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LOST CIRCULATION MODELING THROUGH NATURALLY FRACTUREDFORMATIONS

نمذجة الفقد في دورة سائل الحفر في طبقات الكسر الطبيعية

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الإستهلال

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(آَتُونِي زُبَرَ الْحَدِيدِ حَتَّى إِذَا سَاوَى بَيْنَ الصَّدَفَيْنِ قَالَ انْفُخُوا حَتَّى إِذَا جَعَلَهُ نَارًا قَالَ آَتُونِي أُفْرِغْ عَلَيْهِ قِطْرًا) (96)

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صدق الله العظيم

Dedication

We would like to donate this unpretentious effort to

Our parents; who have endless presence and for the never ending love and encouragement

Our brothers and sisters; who sustained us in our life and still

Our teacher; ho lighted candle in our ways and provided us with light of knowledge

Finally; our best friend

Acknowledgement

Everything that has beginning must equally have end .thanks ,of Allah for the gift of life in good health and abundant grace throughout our stay in this greatcitadel.it is indeed a privilege and honor to pass through this college . we acknowledge the effort of every lecture that has impact knowledge into us ,without your contribution we would not be who we are today .

Abstract

Lost circulation is frequent problem during the drilling of oil wells .That occurs when a considerable amount of pumped drilling fluid flows into the formation .This problem impairs safety ,efficient and economic viability process .for these reasons many previse study‟s were developed to understand problem and other to solve the problem in this work we applied mathematical model that takes into account rheological properties of the drilling fluid to estimate mud loss and maximum invasions radius in the fracture formation. To achieve the goals and ordinary differential equation we created but duo to complexity of equation it was resolved to diminution less equation and solve diminution less equation using 4 order Runge_ktta.the model incorporate three rheological models and allow analyzing fluid flow through fracture for constant width. Out puts of the models maximum volume and radius have been estimated sensitive analyses conducted to invested ,the effect of rheological properties ,and conceded that power law fluids are not suitable fluids in case of lost circulation

Key words:

Lost circulation –loss modeling-naturally fractured formation-rheological models-simulation

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التجريد

يعد التدوير الضائع مشكلة متكررة أثناء حفر آبار النفط ، ويحدث ذلك عند تدفق كميات كبيرة من المضخات والحفر في المعلومات ، وتضعف هذه المشكلة عملية السلامة والفعالية والجدوى الاقتصادية ، ولهذه الأسباب ، تم تطوير العديد من الدراسات السابقة لفهم المشكلة وغيرها لحل المشكلة في هذا العمل قمنا بتطبيق نموذج رياضي يأخذ في الاعتبار الخصائص الريولوجية لمائع الحفر لتقدير فقد الطين والحد الأقصى لنصف قطر التوغل في تكوين الكسر. لتحقيق الأهداف والمعادلة التفاضلية العادية التي أنشأناها ولكن ثنائية التعقيد في المعادلة ، تم حلها لتقليل معادلة أقل وحل معادلة تقليل تقليل باستخدام 4 orderRunge_ktta. يشتمل النموذج على ثلاثة نماذج ريولوجية ويسمح بتحليل تدفق السوائل من خلال الكسر لعرض ثابت. تم تقدير الحجم النهائي للنماذج ونصف القطر بالتحليلات الحساسة التي تم إجراؤها على الاستثمار ، وتأثير الخصائص الريولوجية ، واعترف بأن سوائل قانون الطاقة ليست سوائل مناسبة في حالة فقدان الدورة الدموية

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CHAPTER 1

INTRODUCTION

1.1 Introduction :

The circulation loss occurs when a considerable amount of pumped drilling fluid flows through the formation. Lost circulation is one of the most common and costly problems in drilling operations. It may occur into permeable formations, depleted zones induced or natural fractures And cavernous formation while drilling, cementing or during work over jobs in the well. The circulation loss could be a significant problem during the drilling, increasing the nonproductive time (NPT). This NPT costs approximately US$ 800 million per year to the petroleum industry. Also established that this circulation loss occurs through the rock matrix, natural and induced fractures.

There most likely is no segment of drilling non- productive time in which is more difficult to make this decision than lost circulation .economic impact ground in their very large magnitude. Slight improvements in technology that reduce drilling non-productive time translate into millions of dollars of operating cost savings. The application of lost circulation materials (LCM) in the drilling fluid for plugging flow paths has been widely accepted practice. (LCM) like ground marble, graphitic carbon and fibers are well _ known to the industry.

1.2 Problem Statement :

Problem of lost circulation during drilling of oil and gas wells is one of the major and frequent problem in drilling engineering it because economic losses and it can lead to other drilling problems, so there for several techniques and method have been developed to solve this problem and other techniques to clearly understand what the problem.

This research is towards in understand the problem of losses and modeling the losses volume in naturally fractured layers.

1.3 Objectives :

In order to fulfillment the research questions the listed point have been achieved :

1-.Estimate maximum volume that lost inside natural fracture zones.

2- Estimate maximum invasion radius.

3- Comparing the volume and radius of lost fluids in means of different drilling fluid rheology.

1- Sensitivity analysis of models.

1.4 Methodology :

In order to achieve the mentioned goals, an ordinary differential equation was created that describes the loss in the naturally fractured layers, but due to the complexity of the equation , dimensionless analysis is used to facilitate the solution, , then 4 order Range_kutta method was used to solve this problem ,the solution in general was represented by the computer using (matelab).

1.5 Lay Out :

This dissertation is composed of five chapters:

Chapter 2 : contains drilling fluid properties, functions, and type and additives .Describe lost circulation, type of losses, who can identify it and lost circulation models by combining between pa pers in literature review.

Chapter 3 : describes a selected model from the literature that allows predicting the invasion radius in the function of the time when lost circulation is present. This model was used from field-scale and is the basis for the developed Bingham plastic and power law and modified yield power low .turning possible to evaluating formulation of drilling fluid to minimize the circulation by field application.

Chapter 4 : focuses on model applications and subsequent analysis. The Bingham radial model was run to model the lost circulation, then a sensitive analysis of the rheological parameters of the drilling fluid was carried. Measure total volume loss by dimensionless curve.

Chapter 5 : summarizes the main conclusions and recommendations obtained in this work.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 BACKGROUND :

This chapter contains basic definitions of drilling fluid and information regarding the main focus of this work, which is the circulation loss. First, we will present concepts on drilling fluid types and rheological behavior. Then, circulation loss is described, associated with formations susceptible to this problem, and classified according to the severity of loss and remedial methods. Finally, a summary of the most representative predictive models developed to date will be shown.

2.1.1 Drilling Fluid :

The success of the rotary-drilling process (completion of an oil or gas well) and its cost depend substantially on three important factors:

- The bit penetrating the rock.
- The cleaning the bit face and transport of the cuttings to surface.
- The support of the borehole the drilling fluid used affects all of these critical items.

The drilling fluid density and ability to penetrate rock have an effect on the rate of penetration. The hydraulic energy expended on the bottom of the hole and the viscosity and flow rate of the fluid affect the cuttings transport. And the density of the fluid and its ability to form a layer on the wellbore (wall cake) affects the wellbore stability and support. It is often said that the majority of the problems in drilling are related in some manner or another to the drilling fluid .The drilling engineer is concerned with the selection and maintenance of the drilling fluid because of its relation to most drilling operational problems. The cost of the drilling fluid, commonly known as “drilling mud” or simply “mud,” is comparatively small as compared to the rig or casing costs; but, the selection of the proper fluid and the testing and control of its properties has considerable effect on the total well cost. The additives needed to create and maintain the fluid properties can be expensive. In addition, the penetration rate of the rotary bit and operational delays caused by circulation loss, stuck drill pipe, caving shale, and the like are significantly affected by the drilling-fluid properties. Fluid properties also profoundly influence the rig days needed to drill the total depth (TD) (Bourgoyne.1991; Darley and Gray 1988).

(Rabia.H.2001)

2.1.2 Functions and Properties of a Drilling Fluid :

Just as the nature of drilling-fluid solids affects the efficiency of solids control equipment, the nature of the solids also plays an integral role in the properties of drilling fluids, which in turn affect the properties of the solids and the performance of the equipment. This intricate and very complex dynamic relationship among the solids, drilling fluid, and solids-control equipment is represented in Figure 2.1. Any change made to one of these affects the other two, and those in turn affect all three And so on. To optimize a drilling operation, it is important to understand how the solids affect bulk mud properties, particularly rheology, hole cleaning, filtration, drilling rate (rate of penetration [ROP]), along with surface properties such as shale inhibition potential, lubricity, and wetting characteristics.

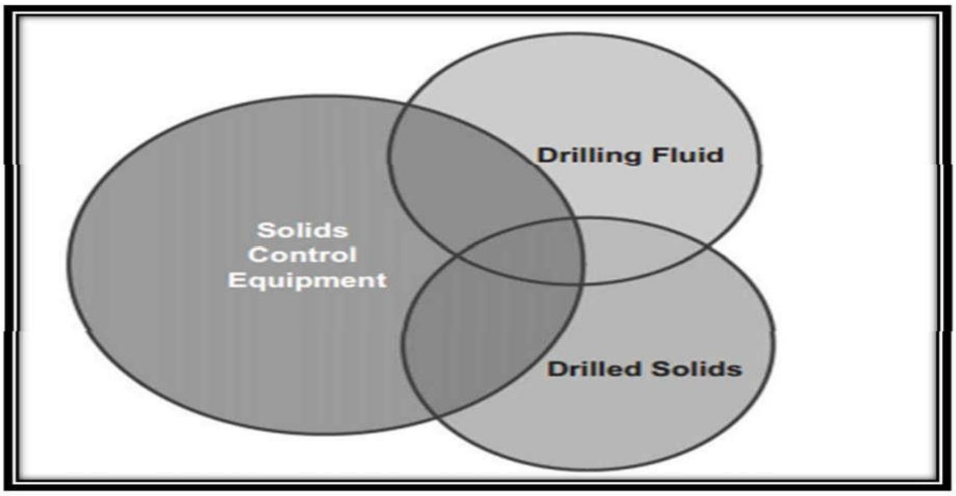
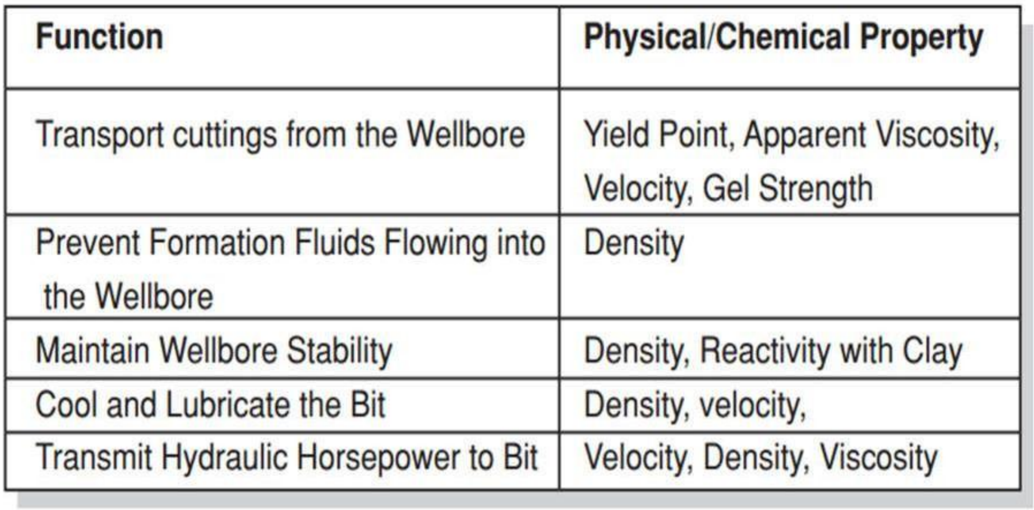


Figure (2. 1) : **Mud Processing Circle**

The main functions of drilling aid and the properties which are associated with fulfilling‟s these functions are summarized in **Table 1**, and discussed below:

Table (2. 1) : Function and Physical Properties of Drilling Fluid



Function	Physical/Chemical Property
Transport cuttings from the Wellbore	Yield Point, Apparent Viscosity, Velocity, Gel Strength
Prevent Formation Fluids Flowing into the Wellbore	Density
Maintain Wellbore Stability	Density, Reactivity with Clay
Cool and Lubricate the Bit	Density, velocity,
Transmit Hydraulic Horsepower to Bit	Velocity, Density, Viscosity

(Heriot-watt.2001)

2.1.3 Type Of Drilling fluid :

1. Water Based mud(WBF).

2. Oil Based mud(OBF).

3. Gas Based mud (Pneumatic Fluid).

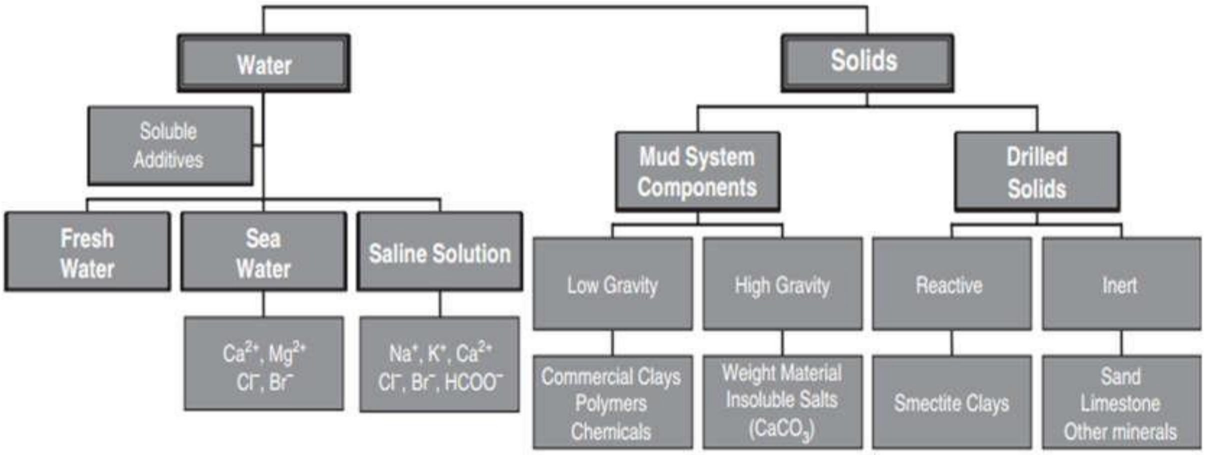


Figure (2. 2) : Types from of “HAND BOOK” Water-Based Muds.

