BIT DESIGN AND HYDRAULICS AND ANALYSIS OF HYDROCYCLONE FOR OIL WELL DRILLING OPTIMIZATION

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CERTIFICATION

This is to certify that this project work **"BIT DESIGN AND HYDRAULICS AND ANALYSIS OF HYDROCYCLONE FOR DRILLING OPTIMIZATION"** was carried out by **WOGOR JOHN AGU** with matriculation number **ENG1704433** in partial fulfillment for the award of Bachelor of Engineering, University of Benin, Benin-City, Edo state, Nigeria.

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DEDICATION

This project is dedicated to Almighty God for His infinite mercy in seeing me through the project, my supervisor for his impact and perseverance, and to my family for their morale and financial support throughout my stay in the University of Benin, department of petroleum engineering.

ACKNOWLEDGEMENT

I wish to express my appreciation of the efforts of my parents MR AND MRS LIVINUS AGU WOGOR AND MY LOVELY SIBLINGS for their moral and financial support and prayers, my supervisor, Professor K.O BELLO for his unwavering support and guidance towards the completion of this project, the HOD ASSOC. PROF S. A. IGBINERE, and the entire lecturers and staff of the Department of Petroleum Engineering, University of Benin for their knowledge and impacts to my success so far, to my extended family for their support and selfless services towards my success, may GOD abundantly bless you all.

ABSTRACT

The efficient execution of drilling operations hinges upon a comprehensive evaluation of surface facilities, encompassing an array of parameters and factors. This project delves into the intricate web of variables that influence drilling efficiency, wellbore stability, and equipment selection. Through meticulous analysis, it uncovers critical insights into mud weight control, pump displacement, pipe diameter considerations, and the deployment of solids control equipment such as desilters and desanders (hydrocyclone). These findings are poised to empower drilling engineers and operators with the knowledge needed to optimize surface facilities during drilling operations, ensuring a harmonious interplay of equipment, drilling fluid properties, and operational parameters. By bridging the gap between theory and practical application, this project not only contributes to the advancement of drilling engineering but also offers tangible recommendations to enhance drilling endeavours' efficiency, safety, and overall success.

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CHAPTER ONE

INTRODUCTION

Drilling operations are complex and multifaceted, often spanning vast geographical areas, operating in extreme environments, and demanding a high level of technical expertise. The successful execution of drilling operations heavily relies on the efficacy and reliability of the surface facilities and equipment deployed. Surface facilities encompass a wide range of critical components, including drilling rigs, wellheads, mud systems, blowout preventers, and auxiliary equipment such as pumps, valves, and control systems.

Various drilling operations can be carried out using surface and subsurface equipment. Surface drilling equipment in the context of oil and gas production, refers to the physical infrastructure and equipment located above ground that support and facilitate oil and gas extraction. The surface facilities typically include drilling rigs and its components, production platforms, processing plants, storage tanks, and pipelines that transport the extracted oil and gas to onshore processing facilities or to markets. Surface facilities also play a critical role in ensuring safety and environmental protection by monitoring and controlling the production process and mitigating any potential hazards or spills.

Drilling operations also involves the use of drilling fluids. The drilling fluid plays a vital role in drilling operations, and nearly all challenges faced during drilling are connected to the properties of the drilling fluid, either directly or indirectly (Adams 1985; Chilingarian and Vorabutr 1983; Patel 1998; Plank and Gossen 1991). Drilling fluid, also called drilling mud, is a mixture of fluids, solids, and chemicals that helps the drill bit function smoothly by reducing friction and heat, transporting rock cuttings to the surface, and keeping the wellbore pressure stable during drilling. The advancement of drilling fluid technology has played a vital role in successful drilling of oil and gas wells.

1.1 RESEARCH BACKGROUND

Solids control equipment is specifically designed to manage and control the gradual build-up of undesirable solids, such as drilled solids or low-gravity solids, within a drilling mud system. Proper use of solid control equipment is important for preserving the desired properties of drilling fluid, ensuring the appropriate distribution of solid particles, and minimizing the generation of unnecessary waste streams during the drilling process (Bouse and Carasquero, 1992).

Solids control equipment includes several essential components such as a gumbo remover, scalper shakers, dryer shakers, desanders, desilters, mud cleaners, and centrifuges. These components, arranged in different configurations, are used to effectively remove particles of specific sizes from the drilling fluid. It is also important to have a comprehensive understanding of the operational principles of auxiliary equipment like agitators, mud guns, mud hoppers, gas busters, degassers, and centrifugal pumps in order to properly handle the processing of drilling fluid in surface systems.

It is important to know and classify the sizes of drilled cuttings which the various solids control equipment can handle so as to determine their capabilities. The typical measurement unit for particle size is microns (µm), which is equivalent to 0.001 mm or 3.937×10^{-5} in. Particles larger than 74 µm are classified as sand-sized particles, regardless of their composition. Within this category, there are further subdivisions based on size: coarse (greater than 2mm = 2000 µm), intermediate (between 2mm = 2000 µm and 250 µm), medium (between 250 µm and 74 µm), and fine (between 74 µm and 44 µm). Particles ranging from 74 µm to 2 µm are categorized as silt-sized particles, while particles smaller than 2 µm are referred to as colloidal particles. Clay particles fall into the colloidal size range. Unlike sand and silt particles, which can be physically separated in a liquid, colloidal-sized particles cannot be separated using purely physical means. They require a chemical reaction to enlarge the particle size and make it amenable to physical separation.

