

Effects of Mud Properties, Hole size, Drill String Tripping Speed and Configurations on Swab and Surge Pressure Magnitude during Drilling Operations

***Uduak Mme and Pål Skalle**

*Department of Petroleum Engineering and Applied Geophysics,
NTNU, Trondheim, Norway*

**Corresponding Author E-mail: uduak.mme@ntnu.no*

Abstract

Factors which affect swab and surge pressures must be precisely selected in order to control kicks or blowouts and to prevent loss of circulation. In this paper a sensitivity analysis is carried out to investigate the effect of drilling fluid density, plastic viscosity, yield point, bore hole diameter and drillcollars-to-drillpipe length ratio on swab and surge pressures. The analysis is based on:

- i. The theory of hydrostatic drilling fluid mechanics, taking the effect of mud clinging constant into consideration.*
- ii. Developing a Matlab code to compute and simplify the flow equations*
- iii. Transforming the output of this code into graphical form from which effects of mud properties, drillstring tripping speed, and hole and drill string configuration; on swab and surge pressures could be predicted.*

The developed code requires fairly simple input data which can be obtained from the rig site mud engineer. Important conclusions and industrial implications of the findings are

1. Mud weight, rheology and drill collars length and size are predetermined factors which have been chosen carefully and maintained at the desired level during drilling and tripping operations in order to avoid blowout or loss of circulation problems. These can be varied only to a limited degree.
2. Safe tripping speeds are greatly influenced by hole size.
3. The developed computer programme can be used to predict safe drill string tripping.

4. Tripping speed is the only manipulative parameter with respect to controlling surge and swab pressure. This has been built into a graphical view for certain critical circumstances.
5. Whenever a critical situation demands that tripping-out should be supported by simultaneous pumping, a graph has been developed for this purpose.

Keywords: Mud properties, Kick, Loss circulation, Mud clinging constant, Swab and Surge pressure

Introduction

When tripping, the drillstring acts as a large piston moving through the borehole. This movement creates pressures due to friction losses between the moving string and mud. Swab pressures are created when the string moves upward and surge pressures when the string moves downward. If swab pressures are large enough, they can reduce the mud hydrostatic pressure below the formation pressure and cause a kick. Large surge pressures can fracture the formation and result in loss of circulation. Also, during the drilling operation, it is often necessary to remove the drill string in order to change the drill bit. It may also be necessary to remove the drill string for other reasons, such as to perform desired logging operations. After the bit is changed or after such logging operations are completed, the drill string must return to the borehole. The process of pulling out and running in the drill string is known as tripping operations.

It has long been observed in the field that circulation is frequent lost after making a trip. Similarly, blowouts often occurred during the pipe removal part of a trip due to formation gas (trip gas) entering the hole and lightening the mud column. Experiment (Goins et al, 1951) and analytical (Cardwell, 1953) work showed these problems to be largely due to down hole pressure variations caused by the piston-cylinder action of the pipe and borehole.

Swab and surge pressures have been studied by many researchers (Marken, 1992, Mutomino, 1995; Zhong, 1995). Hussain and Sharif (2009) indicated the reduction of surge pressure with the increase in eccentricity. For a partially blocked eccentric annulus with cuttings bed, the surge pressure decreases with the increase in the bed thickness. Ahmed *et al.* (2010) presented hydraulic model to predict pressure losses while drilling and circulating drilling fluid. Hydraulic analysis of annular flow with axial motion of the inner pipe have been carried out (Haige and Xisheng 1996, Filip and David 2003) for different pipe/borehole configurations and fluid models. Unfortunately, most of these studies have developed models which lack in simplicity and require complex input parameters. In our work, effects of mud properties, drillstring tripping speed, and hole and drill string configuration; on swab and surge pressures were investigated by developing a computer code and transforming this code into a graphical technique. The developed code require only simple data which could be gotten from the rig site mud engineer.

