Ministry Of High Education And Scientific Research

University of Kasdi Merbah -Ouargla-

Faculty of Hydrocarbures, Renewable Energies and Sciences of Earth and Universe.

Memory

To getting the master degree

Option : MCP

Presented by

Messaoudi Abdelhak

Title :

Gel breaking modeling and control by managed pressure drilling system in drilling operations

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In :   /   / 2017   Supervised by Mr. Hachana Oussma

Jury:

President: Khantout Abdelkader

Examiner: Chouicha Samira

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Dedication

I introduce this work to my parents.

Acknowledgements

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All the work was conducted at university of Kasdi Marbah.

I would like to thank my supervisor, Mister Hachana Oussama, for his helpful; I say: our God bless you; and I apologize to him from the under acting in work and his more tired with me.

Finally, I have to thank all of my fellow students, and all my teachers, whose consistently has been backing up and giving feedback on problems, often totally irrelevant for them.

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Nomenclature

Symbol	Signification
c_{v}	Flow coefficient.
k	Numerical constant used for valve fitting.
P_{P}	Pump pressure.
P_{c}	Choke pressure.
P_{b}	Bit pressure.
q_{c}	Choke flow.
q_{p}	Pump flow.
q_{b}	Drillbit flow.
ΔP_{f}	Pressure loss due to friction.
ΔP_{sc}	Pressure loss due to surface connections.
ΔP_{o}	Pressure drop due to other dynamics.
M	Integrated density per cross-section over the flow path.
$\mathrm{G}\,(.)$	Total gravity affecting the fluid.
V_{a}	Volume in the annulus.
β_{a}	Bulk modulus for the fluid in the annulus.
V_{d}	Volume of the drillstring.
β_{d}	Bulk modulus for the fluid in the drillsting.
ΔP_{b}	Pressure loss in drill bit.
$\frac{\mathrm{d}\lambda}{\mathrm{dt}}$	Working parameter.
λ	Drillig mud factor of viscosity.
λ_{inti}	Initial factor of viscosity for the mud.
τ_0	Yield Stress.
τ_{w}	Shear stress.
γ	Shear rate.
v	Velocity.
μ_P	Plastic viscosity.
a, b	Coefficients for working parameter.
L_{a}	Length of annulus.
L_{d}	Length of drillstring.
$\mathrm{h_a}$	Height of annulus "True vertical depth of bit".
$\mathrm{d_i}$	Diameter inside.
$\mathrm{d_o}$	Diameter outside.
$\mathrm{d_h}$	Diameter of hollow.
$\mathrm{A_a}$	Area of annulus.
$\mathrm{p_s}$	Pressure set point.
g	Gravity.
$\mathrm{g_s}$	Specific gravity of mud.
$\mathrm{T_c}$	Time constant for chock opening.
$\mathrm{K_p}$	Proportional gain.
$\mathrm{K_i}$	Integral gain.
ρ_{m}	Density of mud.

General introduction

In drilling system can deduce a closed circuit of drilling fluid circulation through a pump; canals; bit; chock and pit. The principal objective of using mud as fluid in drilling operations is to help the drill string. Inasmuch we get information about drilling mud; his properties are changing during time; it means that if each time the mud at rest will, after some time, start a process of gelling. When the system is set to motion again, a considerable amount of force is therefore required to break the gel so we must stabilize the pressure. In order to minimize the occurring of gelling process and its period. As we can't never prevent this process because the method of drilling dictate these. The operators and equipments don't be able to working in permanent regime; and we need this phenomena in certain boundaries to suspend the cuttings then eliminate them outside.

Therefore; if its pressure variations were not been controlled; the mud might work the counteractive role; such as cause an instability in our drilling system and may cause damage to our equipments or a catastrophe in the petroleum field.

In this work the main purpose is to develop an automatic control to stabilize the downhole pressure and make it following a desired set point. Mud pump (startup; shutdown) and chock valve opening are one of the main reasons for increased and decreased pressure so these are intended equipments to get a control in managed pressure drilling.

I.1. Introduction

In this chapter we give an outline about drilling system which contains drilling mud accurately, and a simple equipments definition. We will meanly focus in this study about the closed loop equipments which ensure drilling mud circulation and pressure control.

I.2. Drilling mud equipment

Generally the drilling system, consists of several principal parts; Drillstring, Choke Valve, Check valve and so. Figure I.1 shows the mean several parts of drilling system.

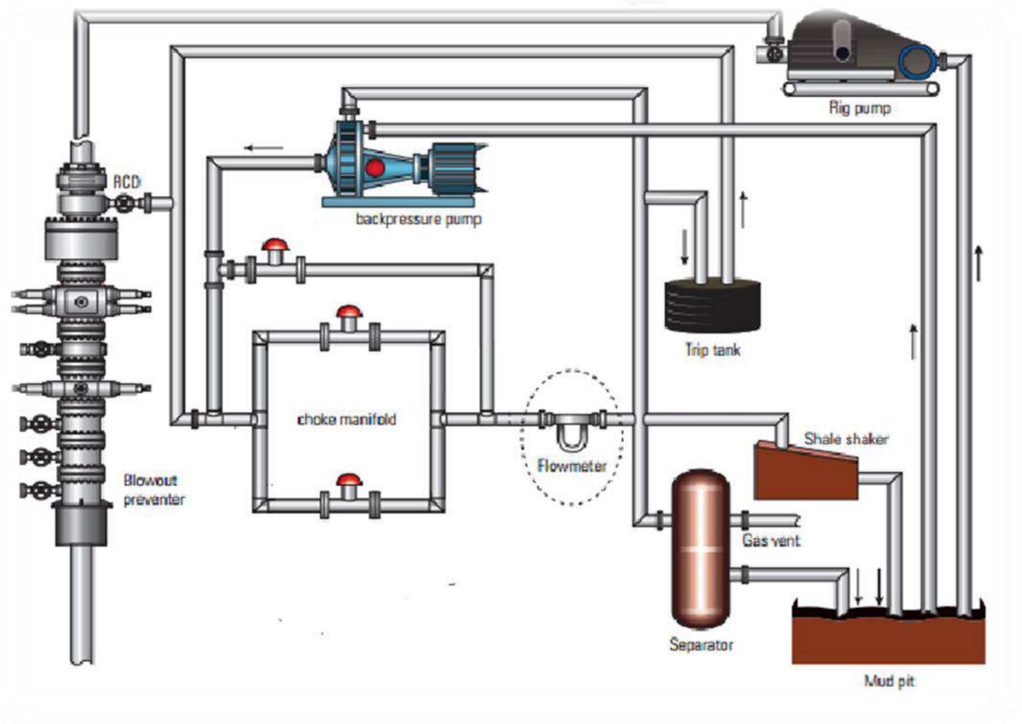

Figure I.1: Fundamental illustration of system equipments.

I.2.1. Drillstring

It has several functions, such as drilling, fluid transportation, stabilizing and steering;

I.2.1.A. Rotating control devices (RCD)

An interesting part of the drillstring, its main function is to divert flow and to prevent any surface release from returning fluids, thus maintaining a safe environment on the rig floor (Fig.I.2). During drilling operations, the RCD is a primary containment device. Its failure can have catastrophic consequences. The RCD provides a seal at the uppermost part of the well system, diverting annular flow to processing and measurement equipment [1].

I.2.1.B. Drill pipe

Drill pipe has a connection with drill bit (Fig.I.3). It is receiving the rotating movement and it has several measurements or types (Fig.I.4). It has several roles such as allowing easy stabbing, transmitting torque and giving pressure tight seal.

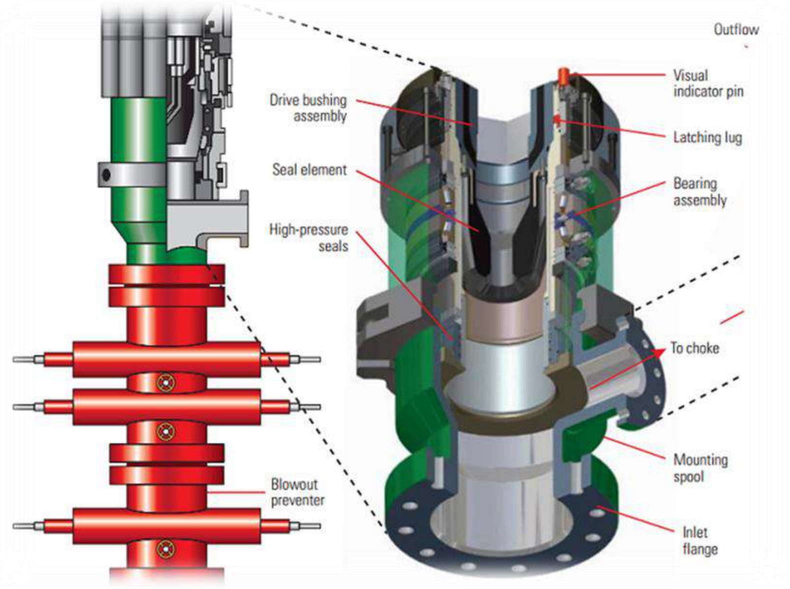

Figure I.2: RCD model.

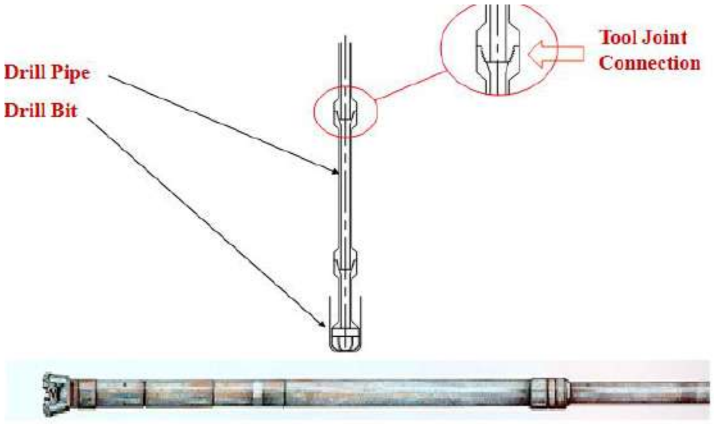

Figure I.3: Drill pipe illustration.

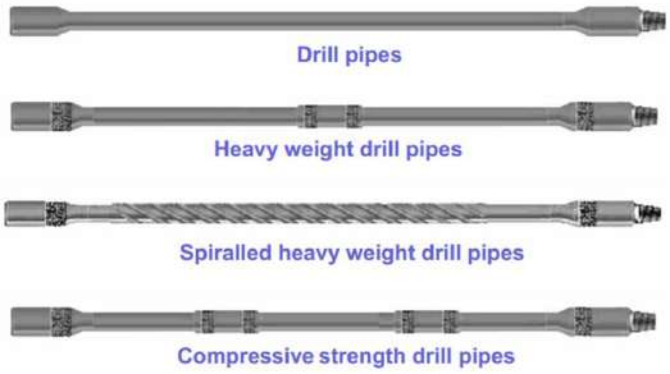

Figure I.4: Drill pipe types.

I.2.1.C. Drill bit

It breaks up the rock in order that the well becomes deeper. Steel bits (Fig.I.5) may be faced with tungsten carbide or polycrystalline diamond, depending on the rock type being cut.

It also contains, among other things a check valve, which prevent the mud from going backwards;

Figure I.5: Drill bit models.

A. Check valve

Today's technology allows for control valves to be equipped with several measurement tools, such as position indicator, a digital pump rate meter, or a timer. Thus the valves might, for example, have the ability to control the mud pump startup and shutdown, the making and breaking of drill pipe connections, as well as automatically adjusting the orifice size.

Figure I.6: Check valve model.

Several types of check valves are used in pipes. The ball valve seems to be the most convenient valve to use in a drill bit. In this work, it is assumed that there is a check valve (ball valve) in the drill bit. A ball in the fluid passage can freely be moved by the mud between the front and the rear seat. When drilling, the mud flows downwards from the mud pump and through the bit. The ball will then be situated at the front seat. If the downhole pressure is larger than the pressure in the fluid passage in the drill bit, there will be a backflow. This backflow will push the ball to the rear seat, sealing the pipe. The ball will move back and forth between the surfaces frequently and can cause heavy wear and tear. For this reason it is usually made out of soft/elastic materials [1].

I.2.2. Choke valve

A choke valve is installed downstream of high pressure piping leading from the RCD outlet flange. The choke should be used to control annular wellhead pressure as needed, and also to reduce pressure on the annular returns from the well in advance of the fluid processing equipment. Similar to the high-pressure flowline leading to the choke and following on to the separation system [2].

Figure I.7: M-I- SWACO autochoke valve.

The choke console is constructed of stainless steel and includes drillpipe and casing-pressure gauge and a hand operated hydraulic backup pump. The choke is equipped with an electronic position indicator, digital pump-stroke-rate meter, timer and clock [2].