(Rabia H.2001)

2.1.4 Drilling Fluid Rheology :

Rheology is the study of the deformation and flow of matter. Viscosity is a measure of the resistance offered by that matter to a deforming force. Shear dominates most of the viscosity-related aspects of drilling operations. Because of that, shear viscosity (or simply, „„„viscosity‘‘‘) of drilling fluids is the property that is most commonly monitored and controlled.

Drilling fluids with elevated viscosity at high shear rates tend to exhibit greater retention of mud on cuttings, Conversely, elevated viscosity at low shear rates reduces the efficiency of low-shear devices like centrifuges.

2.1.5 Rheology Model :

Shear viscosity is defined by the ratio of shear stress (v) to shear rate (y):

$$\mu = v\backslash y$$ equation (2. 1)

For Newtonian fluids, such as pure water or oil, viscosity is independent of shear rate Thus, when the velocity of a Newtonian fluid in a pipe or annulus is increased, there is a corresponding increase in shear stress at the wall. Various models are used to describe the shear-stress versus the shear-rate behavior of drilling fluids:

Bingham Plastic model it introduces nonzero shear stress at zero shear rate

$\mu_p = \mu_{p.y} + t_0$ equation (2. 2)

Power Law model Indeed, in this model, the value of at zero shear rate is always

$v = k\, y^n$ equation (2. 3)

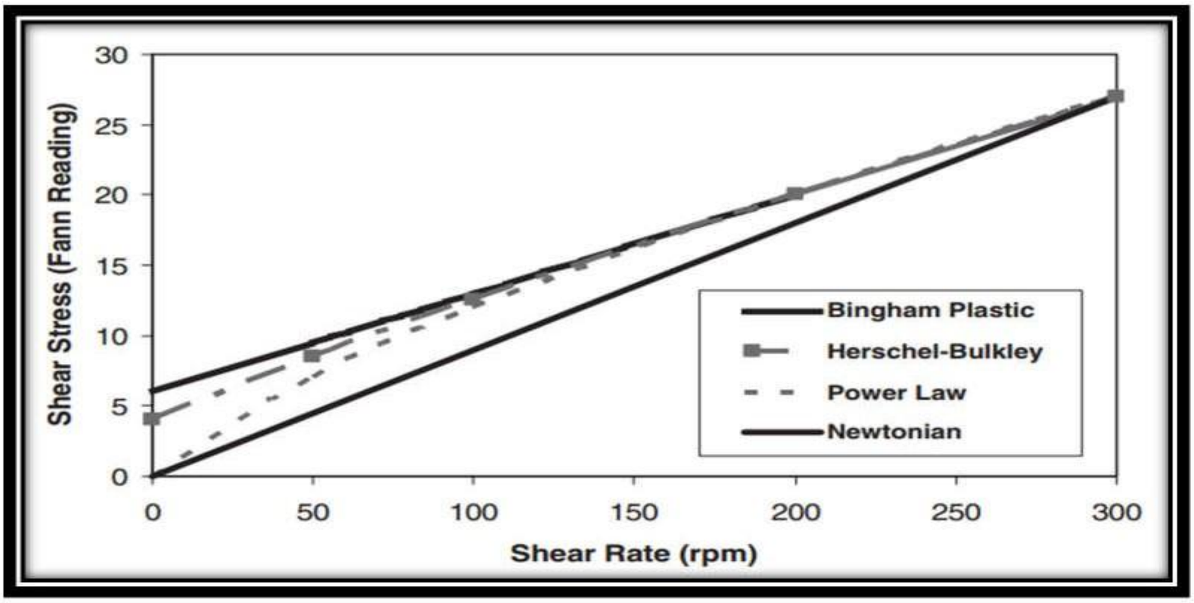


Figure (2. 3) : Drilling Fluid Rheology Models

2.1.6 Lost Circulation :

Lost circulation—the significant and continuing loss of whole mud or cement slurry to a formation—is one of the most common and troublesome downhome problems.

It has been a hindrance to drilling, completion, and work over operations ever since rotary rigs first came into use, and it continues to have a profound negative impact on well economics.

Estimates of the direct and indirect costs of lost-circulation problems in the drilling industry worldwide run into the hundreds of millions of US dollars annually. Although drilling ahead and primary cementing pose particular risks, lost circulation can occur during any well procedure that involves pumping fluid down the hole. Indications of lost circulation may range from a gradual drop in pit level to a partial or complete loss of returns. In extreme cases, the fluid level in the annulus may drop rapidly, sometimes by hundreds of feet.

Lost circulation_invariably results in higher costs for materials, services, and additional rig time. Depending on the timing and severity of its occurrence, it can lead to the loss of formation-evaluation data because the information normally obtained from mud returns and drilled cuttings is no longer available.

Lost circulation_can also result in reduced well productivity if the loss zone is also a potential pay interval. If the wellbore-fluid level drops far enough and fast enough, the drop can allow fluid to enter the wellbore from a higher-pressure formation. When this influx or kick does occur, it makes well control all the more difficult because of the inability to circulate kill fluid (Ivan et al. 2003**).**

(Mitchell and Miska.2011)

2.1.7 Occurrence Of Lost Circulation :

For lost circulation to occur, there must be (1) a formation with flow channels that allow passage of whole fluid from the wellbore and (2) an overbalance or positive pressure differential between the wellbore and the formation. Both of these conditions must be present, although one or the other may predominate. For example, a very small overbalance may be sufficient to drive fluid into a highly porous and permeable rock, while even a relatively nonporous, impermeable rock can accept considerable **(Mitchell and Miska.2011)**

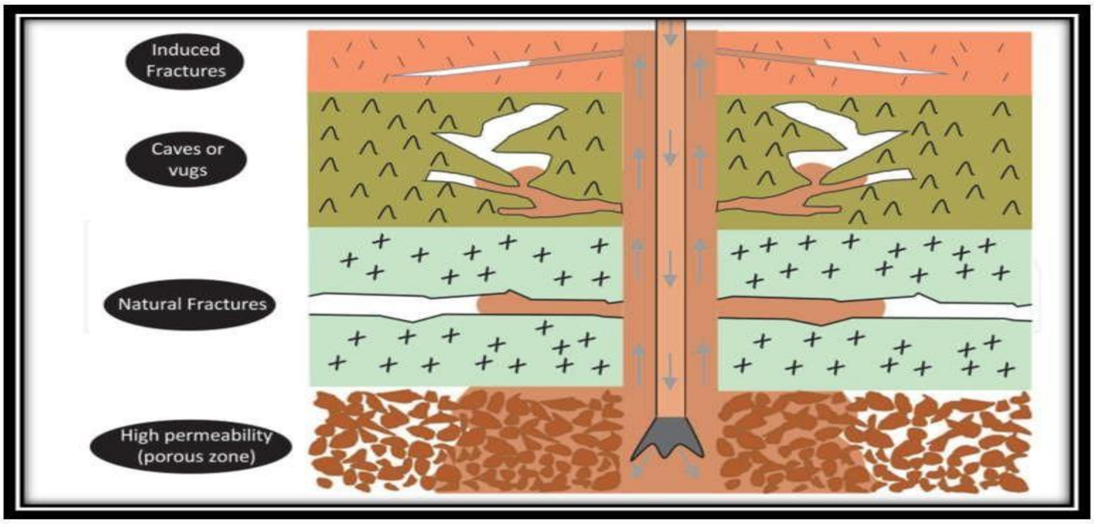


Figure (2. 4) : **amounts of fluid if the overbalance is large enough to induce hydraulic fracturing.**

Figure 2.3 Four types of rock formations causing loss-circulation. The arrows indicate the direction of circulating fluid starting from the surface within the drill pipe going to the open-hole and to the annulus of the wellbore back to the surface.

- **Permeable Zones :**

Some types of rocks, because of their high primary porosity and permeability, almost seem to be designed to cause lost-circulation problems. Unconsolidated formations, gravel beds, loose conglomerates, and shallow or highly depleted sandstones have long been recognized as having natural lost-circulation tendencies. Lost circulation in these rocks most often manifests itself as a gradual drop in pit level, although continued drilling time and additional exposure to the wellbore may result in partial or complete mud losses (see Figure . 2.2 the sections marked with an“A”).

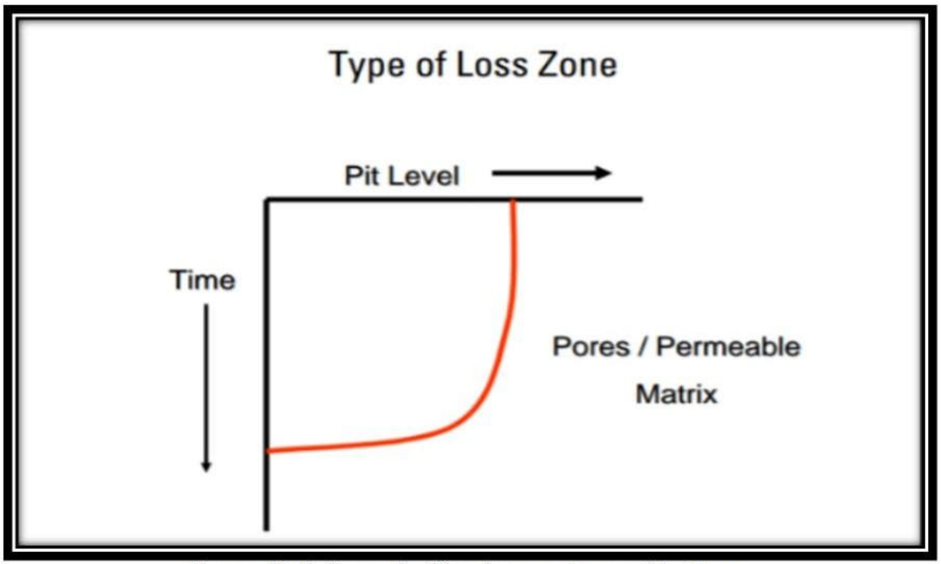


Figure: (2.4) from of schlumberger - Permeable Zones

Figure (2. 5) : Drilling Fluid Rheology Models

- **Natural Fractures :**

Secondary porosity and permeability such as occur in naturally fractured sandstones, shale‟s, and carbon assure also conducive to lost circulation Figure 3.2 the section marked with a “C”). Natural

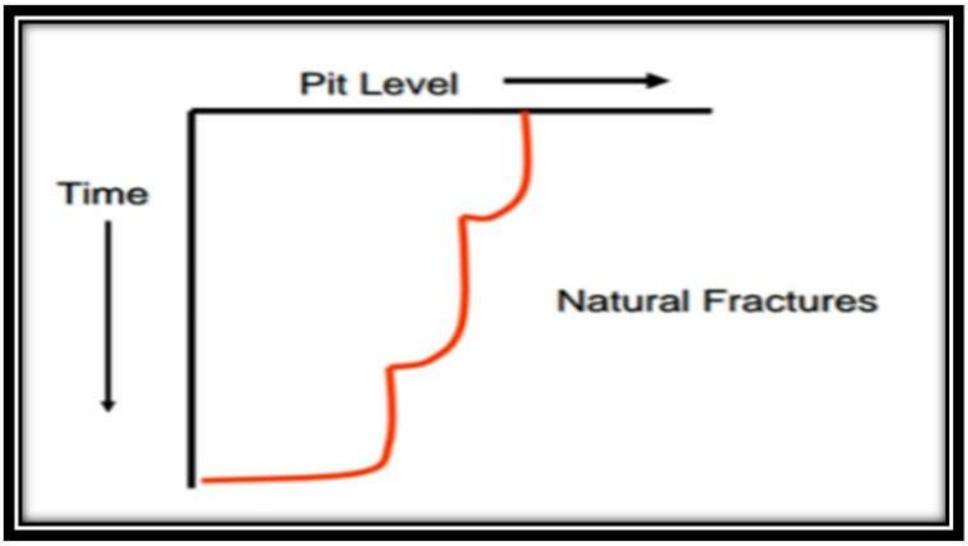


Figure (2.6) : from of Schlumberger Natural Fractures

- **Induced Fractures :**

If lost returns occur in an area where offset wells have not experienced lost circulation, then the problem is likely the result of fracturing that is induced during well operations, rather than the result of a natural fracture network. Most induced fractures are related in some way to drilling-fluid or cementing programs, although sometimes the well architecture may itself be a contributing factor as, for example, when a surface or intermediate casing string is set too high. Mechanical failures, such as leaks in a shallow casing string, can also result in lost circulation (Figure 3.5the section marked with a “D”).