Mud Flow Physics

The flow behaviour of drilling fluids is complicated by the variation of apparent viscosity with rate of shear or flow. Consequently, the Newtonian fluid equations are altered for application to typical drilling mud systems. Swab and surge pressures can be computed using a calculation steps based on basic mud flow Equations 1 to 10. The calculation procedure is based on the theory of hydrodynamic viscous drag presented by Maidla and Wojtanowicz (1987) for Bingham-plastic fluids in wellbores. Hydrodynamic viscous drag is defined as the friction force between the pipe string and the drilling fluid, which resist against pipe movement. It depends on drilling fluid properties, tripping velocity, flow regime, pipe outer diameter and wellbore diameter. The more viscous drilling fluid results the more viscous drag force. It also shows effect of clearance between string and the wellbore. The calculation procedures includes:

Step 1

Calculation of the average effective annular velocity, V_{ae} around the drill collars and around the drillpipe Average effective annular velocity is the mud velocity which produces the viscous drag component of surge or swab pressure and its frame of references is the wellbore wall. The value of effective mud velocity due to moving pipe wall is related to pipe velocity, V_p by mud clinging constant C_c . The value of C_c depends upon the ratio of pipe and hole diameters.

$$V_{ae} = V_p \times \left[\frac{\delta^2}{1 - \delta^2} + C_c \right] \quad 1$$

Where δ represents the ratio of pipe diameter to borehole diameter

$$C_c = \frac{\delta^2 - 2\delta^2 \ln \delta - 1}{2(1 - \delta^2) \ln \delta} = \frac{1}{2 \ln \delta} + \frac{\delta^2}{1 - \delta^2}, \text{ for laminar flow} \quad 2$$

And

$$C_c = \frac{\sqrt{\frac{\delta^4 + \delta}{1 + \delta}} - \delta^2}{1 - \delta^2}, \text{ for turbulent flow} \quad 3$$

Step 2

Is the mud flow laminar or turbulent? The flow critical velocity, V_c around the drillcollars and around the drillpipe is calculated as follows:

$$V_c = \frac{1.08\mu_p + 1.08\sqrt{\mu_p^2 + 9.3\rho(d_h - d)^2 Y_p}}{\rho(d_h - d)} \quad 4$$

Step 3

If the flow is laminar, the pressure drop around the drillcollars and around the

drillpipe is calculated as follows:

$$\Delta P = \frac{L}{300(d_h - d)} \left[Y_p + \frac{\mu_p V_{ae}}{5(d_h - d)} \right] \quad 5$$

L is the length of drillpipe or drillcollars as the case may be.

Step 4

If the flow is turbulent, the pressure drop around the drillcollars and around the drillpipe is calculated as follows:

$$\Delta P = \frac{fL\rho V_{ae}^2}{25.8(d_h - d)} \quad 6$$

Step 5

The friction factor, f can be calculated using the following equations:

$$\text{Re} = \frac{926.4 \times \rho V_{ae} (d_h - d)}{\mu_p} \quad 7$$

$$f = e^{\left[c_1 + \frac{c_2}{\text{Re}} \right]} + c_3 \ln(\text{Re}) \quad 8$$

Where,

$$c_1 = -3.5378591164$$

$$c_2 = 300.26609292$$

$$c_3 = -0.126153971$$

Step 6

Surge and swab pressure can be calculated from Equation 9 and Equation 10 respectively.

$$P_{surge} = \Delta P_{ap} + \Delta P_{ac} + 0.052 \rho h \quad 9$$

$$P_{swab} = 0.052 \rho h - \Delta P_{ap} - \Delta P_{ac} \quad 10$$

Where ΔP_{ap} is pressure drop around drill pipe and ΔP_{ac} is pressure drop around drillcollars. Formation fracturing pressure can be estimated using the following equation (Hubbert, 1957):

$$P_f = \frac{2\nu}{1-\nu} \sigma_{ov} + \sigma_t \quad 11$$

Normally, the tensile strength of reservoir rocks is neglected as a worst case could be encountered (equal zero). The overburden stress for normally stressed formations

can be evaluated as follows:

$$\sigma_{ov} = 1 \frac{Psi}{ft} h \tag{12}$$

Formation fracture gradient for deep wells can be estimated using the following equation:

$$G_f = \frac{2\nu}{1-\nu} \tag{13}$$

Assuming that average Poisson’s ratio, ν for most reservoir rocks equal to 0.25, the formation fracturing pressure gradient (computed using Equation 13) equals to 0.67 psi/ft. Formation pore pressure gradient normally constant and assumed to be 0.45 psi/ft in this study.

