Adaptive Observer for Kick Detection and Switched Control for Bottomhole Pressure Regulation and Kick Attenuation during Managed Pressure Drilling

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Abstract—Control of the annulus pressure during drilling of oil and gas wells can be a challenging task, due to the complex dynamics of the multiphase flow. Since well kicks and fluid losses are potentially dangerous, it is important to improve the performance and the capabilities of estimation and control and to initiate an automatic well control system. Novel adaptive observers for estimation the flow rates through the well are developed for kick and loss detection, and asymptotic convergence properties are established. A switched control algorithm for feedback control of the choke and the back-pressure pump is proposed for pressure control and kick attenuation and asymptotic convergence is achieved. A new observer is developed to estimate the reservoir pore pressure for improved kick management. Simulation results obtained with a high fidelity drilling simulator are presented to demonstrate the effectiveness of the proposed observer and control scheme. The results show that the proposed observers effectively detect kicks in the early phase and that the automatic control scheme improves the kick handling.

Keywords: Adaptive observer, pressure control, managed pressure drilling, kick/loss detection, well control

I. INTRODUCTION

Recent experience indicates that in order to optimize the drilling operation the entire drilling system, not just the mechanics or software, needs to be designed from a control system point of view. Automatic control of drilling operations in a well can be a challenging task, due to the very complex dynamics of the multiphase flow potentially consisting of drilling mud, oil, gas and cuttings. Managed Pressure Drilling (MPD) [1] is a technology which enables precisely control of the annular pressure during drilling and to prevent these drilling related problems.

A. Kick Detection and Well Control

While drilling in the reservoir section, one may drill into a reservoir section with an unexpected high pore pressure, such as a high-pressure gas pocket. The resulting intrusion of formation fluids into the well bore is termed a kick. If it is not counteracted, the unstable effect can escalate into a blow out causing severe financial losses, environmental contamination and potentially loss of human lives. Therefore, it is of great importance to be able to detect a kick in its early phase, so that it can be attenuated in a controlled manner.

The conventional kick indications are summarized in [2] as follows: sudden increase in fluid return to surface, change in flow in and flow out, sudden increase in drilling rate, mud pit volume change, standpipe pressure drop/increase, etc. It is widely accepted in the literature that flow measurements give the most rapid indication of a kick [3]. A gas kick warner is presented in [4], where the principle is to measure the propagation time of a pressure pulse through the well by using a sonic technique. Software-based kick detection is suggested in [5], [6]. A new drilling method was developed in [7] by using the concept of micro-flux control, which is based on detecting a minimum loss or influx of fluids, and instantly adjusting the return flow and the bottomhole pressure to regain control of the well. Kick detection in oil-based mud was studied in [8], where microflux control equipment was used to detect very small influxes of natural gas into the mud. Recently, [9] presented a new kick detection system for deep water drilling where the detector used a Bayesian probabilistic framework to make good decisions based upon noisy drilling data. In [10], a new estimation technique was presented for estimation of formation pore pressure based on real-time surface backpressure measurements, which is to improve kick management.

When a kick is suspected, the standard shut-in procedure is started by shutting down the main fluid pumps, that is the mud pump and the annulus pump. Then the flow rate out of the well is monitored for several minutes, and if the pit gain continues to increase rapidly, one can conclude that a kick situation is in progress. The next step is to isolate the well by closing an annulus safety valve on the surface called the blow-out preventer (BOP). In this event, the choke is closed completely, causing the pressure in the well to increase quickly until the bottom hole pressure is equal to the reservoir pore pressure. When the well is in balance one proceeds to kill the well. However, there is a significant potential to improve existing kick detection and control methods, which is the main topic of this paper.