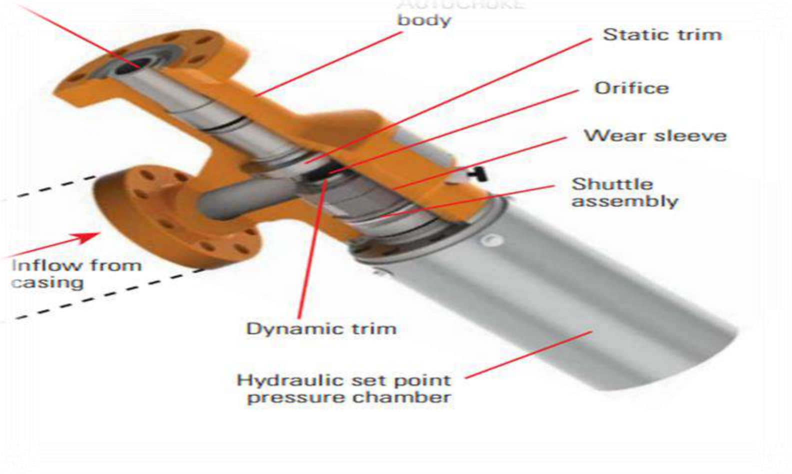

Figure I.8: Choke valve structure.

The unique design of the auto chock features dynamically positioning shuttle that moves back and forth on an axis housed inside a hard faced wear sleeve. Hydraulic pressure, which is adjusted through a set point pressure regulator is applied to the backside of the shuttle. This creates a pressure balance between the casing pressure of the well and the hydraulic pressure of the choke unit.

If the casing pressure is higher than the hydraulic pressure, the shuttle opens, which increases the orifice size. If the casing pressure is lower than the hydraulic pressure, the shuttle closes, decreasing the orifice size. As the shuttle moves, it regulates the flow of fluid or gas from the well through the orifice. The set point pressure applied to the backside of the shuttle assembly is adjusted by a pressure regulator and measured by the set point gauge located on the choke control panel.

The annulus pressure is applied to the front side of the shuttle assembly. An increase in annulus pressure or a decrease in the hydraulic set point pressure will cause the shuttle assembly to move away from the static trim, increasing the orifice size. This allows fluid to flow from the well and decrease the casing pressure until it equals the set point pressure [2].

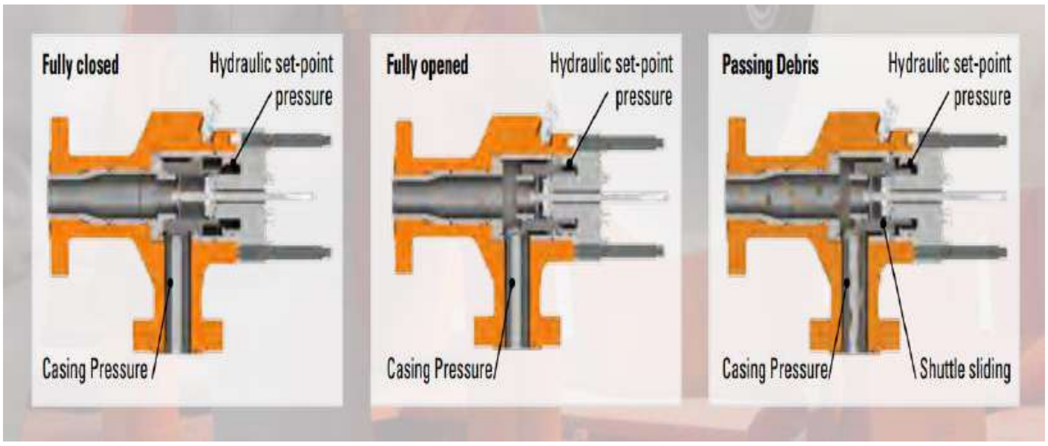

Figure.I.9: Illustration of the chock valve working principle.

I.2.3. Mass flow meter

Mass flow meter, is installed on the manifold. The flow meter provides: Mass flow; volumetric flow; density; return mud temperature.

Figure I.10: Flow meter (A CMF 400M, Coriolis type).

I.2.4. Coriolis meter

Its principal properties:

- Has specifically designed meter body, so only fluid properties influence measurement intrusive type meter;
- Simple installation, minimal technical knowledge required;
- Change in fluid properties has minimum impact on (taken care of) measurement;
- Mass flow and density measurement are possible;
- Proper installation of meter avoids the gas/ solid accumulation and it is ideal for slurry flow measurement;
- Coriolis force is not affected by external forces (noises);
- Risk of erosion during high flow rates specially with solids [3].

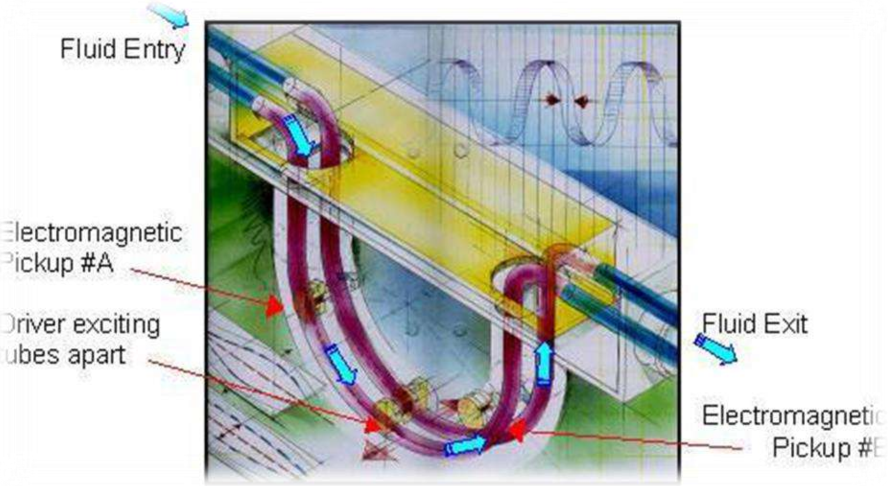

Figure I.11: Illustration of the mud behavior on the flow meter.

I.2.5. Separator

Separation system can range from atmospheric degassers, which remove only entrained gases, to sophisticated pressure vessels, capable of separating solids, gases, and discrete liquids.

Figure.I.12: Separator in Weatherford Company.

I.2.6. Mud pump

The injection side operation uses the lines downstream of the pumps (usually the rig pumps) for liquid injection to the standpipe along with the inert gas supply lines, in some case with inert gas addition. Line pressure ratings shall be above probable pump maximum pressures and should be capable of handling anticipated flow rates with minimal pressure drop. If gas supplies are added to the circulation fluid, a tie-in is required at the rig's standpipe manifold. Valves should be provided that can shut-off the gas supply and allow connections. Ensure gas cannot backflow from the standpipe to the pumps.

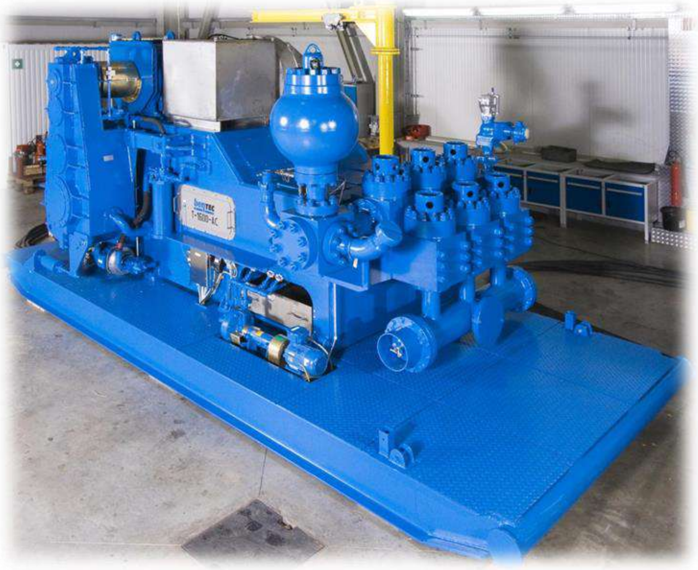

Figure.I.13: Mud pump model.

I.2.7 Trip tank systems

Trip tank is a component of the auxiliary tank system for the drilling mud recycling system. It is shaped as a small metal tank which equipped with liquid level gauge. concerning the capacity of trip tank. Whatever, it is certain that the trip tank capacity is depended on the maximum well depth and the drill string size.

Figure I.14: Trip tank manufacturer GN solids control model.

I.2.8. Blowout preventer

Blowout Preventer (BOP) is a mechanical device to seal the top of the well (a secondary means of well control). Once sealed, it allows access to the wellbore below the BOP to control the well.

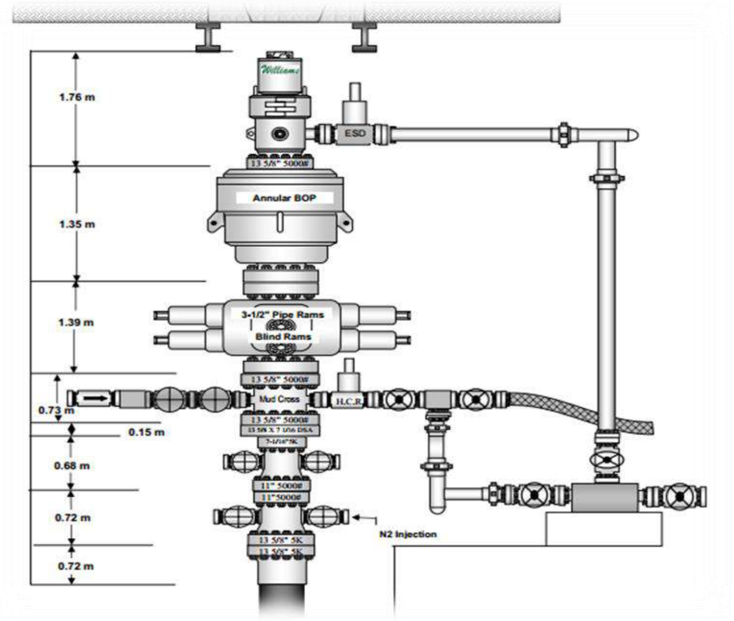

Figure I.15: BOP model.

The installation of a BOP is a normal regulatory requirement and is a common insurance warranty. The BOP is of fundamental importance to well out of control. It is installed as follows:

- The BOP attaches to the wellhead using flanged or collets connectors;
- Onshore – located below the rig floor in the cellar;
- Offshore (bottom supported drilling unit) – below the rig floor on the Texas deck and Offshore (floating drilling unit) – on the seabed [4].

I.2.9. Shale shaker

Is an equipment of solid control in drilling mud; used for cleaning drilling fluid by separating the fluid from the cuttings through a set of vibrating shaker screens. Through a vibrating motion the liquid falls through and the cuttings are removed.

The double-decker shale shaker has two screens mounted on a flat-bed construction. The screens can range down to 100 meshes with the mesh cross section varying from square to an exaggerated rectangle. Drilled solids down to 177 microns are removed by 80 mesh screens and 840 micron size particles by 20 mesh screens [5].

Figure I.16: Shale shaker model.

I.2.10. Back pressure pump

The back pressure pump provides mud to the well when the main mud pump is shut down. This is to maintain the downhole pressure while a new drillpipe is being attached, or when there is some other reason for suspending drilling activity. The back pressure pump has the same output with choke valve which is the input of BOP (Figure.I.17).

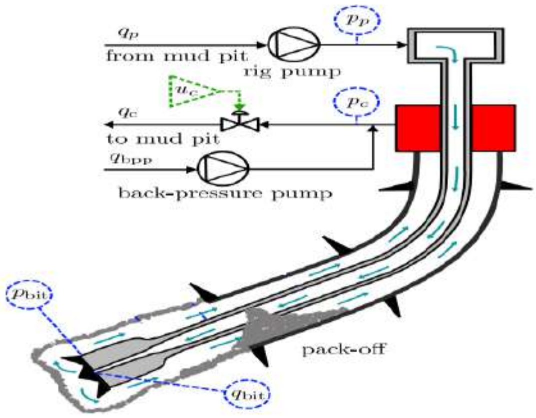

Figure I.17: Illustration of drilling operation.

The mud provided by the pump is a constant flow treated as a disturbance to the choke flow. In this case, the pressure control is taken care by the choke valve [6].

I.3. Conclusion

The drilling mud are having a very important role in petroleum field; therefore every these equipments are created to manage its circulation. In this chapter we have mentioned the meaningful drilling system equipments which will serve to apply a control mud circulation technique to manage the several well pressures. In the following chapter we discuss the modeling strategy adopted to apply this technique.

II.1. Introduction

As the mud is the principal fluid to control the system pressure. In this chapter we go to study the mud behavior in several stations; and we give the rheological model needed to build the complete model, and the several assumptions to be considered in the following steps.

II.2. Drilling mud definition

Drilling mud are complex heterogeneous fluids, consisting of several additives (Fig II.1) that were employed in drilling of oil and natural gas wells since the early 1900. The original use of the drilling mud was to remove cuttings continuously. Progress in drilling engineering demanded more sophistication from the drilling mud. In order to enhance its usage, numerous additives were introduced and a simple fluid became a complicated mixture of liquids, solids and chemicals.