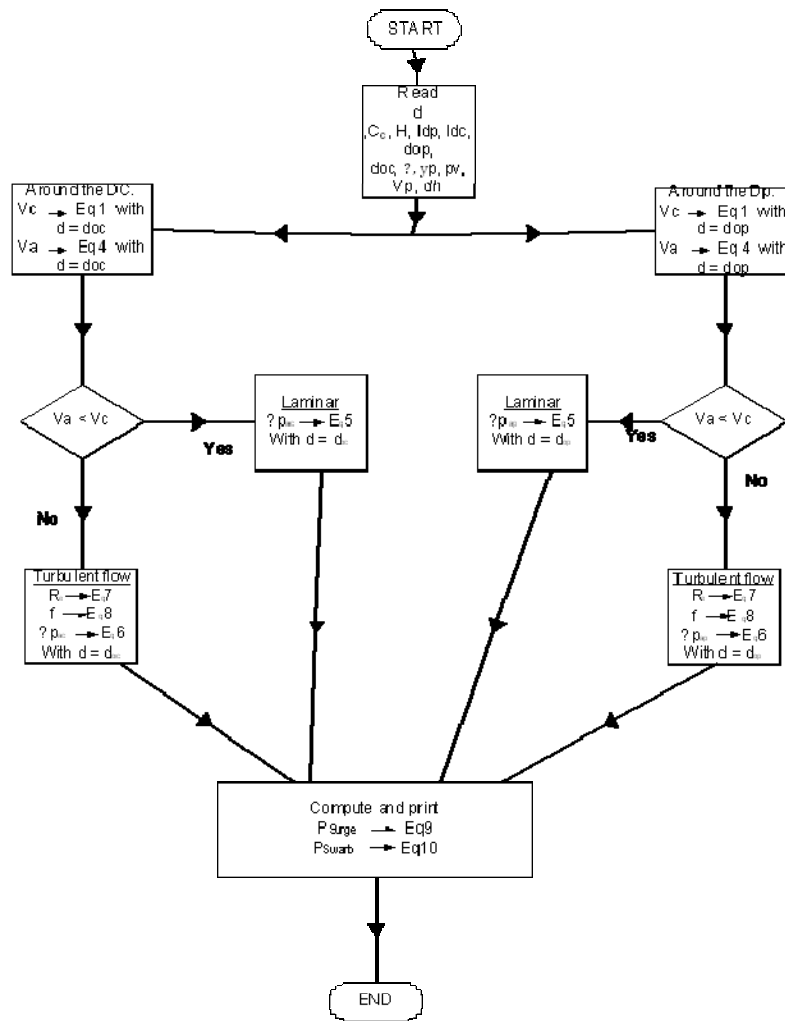


Figure 1: Flow chart for the developed Matlab code

Figure 1 indicates the flow chart for the Matlab code that has been developed to do all the above mentioned calculations. Based on the above procedure a sensitivity analysis was performed to investigate the effect of fluctuation of the model parameters on surge and swab pressures including:

- i. *Mud properties (mud weight, plastic viscosity and yield point)*
- ii. *Hole diameter*
- iii. *Drillcollars-to-drillpipe length ratio*
- iv. *Formation pore fluid pressure*
- v. *Formation fracturing pressure*

Table1: Matlab Code Input Data

Parameter	Value or Range	Unit
Mud weight, ρ	8.5-12.5	ppg
Mud plastic viscosity, μ_p	15-55	cp
Mud yield point, Y_p	5-200	lb/100sq.ft
Well depth, h	6000-15000	ft
Hole size, d_h	7.875-9.875	inches
Drillcollars-to-drillpipe ratio	0.0345-0.1538	fraction
Drill pipe size (ID,OD)	3.826, 4.5	inches
Drillcollars size (ID,OD)	2.813, 6.75	inches
Drill string tripping speed	0-18	ft/sec
Formation pore fluid pressure gradient	0.45	Psi/ft
Formation fracturing pressure gradient	0.67	Psi/ft
Poisson's ratio	0.25	fraction

By using the input data presented in Table 1 above and the developed computer code, a sensitivity analysis was conducted.