The efficiency of solids control equipment relies on the analysis of particle size distribution. This analysis involves examining the particle size present in the drilling mud and the return stream from each equipment unit to determine the remaining solids that require further processing. Inefficient methods of controlling drilled solids can lead to increased costs in achieving the desired properties of the mud. The accumulation of solids during the process puts additional strain on the drilling bit and pumps, necessitates more dilution water, leads to excessive build-up of wall cake, increases the power requirements due to pressure loss in the annular space, contributes to costly issues in the borehole, and reduces the drilling rate.

The use of mud weighting materials can also have an impact on the efficiency and performance of drilling solid removal equipment. When mud weighting materials, such as barite or hematite, are added to the drilling fluid to increase its density, it can affect the behavior of the drilling solids and the separation process in solid removal equipment.

One of the main effects of mud weighting materials is an increase in the settling velocity of drilling solids. As the density of the drilling fluid increases, the settling velocity of the solids also increases. This can result in faster sedimentation and potentially higher concentrations of solids in the mud. Solid removal equipment, such as hydrocyclones or shale shakers, may need to be adjusted or optimized to handle the increased solids loading and ensure efficient separation.

Additionally, mud weighting materials can affect the rheological properties of the drilling fluid, including its viscosity and gel strength. These changes in fluid properties can impact the performance of solid removal equipment. For example, increased viscosity may require adjustments to the operational parameters of equipment to ensure proper fluid flow and separation efficiency.

Furthermore, the presence of mud weighting materials can increase the abrasiveness of the drilling fluid. This can lead to additional wear and tear on solid removal equipment, potentially affecting its longevity and efficiency over time. Equipment maintenance and monitoring become crucial to prevent excessive damage and ensure continuous operation.

According to this study, taking into account constant particle size distribution, this study focuses on determining solid control equipment parameters and optimizing their performance.

1.2 PROBLEM STATEMENT

Surface drilling facilities are essential elements of the oil and gas drilling process. The efficient operation of these facilities depends on precise calculations for sizing of facilities such as pumps and tanks, ratings and appropriate flow rates which the solid control equipment can accommodate etc. However, such calculations can be intricate and susceptible to errors, which can lead to inefficient operation, safety risks, and higher expenses.

Also, determining the properties of drilling fluids is crucial for the success of oil and gas exploration and production. Nonetheless, accurately determining the properties can be challenging. Inaccurate estimation can lead to unproductive operation, resulting in increased costs, safety hazards, environmental damage and decreased productivity.

1.3 AIM AND OBJECTIVES

Aim:

The aim of this research project is to evaluate the Hydrocyclone and analyze bit design for drilling optimization

Objectives:

1. To examine the Hydrocyclone and analyze drill bit and also determine the parameters using simple mathematical calculations
2. To provide recommendations for improving the surface facilities

1.4 RESEARCH QUESTION

1. To what extent do current methods for calculating Hydrocyclone parameters accurately reflect the requirements of drilling operations?
2. What are the best practices for maintaining Hydrocyclone to ensure optimal performance and minimize downtime during drilling operations?
3. How can digital technologies and automation be used to improve the efficiency and accuracy of surface facilities used for drilling operations?

1.5 SCOPE OF RESEARCH

The primary focus of the research would be to understand the design principles and operating parameters of Hydrocyclone and drill bits used in drilling fluid systems.

The scope of the research could be broadened by including a study of the environmental impact of drilling fluid systems and exploring ways to mitigate any negative effects. Additionally, the research could be extended to investigate the use of new materials and technologies for designing and operating drilling fluid systems.

1.6 JUSTIFICATION

Conducting research on the calculations related to surface facilities used for drilling fluids circulation such as mud pumps, Hydrocyclone and drill bit is crucial for multiple reasons.

To begin with, drilling fluids play a crucial role in drilling activities by facilitating the lubrication and cooling of drill bits, as well as the removal of cuttings from the wellbore. Therefore, it is essential to handle drilling fluids efficiently and effectively to avoid costly downtime and lost productivity.

Moreover, the handling and disposal of drilling fluids can have significant impacts on the safety and environmental sustainability of drilling operations. Poor handling practices can lead to contamination of soil and groundwater, and exposure to harmful chemicals can pose health risks to workers. Therefore, research into the design and operation of drilling fluid systems can help to identify opportunities to minimize risks and improve safety and environmental outcomes.

As drilling activities become more complex, there is a growing need for new technologies and approaches to optimize drilling fluid systems. Ongoing research and development can identify new methods for processing and testing drilling fluids, as well as new materials and equipment that can enhance performance and efficiency.

Finally, there is a need for continuous research to ensure compliance with increasingly stringent regulatory requirements for drilling fluid systems. Staying current with the latest regulations and best practices can help researchers ensure that drilling operations are conducted safely and sustainably, with minimal impact on the environment and local communities.

