NTNU

Innovation and Creativity

Adaptive Observer Design for the Bottomhole Pressure of a Managed Pressure Drilling System NPCW - Porsgrunn

Øyvind Nistad Stamnes, Jing Zhou,
Glenn-Ole Kaasa, Ole Morten Aamo

Department of Engineering Cybernetics

30 Jan. 2009

StatoilHydro

Outline

— About the Project

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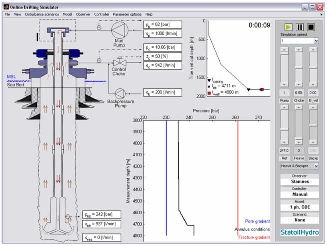

- About the Project
- Drilling 101

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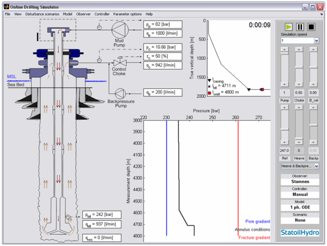

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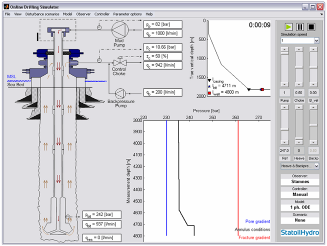

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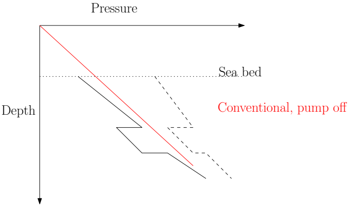

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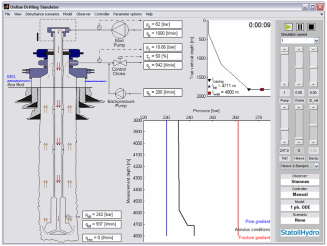

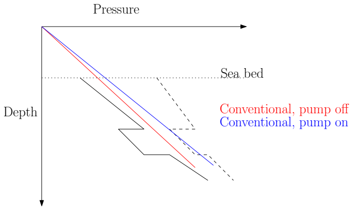

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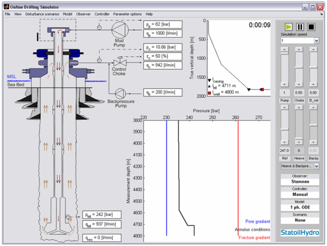
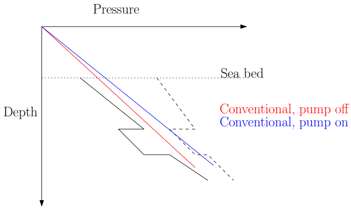
- Simulation Results





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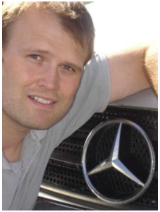

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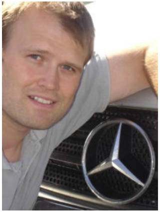


Drilling 101

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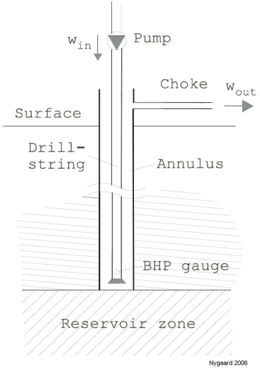
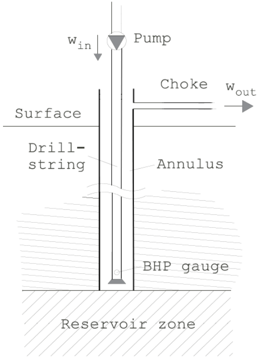
— Conventional Drilling



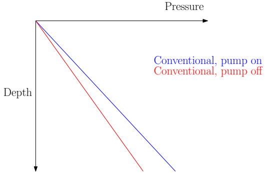
Drilling 101

— Conventional Drilling

$$P_{ann} = P_{fric} + P_{hydro}$$
$$P_{ann} = \text{Annular pressure}$$
$$P_{fric} = \text{Friction pressure}$$
$$P_{hydro} = \text{Hydrostatic pressure}$$



Nygaard 2006



Drilling 101

- Conventional Drilling
- Managed Pressure Drilling (MPD)

$$P_{ann} = P_{fric} + P_{hydro} + P_{choke}$$
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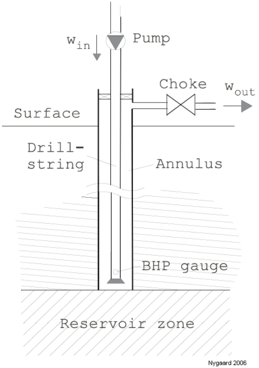