Results and Discussions

Based on the results of the sensitivity analysis, Figures 2 to 6 were plotted. Critical pipe running speeds for both surge and swab cases were clarified in the Figures. Drilling fluid properties including density, yield point, and viscosity are important factors which greatly affect the magnitude of surge and swab pressures generated during trip – in and trip –out operation respectively. Figure 3 shows the effect of mud weight on critical pipe tripping speeds range.

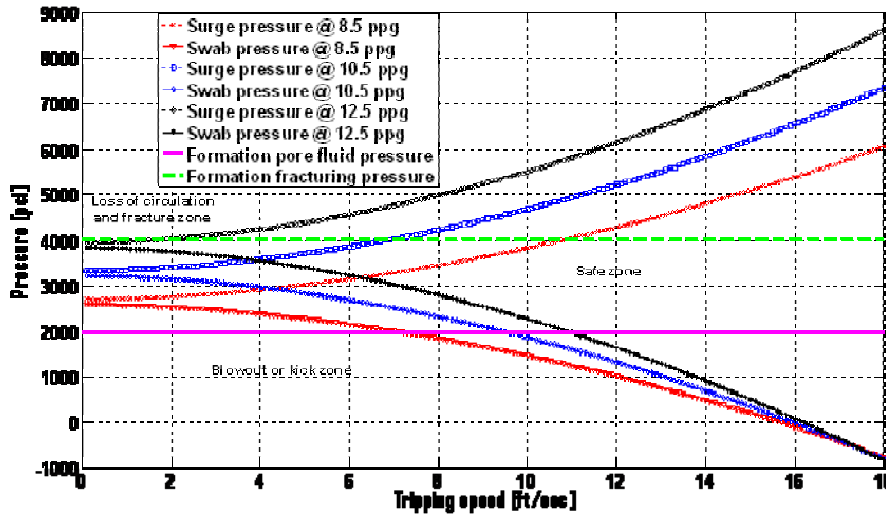


Figure 2: The effect of mud weight on surge and swab pressure magnitude

The critical pipe tripping speed is the speed beyond which loss of circulation or blowout could happen. When the mud density increases the range of safe pipe trip –in speed decreases. This effect is attributed to the large increase in mud pressure (in addition to the piston-cylinder action caused by the drill string) opposing the formation being drilled and the results will be serious fractures leading to loss of circulation problem. On the other hand, the increase in mud density can easily control formation pore fluid pressure, therefore, wide range of safe pipe trip-out speeds can be applied as shown in Figure 2. Safe pipe tripping speeds are affected by mud rheological properties such as mud plastic viscosity and yield point.

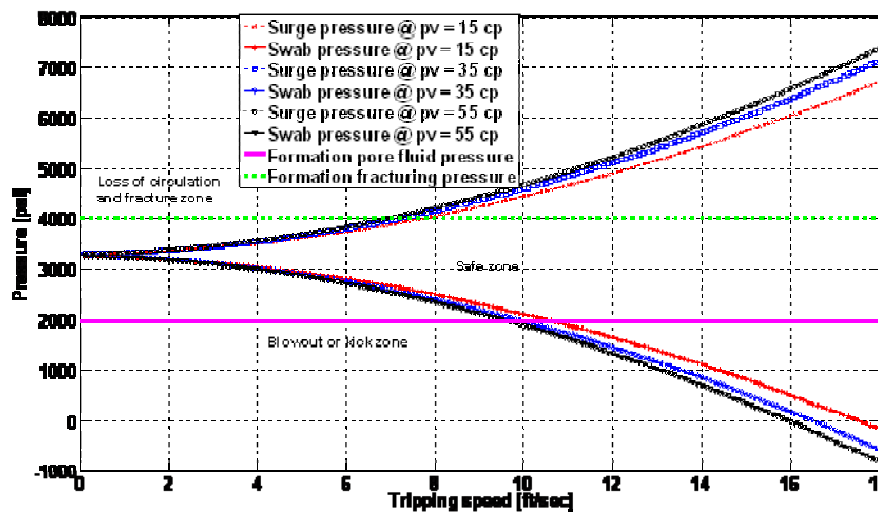


Figure 3: The effect of mud plastic viscosity on surge and swab pressure magnitude

This effect could be due to the fact that viscous mud magnify the piston-cylinder action produced by drillstring up and down movements as shown in Figures 3 and 4.

