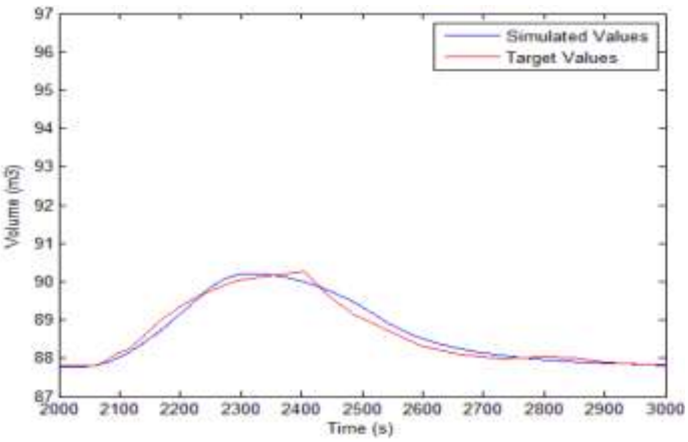

Fig. 3.6. Dual Tank 1700l/m flowrate: Graph of compared values of D.P. McCann et al. with that of tuned dual tank model with a correct flowback volume. Initial flowrate from a value of 1700l/m

From the curves of the graph in figure 3.6 above, it can be seen that the 1700l/m simulated with the simplified model produced a better curve fitting than the 3700l/m simulated using the triple-tank system. It is noticeable how the curves fits well in the flowback as well as the pipe filling scenarios , however just like the 3700l/m it can be seen how the simulated outcome stabilizes at its peak volume values whilst the compared value maintains an abrupt peak. In essence it can be said that even the earlier comparison of the simulated curve with the target curves shows a fairly good fit, though several adjustments were needed to improve on the curves fitting with the simplified model giving an overall better fit than the triple-tank models.

(c) 2^{nd} run: Introducing Influx into Active System during Steady Condition

In this run an influx of $3m^3/h$ into the shakers was simulated to begin at a 2200^{th} time mark. The outcome seen in the active system is presented alongside the response of the active system to the 3700l/m flowrate from the comparison during the first run. Below is the input values and graph of the simulation in table 3.6 and figure 3.7 respectively.

TABLE 3.6. Input data used in simulating 3700l/m flowrate (with kick introduced during steady condition)

Dual Tank: 3700l/m flowrate			
Data	**Value**	**Data**	**Value**
Low flow- rate	0l/m	Reduce start of flow	2030secs
High flow-rate	3700l/m	Increase start of flow	2435secs
Co-shaker	6.55	Flow ramp timing	180secs
Shaker drain Area	1.5x 10^{-3} m^2	Delay via shaker	10secs
Shaker Area	$4m^2$	Base volume shaker	$20m^3$
Active base Volume	$96m^3$	Maximum shaker volume	$45m^3$
Kick start time	1600secs	Rate of influx	$3m^3/h$

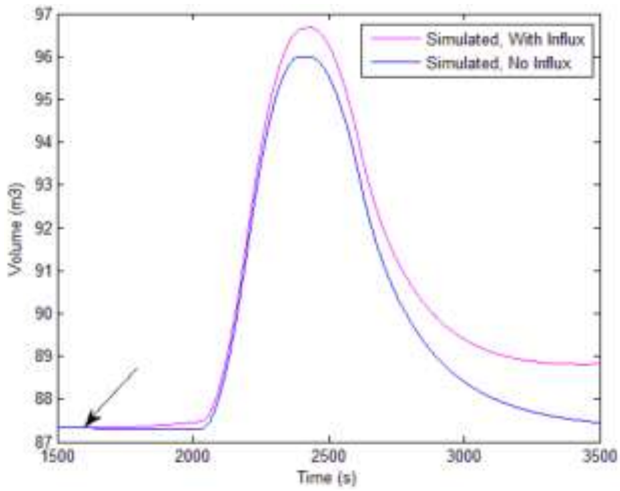

Fig. 3.7. Dual Tank flow, Kick situation in steady flow condition: Graph of compared simulated results of kick and no-kick situation. Arrow pointing at kick initiation time

At the reading of time 3500^{th}, the difference in active system's volume was almost $1.50m^3$. It is observable how the simulated influx delays for about 100-150 seconds while moving from shaker to the active pit. Thus results in delay of detection of the difference in the volumetric flow into the active system. Noticeable also is how the slope of increase /decrease in the volume remained almost same for most parts of the connection, thus making it more challenging to detect a kick if depending on only this interval of the displayed graph. This is of concern since at most time the drilling personnel might be monitoring the flowback with the influx, neglecting the non-influx flowback for linear comparison.