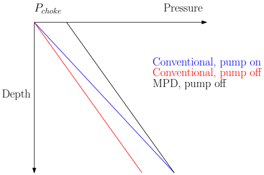

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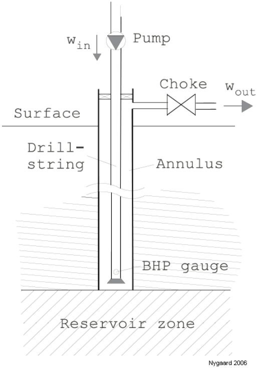
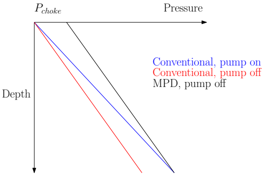
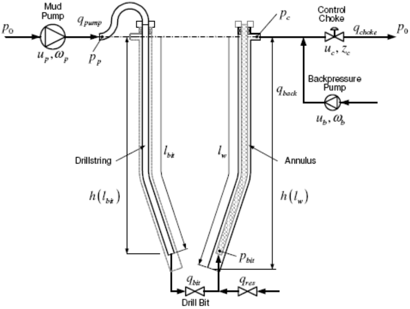


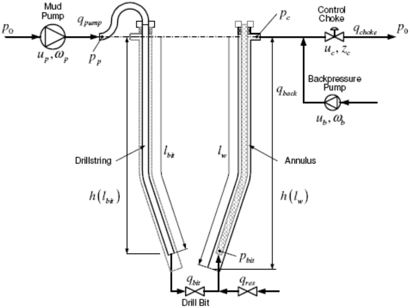


Model- Main Assumptions



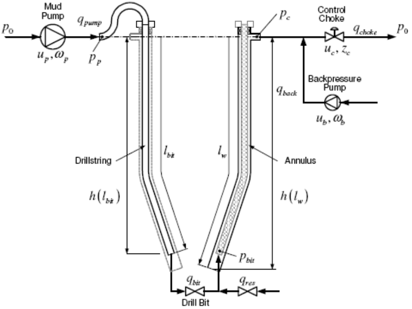
Model- Main Assumptions

- 1. phase, effect of gas in well included in density and effective bulk modulus



Model- Main Assumptions

- 1. phase, effect of gas in well included in density and effective bulk modulus
- Rigid flow in momentum balance



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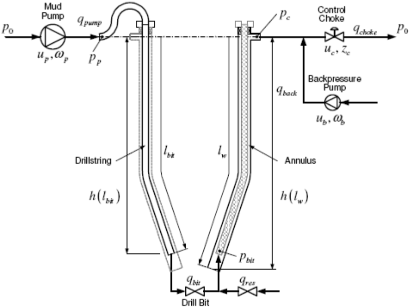
- Turbulent flow regime



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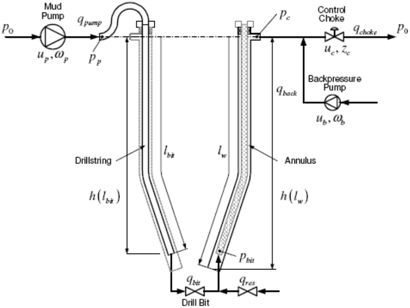

Model- Main Assumptions

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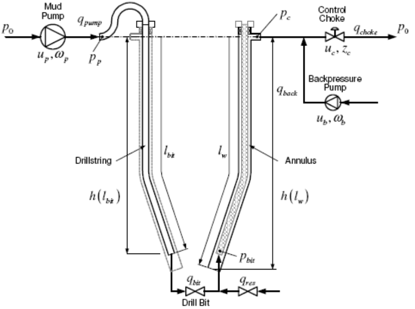
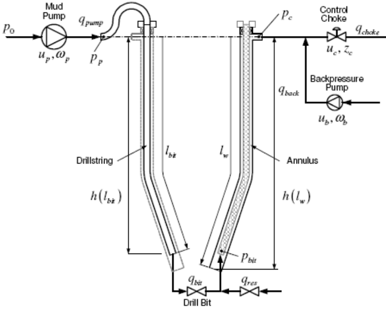
- Rigid flow in momentum balance
- Turbulent flow regime
- 1-dimensjonal flow
- Isothermal conditions



Model



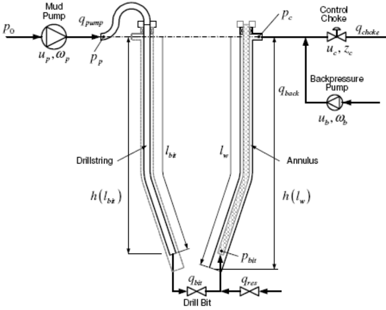
p=[bar], V=[m^3], $q=\left[\frac{m^3}{s}\right]$