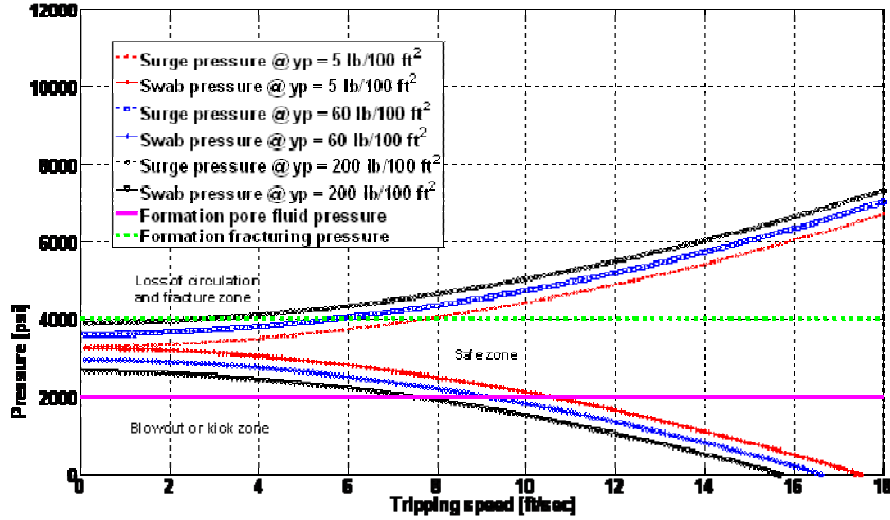


Figure 4: The effect of mud yield point on surge and swab pressure magnitude

Drillcollars has a diameter bigger than the normal drillpipes. Therefore it adds and extra pressure on the formation during tripping in and drain the formation pore fluid into the wellbore during tripping out due to the piston-cylinder action as shown in Figures 5.

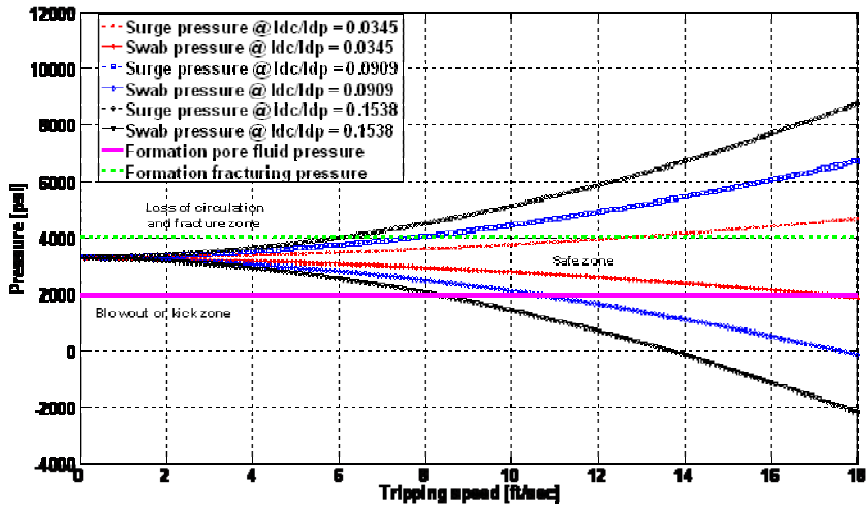


Figure 5: The effect of drillcollars to drillpipe length ratio on surge and swab pressure magnitude

Hole size have a large effect on safe drillstring tripping speeds. This is because during tripping out, large hole diameter allows the drilling fluid to rapidly fill in the place which was occupied by the drillstring, therefore the formation pore fluid pressure is easily controlled and avoid blowouts.

During pipe trip-in, large hole diameter provides bigger passage area for the mud, therefore, the piston-cylinder action acting opposite to the formation is minimized and the formation fracturing can be avoided as shown in Figure 6 (Hole size).