(d) 3^{rd} Run: Simulating influx in Transient Period

This run is carried out in much the same way as the 2^{nd} run, just that the kick in this run was introduced during a connection. Below in table 3.7 and figure 3.8 are the input and graph of the outcome respectively.

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TABLE 3.7. Input data used in simulating 3700l/m flowrate

Dual Tank: 3700l/m flowrate			
Data	**Value**	**Data**	**Value**
Low flow- rate	0l/m	Reduce start of flow	2030secs
High flow-rate	3700l/m	Increase start of flow	2435secs
Co-shaker	6.55	Flow ramp timing	180secs
Shaker drain Area	1.5x 10^{-3} m^2	Delay via shaker	10secs
Shaker Area	4m^2	Base volume shaker	20m^3
Active base Volume	96m^3	Maximum shaker volume	45m^3
Kick start time	2200secs	Rate of influx	3m^3/h

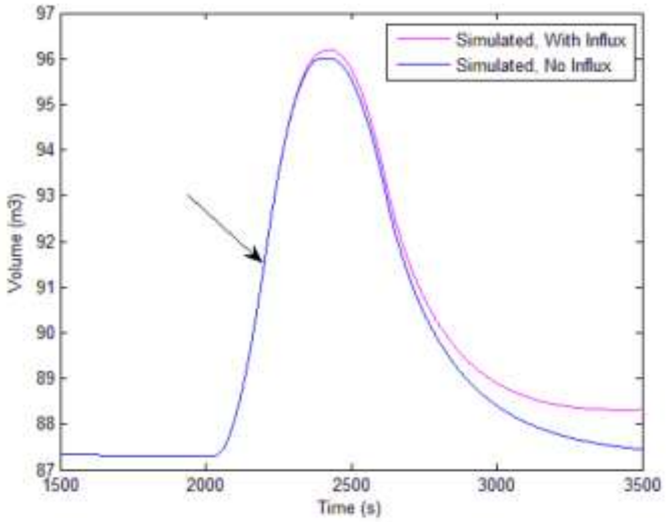

Fig. 3.8. Dual Tank flow, Kick situation in transient condition: Graph of compared simulated results of kick and no-kick situation. Arrow pointing at kick initiation time

The outcome in this run is being compared with the results from the 1st run. Also in this run there is a delay before the volume change is noticeable at the pits due to the introduced kick.

B. Case 2- Niger Delta Dataset

The drilling data from a well offshore Niger Delta with little specifics about the well and its license holders (for privacy reasons) is being used here. Relevant information extracted were the active volumes in meter cube, flow-out (Paddle flow sensor in percentage) and the pumping rate in meter cube per minute, with the observation time of nearly 27hr. Due to some rig related disturbances, the data is been filtered before usage. Below in figure 3.9 is the graph of the data from the well.

Visible from the graph is the gradual drop in the active volume, which can be explained as accounting for the wellbore being drilled and fragments lost along mud treatment units. This can be quantitatively solved by comparison of the rates of penetration to the volume of wellbore drilled.

Also visible were some sudden changes in the active system which can be as a result of addition or removal of pits to the active system. Thus an expected impact from these changes in the active volume is anticipated in the simulation.