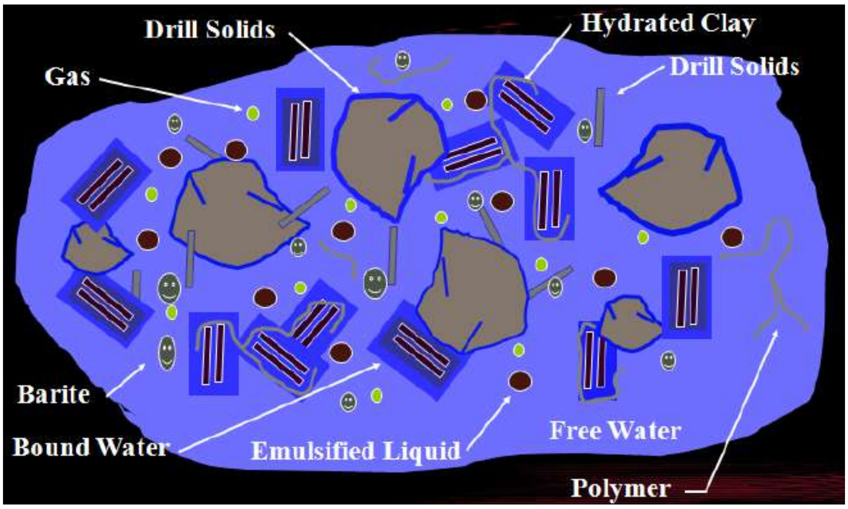

Figure II.1: Illustration of mud composition.

As the drilling evolved, their design changed to have common characteristic features that aid in safe, economic and satisfactory completion of a well. In addition, drilling fluids are also now required to perform the following functions :

- Clean the rock formation beneath the bit for rock cuttings;
- Transport the rock cuttings to surface through annulus;
- Suspend cuttings in fluid if circulation is stopped;
- Cool and clean the bit;
- Manage formation pressure to maintain well-bore stability until the section of borehole has been cased;
- Assist in cementing and completion of well;
- Provide necessary hydraulic power to down-hole equipment;
- Minimize reservoir damage;

- Aid in collection and interpretation of data available through drill cuttings, cores, and electrical logs;
- Be favorable for freshly drilled bore hole’s integrity and assessment;
- Minimize any damaging effects on the sub-surface equipment and piping;
- Provide frictionless environment between the drilling string and the sides of the hole;
- Have minimum negative impact to the environment.

Figure II.2: Fundamental of cuttings transport.

II.3. Drilling mud parameters

Drilling engineers select specific drilling mud with most favorable properties for the job. Most of the drilling mud functions are controlled by its rheological properties. A drilling fluid specialist or a mud Engineer is often on site to maintain and revaluate these properties as drilling proceeds. The main factors governing the selection of drilling fluids are;

- The types of formation to be drilled;
- Temperature range, strength, permeability and pore fluids pressure exhibited by the formation.

Figure II.2. Indicates the fundamental of cuttings transport by mud; While, in addition to the above, selection of the drilling mud can be informed through consideration of other factors such as - production concerns, environmental impact, safety and logistics, the most important factor that governs selection of drilling mud is the overall well cost [7].

II.3.1. Yield Point

It is the resistance to initial flow or stress required to start fluid movement.

II.3.2. Mud weight

Called also density, mud weight provides hydrostatic pressure to maintain borehole stability and control of formation pore pressure. Hydrostatic pressure exerted by a column of fluid due to its vertical length and density. Whereas, the mud has specific gravity (g_s).

II.3.3. Viscosity

- Newtonian fluids:
  - Shear stress is directly proportional to shear rate;
  - Viscosity is a constant.
- Non-Newtonian fluids:
  - Shear stress is a non-linear function of shear rate as (Fig. II.3);
  - Viscosity is a function of shear rate.

There are types of viscosity:

Funnel Viscosity: the amount of time (seconds) it takes for one quart of fluid to pass through the Marsh funnel into a mud cup.

- Qualitative measurement made by rig personnel to monitor mud condition;
- Optimum value is determined by experience for drilling fluid in good condition.

Plastic Viscosity: is related to the internal resistance to flow attributable to the amount, type, size shape and number of solids.

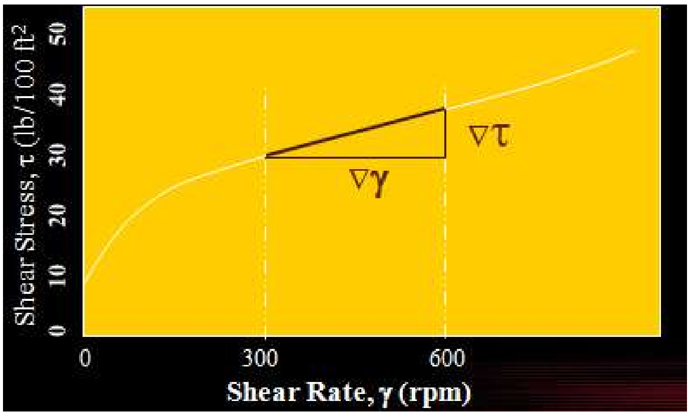

Figure II.3: Shear stress variation depending on the shear rate.

As witted:

- High value of viscosity: fluid more solid;
- Low value of viscosity: thin fluid.

- Gel Strength: that means a measure of the ability of a colloid to form gels (to suspend solids).

II.4. Rheology of drilling mud

Rheology is the study of the deformation of fluids and flow of matter. Its importance is recognized in the analysis of fluid flow velocity profiles, fluid viscosity (marsh funnel viscosity, apparent viscosity and plastic viscosity), friction pressure losses and annular borehole cleaning.

Rheological properties are basis for all analysis of well bore hydraulics and to assess the functionality of the mud system. Rheological characteristics of drilling mud also include yield point and gel strength. Rheological properties (such as density, viscosity, gel strength, etc.) are tested throughout the drilling operations. It is critical to control and maintain rheological properties as a failure to do so can result in financial and loss of time, and in extreme cases, it could result in the abandonment of the well. Besides rheological other tests such as filtration tests, pH, chemical analysis (alkalinity and lime content, chloride, calcium, etc.), resistivity are conducted throughout drilling process [7]. In this section we select the following models:

II.4.1. Bingham Plastic Model

The Bingham Plastic model is one of the rheological models for the drilling fluid. This fluid does not behave like a regular Newtonian fluid, but rather as a rigid body at low shear stress. However, as the stress increases, the material becomes more fluent.

Bingham (1922) initially recognized plastic fluids; therefore they are referred to as Bingham plastics fluids; which are distinguished from Newtonian fluids as they require a finite stress to initiate flow. Bingham plastic fluids flow behavior for laminar flow is described by following equation [7]:

$$\boldsymbol{\tau}_{\mathbf{w}} = \boldsymbol{\tau}_{\mathbf{0}} + \mu_P \boldsymbol{\gamma}. \qquad \rightarrow \qquad \boldsymbol{\tau}_{\mathbf{w}} \geq \boldsymbol{\tau}_{\mathbf{0}} \qquad \text{(II.1)}$$

where ; $\boldsymbol{\tau}_{\mathbf{0}}$ is the yield point or yield stress; $\boldsymbol{\tau}_{\mathbf{w}}$ is the shear stress; μ_P is the plastic viscosity; $\boldsymbol{\gamma}$ is as in equation, shear rate.

Plastic Viscosity is part of the flow resistance of the fluid caused by mechanical friction within the fluid. This friction is due to interaction of individual solid particles, the interaction between solid and liquid particles and the deformation of the liquid particles under shear stress. Units for plastic viscosity are the same as of Newtonian viscosity . The yield stress caused by electrochemical forces within the fluid. The Bingham Plastic model is used as a standard viscosity model all over the industry [7].

As can be seen from Eq.II.1 there will be no fluid movement until a certain amount of stress is applied to the mud. If the value of the yield point is too low, cuttings will (due to gravity) increase the downhole pressure, which may cause damage to the drill bit. This value, along with the flow rate, should therefore be sufficiently high as to ensure that all the cuttings can be transported out of the well without causing damage. The illustration shows how the cuttings are removed with the mud. If the flow rate is too low, and the cuttings too big, the passage might get blocked drilling device. At the same time, the viscosity should be as low as possible, making a higher drill speed more attainable. In reality, the shear stress is not constant even though the shear rate is constant. If the pump is shut down, meaning there is no shear rate, the shear stress will continue to rise. When accounting for this, time-dependency has to be included in the model.

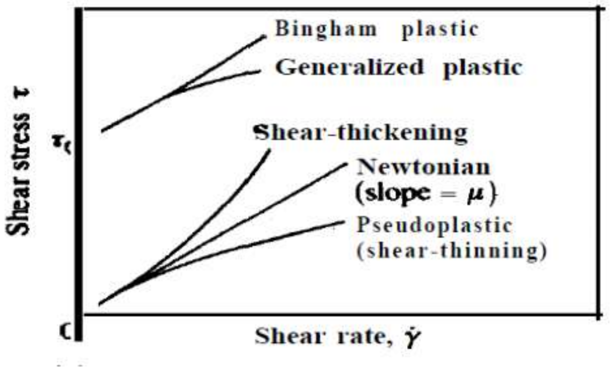

Figure II.4: Basic shear diagram depicting typical fluid behavior.

II.4.2. Thixotropy

Including build-up and break-down, thixotropy is a time-dependent shear thinning property. Certain gels or fluids that are thick, or viscous, under static conditions will flow (become thin, less viscous) over time when shaken, agitated, sheared or otherwise stressed (time dependent viscosity). They then take a fixed time to return to a more viscous state. In other words, some non-Newtonian pseudo-plastic fluids show a time-dependent change in viscosity; the longer the fluid undergoes shear stress, the lower its viscosity. A thixotropic fluid is a fluid which takes a finite time to attain equilibrium viscosity when introduced to a steep change in shear rate.

Some thixotropic fluids return to a gel state almost instantly, such as ketchup, and are called pseudo-plastic fluids. Others such as yogurt take much longer and can become nearly solid. Many gels and colloids are thixotropic materials, exhibiting a stable form at rest but becoming fluid when agitated. Some fluids are anti-thixotropic: constant shear stress for a time causes an increase in viscosity or even solidification. Constant shear stress can be applied by shaking or mixing. Fluids which exhibit this property are usually called rheopectic. They are much less common.

- Thixotropy of a non-Newtonian fluid is a completely reversible process meaning that the fluid is able to go from one state to another and back again;
- When the fluid goes back and forth between high and low viscosity, two key mechanisms arise:

II.4.2.A. Build-up

Build-up caused by inflow collision, it uses particles to fall into place (flocculation) and Brownian motion atoms move around randomly and collide with elements in the microstructure, which move rebuild the structure. This process is referred to as gelling.

II.4.2.B. Break-down

Break-down caused by flow stress, when stress is applied to the structured mud, small flock's starts to secede, giving a shear thinning effect. This process is called flock erosion and is defined by the particles of dispersion. Usually the build-up process takes far more time than the break-down.

II.4.2.C. Cheng model for thixotropic behavior

The Cheng model is one of the rheological models for the drilling fluid. When taking the mud ability of gelling, adding time-dependency to the model will enhance its realism. Friction models, including time-dependency would be the LuGre model, Karnopp's model, or the Cheng model.

In this work we used the Cheng model which is described by following equations :

$$\boldsymbol{\tau}_{\mathbf{w}} = \boldsymbol{\tau}_{\mathbf{0}} + \boldsymbol{\tau}_{\mathbf{1}}\lambda + \mu_P \boldsymbol{\gamma} \tag{II.2}$$

$$\frac{\mathbf{d}\lambda}{\mathbf{dt}} = \boldsymbol{a}(\mathbf{1} - \lambda) + \boldsymbol{b\gamma}\lambda \tag{II.3}$$

Where: $\frac{\mathrm{d}\lambda}{\mathrm{dt}}$ is the working parameter; λ a factor of viscosity for the mud; $\boldsymbol{a}$ a coefficient for working parameter; **b** a coefficient for working parameter; $\gamma = \frac{8}{d} v$; $v_p = \frac{4}{\pi}\frac{1}{{d_i}^2} q_b$; $v_a = \frac{4}{\pi}\frac{1}{d_h - d_o} q_b$. While; v is the velocity; v_p is the velocity extern the pump; v_a is the velocity interne of annuls; d_i is the diameter inside; d_o is the diameter outside; d_h is the diameter of hollow.