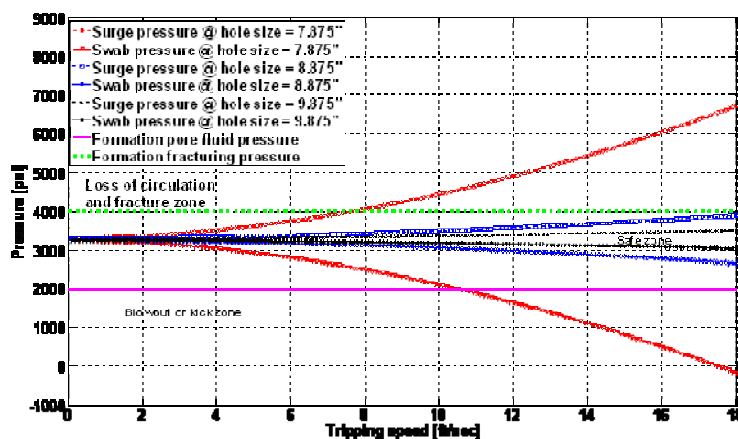


Figure 6: The effect of hole size on surge and swab pressure magnitude

Thus, by plotting data obtained from the developed computer programme, effects of mud properties, hole size, drill string tripping speed and configurations on swab and surge pressure magnitude can be predicted during drilling operations

Conclusions

Based on the performed analysis, the following conclusions can be drawn:

- Mud weight, rheology and drill collars length and size are predetermined factors which have been chosen carefully and maintained at the desired level during drilling and tripping operations in order to avoid blowout or loss of circulation problems. These can be varied only to a limited degree.
- Safe tripping speeds are greatly influenced by hole size.
- The developed computer programme can be used to predict safe drill string tripping.
- Tripping speed is the only manipulative parameter with respect to controlling surge and swab pressure. This has been built into a graphical view for certain critical circumstances.
- Whenever a critical situation demands that tripping – out should be supported by simultaneous pumping, a graph has been developed for this purpose.

References

- [1] Ahmed, R., Enfans, Miftah-El-Kheir, H., Laget, M., and Saasen, A., (2010): "The Effect of Drillstring Rotation on Equivalent Circulation Density: Modeling and Analysis of Field Measurements", paper SPE 135587 presented at the SPE Annual technical Conference and Exhibition held in Florence, Italy, 19-22 September.
- [2] Cardwell, W. T., Jr.,(1953): "Pressure Changes Caused by Pipe Movement", API Drilling and Production Practices, p.97.
- [3] Filip, P. and David, J. (2003): "Axial Couette-Poiseuille flow of Power – Law viscoplastic Fluids in concentric Annuli", Journal of Petroleum Science and Engineering, Vol. 40, pp. 111-119.
- [4] Goins, W. C., Weichert, J. P., Burba, J. L., Dawson, D.D., and Teplitz, A.J., (1951): "Down the Hole Pressure Surges and Their Effect on Loss of Circulation", API Drilling and Production Practices, p.125.
- [5] Haige, W. and Xisheng, L. (1996): "study on surge Pressure for Yield-Pseudoplastic Fluid in a Concentric Annulus", Applied mathematics and mechanics, Vol.17, No. 1, pp 15-23.
- [6] Hubbert, M and Willis, D. (1957): Mechanics of Hydraulic Fracturing.
- [7] Hussain, Q. E. and Sharif M. A. R. (2009): "Viscoplastic fluid flow in irregular eccentric annuli due to axial motion of the inner pipe", The Canadian journal of Chemical Engineering, vol. 75, issue 6, pp. 1038-1045.
- [8] Maidla, E.E., Wojtanowicz, A.K. (1987): "Field Method of Assessing Borehole Friction for Directional Well Casing", *Society of Petroleum Engineers*, SPE Middle East Oil Show, Manama, Bahrain, March 7-10, 15696.
- [9] Marken, C. D., Xiaojun, H. and Arild, S, (1992): "The Influence of Drilling Conditions on Annular Pressure Losses", SPE paper no. 24598 presented at the 67 th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in Washington, Dc., October 4-7.
- [10] Mutomino, M., Rubertone, M. and Cesare, P. (1995): "An Innovative Models for drilling Fluid Hydraulics", SPE paper no. 29259, Asia and Pacific Oil & Gas Conference held in Kuala Lumpur, Malaysia, 20-22 March.
- [11] Zhong, B., Zhou, K. and Yuan, Q. (1995): "Equations helps Calculate Surge and Swab pressures in Inclined Wells", Oil & Gas Journal, September 18, p74-77.