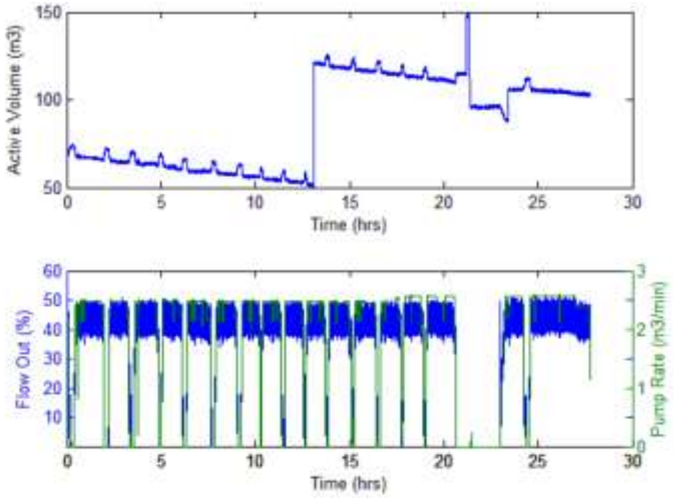

Fig. 3.9. Niger Delta Drilled Well Data plots: Plots of smoothened (below) and Non-smoothened data (above)

(a) 1st run: Simulating without a Kick

For the purpose of showcasing the behavior of the model during stable conditions, the simulation is with no influx. At the beginning, the model learns the routine of the system using the AOT system. After reaching an extent, the model now runs using the learned routine features as input. The figure below is the plot of the measured active volumes without kick intake combined with the modeled active system.

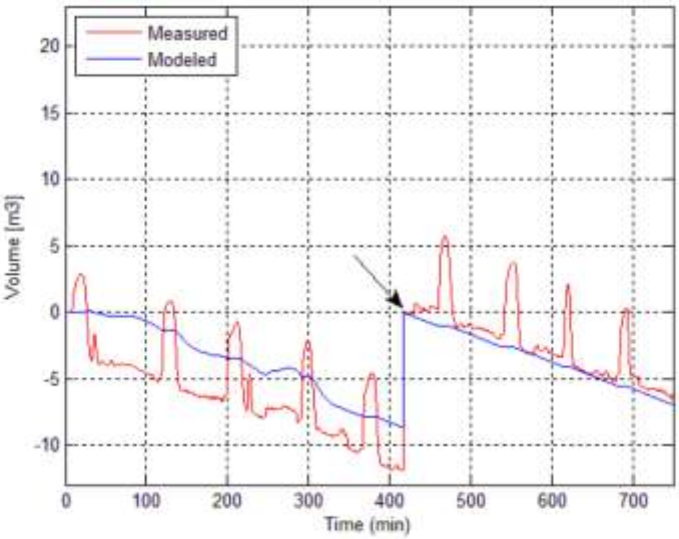

Fig. 3.10. Plot of the measured active volumes without kick intake combined with the modelled active system

In the graph above, the accumulated volume of influx is depicted in red with a decrease in the volumetric-trend whilst a new-hole is being drill and during connection, the curve in blue is representing the modeled volume of influx. As seen here, simulation was initiated at the 8th min mark. Beyond the 333rd min mark input-value becomes fixated as learning ends. The pointer in the graph indicates the 417th min mark when volume gets reset.

It is until the end of the learning session that the model can identify the data points needed for input. Thus, the outcome

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becomes a function of when the learning session ends. In avoidance of this situation, filtered average can be used instead.

(b) 2nd run: Simulating a Kick at Steady Circulation

At this stage, a kick is introduced at the 333rd min at a rate of 100l/m to simulate the reaction of the system to an influx during steady conditions. Figure 3.11 depicts how the measured volume reacts to the presence of a kick. Its reaction is noticeable unlike that of the model which remained unaltered by the influx.