III.5. Pressure equations and pressure losses

III.5.1. Pump pressure equation

Conservation of mass, along with the conservation of momentum, was used to put up the pressure behavior:

$$\frac{\mathbf{d}}{\mathbf{dt}} \boldsymbol{\rho}\mathbf{v} = \boldsymbol{\omega}_{\mathbf{in}} - \boldsymbol{\omega}_{\mathbf{out}} \tag{II.4}$$

So
$$\mathbf{V}\dot{\boldsymbol{\rho}} + \overbrace{\boldsymbol{\rho}\dot{\mathbf{V}}}^{\mathbf{0}} = \boldsymbol{\rho}_{\mathbf{in}}\mathbf{q}_{\mathbf{in}} - \boldsymbol{\rho}_{\mathbf{out}}\mathbf{q}_{\mathbf{out}} \tag{II.5}$$

Where $\mathbf{d}\boldsymbol{\rho} = \frac{\boldsymbol{\rho}}{\boldsymbol{\beta}}\mathbf{dp}$ and assuming constant control volume, and $\frac{\mathbf{dv}}{\mathbf{dt}} = \mathbf{0}$

$$\mathbf{V}\frac{\boldsymbol{\rho}_{\mathbf{o}}}{\boldsymbol{\beta}}\dot{\mathbf{p}} = \boldsymbol{\rho}_{\mathbf{in}}\mathbf{q}_{\mathbf{in}} - \boldsymbol{\rho}_{\mathbf{out}}\mathbf{q}_{\mathbf{out}} \tag{II.6}$$

When assuming equal mud densities $\rho_o = \rho_{in} = \rho_{out}$ they will cancel out. The pressure model will then be:

$$\frac{\mathbf{V}}{\boldsymbol{\beta}}\dot{\mathbf{p}}_{\mathbf{p}} = \mathbf{q}_{\mathbf{in}} - \mathbf{q}_{\mathbf{out}} \tag{II.7}$$

Applying this to the first control volume, the drillstring, using the pump flow as input and the bit flow as output*: Pump Pressure Equation*:

$$\frac{\mathbf{V_d}}{\boldsymbol{\beta_d}}\dot{\mathbf{p}}_{\mathbf{p}} = \mathbf{q_p} - \mathbf{q_b} \tag{II.8}$$

Where: V_d is the volume of the drillstring; β_d is the bulk modulus for the fluid in the drillsting; q_p is the pump flow; q_b is the drillbit flow; $\dot{p}_p$ is the drive of pump pressure.

III.5. 2. Choke pressure equation

The derivation of the equation for the choke pressure is the same as for the pump pressure in the previous section.

The bit flow, as well as the flow from the back pressure pump, is used as an input flow. The output will be the choke flow.

Also, the volume and the bulk modulus have to be for the annulus rather than for the drillstring. Using the same method for the second control volume:

$$\mathbf{V}\dot{\boldsymbol{\rho}} + \overbrace{\boldsymbol{\rho}\dot{\mathbf{V}}}^{\mathbf{0}} = \boldsymbol{\rho}_{\mathbf{in}}\mathbf{q}_{\mathbf{in}} - \boldsymbol{\rho}_{\mathbf{out}}\mathbf{q}_{\mathbf{out}} \tag{II.9}$$

$$\mathbf{V_a}\frac{\boldsymbol{\rho}_{\mathbf{o}}}{\boldsymbol{\beta_a}}\dot{\mathbf{p}}_{\mathrm{c}} = \boldsymbol{\rho}_{\mathbf{in}}\left(\mathbf{q_b} + \mathbf{q_{bpp}}\right) - \boldsymbol{\rho}_{\mathbf{out}}\mathbf{q_c} \tag{II.10}$$

The Choke Pressure Equation is:

$$\frac{\mathbf{V_a}}{\boldsymbol{\beta_a}}\dot{\mathbf{p}}_{\mathrm{c}} = \left(\mathbf{q_b} + \mathbf{q_{bpp}}\right) - \mathbf{q_c} \tag{II.11}$$

Where: V_a is the volume in the annulus; β_a is the bulk modulus for the fluid in the annulus; q_c is the choke flow; q_p is the pump flow; q_{bpp} is the back pressures pump flow; $\dot{\mathbf{p}}_{\mathbf{c}}$ is the drive of choke pressure.

III.5.3. Drillbit flow equation

The equation for an average flow rate is described by:

$$\mathbf{M}(\mathbf{l_1}, \mathbf{l_2})\frac{\mathbf{dq}}{\mathbf{dt}} = \boldsymbol{P_1} - \boldsymbol{P_2} - \mathbf{F}(\mathbf{l_1}, \mathbf{l_2}, \boldsymbol{q}, \boldsymbol{\mu}) + \mathbf{G}(\mathbf{l_1}, \mathbf{l_2}, \boldsymbol{\rho}) \tag{II.12}$$

The bit flow is assumed to be the average flow between the mud pump and the choke valve, including friction loss. The model will then be:

$$\mathbf{M}\left(\mathbf{l_p}, \mathbf{l_c}\right)\dot{\mathbf{q}}_{\mathbf{b}} = \boldsymbol{P}_{\mathbf{p}} - \boldsymbol{P}_{\mathbf{c}} - \mathbf{F}\left(\mathbf{l_p}, \mathbf{l_c}, \boldsymbol{q_b}, \boldsymbol{\mu_p}\right) + \mathbf{G}\left(\mathbf{l_p}, \mathbf{l_c}, \boldsymbol{\rho_m}\right) \tag{II.13}$$

the choke valve are situated at the same level (see Figure 3.1), or close enough as not to have any significant effect, the total gravity affecting the fluid will be zero. Hydrostatic pressure loss is also ignored because it will have only a minor effect compared to the friction loss.

Using the assumptions to rewrite *the Bit flow equation*:

$$[\mathbf{M_d} + \mathbf{M_a}]\dot{\mathbf{q}}_{\mathbf{b}} = \mathbf{P_P} - \mathbf{P_c} - \Delta\mathbf{P_f} - \Delta\mathbf{P_{others}} \tag{II.14}$$

where: ΔP_f is the pressure loses due to friction; ΔP_{sc} is the pressure loses due to surface connections; ΔP_{others} is the pressure drop due to others dynamics; **M** is the integrated density per cross-section over the flow path; **G** is the total gravity function affecting the fluid.

When the mud flows through the system, several pressure losses affect the down-hole pressure. In this section the friction models will be presented as well as other pressure losses.

The pressure loss due to friction is modeled as:

$$\Delta \boldsymbol{P}_{\mathbf{f}} = \Delta \boldsymbol{P}_{\mathbf{f},\mathbf{d}} + \Delta \boldsymbol{P}_{\mathbf{f},\boldsymbol{a}} \tag{II.15}$$

While the pressure loss due to others dynamics are:

$$\Delta \boldsymbol{P}_{\mathbf{other}} = \Delta \boldsymbol{P}_{\mathbf{sc}} + \Delta \boldsymbol{P}_{\mathbf{b}} \tag{II.16}$$

We can recapitulate the above equations, which we will add in the next chapter, the parameters of control and others equations we need to simulating, as follows:

Table II.1: Model summary.

State equation	❖ $\frac{V_d}{\beta_d}\dot{p}_p = q_c - q_b$; ❖ $\frac{V_d}{\beta_d}\dot{p}_c = q_{bpp} + q_b - q_c$; ❖ $[M_d + M_a]\dot{q}_b = P_P - P_c - \Delta P_f - \Delta P_{other}$; ❖ $q_c = k c_V \sqrt{\frac{\lvert\Delta p\rvert}{\rho_m}}$.
Pressure losses	❖ $\Delta P_f = \Delta P_{f,d} + \Delta P_{f,a}$; ❖ $\Delta P_{f,d} = \frac{4}{d_i}\tau_w$; ❖ $\Delta P_{f,a} = \frac{4}{d_h - d_o}\tau_w$; ❖ $\Delta P_{other} = \Delta P_{sc} + \Delta P_b$; ❖ $\Delta P_{sc} = c_{sc}\rho_m \frac{q^{1.86}}{100}$; ❖ $\Delta P_b = \frac{\rho_m}{c_d{}^2 . A^2} q_b{}^2$.
Cheng's model	❖ $\tau_w = \tau_0 + \tau_1 \lambda + \mu_P \gamma$; ❖ $\frac{d\lambda}{dt} = a\left(1 - \lambda\right) + b\gamma\lambda$.

II.6. Gelling phenomena

Because of gelling, the mud causes nonlinear pressure loss throughout the well. It is therefore necessary to derive a model that reflects the properties of the mud as closely as possible, for that rheology and thixotropy are taken into account.

The gelling process of the mud has an important function in preventing the bit from becoming stuck. When the mud flow is shut down, all the cuttings will drop downwards due to gravity. Therefore, the use of gelled mud will lock the cuttings in the well, thereby reducing one of the risk factors that can cause a stuck bit. The size of the cuttings will affect their removal process. Heavy (or large) particles will require increased transport velocities. Small particles, on the other hand, may modify the fluid viscosity, and facilitate the removal of the larger ones.

A drilling device consists of a very substantial number of controllable components, which we will try to consider all of them in this work. It will be divided in three meaning parts, the first one is the mud modeling along with its non-linear properties. The second part deals with the pumps, which provide mud to the system. In the third part, the valves are examined, which choke the flow and which are primarily responsible for the main pressure control in the well.

To enhance the reality of the system, low pass filters are used to limit the rate of change of both choke and flow. A high pass filter is used as a differentiator for the downhole pressure.

Because thixotropy causes different build-up and break down times, the system can be in more than one internal state, depending on which states (solid or fluid) it comes from. This is referred to as hysteresis. As mentioned earlier, the gelling process is completely reversible, meaning that the drilling mud will not change properties after going back and forth between liquid and solid structures. The system may, however, have different them to more favorable positions.

II.7. Conclusion

So the main functions of the mud are to transport cuttings up from the well without damaging the drilling device, as well as to act as a pressure control. This section is very important to understand the following chapter. Because it gives a basic concept of the system fluid proprieties and it embody the principal parts of the control strategy.

III.1 Introduction

This section presents the control strategy, meanly the mud pump and the back pressure pump. Both of these are controlled in order to keep the downhole pressure constant. A P controller will be used as well as an approximation of the downhole pressure. The system ; which supporting and including this technique is Managed Pressure Drilling (MPD) system. Indeed, the choke valve is controlled by a PI controller. We use Matlab/Simulink as simulation tool to implement the model dynamic system. At the end we illustrate and analyze the several extracted results.

III.2 Managed pressure drilling

The International Association of Drilling Contractors (IADC) has defined MPD as: an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. MPD process employs a collection of tools and techniques which may mitigate the risks and costs associated with drilling wells that have narrow downhole environmental limits, by proactively managing the annular hydraulic pressure profile:

- MPD may include control of surface back pressure, fluid density, fluid rheology, annular fluid level, circulating friction, and hole geometry, or combinations thereof;
- MPD may allow faster corrective action to deal with observed pressure variations. The ability to dynamically control annular pressures facilitates drilling of what might otherwise be economically unattainable prospects;
- MPD techniques may be used to avoid formation influx. Any flow incidental to the operation will be safely contained using an appropriate process;

The primary objective of MPD is the avoidance of drilling-related problems and reducing associated Non Productive Time (NPT). Avoiding conventional mud weight increases to combat drilling problems is the key tactic when applying MPD. The intent is not to invite formation fluid influx, but to manage any that may be incidental to the operation.

MPD applications can save drilling costs and reduce drilling cost uncertainty through:

- Avoidance of conventional drilling NPT problems (lost circulation, kick control, nuisance gas zones, and differential sticking);
- Increased the rate of penetration (ROP) and increased bit life;
- In some circumstances, reducing the number of casing strings required [8].

III.2.1 Features and advantages

- Annulus backpressure is controlled at surface which means that changes in BHP normally occurring when operating the mud pumps to circulate and drill ahead do not occur;
- Whether the mud column is static or dynamic, BHP is constant and can be more easily maintained within the bounds of a narrow pore-to fracture-pressure gradient window;
- The ability to more accurately “walk the line” between pore- and fracture-pressure gradients means that the hole section can be drilled deeper before drilling mud density is changed and casing must be set;
- Pore-pressure estimate uncertainty can be easily accommodated by simple adjustment of applied annulus backpressure;
- Drilling with a fluid that is “lighter than conventional wisdom would prescribe” significantly increases rate of penetration;
- A more constant BHP reduces pressure variations that would otherwise promote wellbore instability.

III.2.2 Causes for a formation kick under MPD mode

- Uncertainty of predicted formation pressure;
- Pump shut down procedure improperly followed;
- Underbalanced conditions when tripping out of the hole.

III.2.3 Kick detection during MPD operations

- Increase in choke pressure;
- Change in choke position indicator;
- Increase in flow out (Coriolis meter);
- Increase in tank volume (pit gain) [9].

III.3 MPD control system

III.3.1 Control challenge

Mud at rest will, after some time, start the gelling process and rebuild its structure. When the system is to be set in motion again, a considerable amount of force is therefore needed in order to break the gel. However, a high degree of pressure from the pump may cause problems, such as bubbles (cavitations) that may erode the surface of the drillstring. Another phenomenon that might cause trouble, or at least make the model less valid, is lubrication due to the non-linear break-down of the mud. During start-up of the rotation, shear stress from the wall will be the initial force acting on the mud.

This will lead to lower viscosity close to the wall so that the mud will tend to function as a lubricant. The mud further from the wall will then be affected by less shear stress as the lubrication counteracts the break-down process. This dynamic is in the realm of advanced fluid mechanics and is not counted for in this work.

III.3.2 PID controller

The proportional action delineates to how far from the gain the signal is. As the signal moves further away from the reference line, the proportional term will increase. When the signal approaches the set point value, the proportional term will be very small, but never reach zero. The proportional transfer function ($\mathbf{C_p(s)}$) is defined the following function:

$$\mathbf{C_p(s) = K_p \cdot E(s)} \tag{III.1}$$

Where K_p is the proportional gain and e is the E(s) error signal.