1.7 ORGANIZATION OF THESIS

The thesis is organized in this manner:

- Chapter two gives a brief introduction of the circulating system, the various solids control equipment
- Chapter three presents the methodology employed in this study
- Chapter four contains the discussion of the results.

- Chapter five presents logical conclusions drawn from the results and provides valuable recommendations for future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 MUD CIRCULATING SYSTEM

The circulating system on the rig enables the movement of Drilling Fluid or Mud from the top of the drill string to the space between the drill string and the wellbore. Figure 2.1 presents a typical model of a traditional mud circulating system (McBride, 2012). This system consists of various components such as pumps, distribution lines, storage tanks, storage pits, and cleansing units (Guo & Liu, 2011). Its purpose is to facilitate the drilling fluid in achieving its main objectives.

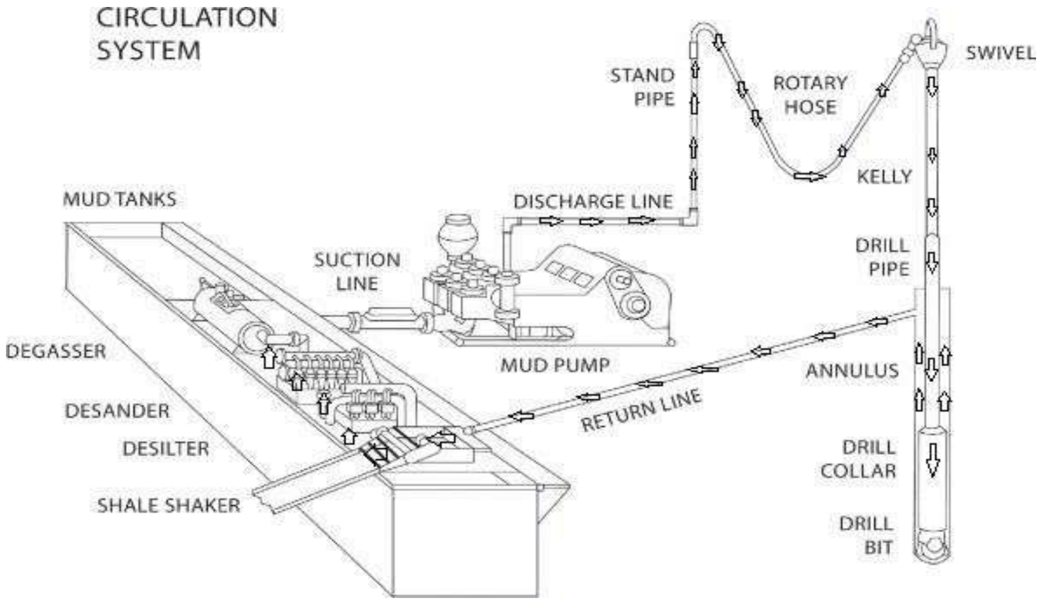

Figure 2.1 Drilling mud circulation system (McBride, 2012)

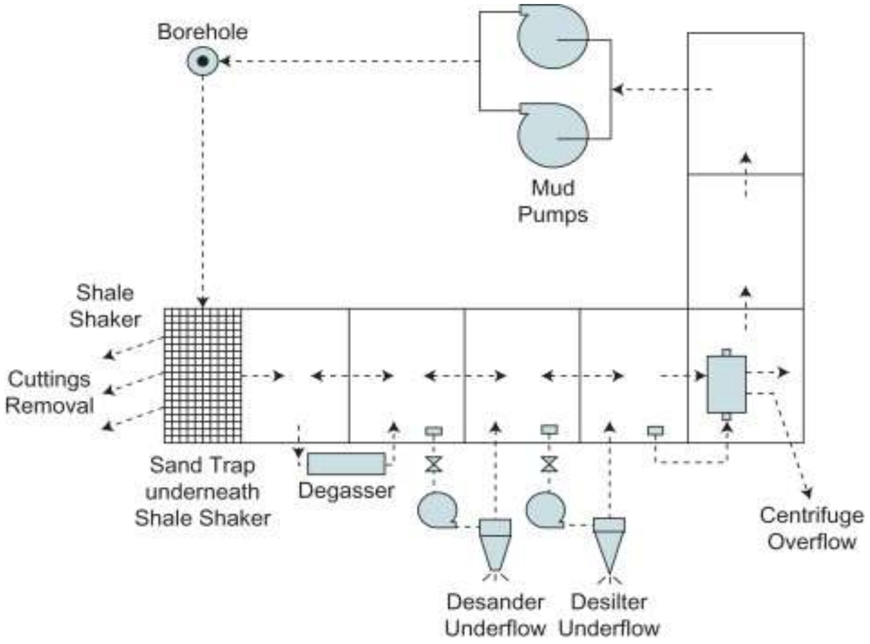

Figure 2.2 Mud circulation system Flowchart (Guo & Liu, 2011)

Figure 2.2 represents the typical drilling mud circulation systems flowchart. However, it is important to note that the specific sequence of equipment may vary depending on the drilling operation, well conditions, and desired level of solids control. It should also be noted that the use of centrifuge is optional. In some drilling operations, especially those involving difficult formations or extreme levels of fine solids, a centrifuge may be used to increase the efficiency of solids removal. However, in many drilling scenarios, the solids control process may be effectively managed without the use of a centrifuge. Solids control equipment such as shale shakers, desanders, and desilters are commonly employed to remove larger particles and achieve satisfactory solids control.