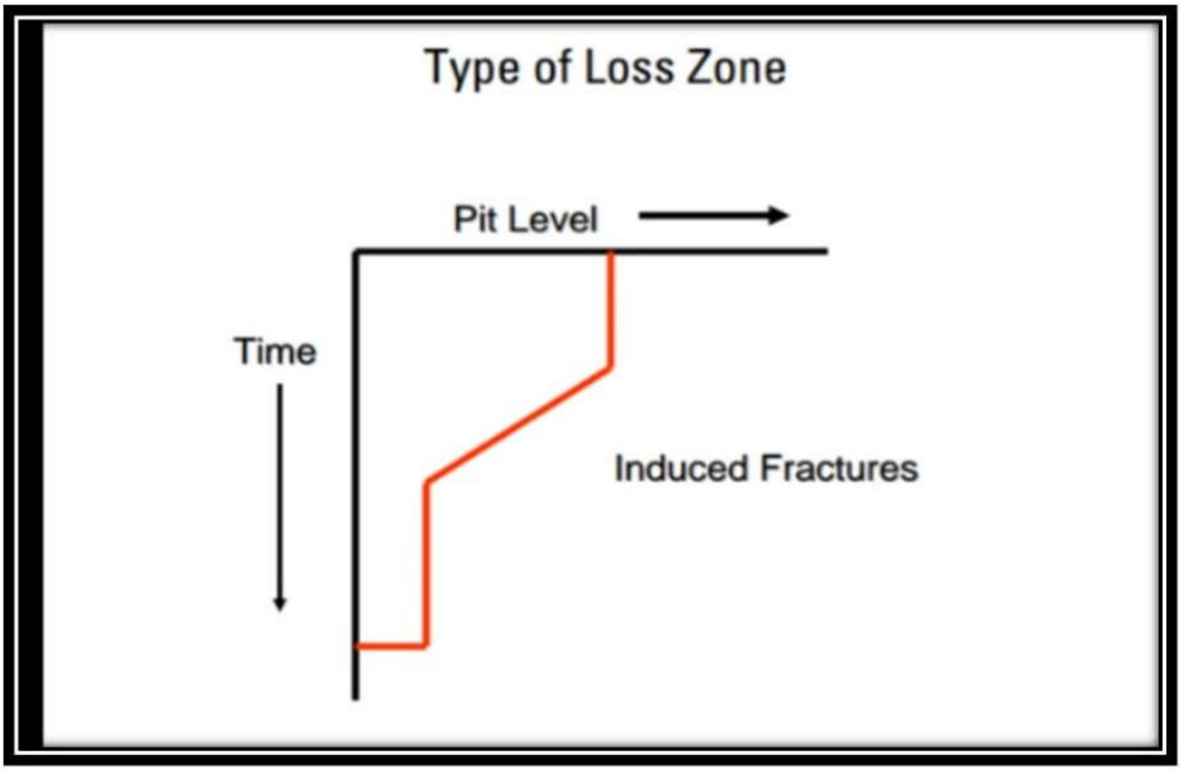


Figure (2. 6) :from of Schlumberger Induced fractures

- **Caverns:**

The most severe lost-circulation problems occur in cavernous or extremely jugular formation. (Figure 3.2 the section marked with a “B”). These are typically limestone‟s that have been leached by water. The void spaces in these formations can be large enough that when they are encountered, the drill string may actually drop by as much as several feet preceding a sudden, complete loss of returns Rough drilling may occur just before a bit encounters a cavernous zone.

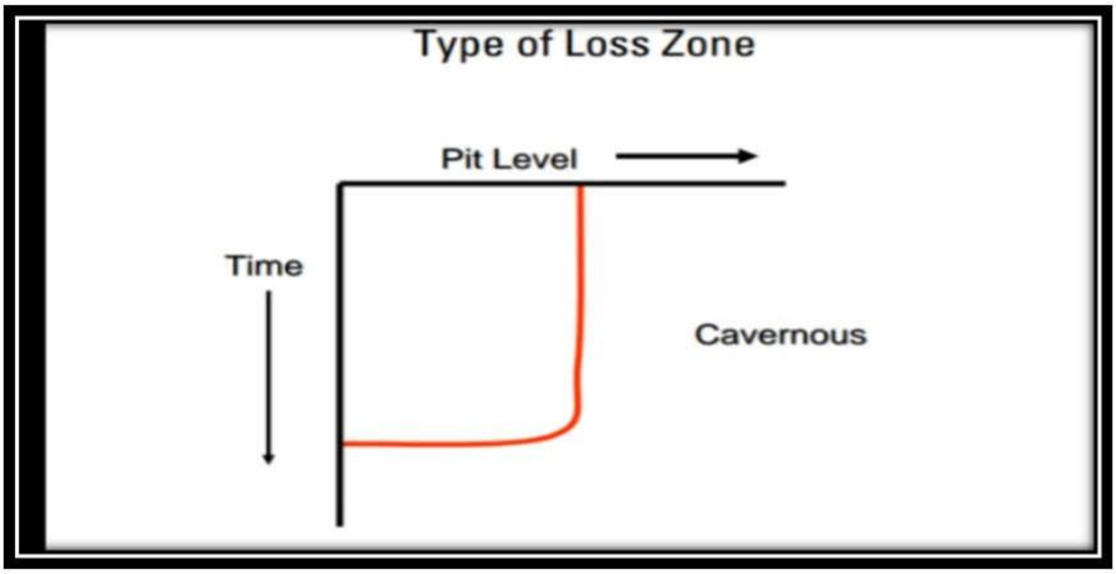


Figure (2. 7) : from of Schlumberger caverns

2.1.8 CAUSES OF LOSTCIRCULATION:

Lost circulation is the loss of mud or cement to the formation during drilling operations:.

- increased well costs, due to lost rig time and loss of expensive drilling fluid.
- Loss of accurate whole monitoring.
- Well control problems.

(Mitchell and Miska.2011)

2.1.9 Diagnosis of Lost Circulation:

There are a number of methods for combating lost circulation, each of which is effective when properly used. Selecting the best method for a particular situation involves three diagnostic steps:

- Determining at what depth the loss is occurring

- Describing the type of loss zone
- Evaluating the severity of the loss

(MitchellandMiska.2011)

2.1.10 Methods of Locating Lost-Circulation Zones:

The usual way to combat lost circulation during drilling is to monitor the possible presence of LCM across the suspected zone of loss. At shallow depth, the location of the losses into naturally permeable zones need not be known exactly.

At greater depths [more than 5,000ft. (1,500m)] or when severe losses are occurring, the exact location of the "thief" zone must be determined before efficiently sealing the hole and continuing to drill.

A number of methods have been developed for this purpose and are discussed below.

(Mitchell and Miska.2011)

Temperature Survey:

A temperature-recording device is run twice on wire and records the temperature at various depths (Figure 6) First, the device is run under static conditions—when the mud temperature is in equilibrium with the formation—to provide a base log. Enough fresh, cool mud is then pumped into the hole so that the change in temperature can be recorded by a second survey. The temperature above the loss zone will be lower than that recorded in the first run. Below the thief zone, the mud remains static and its temperature will be higher than that of the mud FL owing into the formation. The new temperature survey will show an anomaly across the zone where the losses are occurring, and their location can be determined by the depth where the recorded line changes its gradient. This method gives good results in areas where the temperature gradient is of the order of 1°F/100 ft. (1.8°C/100 m). One benefit of this method is that it can be used with drilling fluids containing large amounts of LCM.

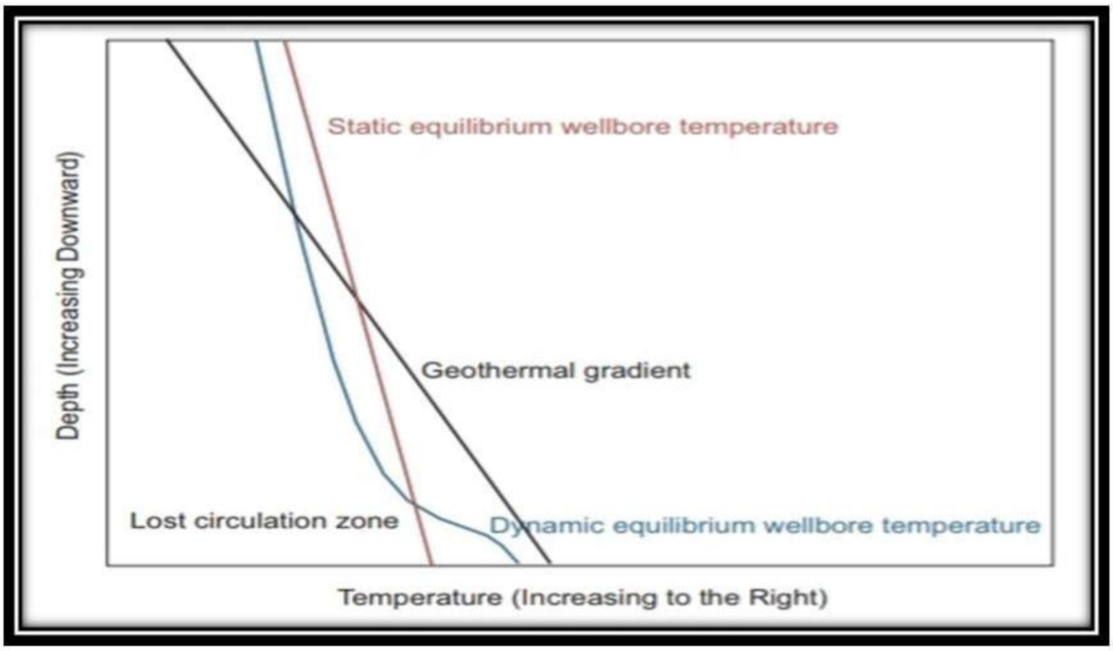


Figure (2. 8) :from of Schlumberger Temperature Survey

- **Radioactive-Tracer Survey**

Two gamma ray logs are run to determine the exact position of the thief zone. The first is recorded to establish the normal radioactivity of the downhome formation as a basis for comparison. Then, a small amount of radioactive material (e.g., craniate) is displaced around the hole where losses are suspected to occur. A second gamma ray log is run and compared with the base log. At the thief zone, a steep change of radioactivity can be seen. The precise point of loss can be determined with this method, although it requires special equipment and is expensive.

- **Hot-Wire Survey:**

As in the temperature survey, the change in mud temperature is monitored. A calibrated resistance wire that is sensitive to changes in temperature is run to a certain depth, and then fresh, cool mud is pumped into the hole. If a change of temperature at the tool is observed, then the tool is placed above the point of loss. If no change is recorded, then it is placed below the thief zone. This method can be used in any mud system, but a large amount of mud is required to find the exact location of the loss.(Mitchell and Miska.2011)

- **Spinner Survey:**

A small spinner attached to the end of a cable is run in the hole to the location where the losses are suspected to occur. The spinner either spins or turns in response to mud movement, and the revolutions per minute of this response are recorded on film. Near the thief zone, acceleration can be observed as mud flows into the formation. This method delivers the best results when there are no sealing agents in the mud, but it requires large volumes of mud.

2.1.11 Type and Severity of Losses:

Once the loss zone is located, it can be described in terms of its lithology and the type of loss that is occurring.

For example, if there is a slow but steady decrease in pit level and if mud logs or other data indicate that the loss zone is composed of sandstone, then high permeability and porosity are likely the causes of the problem. On the other hand, if the loss of returns is sudden, induced fracturing is the most likely cause.