β=[bar], h=[m], g=9.81 $\left[\frac{m}{s^2}\right]$

F=friction factor, $\rho=\left[\frac{kg}{m^3}\right]$

Model

$$\frac{V_a}{\beta_a}\dot{p}_c + \dot{V}_a = q_{bit} + q_{back} + q_{res} - q_{choke}$$



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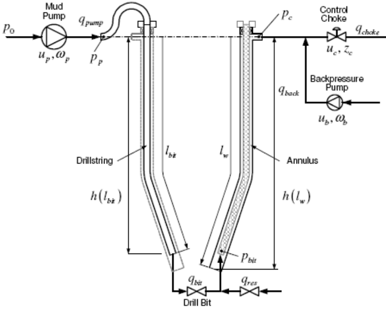

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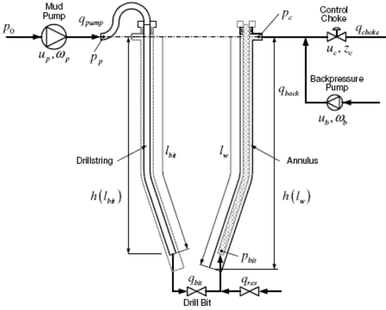
$$M\dot{q}_{bit} = p_p - p_c - (F_d + F_a)|q_{bit}|q_{bit} + (\rho_d - \rho_a)gh_{bit}$$



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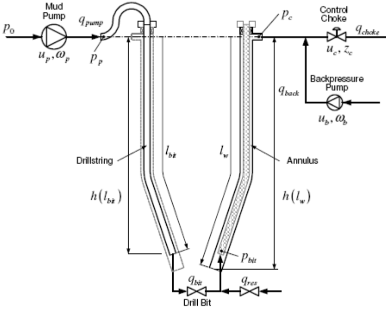
F=friction factor, ρ=$\left[\frac{kg}{m^3}\right]$

$$M = M_d + M_a$$

$$M_d = \rho_d \int_0^{l_{bit}} \frac{1}{A_d(x)}dx,$$

$$M_a = \rho_a \int_0^{l_w} \frac{1}{A_a(x)}dx$$

Model



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$$M\dot{q}_{bit} = p_p - p_c - (F_d + F_a)|q_{bit}|q_{bit} + (\rho_d - \rho_a)gh_{bit}$$

$$p_{bit} = \begin{cases} p_c + M_a\dot{q}_{bit} + F_a|q_{bit}|q_{bit} + \rho_a gh_{bit} \\ p_p - M_d\dot{q}_{bit} - F_d|q_{bit}|q_{bit} + \rho_d gh_{bit} \end{cases}$$

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Model- Verification

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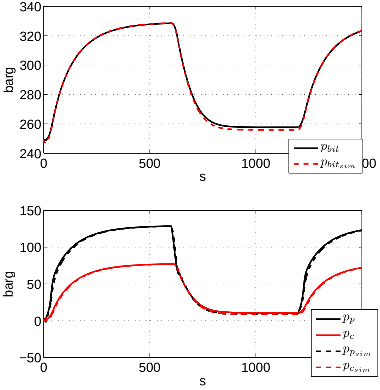

Figure: Model fitted to WeMod

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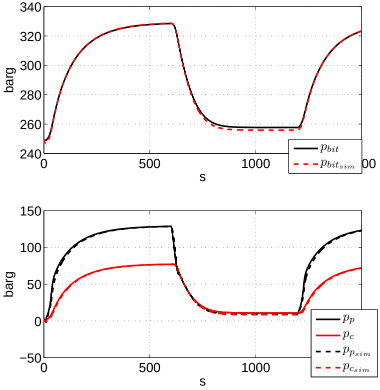

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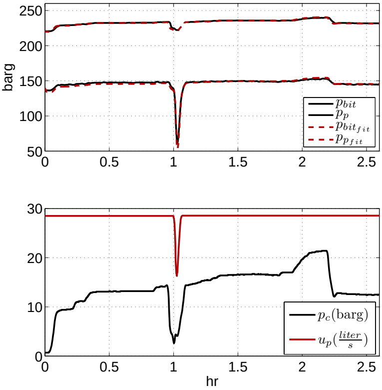
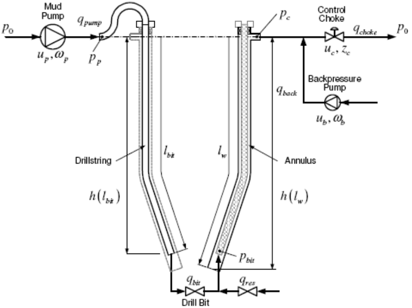