The integral action, ensures that the signal spends the same amount of time on each side of the set point. For every moment the signal is at one side of the set point, $\mathbf{C_i(s)}$ (Integral term transfer function) increases. In order for $\mathbf{C_i(s)}$ to decrease, the signal has to pass the set point and stay there for the same amount of time (Eq. III.2).

$$\mathbf{C_i(s) = \frac{K_i}{s}(E(s))} \tag{III.2}$$

The derivative action ($\mathbf{C_d(s)}$), is described by Eq. III.3, its action is to counteract the other control signals; the more the control signal changes, the more effort $\mathbf{C_d(s)}$ will put in to slowing down. This is an advantage if overshoots are crucial.

$$\mathbf{C_d(s) = s \cdot K_d(E(s))} \tag{III.3}$$

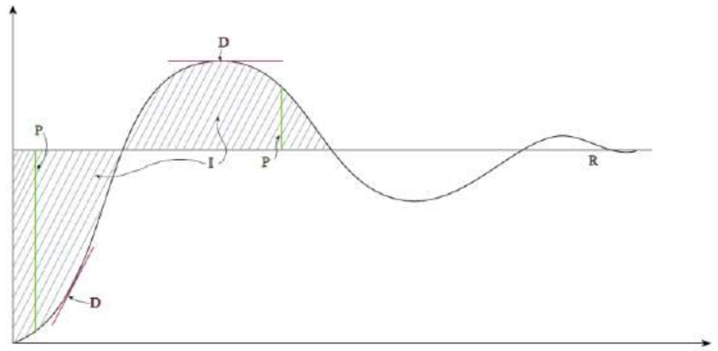

Figure.III.1: PID controller terms behavior.

The illustration in Figure III.1 shows a variable signal along with the error signal.

III.3.3 Windup and anti-windup

In reality there will be constraints (max opening, max speed etc.) on the control signal, meaning that it saturates before it reaches the static gain. This makes $\mathbf{C_i(s)}$ run wild because of the time spent below the static, and it will not decrease again before the same amount of time is spent above the static gain, which might never happen.

This windup makes the whole system uncontrollable. Because $\mathbf{C_i}(\boldsymbol{s})$ increases for every moment below the line, it has to be reset from time to time, such that it does not grow beyond boundaries. This reset procedure is known as anti-windup.

There are several anti-windup methods, which are incremental, conditional integration, observer approach and back calculation. However, only back calculation will be considered in this work. The back calculation subtracts the signal before saturation from the signal after saturation. When the signal does not saturate, this difference will be zero. When in saturation the difference will be amplified and added to the error fed into the integrator.

Saturation in combination with a constraint on the choke opening will cause heavy windup every time the controller is unable to reach the reference (saturation) in a sufficiently short time. The integrator starts to windup for every instant that the saturation is in progress. Therefore, an anti-windup back-calculation loop is created. Otherwise, the anti-windup loop resets the integrator, making the integral action forget for how long the error has been positive.

III.3.4 System control

When we add the parameters of control to the hydraulic model we will get the following equations:

III.3.4.A Choke valve

$$\boldsymbol{q}_{\mathbf{c}} = \sqrt{\frac{2(\boldsymbol{P}_{\mathbf{s}}-\boldsymbol{P}_{\mathbf{c}})}{\boldsymbol{\rho}_{\mathbf{m}}}}\,\mathbf{C}(\boldsymbol{s}) \qquad \text{(III.4)}$$

The *PI controller* used for the choke is implemented as follows:

$$\boldsymbol{U}(\boldsymbol{s}) = \mathbf{K_p}\,\boldsymbol{E}(\boldsymbol{s}) + \frac{\mathbf{K_i}}{\mathbf{s}}\boldsymbol{E}(\boldsymbol{s}) \qquad \text{(III.5)}$$

$$\boldsymbol{E}(\boldsymbol{s}) = \boldsymbol{P}_{\mathbf{dh}}^{\boldsymbol{ref}} - \boldsymbol{P}_{\mathbf{dh}} \qquad \text{(III.6)}$$

$$\boldsymbol{C}(\boldsymbol{s}) = \mathbf{K_p}\,\boldsymbol{E}(\boldsymbol{s}) + \frac{\mathbf{K_i}}{\mathbf{s}}\boldsymbol{E}(\boldsymbol{s})\,.\boldsymbol{sat}(\mathbf{0.1}).\frac{\mathbf{1}}{\boldsymbol{sT_c}+\mathbf{1}}.\boldsymbol{anti\,windup} \qquad \text{(III.7)}$$

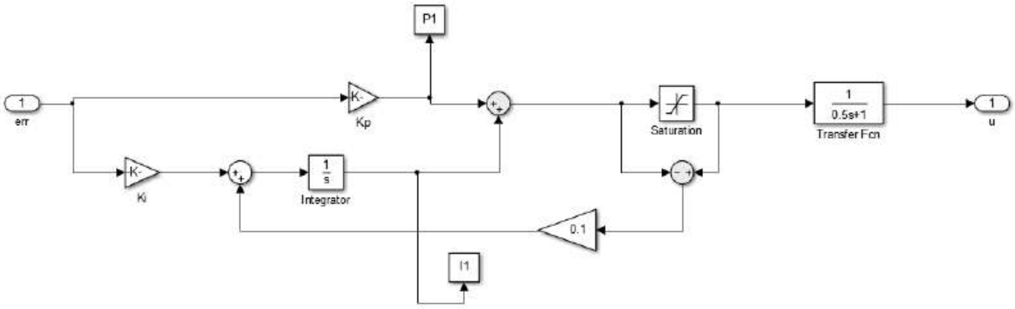

Figure III.2: back calculation windup with pi choke valve controller.

The PI controller valued adopted are: $K_p = 10$ and $K_i = 0.8$. This is done by using a standard PID tuning, as we have a simulation model and we did not risk to weak a practical components.

III.3.4.B Mud pump

Two P controllers are used to control the flow from the mud pump, one monitoring the downhole pressure, the other using an estimate of the structural state of the mud. The inputs of each of these controllers are therefore: the rate of change of $\boldsymbol{p}_{\mathbf{dh}}$; and the rate of change of the working parameter.

The output from the controllers are added and used as a disturbance on the reference pump flow:

$$\boldsymbol{q}_{\mathbf{p}} = \boldsymbol{q}_{\mathbf{dh}}^{\boldsymbol{ref}} - \boldsymbol{q}_{\mathbf{d\_p}_{\mathbf{dh}}} - \boldsymbol{q}_{\mathbf{d\_\lambda}} \qquad \text{(III.8)}$$

a. Downhole Pressure control

The first controller monitors the rate of change in the downhole pressure, and use the signal as a control parameter. By adding a high pass filter as a differentiator, it is possible to distinguish periods during which the pressure increases too fast.

When the high pass filter is functions as a differentiator, only inputs with a rate of change larger than $\frac{1}{\tau}$ will pass without changes. Signals containing smaller changes will be suppressed and are not visible on the output. This approach to selecting parts of the signal makes it possible to adjust the pump flow only when needed.

The pump is modeled as follows. For convenience, the Laplace domain is:

$$\mathbf{q}_{\mathbf{d\_p}_{\mathbf{dh}}} = \left(\frac{\mathbf{s}}{\mathbf{s+1}} \mathbf{p}_{\mathbf{dh}} \mathbf{f}_{\mathbf{dh}}(\boldsymbol{s}) - \mathbf{p}_{\mathbf{dh\_ref}}\right) \mathbf{K}_{\mathbf{p}} \qquad \text{(III.9)}$$

Where: $\mathrm{K}_{\mathrm{p}} = 5$.

$$\mathbf{f}_{\mathbf{dh}}(\boldsymbol{s}) = \begin{cases} \mathbf{0}, & -\infty < u < 0.05 \\ \mathbf{1}, & \boldsymbol{otherwise} \end{cases}$$

The pump model in the time domain is somewhat more complicated and less intuitive, and is therefore omitted. If wanted, the modern in time domain is found by applying a Laplace transform to the above model.

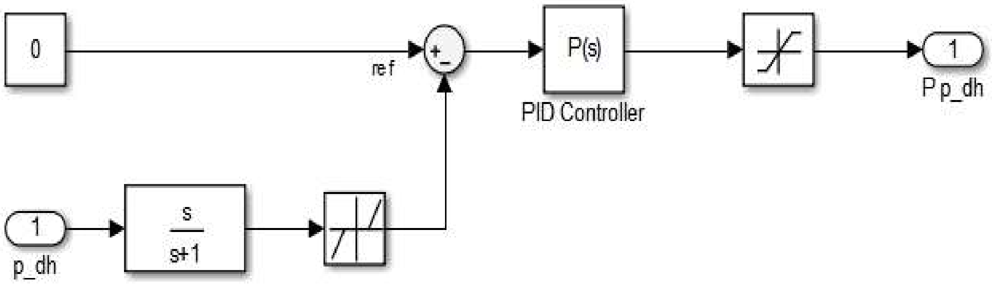

Figure III.3: Downhole pressure control with p controller in the mud pump.

b. Mud structure control

In order to suppress the downhole pressure peaks even more, it might be worthwhile to look at the mud structure in addition to the downhole pressure. Moreover, it is assumed that the structure of the mud is possible to predict using a mathematical model.

The controller takes the working parameter, as an input. Even though the point is to obtain a viscous mud as fast as possible, the desired effect is to ease down the flow rate whenever the process of break-down develops too fast.

This is because a fast breakdown indicates an excessively increasing rate of the pressure down hole. The input signal is differentiated using a high pass filter. The highest peaks are then amplified by a P controller, which are used as a disturbance to the mud pump flow. The model can be written in Laplace domain as follows:

$$q_{d\_\lambda} = \left(\frac{s}{s+1} s\lambda f_{d,\lambda}(u) - \left(s^2{}_{\lambda ref}\right)\right) K_p \qquad \text{(III.10)}$$

Where

$$f_{d,\lambda}(u) = \begin{cases} 0, & -3.10^{-5} \leq u \leq \infty \\ 1, & otherwise \end{cases}, \quad (s^2\lambda)^{ref} = 0 \quad and \quad K_p = 25.10^6.$$

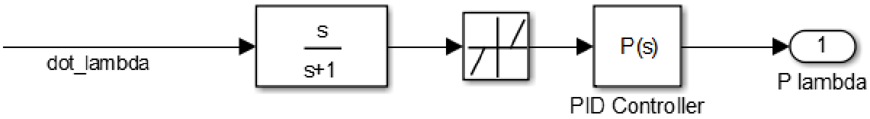

Figure III.4: PI controller with high pass filter to downhole pressure peaks control.

c. Back pressure pump control

The back pressure pump is modeled as a constant flow, which is turned on when the mud pump is shut down. For the standard MPD system the back pressure pump provided a constant flow rate, starting simultaneously as the mud pump shutdown. Another approach for improved pressure control might be to apply automatic control to the pump, with the downhole pressure as a control parameter.

When controlling the back pressure pump, a regular P controller is used:

$$q_{\mathrm{bpp}} = \left(p_{\mathrm{dh}}^{ref} - p_{\mathrm{dh}}\right) - K_{\mathrm{p}} \overbrace{sat(q_{\mathrm{bpp\_low}} - q_{\mathrm{bpp\_high}})}^{\text{flow limitation}} \qquad \text{(III.11)}$$

In the flowing table we will add the control parameters to the hydraulic model by using entirety of equations that we were getting in the above explaining:

Table III.1: Managed Pressure Drilling system model.

State equation	❖ $\frac{V_{\mathrm{d}}}{\beta_{\mathrm{d}}}\dot{p_p} = q_{\mathrm{c}} - q_{\mathrm{b}};$ ❖ $\frac{V_{\mathrm{d}}}{\beta_{\mathrm{d}}}\dot{p_c} = q_{\mathrm{bpp}} + q_{\mathrm{b}} - q_{\mathrm{c}};$ ❖ $[M_d + M_a]\dot{q_b} = P_{\mathrm{P}} - P_{\mathrm{c}} - \Delta P_{\mathrm{f}} - \Delta P_{\mathrm{other}};$ ❖ $\mathrm{q_c} = \mathrm{k}c_{\mathrm{V}}\sqrt{\frac{\lvert\Delta \mathrm{p}\rvert}{\rho_{\mathrm{m}}}}.$
Pressure losses	❖ $\Delta P_{\mathrm{f}} = \Delta P_{\mathrm{f,d}} + \Delta P_{\mathrm{f},a};$ ❖ $\Delta P_{\mathrm{f,d}} = \frac{4}{\mathrm{d_i}}\tau_{\mathrm{w}};$ ❖ $\Delta P_{\mathrm{f},a} = \frac{4}{\mathrm{d_h - d_o}}\tau_{\mathrm{w}};$ ❖ $\Delta P_{\mathrm{other}} = \Delta P_{\mathrm{sc}} + \Delta P_{\mathrm{b}};$ ❖ $\Delta P_{\mathrm{sc}} = c_{\mathrm{sc}}\rho_{\mathrm{m}}\frac{\mathrm{q}^{1.86}}{100};$ ❖ $\Delta P_{\mathrm{b}} = \frac{\rho_{\mathrm{m}}}{c_{\mathrm{d}}^{2}.\mathrm{A}^{2}}\mathrm{q_b}^{2}.$
Cheng's model	❖ $\tau_{\mathrm{w}} = \tau_0 + \tau_1\lambda + \mu_P\gamma;$ ❖ $\frac{\mathrm{d}\lambda}{\mathrm{dt}} = a\left(1 - \lambda\right) + b\gamma\lambda.$
Choke valve Controller	❖ $\overbrace{\mathrm{K_p}\,E(s) + \frac{\mathrm{K_i}}{\mathrm{s}}E(s)}^{PI}\;.\;\overbrace{sat(0.1).\frac{1}{T_c s+1}}^{opening\ and\ rate\ limite}\;.\,anti\ windup.$
Mud pump	❖ $q_{\mathrm{p}} = q_{\mathrm{dh}}^{ref} - q_{\mathrm{d\_p_{dh}}} - q_{\mathrm{d\_\lambda}};$ ❖ $\mathrm{q_{d\_p_{dh}}} = \left(\frac{\mathrm{s}}{\mathrm{s+1}}\mathrm{p_{dh}f_{dh}(s)} - \mathrm{p_{dh\_ref}}\right)\mathrm{K_p};$ ❖ $q_{\mathrm{d\_}\lambda} = \left(\frac{s}{s+1}s\lambda f_{d,\lambda}(u) - \left(s^2{}_{\lambda ref}\right)\right)K_p.$
Back pressure pump	❖ $q_{\mathrm{bpp}} = \left(p_{\mathrm{dh}}^{ref} - p_{\mathrm{dh}}\right) - K_{\mathrm{p}}\overbrace{sat(q_{\mathrm{bpp\_low}} - q_{\mathrm{bpp\_high}})}^{\text{flow limitation}}.$

Downhole pressure	❖ $P_{\mathrm{dh}} = P_{\mathrm{c}} + \Delta P_{\mathrm{f,a}}(q_{\mathrm{b}}\, , L_{\mathrm{a}}) + \rho_{\mathrm{m}} g h_{\mathrm{a}}$.