B. Automatic Control

Control of annulus pressure during well drilling is a challenging task. MPD provides a means of quickly affecting pressure to counteract disturbances by allowing manipulation of the topside choke and pumps. A more elaborate description of the drilling process is given in [12], [13], [14]. In [12], [15] a sophisticated two-phase flow simulator is used to predict the downhole pressure. In [16], an unscented Kalman
filter exploiting downhole measurements is used to tune the predicted pressure loss due to friction in both the drill string and the annulus. To facilitate model-based observer and controller design, low order models for the downhole pressure have recently been developed [14]. In [17], [18], nonlinear adaptive observers were developed based on the simple dynamic model from [14]. In [19], nonlinear model predictive control in combination with an unscented Kalman filter was used to control the bottomhole pressure based on a two-phase flow model in [12], [15]. In [20], the dynamic shut-in procedure is performed during a kick incident in drilling and the automatic coordinated control is applied for pump rates and choke valve opening. [21] presents automatic control requirements for drilling operations. [22] evaluates various automatic control designs for coordinating pump rate and choke valve during MPD operations. In [23], [24], a new automatic control scheme is developed for pressure regulation and kick attenuation in a MPD system. The objective of this paper is to improve existing estimation and control schemes for kick/loss detection and attenuation and therefore to improve the drilling efficiency and safety. Novel observers for kick/loss detection are developed to estimate the flow rate through the drill string and annulus. The automatic control procedure is developed to be implemented on a drilling system with an MPD choke manifold and annulus pump which control the bottom hole pressure. The switch controller has two modes of operation. In normal operation, the bottom hole pressure is kept constant at a setpoint. If a kick or loss is detected, the controller is switched to pure flow control mode, and this will attenuate the kick or loss. A new adaptive observer is developed to estimate the reservoir pore pressure, which is used to set the new reference for bottom hole pressure.

II. Model

In this section, a simplified model is presented that captures the dominant phenomena of the drilling systems and forms the observer and controller design. It avoids measuring a high number of states and adjusting a large set of drilling parameters for the updated drilling process. Figure 1 shows the two control volumes considered, one control volume for the drill string and one for the annulus which are connected by the flow through the drill bit. The detailed dynamics of the drilling system in [14] can be described by

\[ \frac{V_d}{\beta_d} \dot{p}_p = q_{pump} - q_{bit} \]  
\[ \frac{V_a}{\beta_a} \dot{p}_c = q_a + q_{back} - q_{choke} \]

where states \( p_p \) and \( p_c \) are the inlet mud pump and outlet choke pressure [bar], \( q_{bit} \) and \( q_a \) are the flow rate through the drill bit and the annulus \([m^3/s]\), \( q_{pump}, q_{back}, \) and \( q_{choke} \) are the flow rates \([m^3/s]\) through the mud pump, the back pressure pump, and the choke valve, respectively. \( \beta_d \) and \( \beta_a \) are the bulk modulus of drill string and the annulus [bar], \( V_d \) and \( V_a \) are the volume of the drill string and the annulus \([m^3]\). These parameters are known constant in normal operation.

A. Reservoir fluid flow

During the drilling, there may be influx from the reservoir or loss to the formation. The most important disturbance in the system is an influx \( q_{res} \), (inflow if positive or outflow if negative), since influx of fluids influences the pressure gradient of the well and causes the pressure fluctuation.

\[ q_{res} = q_a - q_{bit} \]  

which is unknown bounded that should be zero under normal conditions.

III. Adaptive Observer Design

In this section, we will develop new adaptive observers which are used to estimate the flow rates through the drill bit \( q_{bit} \) and the annulus \( q_a \). The following assumptions regarding boundedness and knowledge of signals will be made:

Assumption 1: \( q_p \) and \( q_c \) are measured and bounded.

Assumption 2: \( q_{pump}, q_{back} \) are known constants.

Assumption 3: The control variable \( q_{choke} \) is known and bounded designed in Section IV.

A. Flow Rate Measurement

While drilling, flow rate measurements are used to mitigate potential well control risks through:

- Detection of kick, which involves detecting the influx of fluids from permeable or fractured formations into the wellbore, e.g. \( q_{res} \) is positive.
- Detection of lost circulation, which involves detecting the loss of drilling fluid from the wellbore into permeable or fractured formations, e.g. \( q_{res} \) is negative.

Eliminating or minimizing drilling fluid influx and losses reduces costs, improves safety, increases well bore stability, and decreases formation damage. In addition, the estimation of flow rates can also be used to estimate the bottomhole pressure, e.g. [18], [17].