Figure: Model fitted to data

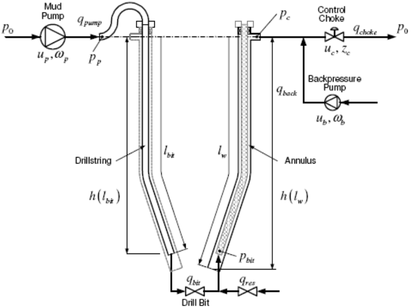
Observer Design - Assumption

— Measure top-side pressures and flow through main pump



Observer Design - Assumption

- Measure top-side pressures and flow through main pump
- measure/know the geometry of the well



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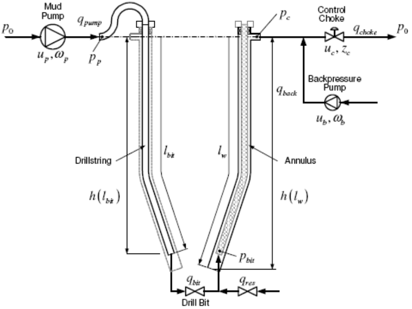
- Measure top-side pressures and flow through main pump
- measure/know the geometry of the well
- all parameters except friction and density in annulus known



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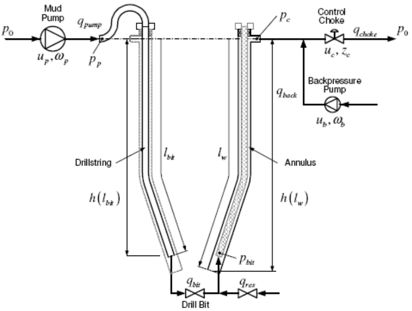
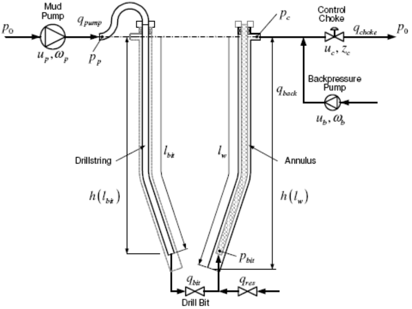


Observer Design - Assumption

- Measure top-side pressures and flow through main pump
- measure/know the geometry of the well
- all parameters except friction and density in annulus known
- $q_{res} = 0$
- $q_{bit} > 0$, in reality $q_{bit} \geq 0$



Observer Design - Model

Same model, unkown friction and density

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$$\dot{p}_p = -a_1 q_{bit} + b_1 u_p$$

$$a_1 = \frac{\beta_d}{V_d}, \qquad b_1 = a_1$$

Observer Design - Model

Same model, unkown friction and density

$$\dot{p}_p = -a_1 q_{bit} + b_1 u_p$$
$$\dot{q}_{bit} = a_2(p_p - p_c) - \theta_1 |q_{bit}| q_{bit} + \theta_2 v_3$$

$$a_1 = \frac{\beta_d}{V_d}, \qquad b_1 = a_1$$
$$a_2 = \frac{1}{M}, \qquad \theta_1 = \frac{F_a + F_d}{M}$$

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$$\theta_2 = \frac{(\rho_d - \rho_a) g}{M}, \qquad v_3 = h_{bit}$$

Observer Design - Model

Same model, unkown friction and density

$$
\begin{aligned}
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\dot{q}_{bit} &= a_2(p_p - p_c) - \theta_1 |q_{bit}| q_{bit} + \theta_2 v_3 \\
p_{bit} &= p_c + M_a \dot{q}_{bit} + (M\theta_1 - F_d)|q_{bit}|q_{bit} + (\rho_d - \frac{M}{g}\theta_2) h_{bit}
\end{aligned}
$$

$$
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\theta_2 &= \frac{(\rho_d - \rho_a)g}{M}, & v_3 &= h_{bit}
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Define $\xi = q_{bit} + l_1 p_p$. l_1 is a tuning gain.