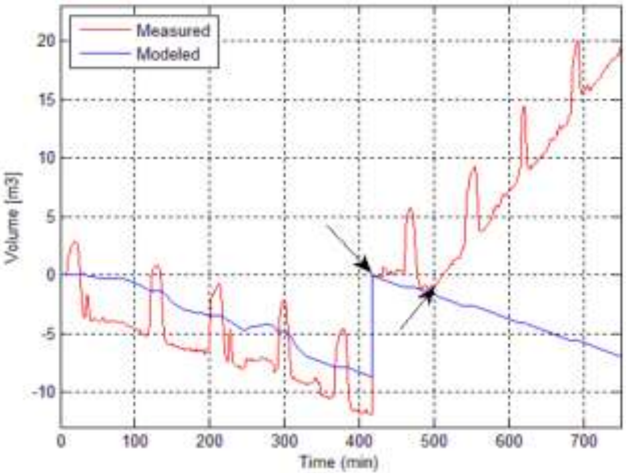

Fig. 3.11. Plot of measured and modeled volume in the presence of a kick

In this case kick was introduced at the 500th min mark at a rate of 100l/m as indicated by the pointer on the red curve looking up. While up till the 333rd min mark, the modeled volume without influx situation is in learning-mode with a volumetric-reset at the 417th min mark depicted by the pointer facing down. For the measured-volume, kick is noticeable at initiation. Whilst for the modeled is computing on the basis of pumping-rate and operates with no influence from the introduced kick.

(c) 3rd run: Simulating a Kick Taken during Transient Periods

Here the simulation is done with a kick taken at a time of 461st minute at a rate of 100l/m, this is done to simulate how the system reacts to a kick taken at transient conditions.

As seen in figure 3.12 below, the model showed no response to the presence of a kick, while the measured volume reacts to the presence of the kick. Also by mere visual monitoring of the plots it is not noticeable till the connection itself becomes noticeable with the indication of the re-start of circulation. Typically a fingerprint of the flowback volume could have been indicative of anomaly, however due to the dissimilarity between flowbacks at connections; here it becomes impossible to compare with a base case. However with a filtered dataset, as in the figure above, the kick is noticeable just as it is introduced. As seen in the separation between the trends in the measured and the modeled plots. Thus, enabling an easy confirmation of the presence of an influx during connection, even before it could have been noticeable by mere monitoring of the volume.

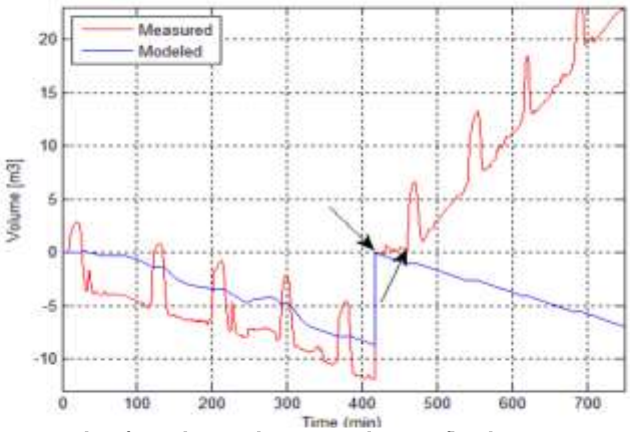

Fig. 3.12. Plot of cumulative volume responding to influx during connections at an estimated time of 460th min mark

In this particular case in figure 3.12 above it seems difficult detecting the kick. May only become detectable when connection has ended i.e. Some 30 minutes after the influx has started. At the 410th min mark it is indicating the time for the volume reset while the 460th min mark corresponds to the initiation of influx.

IV. CONCLUSION

The dangers posed by kicks to drilling rig, rig personnel, environment and drilling budgets cannot be overemphasized. A significant approach to restraining the severity of such occurrence is detection as early as possible. During steady circulation, an influx can be noticed by mere monitoring of flow and volume however, same cannot be for transient situations, as influx detection has proved to be more difficult during connections. Thus resulting to intake of large volumes of reservoir fluid without being noticed with great dangers of possibly loss of well control.

In this work, an approach of forecasting the active-volume behavior as it varies with pumps flowrate is presented. Well control events can be noticed if one is able to predict volumetric changes occurring in transient periods for example during connection.

Results obtained from the simulation demonstrated the possibility of using basic programming technique in order to model rig circulatory system. As seen in this thesis, basic programming tool was used to recreate real active volume data from the work of (D.P. McCann 1991) in addition to that of a rig in the Niger Delta data set. With a near-perfect model of the active volume, it was seen possible to detect an influx by mere comparison of the predicted volume to that from the real data being measured.

With the ability of the presented method to detect influx during transient period, at a relatively short timing, it won't be out of place to suggest that, if field trials show an improvement in early kick detection as compared to other techniques available, that it be deployed for early kick detection. With a futuristic view that the method incorporates Artificial intelligence in order to have an enhanced and more reliable outcome.

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