The severity of the problem can be expressed in terms of the amount of mud lost and the static fluid-level drop, Seepage causes a gradual lowering of the pit level (generally from 1 to 10 bbl./hr.). Losses in the 10- to 50-bbl/hr. range are considered partial, Complete losses involve fluid-level drops ranging from 200 to 500-bbl/hr. (60 to 150-bbl/hr.), while severe complete losses involve drops of more than 500 where there is evidence of caverns. In the worst case of lost circulation, an underground blowout, the loss zone is taking not only drilling mud, but also formation fluid from a higher-pressure interval.(Mitchell and Miska.2011)

2.2 LITERATURE REVIEW:

2.2.1 LOST CIRCULATION MODELING :

Rami and Hussein(2020). Modeling of Drilling Fluid Losses in Naturally Fractured Formations Newtonian drilling -presents a new model for mud loss of non fluids into naturally fractured formations. Flowof Yield-Power-Law (Herschel-Bulkley) fluids has been coupled with Newtonian reservoir fluid in a single fracture. The governing equations are derived based on principles of conservation of mass and linear momentum for drilling fluid andpressure diffusion for reservoir fluid. Results are obtained based on semi-numerical solutions and plotted in terms of mud loss volumes versus time. The results demonstrate how rheology of the drilling fluid and formation fluid properties caninfluence mud losses. The relative contributions of both drilling and reservoir fluids is determined and compared. This model allows for predicting fluid losses for a given drilling fluid, formation fluid and operational .conditionsConversely, one can evaluate hydraulic aperture of the fractures by continuously monitoring mud losses and finding the best fit of field measurements of mud loss to the model. Field data are used to demonstrate the practical application of theproposed technique.del is valuable for drilling operations because The proposed mo it can help in minimizing the loss of expensive drillingfluids through optimization of drilling fluid rheological properties and selecting appropriate lost circulation materials. The uction operations by minimizing formation damage. In model also benefits prod addition, well completion schemes can beoptimized based on the improved knowledge of the near-wellbore fracture characteristics.

Majidi et al Circulation into-Modeling Lost Fractured Formation in Rock Drilling Operations. Analytical modeling of fluid flow is a tool that can be quickly deployed to assess lost circulation and perform diagnostics, including leakage rate decline and fracture conductivity. In this chapter, various analytical methods developed to model the flow of non-Newtonian drilling fluid in a fractured medium are discussed. The solution methods are applicable for yield-power-law, including shear-thinning,ةshear-thickening, and Bingham plastic fluids. Numerical solutions of the Cauchy equation are used to verify the analytical solutions. Type-curves are also described using dimensionless groups. The solution methods are used to estimate the range of fracture conductivity and time-dependent fluid loss rate, and the ultimate total volume of lost fluid. The applicability of the proposed models is demonstrated for several field cases encountering lost circulations.

Rami and Hussein(2021). A Semi-Analytical Approach to Model Drilling Fluid Leakage Into Fracture Formation deling of fluid flow in fractures is a Analytical mo tool that can be quickly deployed to assesslost circulation and perform diagnostics, including leakage rate decline, effective fracture conductivity, and selection of the -to Newtonian, as well as non optimum LCM. Such models should be applicable Newtonianyield-stress fluids, where the fluid rheology is a nonlinear function of fluid flow and shear stress. In this work, analytical solution is developed to -a new semi racturedNewtonian drilling fluid in a f-model the flow of nonmedium. The solution model is applicable for various fluid types exhibiting yield-power-law (HerschelBulkley). We use high-resolution finite-element simulations based on the

Cauchy equation to verify our and compare curves-solutions. We also generate type them to others in the literature. We then demonstratethe applicability of the proposed model for two field cases encountering lost circulations. To address the subsurface simulations Carlo-analytical solutions with Monte-uncertainty, we combine the semi andgenerate probabilistic predictions. The solution method can estimate the range of fracture conductivity, -parametrized by the fracture hydraulic aperture, and time dependent fluid loss rate that can predict thecumulative volume of lost fluid. The proposed approach is accurate and efficient enough to support making for -decision .time drilling operations-real

Cai et al(2021) Mathematical Simulation of Lost Circulation in Fracture and Its ControlXiao. This paper presents an easy-to-use method to identify types of lost circulation in fracture and the corresponding control. Three analytical models are presented based on three loss mechanisms, namely, seepage/filtration in a fracture, pipe flow in a fracture, and gravity displacement in a fracture. A numerical model is developed to simulate the deposition of lost circulation materials in fractures and predict the time and the volume of drilling fluid needed for lost circulation control. Case studies with these analytical models provide a deeper insight of this subject. Sensitivity analyses with the numerical model identify the major factors responsible for lost circulation control. High viscosity of drilling fluid may prevent lost circulation, while low viscosity is desired for a fast control of lost circulation. Lowering the density of drilling fluid is another way to prevent the lost circulation and facilitate the deposition of lost circulation materials. Lost circulation materials with high density could deposit faster close to the wellbore and therefore accelerating the control process. High concentration of lost circulation materials is likely to shorten the plugging time, which should be determined referring to the severity of loss. This work provides drilling engineers a practical method for simulating the lost circulation and selecting lost circulation material.

Chen et al(2014) modeling transient circulating mud temperature in the event of lost circulation and its application in locating loss zones. This paper presents an approach to predict the location of loss zone from the transient mud circulation temperature profile altered by the mud loss. A numerical model in estimating the transient mud circulating temperature profile during a lost circulation event is developed. The temperature profile in both the flow conduits (drillpipe and annulus) are modeled using mass and energy balance. The flow rate of drilling mud decreases in the annulus above the loss zone as part of the fluids lost into the fractures, which in turn alters the heat transfer between the drillpipe, annulus, and formation. The wellbore is divided into two multiple sections, which account for single multiple loss circulation zones. Rigorous heat transfer in the formation is included. Case studies are performed and numerical solution results are presented and analyzed. According to the results, temperature alterations induced by mud loss include: 1) Declines in both bottom-hole temperature (BHT) and mud return temperature over time, and 2) Discontinuity in the first order derivative of annulus temperature with respect to depth at the location of loss zone; meanwhile, the temperature alterations are mainly controlled by the mud loss rate and location of loss. By 1 Now with Halliburton matching the simulated results with the distributed temperature measurements at different times, the depth of the loss zone can be identified. This piece of information is important for the spotting of LCM (lost circulation material) pills, the optimization of overbalance squeezing pressure, as well as the consideration of setting the cement plug or additional casing.

L. Whitfill et al(2006) New Design Models and Materials Provide Engineered Solutions to Lost Circulation . A feasibility study by technology specialists may include a wide range of tools during the planning stage to support data acquisition, modeling and design of the application stage. Planning services include hydraulics and fracture characterization modeling to assess expected Equivalent Circulating Densities (ECD) and their effect on potential lost circulation intervals. The fracture characterization modeling for borehole stress treatments uses a module that calculates both the expected fracture width and the particle size distribution required to plug the induced fracture and prevent propagation. The effect of these additions on the rheology of a non-aqueous drilling fluid can then be determined by the use of a new predictive rheology model. Application services may include real-time data acquisition to support delivery of specialized lost circulation materials and systems in either a preventive (pretreatment and/or borehole stress treatments to strengthen the wellbore) or corrective mode (mitigating lost circulation and, where possible, providing additional wellbore strength).

Yongcun Feng and K. E. Gray(2017) Modeling Lost Circulation Through Drilling-Induced Fractures. Previous lost-circulation models assume either a stationary fracture or a constant-pressure- or constant-flowrate-driven fracture, but they cannot capture fluid loss into a growing, induced-fracture driven by dynamic circulation pressure during drilling. In this paper, a new numerical model is developed on the basis of the finite-element method for simulating this problem. The model couples dynamic mud circulation in the wellbore and induced-fracture propagation into the formation. It provides estimates of time-dependent wellbore pressure, fluid-loss rate, and fracture profile during drilling. Numerical examples were carried out to investigate the effects of several operational parameters on lost circulation. The results show that the viscous pressure losses in the wellbore annulus caused by dynamic circulation can lead to significant increases in wellbore pressure and fluid loss. The information provided by the model (e.g., dynamic circulation pressure, fracture width, and fluid-loss rate) is valuable for managing wellbore pressure and designing wellbore-strengthening operations.

LEONARDO (2020) CIRCULATION LOSS MODELING FOR FRACTURED FORMATIONS : RHEOLOGICAL APPROACH. Literature reports mud losses in 35% of drilled wells in naturally fractured carbonates in an Iranian field and 10% of wells in the Khuff Formation in Saudi Arabia (Lavrov, 2016). According to the U.S. Department of Energy, an average of 10 to 20 % of the total cost of drilling HTHP wells came from mud losses problem (Growcock, 2010). Deepwater drilling in the Gulf of Mexico, offshore Brazil and West Africa have introduced lost circulation challenges beyond narrow drilling margins. The cost of lost circulation and NPT are exacerbated due to the use of synthetic-base muds (SBMs) that ranges from US$ 100 to US$ 200 per barrel and by high rig time costs (Cook et al., 2011).Many efforts to create an optimal solution to combat this problem have been underway in recent times (Hettema et al., 2007)(Hashmat et al., 2016)(Hashmat et al.,2017)(Wagle et al., 2018). The solutions include using fibrous materials (cedar bark, shreddedcane stalks, mineral fiber, and hair), flaky (mica flakes and pieces of plastic or cellophane sheeting) or granular (ground and sized limestone or marble, wood, nut hulls, Formica, corncobs, and cotton hulls), some of these materials were evaluated at laboratory scale by Miranda et al. (2017). Rheological parameters optimization is currently under development and evaluation as a friendlier alternative to reservoir formation

(Sacramento et al., 2019)(Barbosa et al., 2019). Predictive models of circulation loss with a rheological approach have been developed to support the design of news formulations of drilling fluids. That allows evaluating new fluids formulations (Majidi et al., 2010)(Albattat and Hoteit, 2019)(Dokhani et al., 2020)

CHAPTER 3

METHODOLOGY

3.1 Lost Circulation Problem :

Lost circulation can cost operators millions dollars annually. generally speaking , the drilling industry handles lost circulation much as it did 40 years ago a significant effort to understand the mechanics behind lost circulation ,to minimize or eliminate this problem.

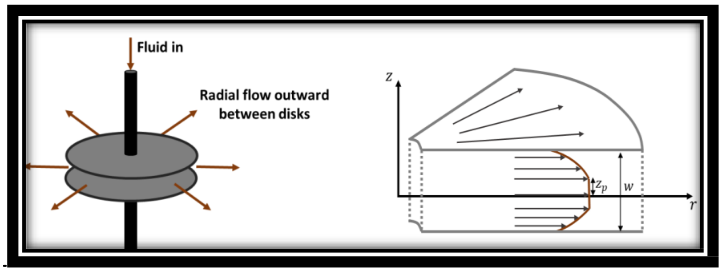


Figure (3. 1) *: from of Rosangla Barros 2020 (adapted from (a) Bird et al., 1964 and (b) Majid et al., 2010*

(a) Radial flow of drilling fluid use two parallel disks and laminar flow of fluid between that.

(b) Explain (the laminar flow of fluid losses into the fracture formation in (r) direction with constant fracture width (w).

The main governing equations for the three rheological models are a combination of the continuity equation and the momentum equation.

(Function of width, invasion radius)

$$V_r = \pi {r_f}^2 W$$

Equation (3. 1)

3.2 MODEL ASSUMPTION:

In order to facilitation the arithmetic operations to solve the main equation governing the model, were developed the fallowing hypotheses.

1-fluid used in the drilling operation non Newtonian incompressible fluid.

2-constant over balance pressure.

3-steady state laminar flow.

4-neglect plugging by mud particles and fracture wall permeability.

3.3 Lost circulation modeling:

Three rheological models to predict the mud invasion radius and volume losses as future according to the type of fluid (Bingham plastic , power law ,yield power law)and considering input parameters , like over balance pressure , geometry parameters (well bore radius , fracture width) and different rheological parameters depend on the type of rheological model dimensionless equation and parameter using for the models to predict the dimension loss volume and radius as function of the dimension time
The following dimensionless less equation using in the three models.

$$r_{fd} = \frac{r_f}{r_w}$$ Equation (3. 2)

$$t_{DR} = \mathrm{Q}\ t_R$$ Equation (3. 3)

$$r_{fDmax} = 1 + \frac{1}{a}$$ Equation (3. 4)

Where is:

r_{fD}: Dimensionless radius of mud front

r_w: Wellbore radius (in)

r_f: Invasion radius (in)

t_{DR}: Infinity dimensionless invasion time.

β : Radial time factor.

r_{fDmax}: Maximum dimensionless invasion radius.

a: Radial invasion factor is a measure of the ratio between the yield stresses of the drilling fluid (r_y), and the applied overbalance pressure (ΔP). It represents the relative fluid flow resistance due to the yield stress to the driving force.