B. Drillbit flow rate estimation

Assuming that \( q_{bit} \) can be treated as an unknown constant, which is reasonable during well drilling operation with nearly
constant mud pump flow, an observer is developed based on (1) given as
\[
\dot{q}_{p} = \frac{\beta_d}{V_a} \left( q_{pump} - \dot{q}_{bit} + l_1 (p_p - \dot{p}_p) \right),
\]
where \( l_1 \) is a positive design constant, and a parameter update law for \( \dot{q}_{bit} \) given as
\[
\dot{q}_{bit} = -\gamma_1 (p_p - \dot{p}_p),
\]
where \( \gamma_1 \) is a positive design constant. Defining the error variables \( \tilde{p}_p = p_p - \dot{p}_p \) and \( \tilde{q}_{bit} = q_{bit} - \dot{q}_{bit} \), the error dynamics becomes
\[
\begin{align*}
\dot{V}_d \tilde{p}_p &= -l_1 \tilde{p}_p - \tilde{q}_{bit}, \\
\dot{\tilde{q}}_{bit} &= \gamma_1 \tilde{p}_p,
\end{align*}
\]
which is linear with an exponentially stable origin.

C. Annulus flow rate estimation

Similar to the estimation of \( q_{bit} \), we propose an observer based on (2) assuming that \( q_a \) be an unknown constant. The observer is given as
\[
\dot{\tilde{q}}_a = \frac{\beta_a}{V_a} \left( q_a + q_{back} - q_{choke} + l_2 (p_c - \dot{p}_c) \right),
\]
where \( l_2 \) is a positive design constant, and a parameter update law for \( \tilde{q}_a \) given as
\[
\dot{\tilde{q}}_a = \gamma_2 (p_c - \dot{p}_c),
\]
where \( \gamma_2 \) is a positive design constant. Defining the error variables \( \tilde{p}_c = p_c - \dot{p}_c \) and \( \tilde{q}_a = q_a - \dot{q}_a \), the error dynamics becomes
\[
\begin{align*}
\dot{V}_a \tilde{p}_c &= -l_2 \tilde{p}_c - \tilde{q}_a, \\
\dot{\tilde{q}}_a &= -\gamma_2 \tilde{p}_c,
\end{align*}
\]
which is linear with an exponentially stable origin.

D. Reservoir Influx Estimation

Based on the estimations \( \dot{q}_{bit} \) and \( \dot{q}_a \), an estimate for \( q_{res} \) can now be taken as
\[
\dot{q}_{res} = \dot{\tilde{q}}_a - \dot{\tilde{q}}_{bit}.
\]
The estimated reservoir influx is used as a kick indication. A kick is considered to occur when \( \dot{q}_{res} > \dot{q}_{res} \), where \( \dot{q}_{res} > 0 \) is a tunable threshold value.

E. Analysis

Since (6)–(7) and (10)–(11) are linear time-invariant with negative real part eigenvalues, the systems have exponentially stable origins, such that signals \( \tilde{p}_p, \dot{q}_{bit} \) and \( \tilde{p}_c, \dot{q}_a \) are bounded. From the LaSalle-Yoshizawa Theorem in [25], it further follows that \( \tilde{p}_p, \dot{q}_{bit} \rightarrow 0 \) and \( \tilde{p}_c, \dot{q}_a \rightarrow 0 \) as \( t \rightarrow \infty \). In conclusion, we can get the convergence of \( \dot{q}_{res} = \dot{\tilde{q}}_a - \dot{\tilde{q}}_{bit} \).

**Theorem 1:** With the application of the observer (4)–(5), (8)–(9), and (12), the asymptotic convergence of estimates is achieved given as
\[
\lim_{t \rightarrow \infty} \dot{q}_{bit} = q_{bit}, \quad \lim_{t \rightarrow \infty} \dot{q}_a = q_a, \quad \lim_{t \rightarrow \infty} \dot{q}_{res} = q_{res}.
\]