2.2 MUD PUMP

A mud pump is one of the three key components of a drilling site and its lifetime and reliability are related to safety and cost (Deng et al., 2017). It acts as the central component of the mud circulating system, which is extensively employed in drilling oil and gas wells (Guo & Liu, 2011). The mud pump plays a vital role in facilitating the circulation of drilling fluid, commonly known as “mud,” within the drill bit and up to the surface. Additionally, the mud pump applies pressure to prevent any blockages or obstructions from occurring at the drill bit. The benefits of using reciprocating positive-displacement pumps include their capability to handle fluids containing high-solid content and abrasives, ease of operation and maintenance, reliability, and their ability to operate using different configurations. Under normal operating conditions, a mud pump has the capability to produce pressures of up to 7,500 psi (52,000 kPa).

Mud pumps can generally be categorized into two primary types: duplex pumps and triplex pumps. The duplex mud pump employs two pistons or plungers that operate continuously to move the fluid, while the triplex employs three pistons for its operation.

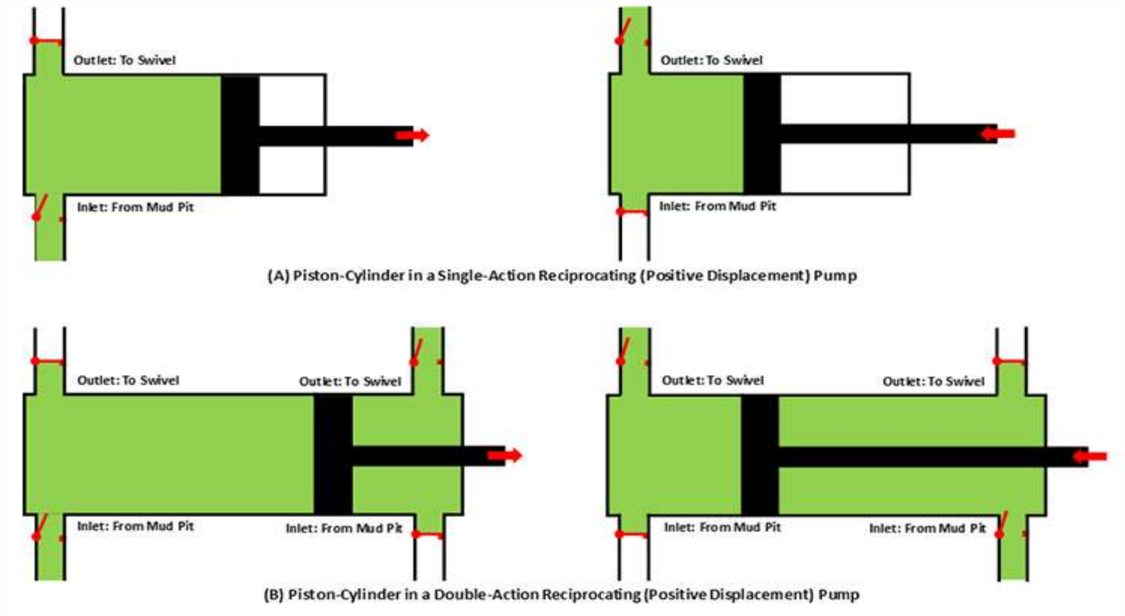

Figure 2.3 Schematic of a Piston-Cylinder in a (A) Single-Action and (B) Double-Action Reciprocating Mud Pump (Greg King © Penn State)

Recent advancements in mud pump technology include the quintuplex and hex versions. These designs, as their names suggest, incorporate five or six pistons arranged in a reciprocating manner. Although not as widely adopted as the triplex design, these mud pumps distribute the pumping action evenly throughout the rotational cycle, resulting in reduced noise from the mud. This allows for more precise measurements and logging to be conducted while the pump is operational

2.2.1 MUD FLOW RATE REQUIREMENTS

The mud flow rate requirements of a drilling mud pump can vary depending on several factors, including the drilling operation, well specifications, and drilling fluid properties.

The mud pump chosen must have the capacity to deliver sufficiently high mud flow rates throughout the drilling process to effectively transport drill cuttings to the surface. It is important to consider the variations in mud properties, mud flow velocity, and annular geometry that occur with different hole depths, as they directly impact the efficiency of cuttings transport.

To maintain safe drilling operations, it is important to consider how the mud properties impact the settling velocity of drill cuttings in the annulus during hole cleaning. To achieve this, it is necessary to identify the anticipated ranges of mud properties from mud programs and associate them with specific hole depths and borehole geometries. By identifying the extreme values within these property ranges, it becomes possible to estimate the settling velocity of cuttings and determine the minimum mud flow rate required from the mud pump.

2.2.2 PRESSURE REQUIREMENTS

Mud pumps should be capable of providing pressure that is strong enough to overcome the total pressure loss and pressure drop at the bit in the circulating system at the total hole depth. The pressure loss depends on the mud properties, the drill string configuration, the borehole geometry, and the mud flow rate.