III.4 Simulation and result discussion

As it was mentioned, we use Matlab/Simulink to express the system modeling and control. We have divided the system simulation in three meaning parts: (1) Pump Pressure, (2) Drill Bit flow, (3) Choke pressure as illustrated by (Figure III.5).

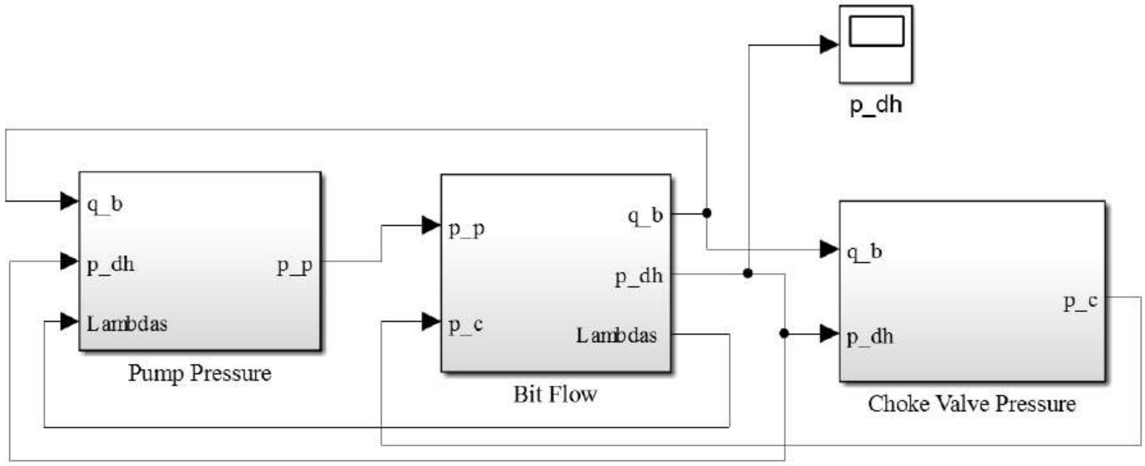

Figure.III.5: System simulation expressed in three meaning parts.

The several parameters are mentioned in the following table

Table.III.2: Several model parameters

Values Parameters		
c_{v} =41	τ_0 =7.5 Pa	$\mathrm{K_p}$ choke controler= 10
c_{sc} =0.05	τ_1 =40.5 Pa	$\mathrm{K_i}$ choke controler =0.8
$\mathrm{M_a} = 1600$ bar $m^2 . s^2$	$a = 1.10^{-3}\,\frac{1}{s}$	$\mathrm{K_{p\_bpp}} = 0.2$
$\mathrm{M_d} = 6000$ bar$m^2 . s^2$	b =$1.44 . 10^{-5}$	$\mathrm{K_{p\_\lambda}} = 25.10^6$
$\mathrm{P_c^{ref}} = 14.1$ bar	$q_{\mathrm{b},ss} = 1500$	$\mathrm{K_{p\_dh}} = 5$
$\mathrm{P_{dh}^{ref}} = 300$ bar	$\mathrm{d_o}$ =0.1270 m	$\mathrm{T_{win}} = 0{,}1$ sec
$\beta_{\mathrm{a}} = 15000$ bar	$\mathrm{d_h} = 0{:}2454$ m	$\mathrm{T_c} = 0.5$ s
$\beta_{\mathrm{d}} = 15000$ bar	$\mathrm{d_i} = 0.1086$ m	$\mathrm{g} = 9.81\, m/s^2$
$\lambda_{\mathrm{inti}} = 0.8$	$L_{\mathrm{a}} = 4000\, m$	$\mathrm{g_s} = 1.18\, m/s^2$

$\rho_m = 1180 \ \ kg/m^3$	L_d =4019 m	$p_s = 1$ bar
$\mu_P = 16.10^3$ bar. s	$h_a = 1826\ m$	$\rho_{H2O} = 10^3 kg/m^3$

III.4.1 Mud pump pressure

Mud pump simulation system is modeled by using Matlab/Simulink as it is illustrated by (Figure.III.6).

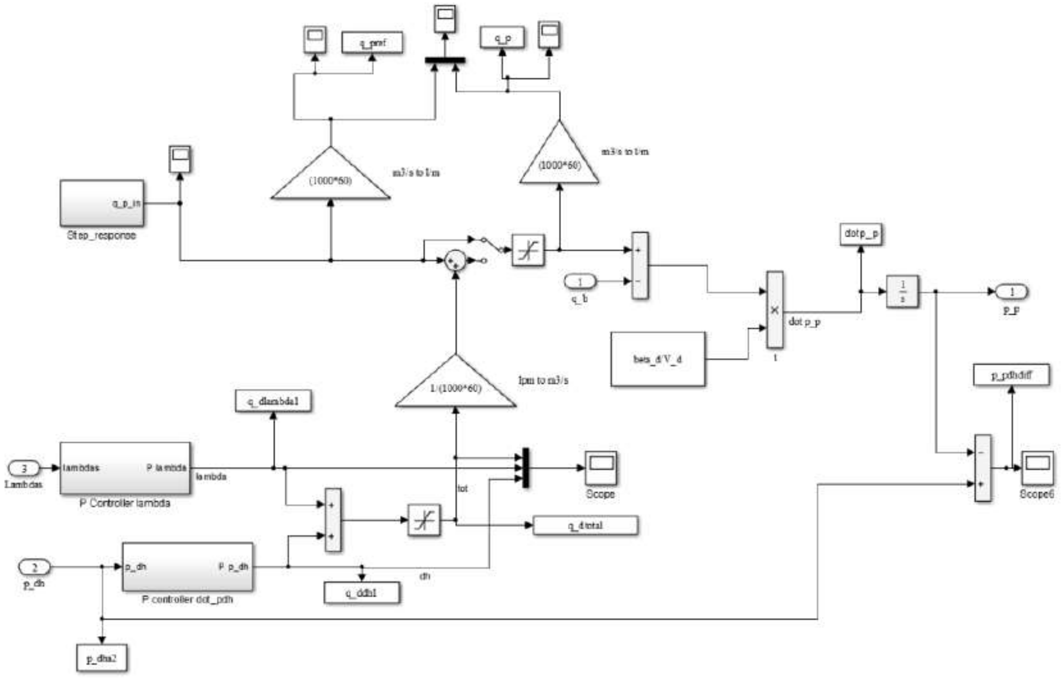

Figure.III.6: Mud pump system simulation.

The step response of the controlled mud pump flow at a set point of 2000 l/m gain is illustrated by the (Figure. III.7). Indeed, its varied step response is shown by (Figure III.8).

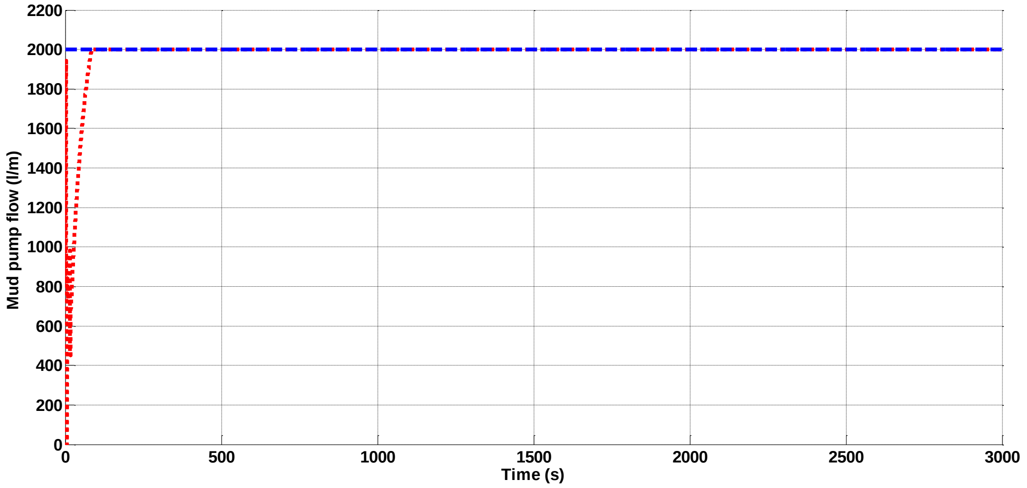

Figure.III.7: Step response of the mud pump flow.

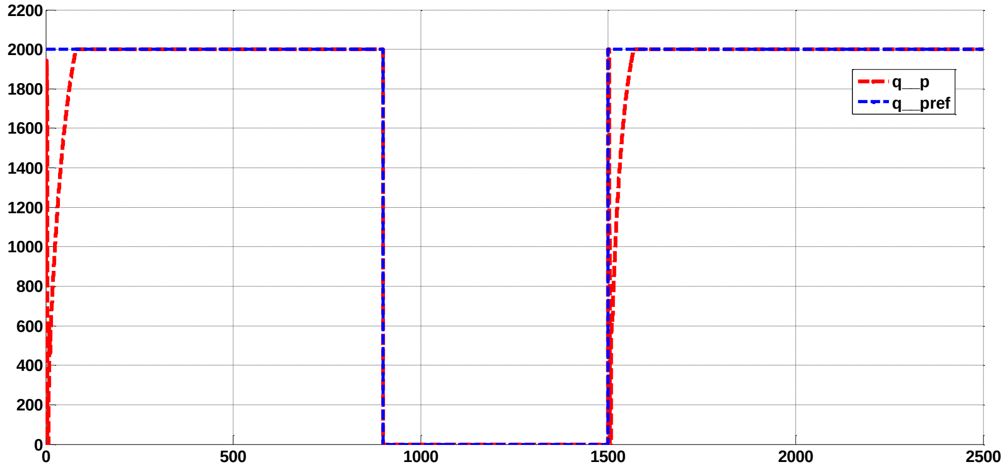

Figure.III.8: Varied step response of the mud pump flow.

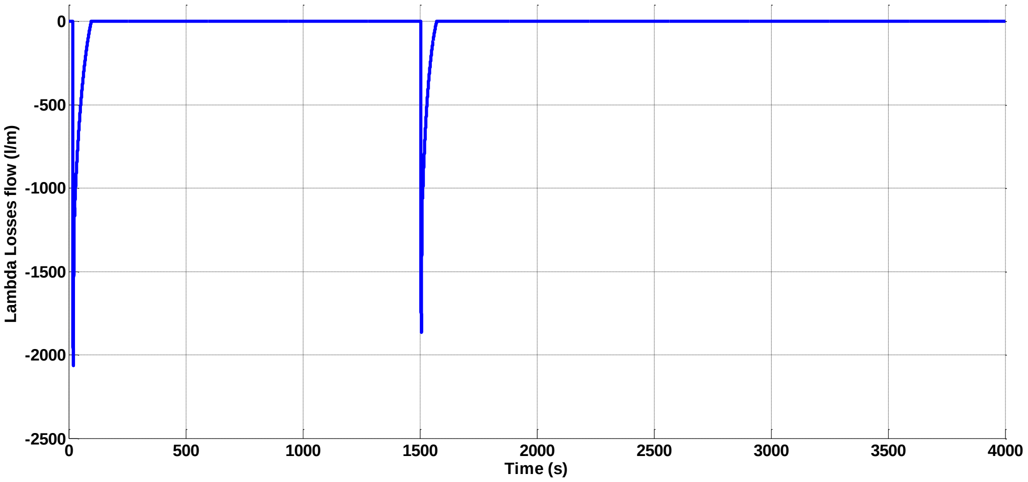

Figure.III.9: Lambda loss flow.

(Figure.III.9). shows how the friction losses flow drop influencing on the downhole pressure.