IV. AUTOMATIC SWITCH CONTROL

The dynamic model for downhole pressure \( p_{bit}(t) \) can be computed through the annulus, obtaining
\[
\dot{p}_{bit} = \frac{\beta_a}{V_a} \left( q_{bit} + q_{res} + u(t) - V_a \right),
\]
where \( u(t) \) is the control input, which is physically applied by distributing the desired \( u(t) \) to the control choke and backpressure pump such that
\[
u(t) = q_{back}(t) - q_{choke}(t).
\]
The objective is to design a control law for the control input \( u(t) \) which stabilizes \( p_{bit} \) at the desired set-point \( p_{ref} \) and to deal with kick incidents without stopping mud circulation. The measurement of \( p_{bit}(t) \) can be obtained by
\[
p_{bit} = p_p + \rho_d(t)gh + F_d p_{pump}^2,
\]
where \( h \) is the vertical depth at the bit \( [m] \), \( \rho_d \) is the density of the fluid \( [10^3 kg/m^3] \) and \( F_d \) is the friction coefficients for the drill string \( [bar \cdot s^2/m^6] \). Now we propose a simple control law as
\[
u = -\sigma(t) k_P (p_{bit}(t) - p_{ref}) - \ddot{q}_{bit},
\]
where \( k_P \) is a positive tunable constant and \( \sigma(t) \) is
\[
\sigma(t) = \begin{cases} 1 & \text{no reservoir inflow/outflow} \\ 0 & \text{kick/loss handling} \end{cases}.
\]
In order to avoid possible chattering phenomenon, a continuous switch signal \( \sigma(t) \) is chosen as
\[
\sigma(t) = \begin{cases} \frac{1}{\tau_{T_w + T_c}} - T_w < \tau < -T_w + T_c \\ 0 & -T_w + T_c \leq \tau \leq -T_c \\ \tau + T_c & -T_c < \tau < 0 \end{cases}
\]
Kick detection: When \( |\dot{q}_{res}| > \dot{q}_{res} \), set \( \tau = -T_w \).

The switching logic contains positive constant dwell time \( 0 < T_c < T_w \), which prevent instability caused by frequent switching and possible scattering or chattering phenomenon in [26]. As the switch signal suggests, the controller has two modes of operation:

- In the normal mode of operation \( \sigma(t) = 1 \), \( k_P \) is selected as a suitable positive constant to regulate the annular pressure \( p_{bit} \) to the desired set-point \( p_{ref} \).
- In the kick handling mode \( \sigma(t) = 0 \), the controller reduces to a pure flow controller, giving the closed loop a self-regulating property with respect to attenuating the kick/loss.
- When \( \sigma(t) \) switching between 0 and 1 in a time constant \( T_c \), the closed-loop system is stable.
A. Normal Operation Analysis

In normal operation, we have \( \sigma(t) = 1 \), and \( q_{res} = 0 \), \( \dot{V}_a = 0 \), and assume that \( \beta_a \) and \( V_a \) are constant. Under these simplifications, the error dynamics \( \dot{e}_{bit} = p_{bit} - p_{ref} \) in closed loop with the controller (19) is

\[
\dot{e}_{bit} = \frac{\beta_a}{V_a} (\dot{g}_{bit} - k_p e_{bit}),
\]

where is the regulation error. Clearly, (22) is a linear system with an exponentially stable origin, driven by the flow estimation error. Since the flow estimation error converges exponentially fast to zero, so does the regulation error \( p_{bit} - p_{ref} \). Thus, we have the following result.

**Theorem 2:** Under the stated assumptions in normal operation, the controller (19) and the adaptive observer (4)–(5) in closed loop with system (16) achieves set-point regulation.

\[
\lim_{t \to \infty} p_{bit} = p_{ref}.
\]

B. Kick Attenuation Analysis

In the attenuation mode \( \sigma(t) = 0 \), the changes of outlume can be considered as as

\[
\dot{V}_a = \frac{\dot{V}(t)}{\beta_a} (q_{res}(t) + \dot{u}(t)),
\]

where \( \dot{V}(t) \) is some effective volume of the inflowing fluid, \( \dot{u} \) accounts for inaccuracies in the flow control. Therefore the equation (16) can be written as

\[
\dot{p}_{bit} = \gamma(t) (q_{res} + \dot{u}(t)),
\]

\[
\gamma(t) = \frac{\beta_a(t + \dot{V}(t))}{V_a}.
\]

Suppose the reservoir is described by the reservoir model

\[
q_{res}(t) = k_0 (p_{res} - p_{bit}(t)) = k_0 \xi(t),
\]

where \( k_0 > 0 \) is the so-called production index and \( p_{res} \) is the reservoir pressure and is assumed constant (slowly varying), \( \xi(t) = p_{res} - p_{bit} \), which denotes the pressure driving force. Suppose \( \gamma(t) \geq \gamma_{min} > 0 \) and assume \( \dot{u} = 0 \), the dynamics of \( \xi \) can be written can be represented by a negative feedback connection consisting

\[
\dot{\xi}(t) = -\gamma_{min} q_{res}(t) + e_1(t)
\]

and the memoryless function as

\[
\phi(t) = (\gamma(t) - \gamma_{min}) e_2(t),
\]

by setting \( e_1(t) = -\phi(t) \) and \( e_2(t) = q_{res}(t) \). Clearly, (29) is passive since \( \phi(t) e_2(t) = (\gamma(t) - \gamma_{min}) e_1^2(t) \geq 0 \) (due to \( \gamma_{min} < \gamma(t) \)). We have the transfer function

\[
G_1(s) = \frac{q_{res}(t)}{e_1(t)} = \frac{k_0(s)}{s + \gamma_{min} k_0(s)},
\]

which is strict positive real for \( k_0 > 0 \). By Theorem 6.4 in [25], we have the following result.