The pressure requirement of a mud pump can be categorized into two main aspects:

- Circulating Pressure: The maximum expected circulating pressure is the total frictional pressure loss and pressure drop at the bit at the total hole depth. The frictional pressure loss depends on the fluid properties, the flow velocity, the flow regime, and the length of the flow path
- Pump Discharge Pressure: The discharge pressure of a mud pump is required to overcome friction losses in the flow system and deliver the desired mud flow rate. Friction losses occur due to the resistance encountered as the drilling fluid flows through the drill pipe, drill collars, drill bit, annulus, and other components of the circulating system. The pump discharge pressure requirement is influenced by the flow rate, pipe diameter, pipe length, and fluid properties.

2.2.3 MUD PUMP OUTPUT

The mud pump output is a very crucial parameter of the mud pump. Mud pump output measures how much drilling fluid or mud a pump can deliver in a given time, usually in gallons per minute (GPM) or liters per minute (LPM) and Barrels per Stroke (bbl/stk). It is an important aspect of drilling operations because it affects the efficiency of the mud circulation system.

The output of a mud pump is influenced by factors like the pump’s design, operating parameters, and the properties of the drilling fluid. It plays a critical role in drilling operations by enabling faster drilling rates and effective removal of drilled cuttings from the wellbore. This helps maintain wellbore stability, ensures proper cleaning and cooling of the drill bit, and allows for control of formation pressures during drilling

2.2.4 MUD PUMP OUTPUT Q (BBL/STK) AND Q (GPM)

DUPLEX PUMPS

Geometric analysis of the duplex pump allows the derivation of the subsequent equation, as presented by Guo et al (2007)

Pump output in gal/stk:

$$Qgs = 0.0068\left(2Dl^2 - Dr^2\right)(S)(e_v) \qquad (2.1)$$

Where,

Q = pump output in gal/stk
Dl = liner diameter in inches
Dr = rod diameter in inches
S = stroke length in inches
e_v = volumetric efficiency in percent (%)

Pump output in bbl/stk

$$Qbs = \frac{0.0068\left(2Dl^2 - Dr^2\right)(s)\ (e_v)}{42} \qquad (2.2)$$

Pump output in gallon per minute:

$$Q = 0.0068\left(2Dl^2 - Dr^2\right)(S)(N)\ (e_v) \qquad (2.3)$$

Where,

Q = pump output in gpm
N = strokes per minute (also rpm of pump flywheel)

2.2.5 MUD PUMP HORSEPOWER

In the case of drilling mud pumps, horsepower signifies the pump's capability to produce the required pressure and flow rate essential for effective drilling activities.

The horsepower of a drilling mud pump is influenced by several factors, such as the pump's design, fluid property, flow rate and pressure, operating speed, depth and wellbore condition, operating parameters etc.

(Circulating Horsepower)

$$\text{HHP} = \frac{(\text{P})(Q)}{1714} \tag{2.7}$$

Where,
HHP = hydraulic horsepower
P = circulating pressure in psi
Q = circulating rate in gpm

(Input Horsepower)

$$\text{HHP} = \frac{(\text{P})(Q)}{1714(\text{e}_v)(\text{e}_m)} \tag{2.8}$$

Where,
HHP = hydraulic horsepower
P = circulating pressure in psi
Q = circulating rate in gpm

e_v = volumetric efficiency in percent (%)
e_m = mechanical efficiency in percent (%)

2.3 HYDROCYCLONE

Hydrocyclones are simple devices that use the pressure from a centrifugal pump to create centrifugal force. This force enables the separation of solid particles suspended in the mud from the fluid. During drilling operations, hydrocyclones have the ability to achieve excellent separation efficiencies when used for the separation of particulate materials within the size range of 5 to 400 microns (Saengchan et al., 2009; Alves et al., 2020). The mixture of solids and fluid is expelled from the lower end of the cone, while the purified drilling fluid is discharged through the overflow outlet (Figure 2.4).

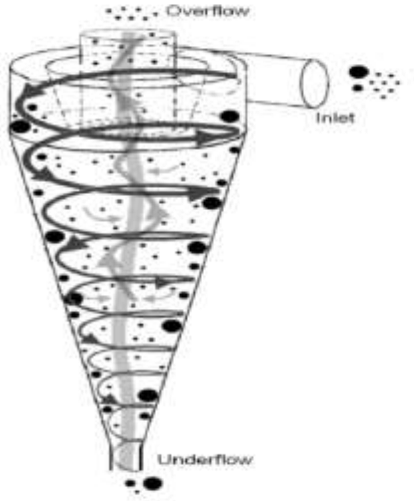

Figure 2.4 Schematic of the hydrocyclone (Davailles et al., 2012).

Hydrocyclones have gained interest in the field of physical processing due to their simplicity, as they are equipment with no moving parts that are easy to operate and maintain. They have been widely recognized for their effectiveness in classifying and separating solids based on their size or density (Nascimento et al., 2013) and also the cleaning of drilling mud from oil rigs during drilling operations (Mognon et al., 2016).