3-3-1 Bingham plastic model :

First we will describe the main equation of model when the type of fluid is Bingham plastic (behavior index, n=1)

$$\frac{dr_f}{dt} = \frac{\Delta p - \frac{3\,y}{w}(r_f - r_w)}{\frac{12\mu_p r_f}{w^2}\ln\left(\frac{r_f}{r_w}\right)}$$ Equation (3. 5)

Where:

w : Fracture width (μm).

r_y : Yield stress. ($Ibf\backslash 100ft^2$)

ΔP : Constant over balance pressure (psi).

μ_p : Plastic viscosity ($Ibf\backslash 100ft^2 s^2$).

$$a = \frac{3r_w\,y}{w\,\Delta p}$$ Equation (3. 6)

$$\beta = \left(\frac{w}{r_w}\right)^2 \frac{\Delta p}{3\mu p}$$ Equation (3. 7)

$$\frac{d_{rfD}}{d_{tfD}} = \frac{1 - a(rf_D - 1)}{4rf_D Lin(rf_D)}$$ Equation (3. 8)

Numerical solution of the dimensionless equation by use 4^{th} order RUNGE-KUTTA, with fallowing initial condition (t_{Dr}i= 0; r_{fDI} = 2) and final condition (r_{fD}i = $r_{fDmax}\, t_{DR} = \infty$)

3.3.2 Power law :

$$\frac{d_{rf}}{d_t} = \frac{(1-n)^{\frac{1}{n}}\left[\frac{n}{2n+1}\left(\frac{w}{2}\right)^{1+\frac{1}{n}}\right]\Delta p^{\frac{1}{n}}}{r_f\left(k\, r_f^{1-n} - r_w^{1-n}\right)^{\frac{1}{n}}} \qquad \text{Equation (3. 9)}$$

Where:

n: Flow behavior index.

k: Consistency index.

Note : “the value of α =∞ . we will assume a value of $\alpha = 10000$ for purpose of facilitate mat lab implementation.

$$Q = \left(\frac{n}{2n+1}\right)\left(\frac{w}{r_w}\right)^{\frac{n+1}{n}}\left(\frac{\Delta p}{k}\right)^{\frac{1}{n}} \qquad \text{Equation (3. 10)}$$

$$\frac{d_{rfD}}{d_{tDR}} = \frac{1}{2^{\frac{n+1}{n}}\left(\frac{r_{fD}^{1-n}-1}{1-n}\right)^{\frac{1}{n}} r_{fD}} \qquad \text{Equation (3. 11)}$$

Same numerical method to solve dimensionless equation with same initial and final

3.3.3 Yield Power Law (Herschel- Buckley) :

The model reviewed here was developed by (Rosangla Barros2020)

$$\frac{dr_f}{dt} = \frac{(1-n)^{\frac{1}{n}}\left[\frac{n}{2n+1}\left(\frac{w}{2}\right)^{1+\frac{1}{n}}\right]*\Delta P_R-\left(\frac{2n+1}{n+1}\right)\left(\frac{2r_y}{w}\right)(r_f-r_w)^{\frac{1}{n}}}{r_f\left[K\left(r_f^{1-n}-r_w^{1-2}\right)\right]^{\frac{1}{n}}} \qquad \text{Equation (3. 12)}$$

$$a = \left(\frac{2n+1}{n+1}\right)\left(\frac{2r_w}{w}\right)\left(\frac{r_y}{\Delta P_R}\right) \qquad \text{Equation (3. 13)}$$

$$Q = \left(\frac{n}{2n+1}\right)\left(\frac{w}{r_w}\right)^{\frac{n+1}{n}}\left(\frac{\Delta P_R}{K}\right)^{\frac{1}{n}} \qquad \text{Equation (3. 14)}$$

$$\frac{dr_{fD}}{dt_{DR}} = \frac{[1-a(r_{fD}-1)]^{\frac{1}{n}}}{2^{\frac{n+1}{n}} * \frac{r_{fD}^{1-n} \ \frac{1}{n}}{1-n} + r_{fD}} \quad \text{Equation (3. 15)}$$

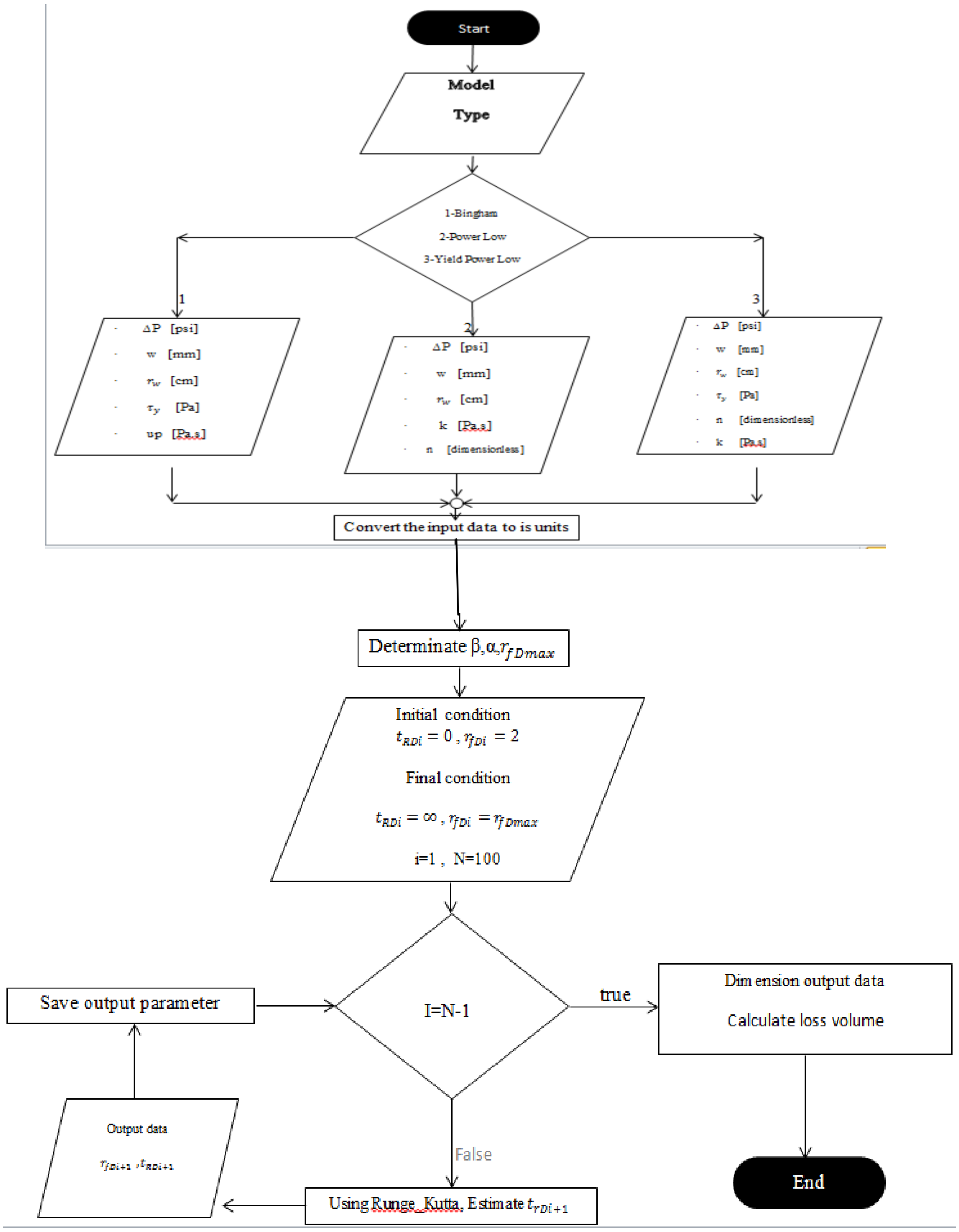
3. 4 Data set :

The data that was used in this research like lost history “volume loss and time “and geometry parameters (“well bore radius, fracture width “) and over balance pressure is from research (circulation loss modeling for fractured formations Rheological approach). values of the rheological parameter were completed using the lost squares means method.

3.5 LOST CIRCULATION CODING :

3.5.1 Flow chart:

The following algorithm (“figure 3.2) shows the work flow of the research to reach the desired goals.



matlab code :

The above flow chart was implemented using Matlab .and the code that was used is show as follows.

```
function [t,LV,rf]=PRELC_Main(x,DPuc,wuc,rwuc,UP,Ysuc,Kuc,n)

clear

clc

x=input('(select the of model: Power Low x=1,Yield Power Low x=2,Bingham
x=3)x=');

if x==1

   DPuc=input('inter Dpcu');

wuc=input('inter wuc');

rwuc=input('inter rwuc');

n=input('inter n');

Kuc=input('inter Kuc');

DP=DPuc*6894.757;

w=wuc/1e+06;

rw=rwuc*0.0254;

K=Kuc*0.478803;


beta=n/(2*n+1)*((w/rw)^((n+1)/n))*((DP/K)^(1/n));

tfD0 =0;

rfD0 =2;

rfDmax=1+4000;

h=200;


f=@(rfD,tfD)(((2^((n+1)/n)))*((((rfD^(1-n))-1)/(1- ...

     n))^(1/n))*rfD)/1;

  elseif x==2
```

```
      DPuc=input('inter Dpcu');
wuc=input('inter wuc');
rwuc=input('inter rwuc');
n=input('inter n');
Ysuc=input('inter Ysuc');
Kuc=input('inter Kuc');
DP=DPuc*6894.757;
w=wuc/1e+06;
rw=rwuc*0.0254;
Ys=Ysuc*0.478803;
K=Kuc*0.478803;

alpha=((2*n+1)/(n+1))*((2*rw)/w)*(Ys/DP);
beta=n/(2*n+1)*((w/rw)^((n+1)/n))*((DP/K)^(1/n));
f=@(rfD,tfD)(((2^((n+1)/n)))*((((rfD^(1-n))-1)/(1- ...
      n))^(1/n))*rfD)/(1-alpha*(rfD-1))^(1/n);

tfD0 =0;
rfD0 =2;
rfDmax=1+(1/alpha);
h=200;
else
    DPuc=input('inter Dpcu');
wuc=input('inter wuc');
```

```
rwuc=input('inter rwuc');

UP=input('inter UP');

Ysuc=input('inter Ysuc');

DP=DPuc*6894.757;

w=wuc/1e+06;

rw=rwuc*0.0254;

Ys=Ysuc*0.478803;

UP=UP*0.478803;


alpha=((3*rw)/w)*(Ys/DP);

beta=((w/rw)^2)*DP/(3*UP);

tfD0 =0;

rfD0 =2;

rfDmax=1+(1/alpha);

h=200;


f=@(rfD,tfD)(4*rfD*(log(rfD)))/(1-(alpha*(rfD-1)));

end

DrfD=(rfDmax-rfD0)/h;

rfD=rfD0:DrfD:rfDmax;

tfD=zeros(h+1,1);

tfD (1)=tfD0;

   for i=1:h

      K1=f(rfD(i),tfD(i));

      K2=f(rfD(i)+DrfD/2,tfD(i)+(DrfD*K1)/2);

      K3=f(rfD(i)+DrfD/2,tfD(i)+(DrfD*K2)/2);
```

```
        K4=f(rfD(i)+DrfD,tfD(i)+DrfD*K3);

        tfD(i+1)=tfD(i)+(DrfD/6)*(K1+2*K2+2*K3+K4);


    end

        rfD2=transpose(rfD);

t=tfD/(beta*3600);

rf=rfD2*rw;

LV=(w*pi*power(rf,2))/0.15898;

   loglog(t,LV,'LineWidth',2.0,'Color','b')

   xlabel('Time, h','FontSize',14)

   ylabel('Loss Volume, bbl','FontSize',14)

   title('Loss Circulation Model','FontSize',14);


end
```

CHAPTER 4

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The main goal of this chapter is to validate the models, present their applications and subsequently analyze their results. First, the radial model is applied in the field-scale situation, and its respective validation is done using data obtained from the literature.

4.1 RAW DATA

The input parameters of the field case are in Table 4.1:

Table (4 .1) : Input Parameters of Field Case.

Parameter	Value	Unit	Value	Unit
ΔP	700	Psi	4826330	Pa
W	880	mμ	0.0088	M
r_w	4.125	In	0.10478	M
r_y	8.4	$lbf/100ft^2$	4.02	Pa
N	0.94	Dimensionless	0.94	Dimensionless
K	0.08	$lbf/100ft^2.s^n$	0.0383	Pa.s^n

4.2 LOST CIRCULATION MODELING

A discussion of lost circulation modeling according to different rheological models, and sensitivity analysis results of these models.

We used the 4th-order Runge-Kutta method for solving the main of the radial model. The applied procedures to do that are following listed.

4.2 .1 Leonardo Flores Model

The methodology used in this model follows the same methodology as (Leonardo Flores. 2020).

Step 1 Convert the input parameters to the international system of units, and arrange equation (3,11):

Step 2 Calculate the radial invasion factor using equation (3,12) (α=0.00029).