**Theorem 3:** In the attenuation mode, suppose \( \gamma(t) \geq \gamma_{min} \) and the reservoir model in (27), the origin of (272–29) is globally uniformly asymptotically stable, such as the controller (19) giving the closed loop a self-regulating property with respect to attenuating the kick/loss.

\[
\lim_{t \to \infty} q_{res} = 0
\]

**Remark 1:** When \( \sigma(t) \) switches between 0 and 1, the closed-loop system

\[
\dot{e}_{bit} = \frac{\beta_a}{V_a} (-\sigma(t) k_p e_{bit} + \dot{q}_{bit} + q_{res}),
\]

is linear time-varying with stable origin since \( \sigma(t) k_p > 0 \) and boundedness of \( \dot{q}_{bit} + q_{res} \).

V. RESERVOIR PORE PRESSURE ESTIMATION

When a kick/loss is detected, the well must be controlled properly in order to attenuate the kick/loss and continue the drilling operation. It is important to obtain accurate estimation of the reservoir pore pressure as quickly as possible. In this section, a new automatic estimation method for reservoir pore pressure will be presented, which is used for computing a new pressure set-point. From (27) we have

\[
\dot{p}_e(t) = \frac{\beta_a}{V_a} (k_0 (p_{res} - p_{bit}) + q_{bit} + u),
\]

Introducing a new variable

\[
\eta = \frac{V_a}{\beta_a} p_e + \frac{V_d}{\beta_d} p_p.
\]

Then the derivative of \( \eta \) in (34) is given as

\[
\dot{\eta} = q_{pump} + k_0 (p_{res} - p_{bit}) + u.
\]

Consider the adaptive observer

\[
\dot{\eta} = q_{pump} + k (\dot{p}_{res} - p_{bit}) + u + k_3 (\eta - \hat{\eta}),
\]

where \( k_3 \) and \( k \) are positive design constants. We cannot use the production index \( k_0 \) in the observer, since it is generally unknown. An adaptive update law for the estimate of \( p_{res} \) is suggested as follows

\[
\dot{\hat{p}}_{res} = \gamma_3 (\eta - \hat{\eta}),
\]

where \( \gamma_3 \) is a positive adaptation gain. Forming the error dynamics by defining \( \tilde{\eta} = \eta - \hat{\eta} \) and \( \tilde{p}_{res} = p_{res} - \hat{p}_{res} \), we
have

\[
\begin{align*}
\dot{\eta} & = -l_3 \eta + k \dot{p}_{res} + (k_0 - k) (p_{res} - p_{bit}) \quad (38) \\
\dot{\tilde{p}}_{res} & = -\gamma_3 \tilde{p}, \quad (39)
\end{align*}
\]

which is linear and time invariant, and driven by \( p_{res} - p_{bit} \) which converges to zero by the results of Section 3.3.

**Theorem 4:** Under the stated assumptions, the adaptive observer (36)–(37) achieves parameter convergence, that is

\[
\lim_{t \to \infty} \tilde{p}_{res} = p_{res}.
\]

**VI. Simulation Results**

The proposed methodology is evaluated on a high fidelity drilling simulator, WeMod, based on the requirements from an off-shore drilling operation of North Sea well. This model has been proven through several onshore and offshore tests [27]. The control signal relates to \( u = q_{back} - q_{choke}(z_c) \), where the exact form of the valve equation \( q_{choke}(z_c) \) is generally unknown. We will employ a PI controller

\[
e_c(k) = q_{\text{set}}(k) - q_{\text{choke}}(z_c),
\]

\[
z_c(k) = z_c(k - 1) + k_{cp} (e_c(k) - e_c(k - 1)) + \frac{\Delta t}{\tau_{ci}} e_c(k),
\]

\[
q_{\text{choke}}(k) = q_{\text{back}}(k) - u(k),
\]

where \( k_{cp}, \Delta t, \tau_{ci} \) are positive constants. The physical parameters are summarized in Table I. The controller design parameters are chosen as \( k_p = 4 \times 10^{-3}, k_{cp} = 0.2, \tau_{ci} = 5, l_1 = 0.05, \gamma_1 = 0.015, l_2 = 0.02, \gamma_2 = 0.0004, l_3 = 0.2, \gamma_3 = 1, T_w = 360 \text{sec}, T_c = 30 \text{sec}. \) The observers and controller are turned on at \( t = 30 \text{sec} \), with observer initials \( q_{\text{bit}}(0) = \bar{q}_a(0) = 1/120, \tilde{p}_{res}(0) = 790. \)