Hydrocyclone can be categorized into two main types: mini hydrocyclone and standard hydrocyclone. Mini hydrocyclones are smaller sized hydrocyclones designed for applications where space is limited or where finer particle separation is required while the standard hydrocyclones are the conventional sized hydrocyclones used in various industries including oil and gas, mining, mineral processing.

Based on the research by (Tavares et al., 2002), hydrocyclones with a diameter smaller than 75 mm are classified as mini-hydrocyclones. However, (Yu et al., 2017) define mini-hydrocyclones as equipment with a characteristic diameter ranging from 1 to 10 mm. Generally, these devices are known for generating significant centrifugal forces due to their small characteristic diameter and are commonly utilized for the separation and concentration of fine particles.

Also, (Bicalho et al., 2012) employed a modular mini-hydrocyclone with a characteristic diameter of 15 mm to effectively separate yeast from alcoholic fermentation broth. They utilized a factorial experimental design and analyzed the outcomes to establish empirical mathematical models. These models were developed to describe various factors such as capacity, underflow to throughput ratio, total efficiency, and reduced total efficiency

Hydrocyclones can also be categorized based on their specific applications and design as: (1) Desanders (2) Desilters.

2.3.1 DESANDER

A desander is a specific type of hydrocyclone, designed to separate drilled cuttings between 50 to 80 micron and barite between 30 to 50 micron (Los, n.d.). Desanders should be used in unweighted mud when shakers are unable to have API 140 screens (100 microns) or finer installed. They are used primarily to remove high solids volume associated with fast drilling of large diameter top holes. The desander is used to remove sand-size and larger particles that pass through the shale shaker screens.

Typically, the usage of desanders is stopped once barite and/or costly polymers are introduced into the drilling mud. This is because desanders tend to remove a significant portion of these materials, making their continued use impractical.

Additionally, desanders are generally not cost-effective when employed with oil-based drilling fluids due to the substantial discharge of the liquid phase caused by larger cones.

2.3.2 DESILTER

A desilter is a specific type of hydrocyclone which is used in the oil and gas industry to remove fine solids, typically ranging from 12 to 40 micron. They also separate barite particles between 8 to 25 micron range, from drilling fluids or mud (Los, n.d.). It forms an integral part of the solids control system and works alongside the desander, which focuses on removing larger particles. The desilter comprises a collection of hydrocyclones arranged either in parallel or series configuration, using centrifugal force just like the desander to separate the fine solids from the drilling fluid. The separated solids are discharged as an underflow, while the clean drilling fluid is returned to the active system. Desilters play a vital role in upholding the quality and performance of drilling fluids by eliminating smaller particles that could otherwise hinder drilling efficiency and equipment integrity.

Figure 2.5 Solid Control System Process

CHAPTER THREE

METHODOLOGY

This chapter focuses on the methods used in carrying out the study. In this chapter, information will be provided on how the data were collected, the sources of the data and method of data analysis.

Specifically, the chapter contains the research design chosen for this research work, the data collection method, the sampling procedures, the sources from which the data are collected, the instrument used in carrying out the research work and finally, the method of analysis and presentation.

3.1 INTRODUCTION

This section explains the research method that was used in carrying out the research. It highlights the following:

1. Design of the Study
2. Sample and Sampling Techniques
3. Method of Data Collection and
4. Method of Data Analysis.

3.2 DESIGN OF THE STUDY

The research design chosen for this research work is descriptive research design. In this research, the descriptive design was used because the main goal was to describe and document the characteristics, behaviors, or parameters being studied without manipulating or changing variables. It focused on providing a detailed and accurate account of the subject under investigation.

3.3 SAMPLING TECHNIQUES

Sampling of data for this study is drawn primarily from published books such as textbooks, journals and articles.

3.4 METHOD OF DATA COLLECTION

In this study, to ensure a comprehensive and well-rounded study, a diverse range of relevant data will be obtained from various secondary sources. These sources include both published and unpublished materials, such as textbooks, academic journals, conference proceedings, industry reports, magazines, and bulletins. Extensive literature review was conducted to identify and select the most pertinent and up-to-date sources that provide valuable insights and information on the subject under review.

3.5 METHOD OF DATA ANALYSIS

The method of analysis used in this research is a mathematical analysis. This Mathematical analysis involves formulating or using already existing mathematical equations or models to describe and analyze data, or systems, using Microsoft Excel to implement various algorithms, analyze, visualize, and interpret.

The data generated will be presented in a tabular form by the researcher and also with the aid of line graphs, and XY Scatter graphs. The researcher intends to use a simple comparative analysis to represent the answers to the research questions.

The data was further analyzed comparatively using Microsoft Excel. Microsoft Excel is a spreadsheet-based software tool that employs formulae and functions to arrange numbers and data. Excel analysis is used by businesses of all sizes all around the world to undertake various analysis.