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A state estimator for q_{bit}

$$\dot{\widehat{\xi}} = -l_1 a_1 \widehat{q}_{bit} - \widehat{\theta}_1 |\widehat{q}_{bit}| \widehat{q}_{bit} + \widehat{\theta}_2 v_3 + a_2(p_p - p_c) + l_1 b_1 u_p$$

$$\widehat{q}_{bit} = \widehat{\xi} - l_1 p_p$$

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Error dynamics for $\tilde{\xi} = q_{bit} - \widehat{q}_{bit}$

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Error dynamics for $\tilde{\xi} = q_{bit} - \widehat{q}_{bit}$

$$\dot{\tilde{\xi}} = -l_1 a_1 \tilde{\xi} - \theta_1 (|q_{bit}| q_{bit} - |\widehat{q}_{bit}| \widehat{q}_{bit}) + \tilde{\theta}^T \phi(\widehat{q}_{bit}, v_3)$$

Observer Design - Transformation

Define $\xi = q_{bit} + l_1 p_p$. l_1 is a tuning gain. Dynamics for ξ

$$\dot{\xi} = -l_1 a_1 q_{bit} - \theta_1 |q_{bit}| q_{bit} + \theta_2 v_3 + a_2(p_p - p_c) + l_1 b_1 u_p$$

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Error dynamics for $\tilde{\xi} = q_{bit} - \widehat{q}_{bit}$

$$\dot{\tilde{\xi}} = -l_1 a_1 \tilde{\xi} - \theta_1 (|q_{bit}| q_{bit} - |\widehat{q}_{bit}| \widehat{q}_{bit}) + \tilde{\theta}^T \phi(\widehat{q}_{bit}, v_3)$$
$$\phi(\widehat{q}_{bit}, v_3) = \left[-|\widehat{q}_{bit}| \widehat{q}_{bit}, \ \ v_3 \right]^T$$

Observer Design - Lyapunov Analysis

Lyapunov type analysis

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— $V = \frac{1}{2}\tilde{\xi}^2 + \frac{1}{2}\tilde{\theta}^T\Gamma^{-1}\tilde{\theta}$

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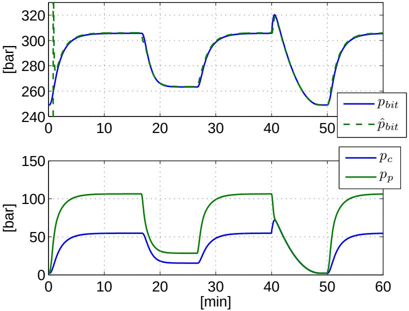
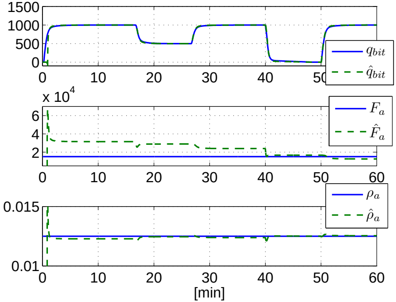
- We also get $\lim_{t\to\infty} \tilde{\theta}^T \phi = \lim_{t\to\infty} \left(-\tilde{\theta}_1 \widehat{q}_{bit} + \tilde{\theta}_2 v_3 \right) = 0$
- $\tilde{q}_{bit} \to 0$ and $\tilde{\theta}^T \phi \to 0$ enables us to get an estimate $\hat{p}_{bit} \to p_{bit}$

Simulation - WeMod



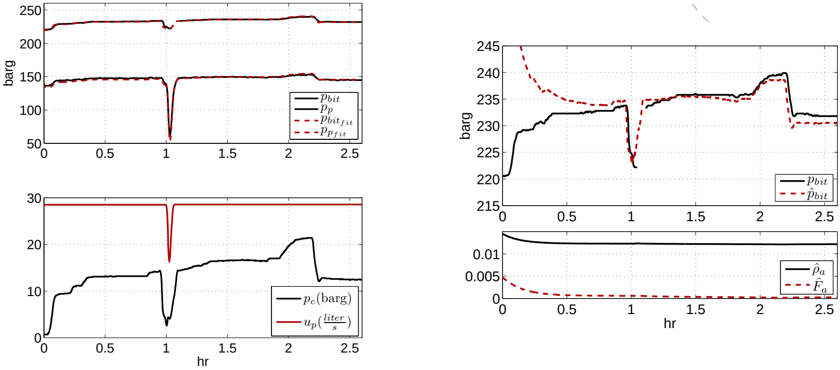


Initial conditions:

$\hat{q}_{bit}(t_0) = u_p(t_0)$, $\hat{\rho}_a(t_0) = 2\rho_a$,

$\hat{F}_a(t_0) = 3F_a$, $t_0 = 50s$

Simulation - Data



Initial conditions:

$\hat{q}_{bit}(t_0) = u_p(t_0)$, $\hat{\rho}_a(t_0) = 1.2\rho_a$,

$\hat{F}_a(t_0) = 1.5F_a$

Conclusion

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Thank you!

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Science and Technology

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