While(Figure.III.10) shows how the check valve operates by illustrating the Pressure difference between the downhole pressure and the mud pump pressure in case of a varied step, where the mud pump flow set point is of 1500 l/m gain, then the pump will shut down between 900s and 1500s, and after it will be feed on. (Figure.III.11) shows how the check valve open and close to compensate for the pressure drop, from 0 (Close) to 1 (fully open).

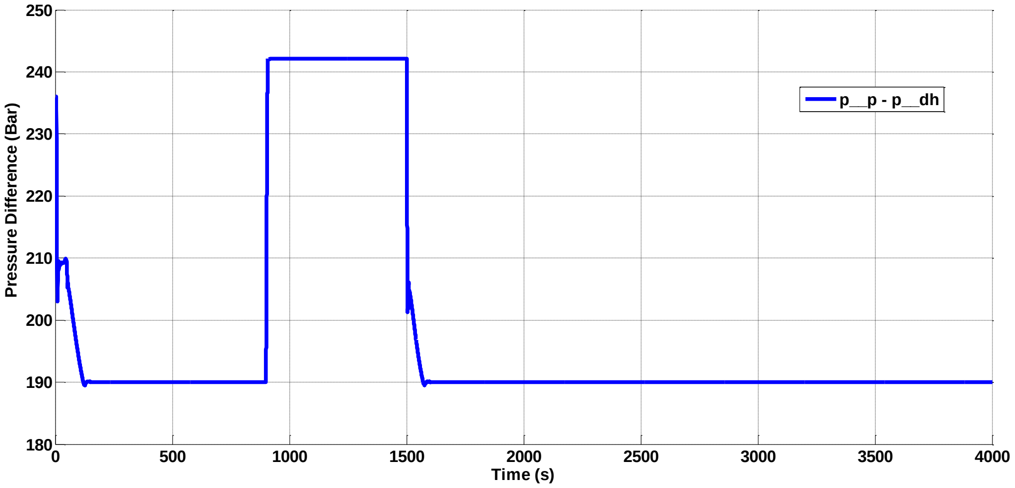

Figure.III.10: Check valve functioning towards pressure variation.

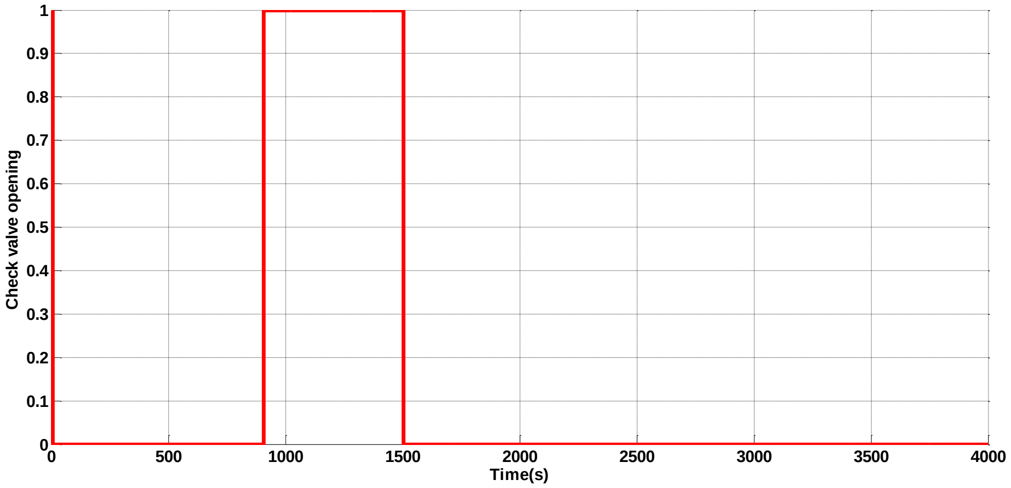

Figure.III.11: Check valve operation when the mud pump flow is varied.

III.4.2 Drill bit Flow

Flow drill bit simulation system is modeled by using Matlab/Simulink as it is illustrated by (Figure.III.12).

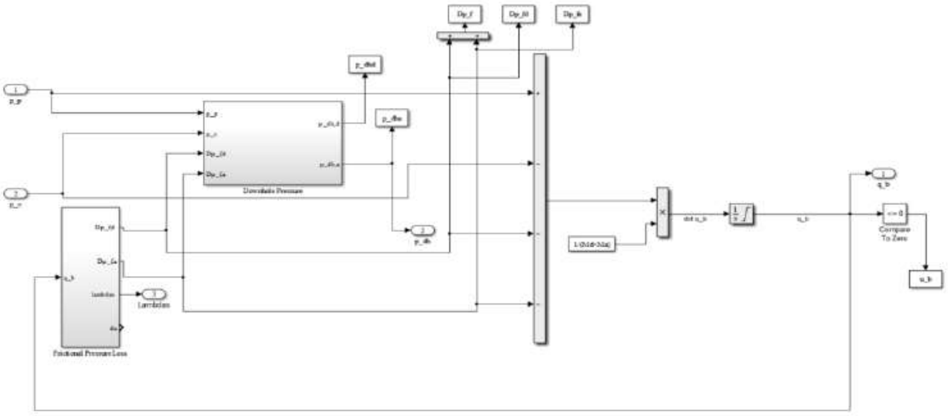

Figure.III.12: Drill bit system simulation.

This is by including the downhole pressure estimation and the several pressure losses Figure III.13.

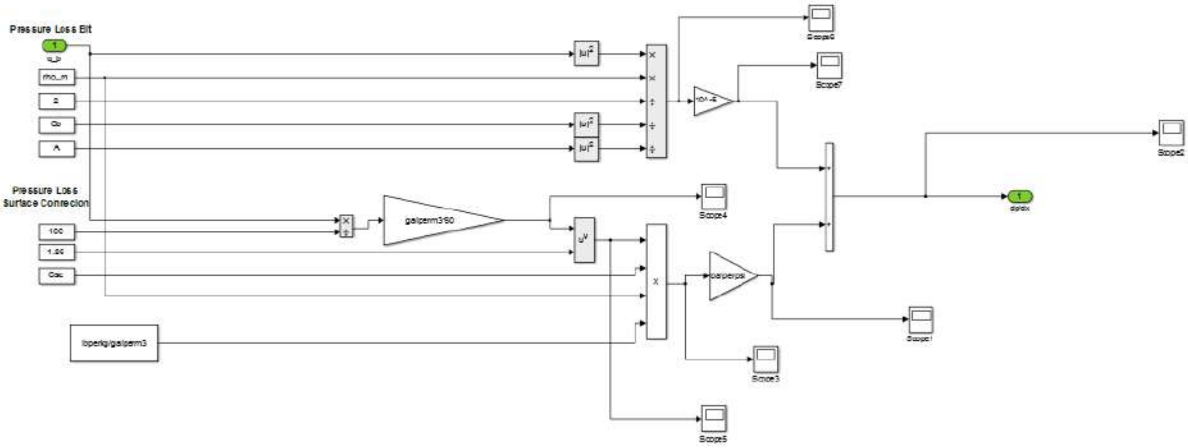

Figure III.13: Simulation of other pressure losses.

III.4.3 Choke valve pressure

The choke valve pressure simulation system is modeled by using Matlab/Simulink as it is illustrated by (Figure.III.14).

The dynamics of the whole system are taken into account, including friction models and fluid viscosity.

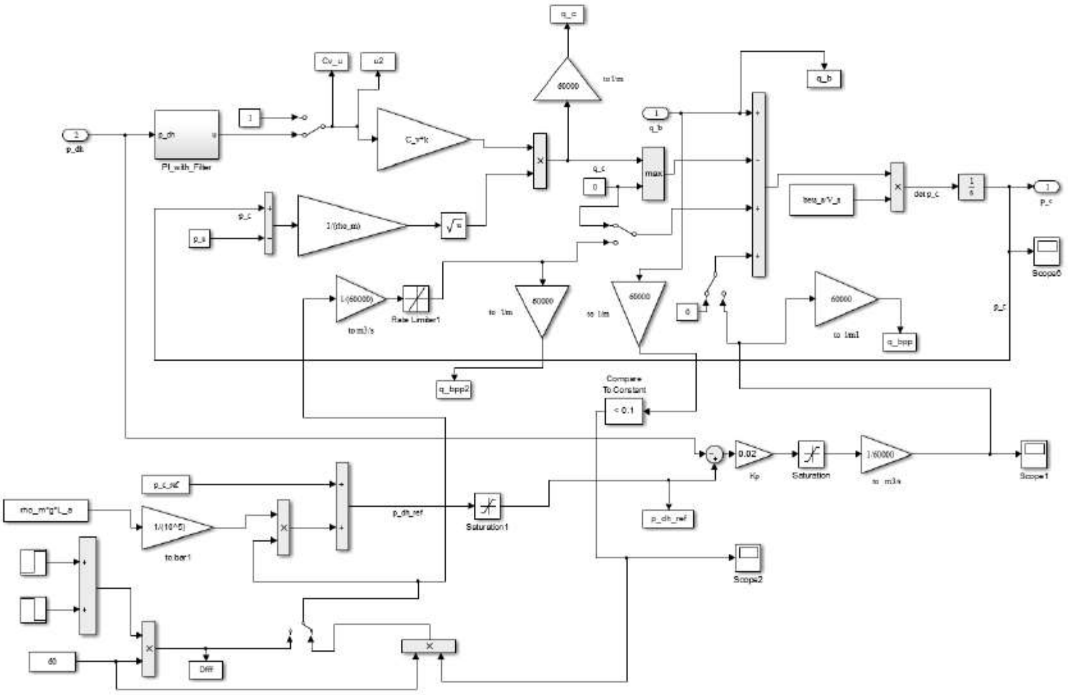

Figure.III.14: Choke valve pressure system simulation.

As the system is a sort of simulation model (is not a real system) we have proceeded to a classic PID controller tuning.

Which means that we have started to implement only the P action; we varied its gain in several parameters. Then we have extracted the more appropriate K_p value which is equal to 10. The P action alone does not achieve the desired result; the static error is not zero. So, it is required to add the integral action, as for the P action we have proceeded to change its gain in classical way, the more appropriate value was 0.05. The following table shows the different tests actions on the choke valve PI controller.

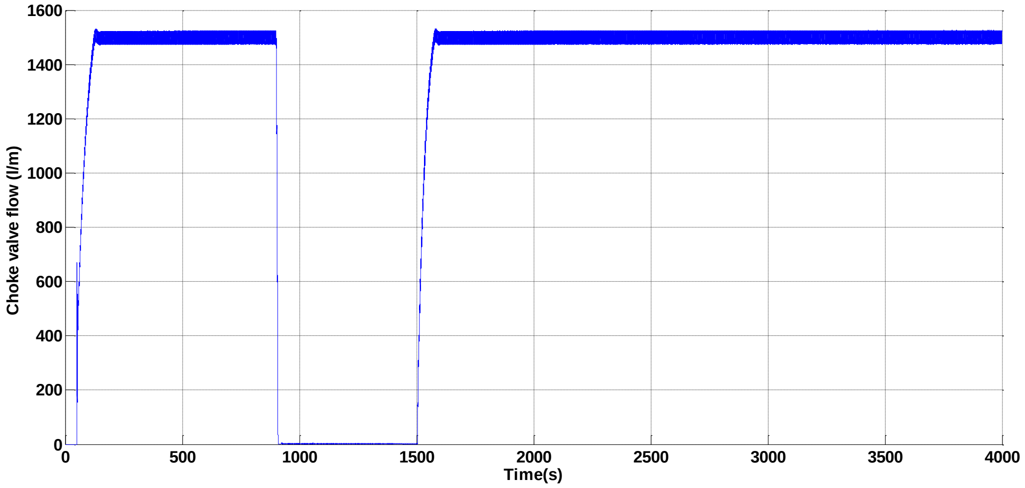

Figure.III.15: Chock valve flow when the mud pump flow is varied.

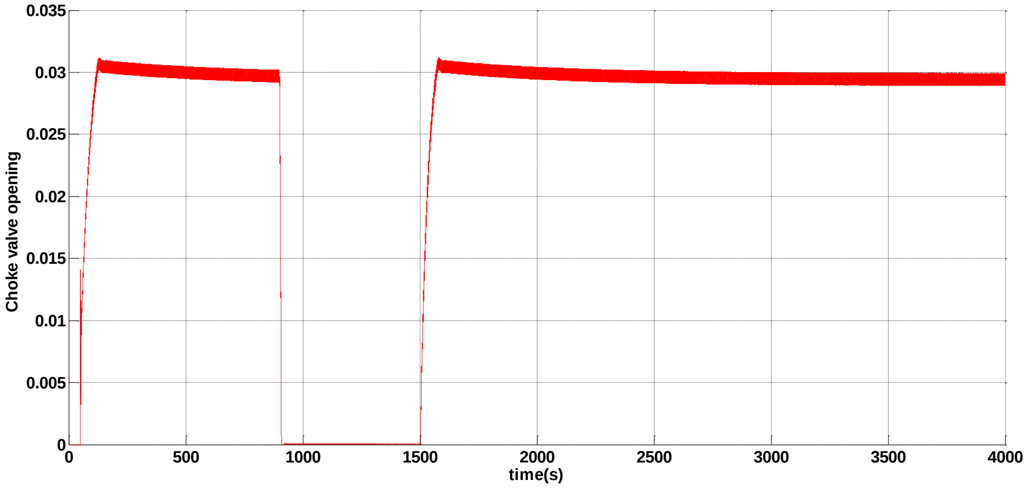

Figure.III.16: Chock valve operation when the mud pump flow is varied.