3.6 EQUATIONS UTILIZED FOR THIS ANALYSIS

3.6.1 Hydraulics Analysis

Inputs

N1= jet size for nozzle (1) (in)

N2= jet size for nozzle (2) (in)

N3= jet size for nozzle (3) (in)

Q = circulation rate (gpm)

Dh = diameter of hole (in)

Dp = diameter of drill pipe (in)

MW = mud weight (ppg)

B =bit size (in)

Ps = surface pressure (psi)

Outputs

AV: Annular velocity (ft/min)

Pb: bit nozzle pressure loss (psi)

HHP: hydraulic horse power at bit (Hp)

HHPba: power per unit area in hp/ sq in, (hp/in^2)

Vn: jet velocity (ft/s)

Ifa: impact force per unit area in squ in (ib/in^2)

$$\text{AV} = \frac{24.5\,Q}{Dh^2 - Dp^2} \tag{3.1}$$

$$\text{Pb} = \frac{156.5\,Q^2 \times MW}{(N_1^2 + N_2^2 + N_3^2)^2} \tag{3.2}$$

$$\text{HHPba} = \frac{QP_b \times 1.27}{1714 \times B^2} \tag{3.3}$$

$$P_{psib} = \frac{p_b \times 100}{p_s} \tag{3.4}$$

$$v_n = \frac{417.2 \times Q}{N_1^2 + N_2^2 + N_3^2} \tag{3.5}$$

$$Ifa = \frac{MW \times V_n \times Q \times 1.27}{1930\,B^2} \tag{3.6}$$

3.6.2 Equivalent Circulating Density Analysis

$$\text{AV} = \frac{24.5\,Q}{Dh^2 - Dp^2} \tag{3.7}$$

$$\Delta \text{P}_\text{a} = \frac{(1.4327 \times 10^{-7}) \times MW \times L \times AV^2}{Dh - Dp} \tag{3.8}$$

ECD = $\left(\frac{\Delta P_a}{0.052 \times TVD}\right) + MW$ (3.9)

3.6.3 Pump Analysis

3.6.3.1 Power required (hp)

$HHP = \frac{Q \times \Delta P}{1714}$ (3.10)

$\Delta P = \frac{(MW)(Q^2)}{12032(cd^2)(A^2)}$ (3.11)

P=nozzle pressure loss

MW = mud weight

Q = flow rate

A = area of the nozzles (in^2)

3.6.3.2 Pump Displacement

Vo = 0.028$\times D \times E \times Ps$ (3.12)

3.6.3.3 Pump Flow Rate

Qc =7.12$\times D \times E \times Ps \times N - Qs$ (3.13)

3.6.3.4 Volume of cuttings generated per foot of hole drilled

Vc=$\frac{Dh^2(1-\emptyset)}{1029.4}$ (3.14)

Dh=hole size

Ø=porosity

3.6.3.5 Mud pump output (gpm)

Q = $0.0102 \times D_l^2 \times S \times N \times e_v$ (3.15)

D_l = liner diameter (in)

S = Stroke length (in)

N = Strokes per minute

e_v = volumetric efficiency

Volume of Solids Entering the Mud System Whilst Drilling

Vc=$\frac{(1-Ø)d^2(ROP)}{1029}$ (3.16)

where:

Vc =volume of cutting (bbl/d)

Ø=avareage formation porosity

d=hole diameter (in)

ROP=rate of penetration (ft/hr)

3.6.5 Hydrocyclone Analysis (Desander and Desilter)

3.6.5.1 Volume fraction of solids discorded by hydrocyclone

Using a water-based mud, volume fraction of solids discorded by hydrocyclone (%)

$Hd = \left(\frac{MW-8.34}{13.37}\right) \times 100\%$ (3.17)

$$VQ = \frac{W(lb)}{\rho_{s\,(lb/quarts)}} \tag{3.18}$$

3.6.5.2 Mass rate of solid discharged by one cone

$$S.R = \left(19.530\left(\frac{Hd}{100}\right)\right)\left(\frac{VQ}{t}\right) \tag{3.19}$$

Volume liquid ejected by one cone of a hydrocyclone

$$VC = 900\left(1 - \left(\frac{Hd}{100}\right)\right)\left(\frac{VQ}{t}\right) \tag{3.20}$$

Where:

Hd: Volume fraction of solid discorded

MW: Solid mud weight

S.R: Mass rate of discharged solids lb/h

VQ: Volume of slurry collected in quarts

t: Time required to collect sample (Solid)

v: Volume of liquid ejected gal/h

W: weight of slurry lb

ρ_s: Slurry density lb/quarts

3.6.5.3 Hydrocyclone Cut Point

$$\text{Hcp} = 144.7\left\{\left(\frac{Pv}{162.5-(MW\times 7.48)}\right)^{0.5}\right\} \tag{3.21}$$

Where Hcp: Hydrocyclone cut point

Pv: Plastic velocity

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. HYDRAULICS ANALYSIS

4.1.1 Relationship between Mud Weight and Bit Nozzle Pressure

The relationship between mud weight and bit nozzle pressure is a crucial parameter in drilling operations. Table 4.1.1 presents this relationship:

Table 4.1.1 Table showing the relationship between mud weight and bit nozzle pressure

dh (in)	dp (in)	mw (ppg)	bit_noz_pres (psi)
8.5	5	13.0	2002.334499
8.75	5	12.5	1925.321633
11	5	12.0	1848.308768
12.25	5	11.5	1771.295903
15	5	11.0	1694.283037
17	5	10.5	1617.270172

17.5	**5**	**10.0**	**1540.257307**
22	**5**	**9.5**	**1463.244441**
24.26	**5**	**9.0**	**1386.231576**
28	**5**	**8.5**	**1309.218711**

The dataset reveals a clear relationship between mud weight and bit nozzle pressure. As mud weight increases, there is a corresponding increase in bit nozzle pressure (Figure 4.1.1). This trend indicates that higher mud weight results in greater pressure at the bit nozzles.