Step 3 Using the radial invasion factor, determine the maximum dimensionless invasion radius using equation (3,3) (r_{fDmax}=3395.57)

Step 4 Considering the initial condition ($t_{rD\mathrm{i}}$=0,$r_{fD\mathrm{i}}$=2) and the r_{fDmax} , calculate the step size of the invasion radius using equation (4,1) For j=20 the step size is Δr_{fD}=169.730.

$\Delta r_{fD} = \frac{r_{fdmax} - r_{fd\mathrm{i}}}{\mathbf{j}}$ **Figure (4.** 1)

Step 5 Apply the 4^{th} Order Runge-Kutta method to solve equation (3,11) to obtain the dimensionless invasion time for each r_{fD}. Table 4.2 shows the results, Table (4. 2) : Results of the 4th-order Runge-Kutta Method for Yield Power low mode

t_{DR}	r_{fD}	K1(10^6)	K2(10^6)	K3(10^6)	K4(10^6)
0	2	0	0.0021	0.0021	0.0051
0.0038	170	0.0051	0.0086	0.0086	0.0126
0.0185	340	0.0126	0.0170	0.0170	0.0218
.	.	.	.	.	.
.	.	.	.	.	.
8.46	3056	1.77	2.48	2.48	3.49
12.90	3225				
∞	3395				

Step 6 Calculate β using equation (3,13) (β = 7032.41 s^{-1}) to determine the dimensionless invasion time. Table 4.3 presents the results of this step.

Table (4. 3): **Determination of the radial invasion time for Yield Power Low Model .**

$t_{DR}(10^6)$	$t_R(s)$	$t_R(h)$
0	0	0
0.0038	54	0.02
0.0185	264	0.07
.	.	.
.	.	.
8.46	120341	33.34
12.90	183269	50.91
∞	∞	∞

Step 7 From equation (3.1), determine the invasion mud radius, and finally, using it, determine the loss volume From equation (4.2). The last value of the lost volume represents the maximum mud lost volume see **Table 4.4**.

$$V_R = \pi {r_f}^2 \mathrm{w} \qquad \text{Figure (4. 2)}$$

Table (4. 4) : Determination of the loss volume for Yield Power Low Model.

r_{fD}	$r_f(m)$	$V_R(bbl)$
1	0.1	0.0002
170	17.89	5.560
340	35.67	22.13
.	.	.
.	.	.
3056	320.20	1782.97
3225	337.99	1986.52
3395	355.77	2201.06

Figure 4.1: shows the results of the lost volume as a function of the time. The values determined by simulation are plotted, to validate the predictive numerical algorithm. to verify the radial model to predict the circulation loss. Including the API classification, this particular case presented partial loss.

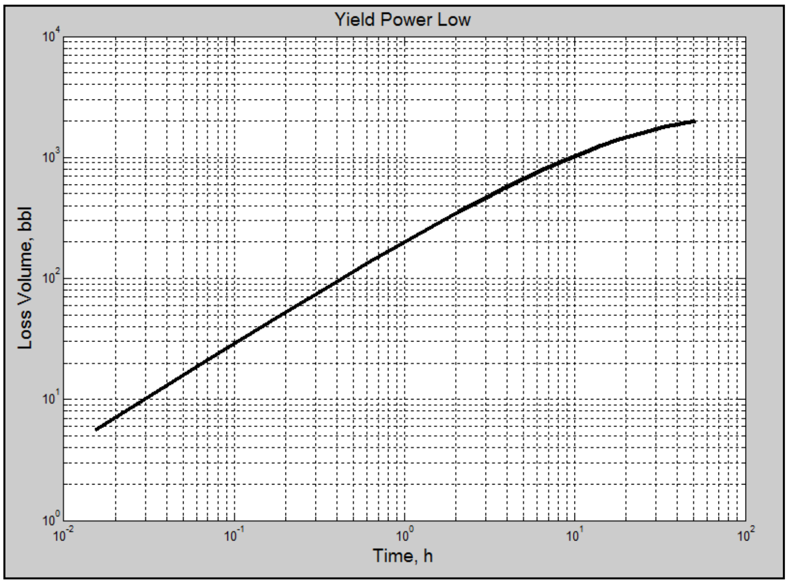


Figure (4. 3) : BINGHAM PLASTIC MODEL

Step 1 estimation of medium values for plastic viscosity and, yield stress of Bingham Model, from the available data for yield Power Low Model, by uses of Least Squares Method in Numerical Analysis, by assuming different values for shear rate γ, ($r_y = 7.5$ lbf/100ft^2 , μp = 0.01 lbf/100ft^2.s^n).

Step 2 Convert the input parameters to the international system of units, and arrange equation (3,4).

Step 3 Calculate the radial invasion factor using equation (3,5) (α= 0.00029)

Step 4 Using the radial invasion factor, determine the maximum dimensionless invasion radius using equation (3,3) (r_{fDma}=3360.6).

Step 5 Considering the initial condition (t_{rD}i=0,r_{fD}i=2) and the r_{fDmax} , calculate the step size of the invasion radius using equation (4,1) For j=20 the step size is Δr_{fD}=167.93.

Step 6 Apply the 4^{th} Order Runge-Kutta method to solve equation (4,1) to obtain the dimensionless invasion time for each r_{fD}. **Table 4.5** shows the results,

Table (4. 5) : Results of the 4th-order Runge_Kutta Method, Bingham Mode.

t_{DR}	r_{fD}	K1(10^6)	K2(10^6)	K3(10^6)	K4(10^6)
0	2	0	0.0116	0.0116	0.0148
0.28	169	0.0036	0.0067	0.0060	0.0087
1.31	337	0.0087	0.0116	0.0116	0.0148
.	.	.	.	.	.
.	.	.	.	.	.
489	3024	0.6063	0.7517	0.7517	0.9699
723	3192				
∞	3375				

Step 7 Calculate β using equation (3,6) (β = 7.1825 s^{-1}) to determine the dimensionless invasion time. **Table 4.3** presents the results of this step.

Table (4. 6) : Determination of the radial invasion time, Bingham Model.

$t_{DR}(10^6)$	$t_R(s)$	$t_R(h)$
0	0	0
0.28	0.01	0.01
1.31	0.05	0.07
.	.	.
.	.	.
489	18	33
723	28	51
∞	∞	∞

Step 7 From equation (3.1), determine the invasion mud radius, and finally, using it, determine the loss volume From equation (4.2). The last value of the lost volume represents the maximum mud lost volume **Table 4.7.**

Table (4. 7) : Determination of the loss volume, Bingham Model.

r_{fD}	$r_f(m)$	$V_R(bbl)$
2	0.1	0.0002
169	17	5.5
337	35	21.8
.	.	.
.	.	.
3024	317	1746.5
3192	335	1945.8
3375	354	2155.9

Figure 4.2 shows the results of the lost volume as a function of the time. The values determined by simulation are plotted, to validate the predictive numerical algorithm. to verify the radial model to predict the circulation loss. Including the API classification, this particular case presented mild loss.

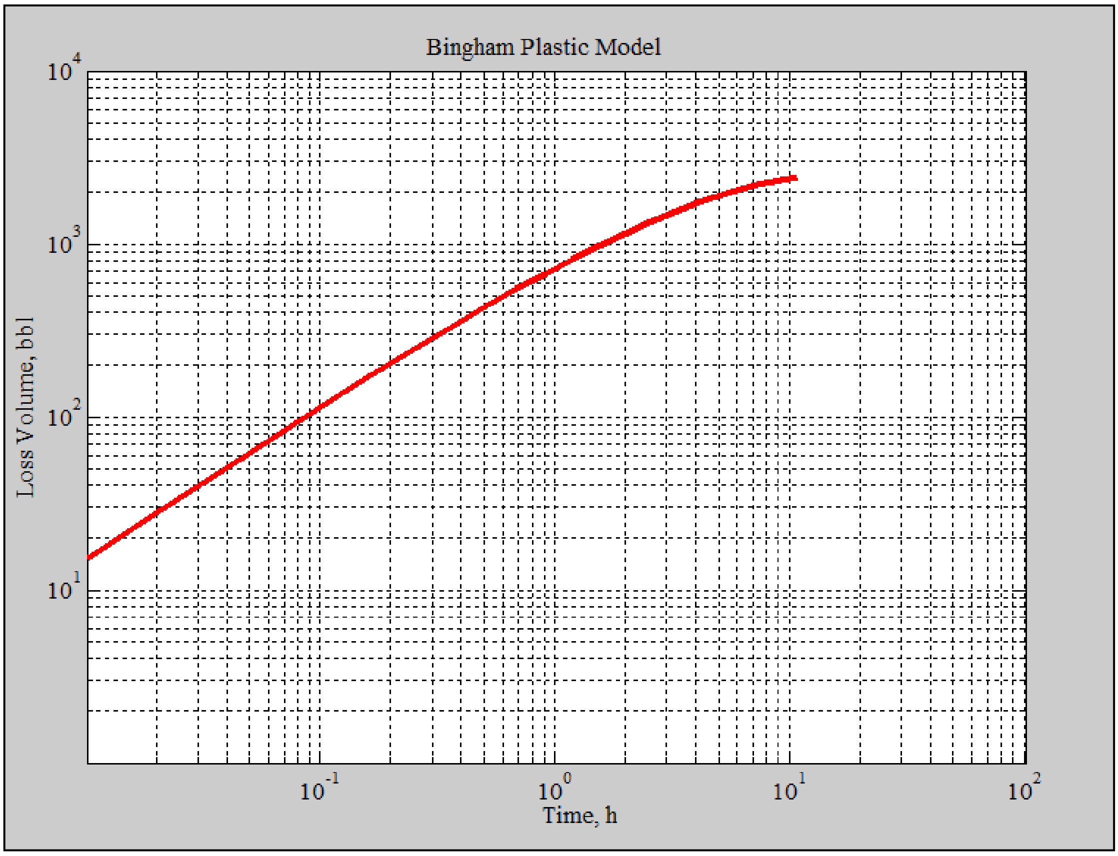


Figure (4. 4): Bingham Plastic Model.

4.2.3 POWER LAW MODEL

Step 1 estimation of medium values for k index and, n index of Power Low Model, from the available data for Yield Power Low Model, by uses of Least Squares Method in Numerical Analysis, by assuming different values for shear rate γ, ($n = 0.22,\ k = 8.33\ \mathrm{lbf/100ft^2.s^n}$**).**

Step 2 Convert the input parameters to the international system of units, and arrange equation (3,8):

Step 3 determine the maximum dimensionless invasion radius using equation (3,3) for α=0 , $r_{fDma}=\infty$ we consider (r_{fDma}=4000).

Step 4 Considering the initial condition (t_{rDi}=0,r_{fDi}=2) and the r_{fDmax} , calculate the step size of the invasion radius using equation (4,1) For j=20 the step size is Δr_{fD}=199.9.

Step 5 Apply the 4^{th} Order Runge-Kutta method to solve equation (3,8) to obtain the dimensionless invasion time for each r_{fD}. Table 4.5 shows the results,

Table (4. 8) : **Results of the 4th-order Runge-Kutta Method, Power Low Mode.**

t_{DR}	r_{fD}	K1(10^6)	K2(10^6)	K3(10^6)	K4(10^6)
0	2	0	0.007	0.007	0.01
0.53	2	0.01	0.02	0.02	0.04
0.24	201	0.04	0.05	0.05	0.06
.	.	.	.	.	.
.	.	.	.	.	.
345	36011	0.5	0.51	0.51	0.53
385	38011				
∞	40010				

Step 6 Calculate β using equation (3,9) (β = 7032.41 s^{-1}) to determine the dimensionless invasion time. **Table 4.9** presents the results of this step.

Table (4. 9) : Determination of the radial invasion time, Power Low Model.

$t_{DR}(10^6)$	$t_R(s)$	$t_R(h)$
0	0	0
0.53	49	0.03
0.24	221	0.16
.	.	.
.	.	.
345	60150	22.1
385	91470	24.7
∞	∞	∞

Step 7 From equation (3.1), determine the invasion mud radius, and finally, using it, determine the loss volume From equation (4.2). The last value of the lost volume represents the maximum mud lost volume see **Table 4.10**.

Table (4. 10) : Determination of the loss volume, Power Low Model.

r_{fD}	$r_f(m)$	$V_R(bbl)$
2	2	0.003
201	211	7.8
401	421	30.8
.	.	.
.	.	.
36011	3773	2475
38011	3982	2758
40010	4192	3055

Figure 4.3 shows the results of power low the lost volume as a function of the time. The values determined by simulation are plotted, to validate the predictive numerical algorithm. to verify the radial model to predict the circulation loss. Including the API classification, this particular case presented total loss.