Indeed, the back pressure pump is set to operate when the mud pump flow is 0. The error signal is thereafter controlled by a P controller, K_p = 0.02, then converted and added as a disturbance to the choke flow.

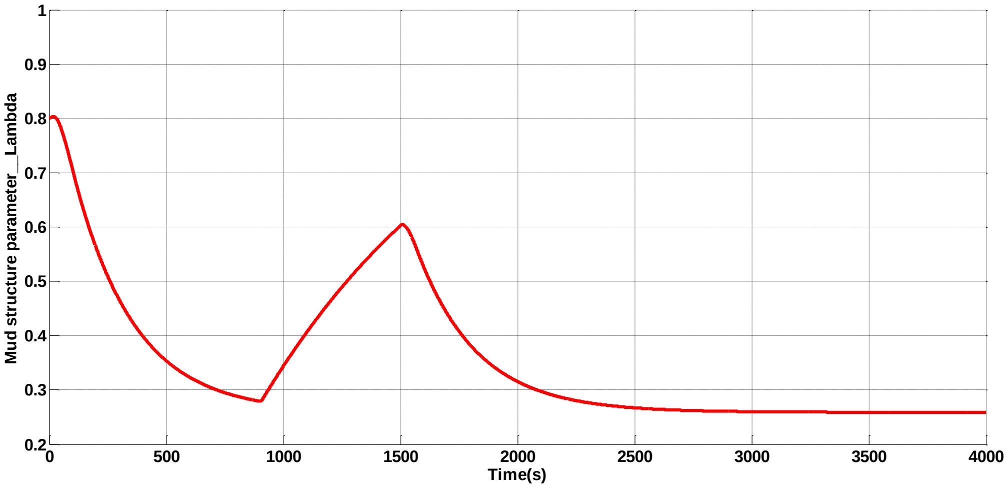

Figure.III.17: Mud structure parameter variation towards pump flow variation.

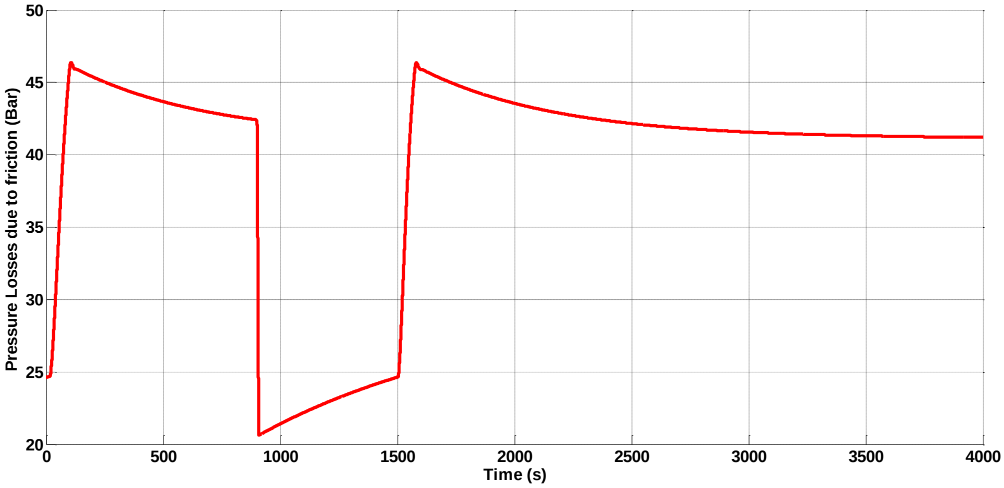

Figure.III.18: Pressure losses due to friction towards pump flow variation.

Generally, in MPD the mud pump is shut down for approximately 10 minutes and the restart. In this work, two start ups are considered, one from a fully gelled structure (**λ** = 0.8) and one where the mud is gelled.

The purpose of this system control is to keep the downhole pressure variation within limits of ±1 bar. Starting the mud pump when the mud is gelled; it cause at maximum a peak of 0.5 bar, it does not exceed the reference pressure. Even in the starting up, it has the same result.

As can be seen from (Figure III.18) the choke valve opening does not exceed 3.5% which allows more feasibility and a long valve life time. Indeed, a well back pressure pump control enhance the choke valve well working and it provides more pressure downhole stabilization.

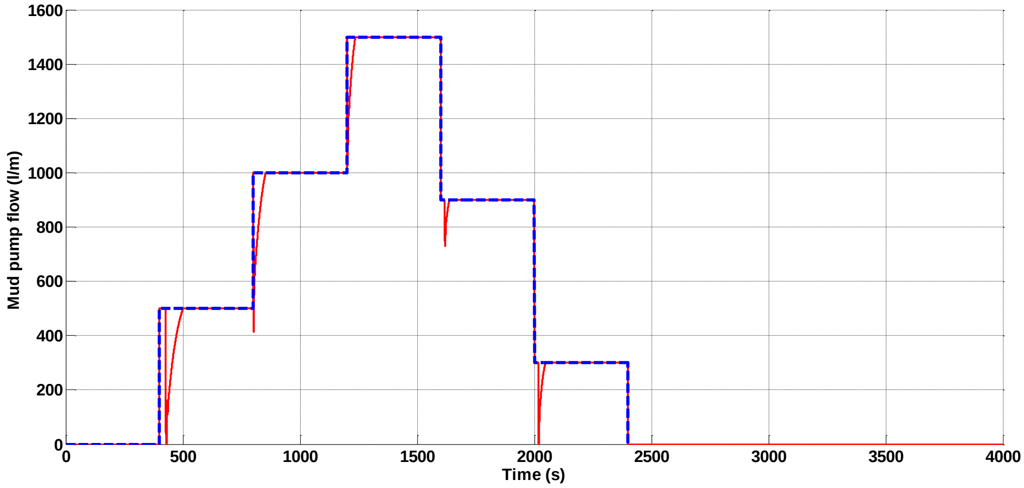

Figure.III.19: Mud pump flow variation.

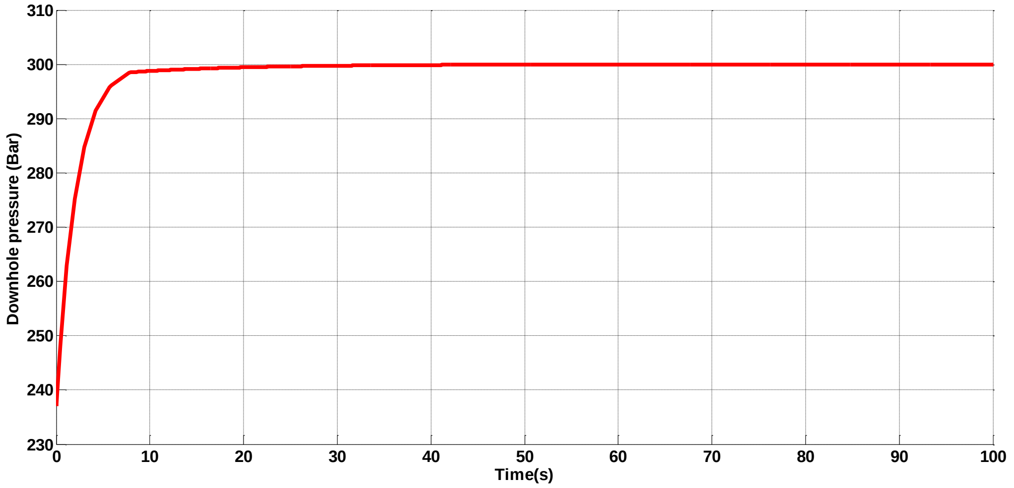

Figure.III.20: Downhole pressure variation.

(Figure.III.20) illustrate how the downhole pressure behaves when we change the mud pump flow according to Figure.III.19. The result indicates the robustness of the control strategy adopted and the controller parameters are well selected.

III.5 Conclusion

The boundaries of downhole pressure variation are very limited; so we can dictate a good control for the gelling phenomena by adjusting the downhole pressure; therefore the changing in mud properties is limited in certain case. That means the operation of build up and break down takes a small of time. In this chapter we have presented the modeling and control strategy simulation. The most influencing controller is the choke valve PI controller, a precise gain estimation could bring more appropriate results. Finally, the extracted results by simulation looks appreciable. But to validate them, this strategy could be implemented in a real system which unfortunately was not possible in our study.

General conclusion

In this study we have based on the Cheng's and the Bingham plastic models with including different losses factors in way to simulation the mud behavior, and meanly its propriety of gelling. Matlab/Simulink software was used to get a feasible drilling mud system simulation by integrating the managed pressure drilling control system. In standard MPD the control system focus meanly on the choke valve action. However, in an extended MPD it is required to add the control role of back pressure pump and the principal pump.

After several simulations and robustness tests we have concluded the feasibility of the control strategy adopted. The boundaries of downhole pressure are very limited and the gelling phenomena is adjusted by a small period of build ups and break downs.

Of course by simulation system we get an acceptable results which could be validated in reality. Meanly by including the several phenomena neglected, such as temperature and drill string rotation, because of modeling and control difficulties. Finally, the conditions that we impose in our study are far out the reality. But it will be as a preface to another study in the similar theme to develop the modeling system; thus will be near to realty.

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Abstract

The gelling process is reversible transformation from liquid to gel solid structure; that’s mean the physical properties of mud are changing during time; consequently we need amount of forces from the drill string rotation to break down the gel which may cause damage to our equipments and add more costs. So we need to implement a controlled mud system to avoid that circumstance.

Managed pressure drilling system (MPD) could be a feasible solution for that, it allows us to control the bottom hole pressure (BHP); when we implement a narrow window on the variation of BHP we get instantaneously a controlled mud in such a way that the period of build up and break down are minimized due to downhole pressure stabilization.

The changing in mud properties is indicated usually by an increasing or decreasing of factor viscosity.

The main factor to implement MPD system is adding a control to mud pump and chock valve in addition to the back pressure pump.

In a way to simulate the MPD control system by Simulink in Matlab program; we use in our study the collects of Cheng's model and Bingham plastic model during thixotropic behavior.

Key words : gelling; model;control ;MPD ;BHP.

ملخص

عملية تحول وحل التنقيب من سائل إلى صلب –هلام – يعتبر تحول عكوس وتعني أن الخصائص الفيزيائية تتغير خلال الزمن ؛ نتيجة لذلك تحتاج ماكينة الحفر كمية من قوة دورانها لتكسير الهلام؛ والذي يمكن أن يتسبب في مضاعفة التكاليف وإتلاف الوسائل. لذلك سنحتاج لتطبيق نظام تحكم في الحل لتجنب هذا الظرف.

إدارة ضغط الحفر يمكن أن تكون هي الحل؛ فهي تسمح بالتحكم في ضغط قاع البئر عند تحقيق نافذة ضيقة لتغيراتها سنحصل بالمزامنة مع ذلك على نظام تحكم في وحل التنقيب.بحيث تقل مدة تشكل الهلام وتكسيره بسبب ا لاستقرار في ضغط قاع البئر .يؤشر الانخفاض والارتفاع في معامل اللزوجة عادة إلى التغيرات في خصائص الوحل.

العامل الرئيسي لتحقيق إدارة الضغط هو إضافة نظام تحكم إلى المضخة والصمام وعلاوة على ذلك المضخة الإرجاعية . لمحاكاة نظام التحكم في ضغط الحفر بواسطة المحاكي في برنامج الماتلاب نستعمل في دراستنا مجموع من النماذج المتمثلة في نموذج تشنغ Cheng‘s ونموذج بنج هام بلاستيك Bingham plastic .

الكلمات المفتاحية:الهلام؛النموذج؛ المراقبة؛ ضغط قاع البئر ؛إدارة ضغط التنقيب.

Résumé

Le processus de gélification est transformation réversible ;à partir de l’état liquide vers structure solide; c'est-a- dire les propriétés physiques de la boue sont en train de changer au cours du temps ; par conséquent, la garniture de forage doit diriger une quantité de force de son rotation pour briser le gel qui peut causer des endommagements aux équipements et ajouter plus de coûts. Nous avons donc besoin de mettre en œuvre un système de commande de la boue pour éviter cette situation.

Le système de pression de forage commandée (MPD) pourrait être une solution envisageable pour nous permettre de contrôler la pression de fond (BHP); on gère la pression quand on met une étroite variation sur le BHP ; instantanément de manière contrôlée la boue au cours de la période d'accumulation et de décomposition réduits au minimum par la stabilisation de la pression de fond de puits.

Le changement dans les propriétés de boue est indiqué habituellement par l'augmentation ou la diminution de facteur de viscosité. Le principal facteur pour appliquer ce système est d'assurer un contrôle de la pompe à boue ; contrôle de la choke valve et la pompe d’anti retour.

Pour simuler le système de commande par MPD, nous utilisons dans notre étude le Matlab/Simulink. Les modèles utilisées sont celui de Cheng et de Bingham plastique au comportement thixotropiques.

Les mots clés : gélification ;modèles ; contrôle; BHP; MPD.