<table>
<thead>
<tr>
<th>Param.</th>
<th>Value</th>
<th>Param.</th>
<th>Value</th>
</tr>
</thead>
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<td>( V_d )</td>
<td>55 (m³)</td>
<td>( V_a )</td>
<td>211 (m³)</td>
</tr>
<tr>
<td>( \beta_d )</td>
<td>13000 (bar)</td>
<td>( \beta_a )</td>
<td>7317 (bar)</td>
</tr>
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<td>( \rho_d )</td>
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<td>( \rho_a )</td>
<td>1580 (kg/m³)</td>
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<tr>
<td>( F_d )</td>
<td>217000 (bar m²/s)</td>
<td>( h_{bit} )</td>
<td>4700 (m)</td>
</tr>
<tr>
<td>( q_{\text{pump}} )</td>
<td>1500(l/min)</td>
<td>( q_{\text{back}} )</td>
<td>200(l/min)</td>
</tr>
</tbody>
</table>

**Table I: Well and Reservoir Data in WeMod**

**A. Flow Rate Estimation**

While drilling, we fix the back pressure pump at \( q_{\text{back}} = 200 \) and choke opening \( z_c = 0.1 \), the mud pump flow rate changes from 1500 to 1100 with step \( \Delta = 200. \) Figure 3 shows that the estimates fit the true variables well with step changes in mud pump flow rate.

**B. Kick Detection and Attenuation**

In this case, we demonstrate that the estimates of flow rate can be considered as a kick indication and the flow control is an effective method to attenuate the kick. The kick occurs at \( t = 900s \). The flow rate estimation in Figure 4 shows that the annular flow rate \( \bar{q}_a \) increases by an amount equal to the influx rate, which is an kick indication. The developed automatic kick attenuation procedure is compared to a simulation of the standard shut-in procedure for a kick incident. In standard shut-in procedure, the mud pumps are shut down 20 seconds after the kick occurs. Then, the flow rate out of the well is monitored for 1 minute, one can conclude that a kick situation is in progress. In this event, the choke is closed. Figure 5 compares the resulting reservoir gas influx. Clearly, the reservoir gas influx is much smaller for our automatic kick attenuation approach than for the standard shut-in procedure.

**C. Switched Pressure Control**

When the pressure regulation is switched off, the downhole pressure will drift. Thus, as soon as a new pressure setpoint that is higher than the pore pressure of the gas pocket can be computed (recall that the pore pressure is unknown), which is estimated to \( p_{\text{ref}} = 488 (\text{bar}) \), pressure regulation should be switched back on. The simulation result in Figure 6 verifies that the proposed switch control algorithm is effective to attenuate the kick during drilling.

**D. Estimation of Reservoir Pore Pressure**

In this section, we test the reservoir pressure estimation for two cases. 1) The reservoir pore pressure is estimated when there is different permeability, 100, 200, 400. 2) The different reservoir pore pressure is estimated \( p_{\text{res}} \)
800, 805, 810 (bar). Figure 7 shows that the estimation method is robust with different reservoir permeability. Figure 8 shows the estimation method is effective to estimate pore pressure and robust with different pressure.

VII. CONCLUSION

In this paper, novel observers for estimation of the flow rates and pore pressure are developed and an automatic switched control is developed for kick/loss attenuation. The proposed methodology is evaluated on a high fidelity drilling simulator. The results in WeMod show that the proposed observers are effectiveness to detect kick/loss in the early phase and the automatic control scheme reduces the reservoir fluid influx during a kick and improves kick handling capabilities.

ACKNOWLEDGEMENTS

The work is supported by the MaxWells project at International Research Institute of Stavanger (IRIS). The MaxWells project is funded by grants from the Research Council of Norway and Statoil ASA.

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