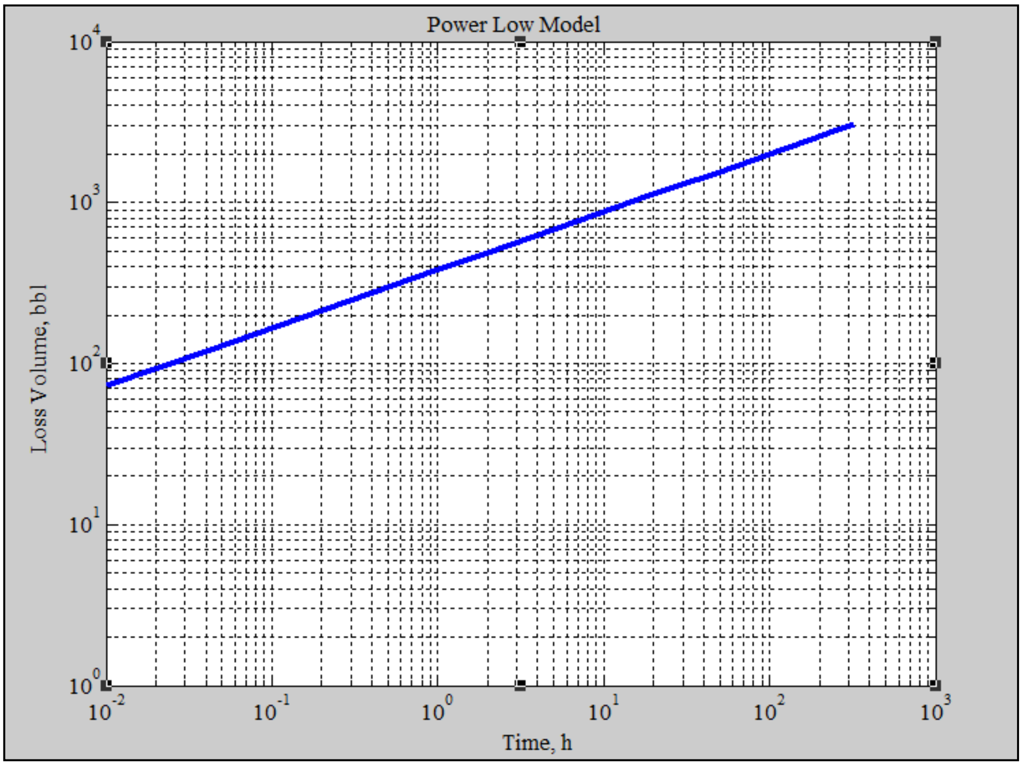


Figure (4. 5): Power Low Model.

4.3 Sensitivity Analysis

A sensitivity analysis of the rheological parameters for the particular field case was performed. The main goal was turning possible to discuss optimum rheological parameters of the drilling fluid to reach the objective of minimize the loss of circulation in a particular situation, we doing that for: Bingham Plastic Fluids, and Power Low fluids. And the comparison between them, evaluate the models in terms of accuracy and effectiveness in simulate the current situation and predicting the real behavior of the drilling fluid inside the well, which includes the classification of losses. The results of Bingham Plastic Model beginning with severe complete loss and reduced to complete loss, Yield Power Low Model beginning with complete loss and reduced to partial loss, finally Power Low Model we also noticed that moved as straight line from severe complete loss to complete loss and ended in partial loss.

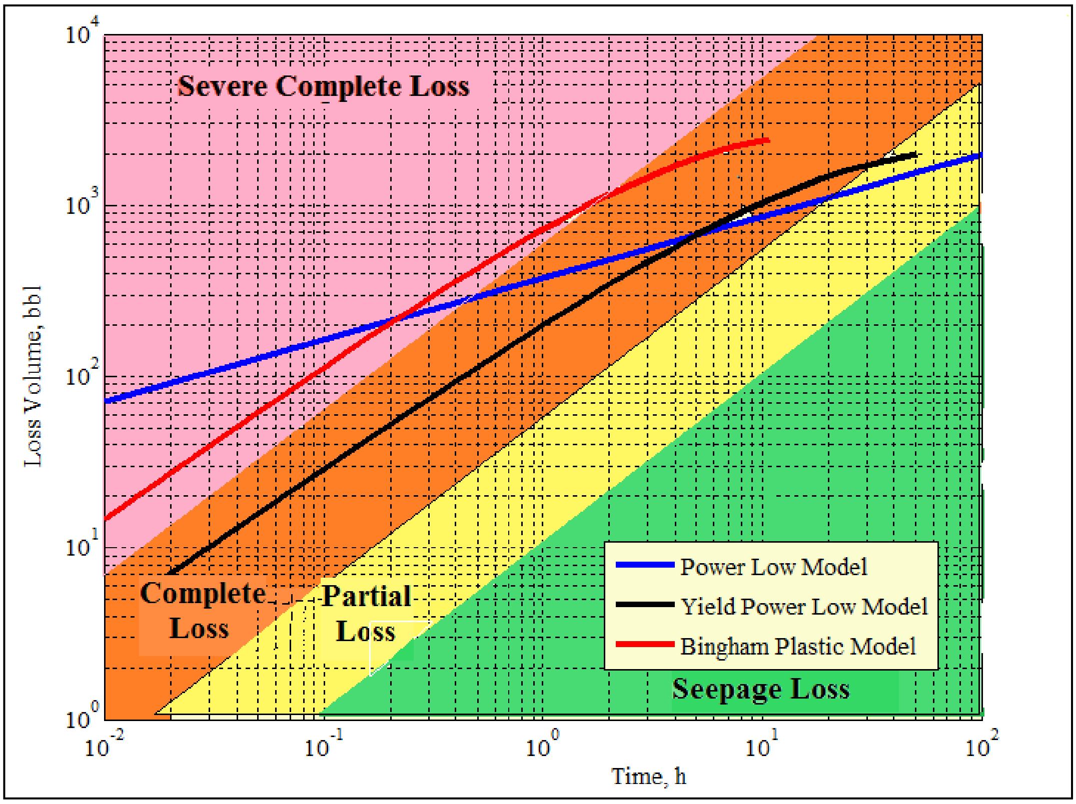


Figure (4. 6): shows that the comparison between the models.

Table 4.11: shows the change in loss volume, due to change of fluid type.

Model Type	r_{fDmax} (M)	% 100	VL (bbl)	% 100
Yield Power Low	3395	0	2201	0
Bingham	3637	-0.071	2704	-0.23
Power Low	4000	-0.18	3055	-0.39

4.3.1 THE YIELD STRESS

Starting with the yield stress, the base case used the original data of the field ($t_y = 8.4\ lbf/100ft^2$(4.79 pa)). For the next cases, the yield stress was changed in 10 $lbf/100ft^2$ (4.79 pa), results are plotted, , but it can be observed that the final loss volume decreases considerably for an increase in yield stress value.

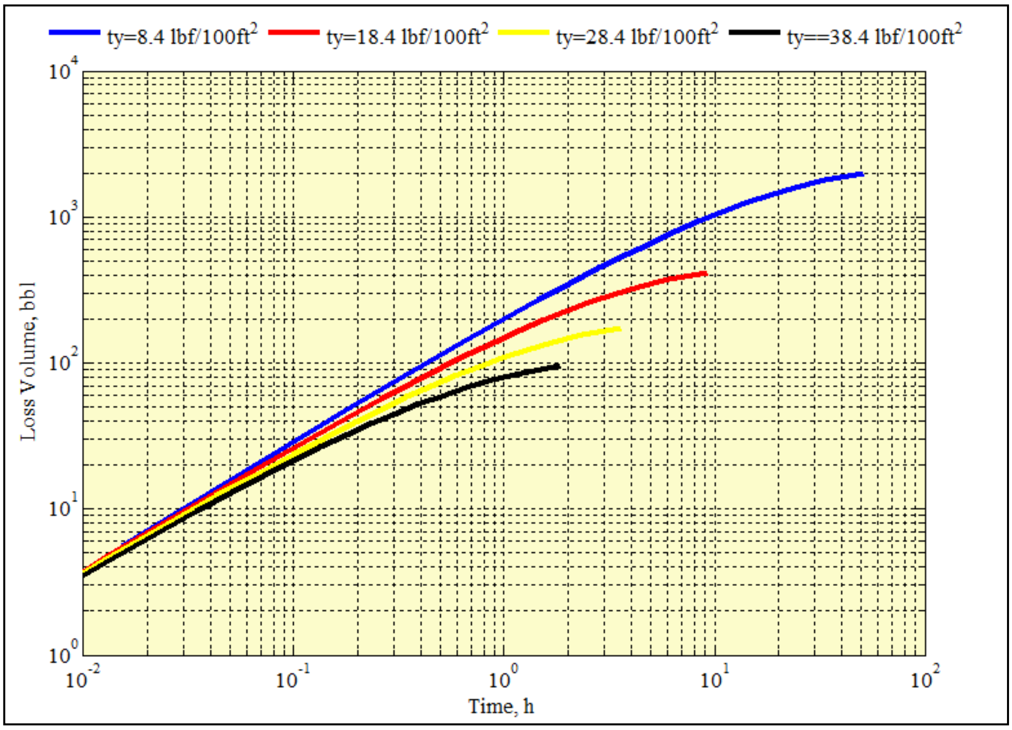


Figure (4. 7): shows the effect of yield stress on yield power low model

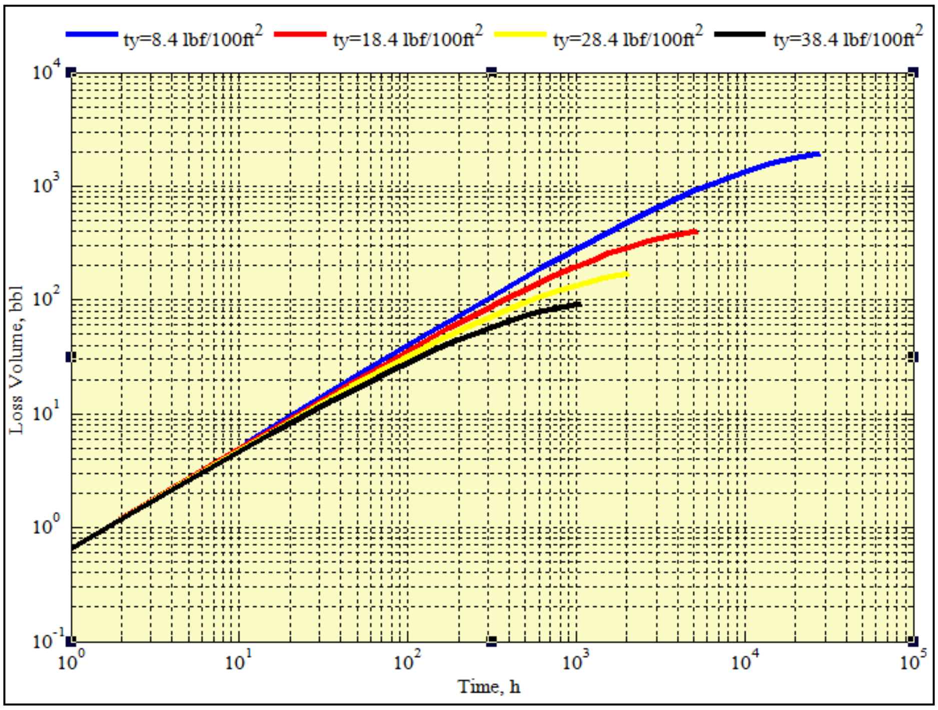


Figure (4. 8) : shows the effect of yield stress on Bingham Plastic model

- **According to last section,** we can say that the third model cannot relied upon, and that is clear from the results obtained, which are characterized by inaccuracy and representing the case. Based on that, we can consider it an ineffective model. That because it ignored the effect of yield stress.

4.3.2 THE CONSISTENCY INDEX AND PLASTIC VISCOSITY

Following the sensitivity analysis, the consistency index for power low fluids was evaluated. This index is correlated with the plastic viscosity of Bingham plastic fluids, so at a higher viscosity, there is higher resistance to flow. Therefore, there will be a lower circulation loss. The increase of K, or µp in four cases. The case with $k = 2\ lbf/100ft^2.\ s^n$ (0.96 pa . s^n), µp = $0.16\ lbf/100ft^2.\ s^n$ (0.96 pa . s^n) is the most favorable because the consistency index, and plastic viscosity are inversely proportional to the lost volume.

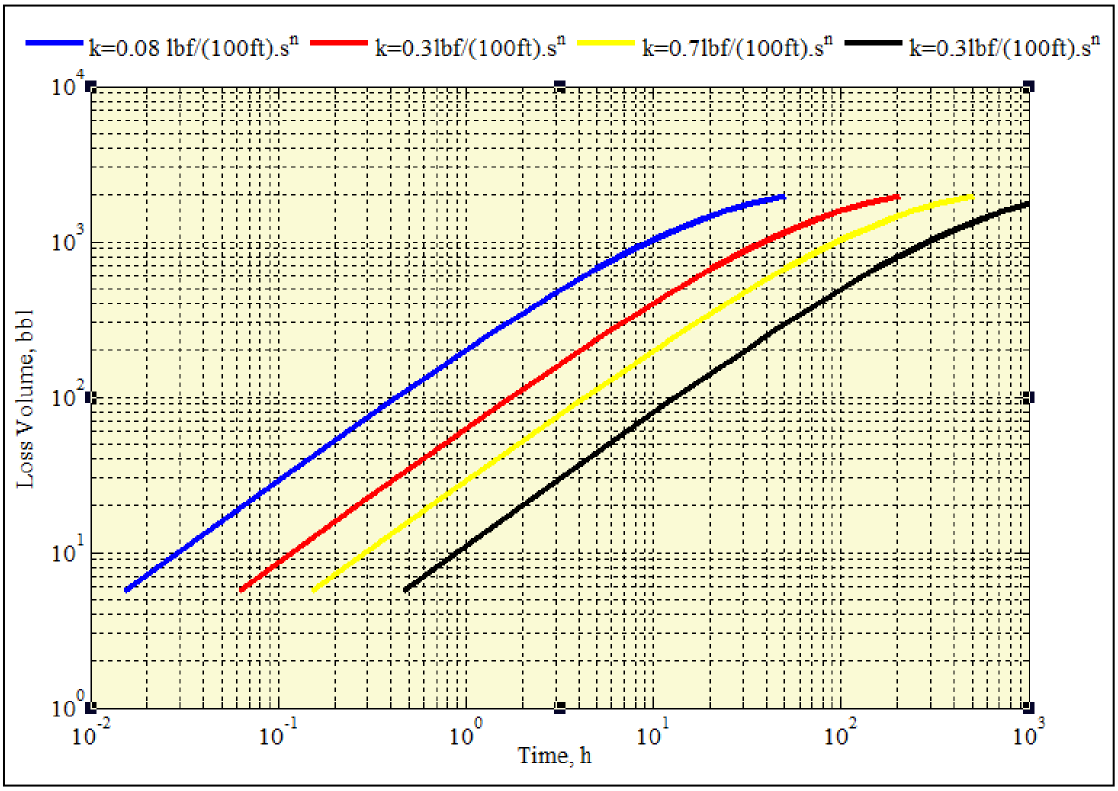


Figure (4. 9) : shows effect of K on Yield Power Low Model

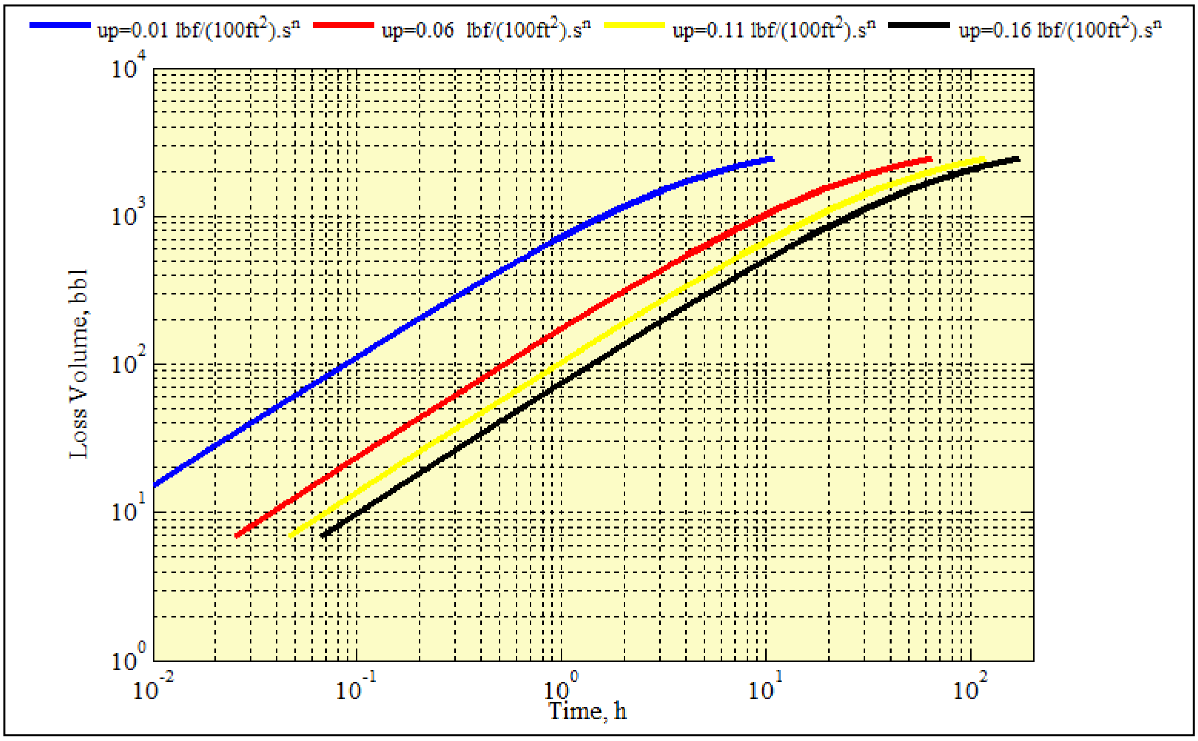


Figure (4. 10) : **shows the effect of plastic viscosity in Bingham Plastic Model**

4.3.3. THE FLOW BEHAVIOR INDEX (N)

Finally, the last parameter studied was the flow behavior index (n). **Figure 4.9** shows the predictive results of the circulation loss depending on the flow behavior index. the flow behavior index (n), Four cases were defined with different values of n in the range of 0.4 to 0.94 for a specific K. At the highest n, the fluid behaves more alike a Newtonian one. On the other hand, when the value of n is low, the fluid is considered pseudo plastic, and a shear thinning effect can be observed. Figure 4.5 shows the predictive results of the circulation loss depending on the flow behavior index**.** In Bingham plastic model a constant n = 1 a Newtonian fluid. Considering that after the fluid invades the fracture, its velocity, and consequently, the correspondent shear rate reduces, the rate of circulation loss is also reduced if compared with the initial one. It is essential to mention that the final lost volume is not affected by the parameter n. That, because after a long time, all cases reach the same loss volume, so the yield stress has higher importance than n.

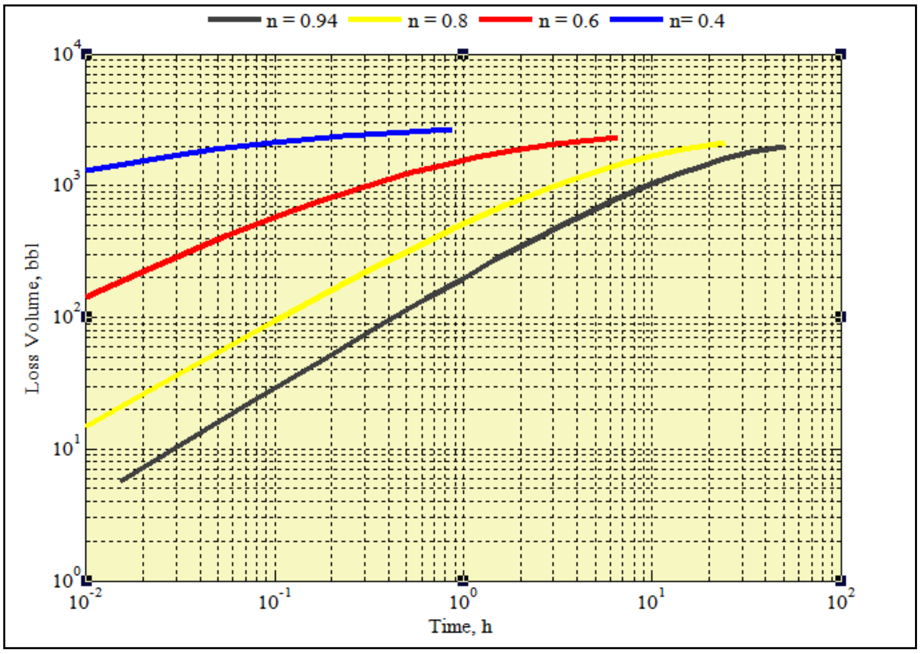


Figure (4. 11)

4.3.4 PRESSURE DIFFERENCE

Flowing the effect of pressure difference on the volume of loss in the three models ,as we can see in **Figure 4.10** the decrease in the value of ΔP is accompanied by a decrease in the lost volume.

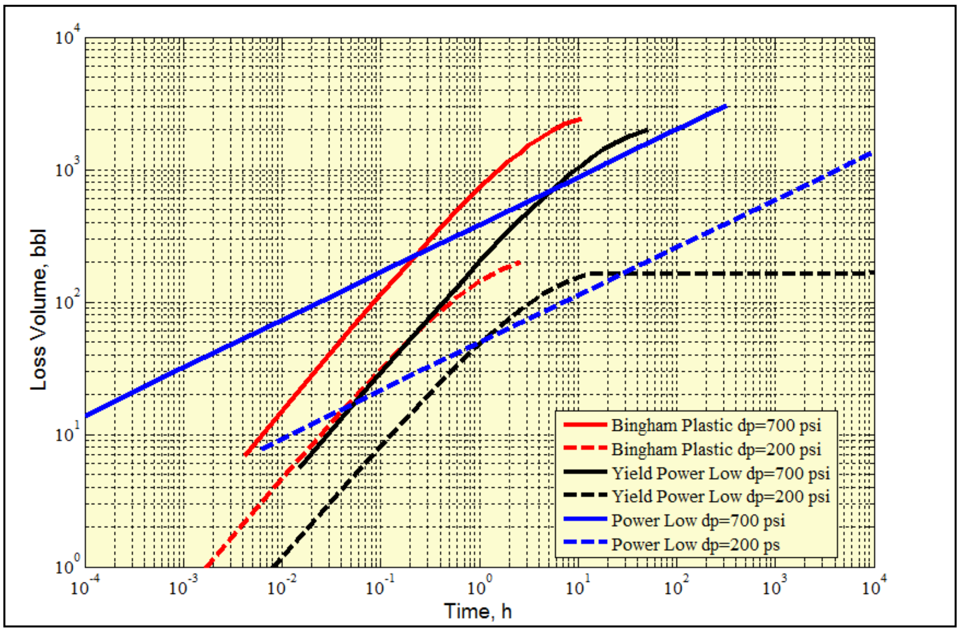


Figure (4. 12)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS :

1. Estimated Maximum lost volume

2. Estimated maximum radius invasion

3.Evaluation of the drilling fluid depending on its rheological proprieties.

4.Enhancing rheological properties of mud by modifying its data to reduce the final volume.

5.Use to predict fluid loss behavior through one fracture.

6.Rheological properties effecting :

A) Either in Bingham plastic yield power low, the volume is reducing with yield stress increase and finding that the lost volume became larger.

B) The parameters of behavior index and fluid index effecting at two case by (fluid index increase and volume decrease, behavior index increase volume decrease in Bingham plastic there are no effect of two index .

7.In Bingham plastic viscosity effecting on the lost volume by (the continues increase of plastic viscosity and share stresses casing decrease of volume but the effecting stop in case of high plastic viscosity because flow resistance

8.The overbalance pressure effect on the fluid behavior because at the pressure decrease loss decrease.

5.2 RECOMMENDATIONS :

1. Create new models for other media (high permeable zone, indicate fracture, caverns)Study the effect of decreasing over balance pressure
2. Don‟t use power law fluids because power law fluids do not have resistance to flowand thus have a large loss volume.
3. Use a large values of yield stress to increase resistance to flow and reducing thevolume losses.
4. In power law model the value of (r_{fDmax}) assumed value just for facilitation implement the model

REFERENCES

i. **(Rabia.H.2001) Well Engineering & Construction**
ii. **(Herior – Watt . 2020) Herior - Watt – University –Drilling .**
iii. **(Mitchell and Miska . 2011)FUNDAMEMTALS OF DRILLNG ENGINEERING**
iv. **Rami AIbattat and Hussein Hoteit (2020). King Abdullah University of Science and Technology (KAUST) Modeling of Drilling Fluid Losses in Naturally Fractured Formations**
v. **Rami and Hussein Hoteit (2021). King Abdullah University of Science and Technology (KAUST) A Semi-Analytical Approach to Model Drilling Fluid Leakage Into Fracture Formation**
vi. **Leonardo (2020) circulation loss modeling for fractured formations**
vii. **Yongcun Feng and K. E. Gray(2017) University of Texas at Austin Modeling Lost Circulation Through Drilling-Induced Fractures**
viii. **L. Whitfill et al(2006) New Design Models and Materials Provide Engineered Solutions to Lost Circulation**
ix. **Yuanhang Chen (2014) University Tulsa OK , USA -) University Shaohus Zhou Saudi Aramco Dhahran , Saudi Arabia modeling transient circulating mud temperature in the event of lost circulation and its application in locating loss zones**
x. **Rami and Hussein(2020). Modeling of Drilling Fluid Losses in Naturally Fractured Formations**
xi. **Majidi et al Circulation into-Modeling Lost Fractured Formation in Rock** Drilling Operations