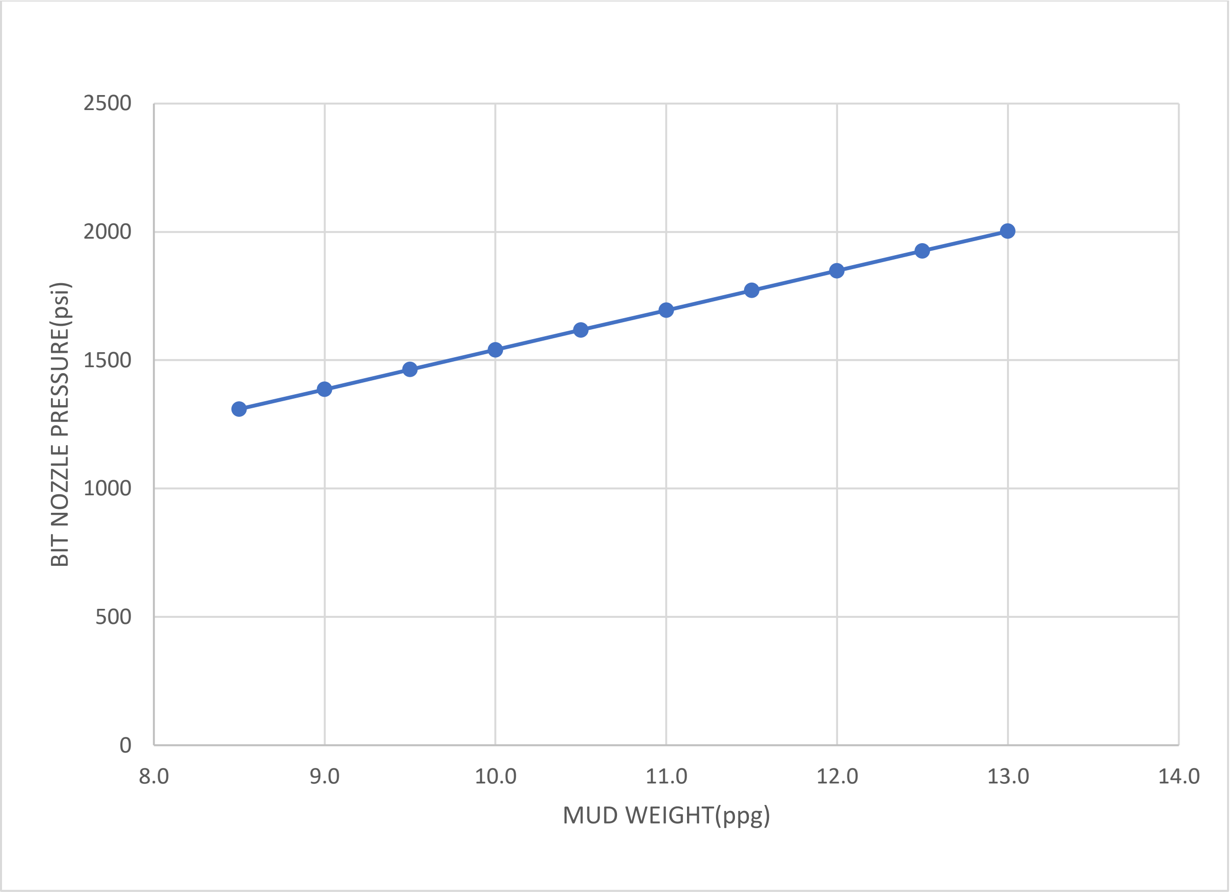

Figure 4.1.1 The relationship between mud weight and bit nozzle pressure

The relationship between mud weight and bit nozzle pressure has significant implications for drilling operations. It directly affects the hydraulic performance of the drilling fluid and the efficiency of cuttings transport.

4.1.2 Relationship Between Mud Weight (mw, ppg) and Equivalent Circulating Density (ECD)

The relationship between mud weight and Equivalent Circulating Density (ECD) is critical in drilling operations. It is presented in Table 4.1.2:

Table 4.1.2 Table showing relationship between mud weight and Equivalent Circulating Density (ECD).

dh (in)	dp (in)	mw (ppg)	ECD
8.5	5	13.0	13.68785322
8.75	5	12.5	13.01836409
11	5	12.0	12.08972462
12.25	5	11.5	11.54193047
15	5	11.0	11.0113699
17	5	10.5	10.50519068
17.5	5	10.0	10.00418147

22	**5**	**9.5**	**9.501096664**
24.26	**5**	**9.0**	**9.000608344**
28	**5**	**8.5**	**8.500265235**

Table 4.1.2 demonstrates a direct relationship between mud weight and Equivalent Circulating Density (ECD). As mud weight increases, the ECD also increases (Figure 4.6.2). This relationship is crucial for wellbore stability and drilling fluid management.

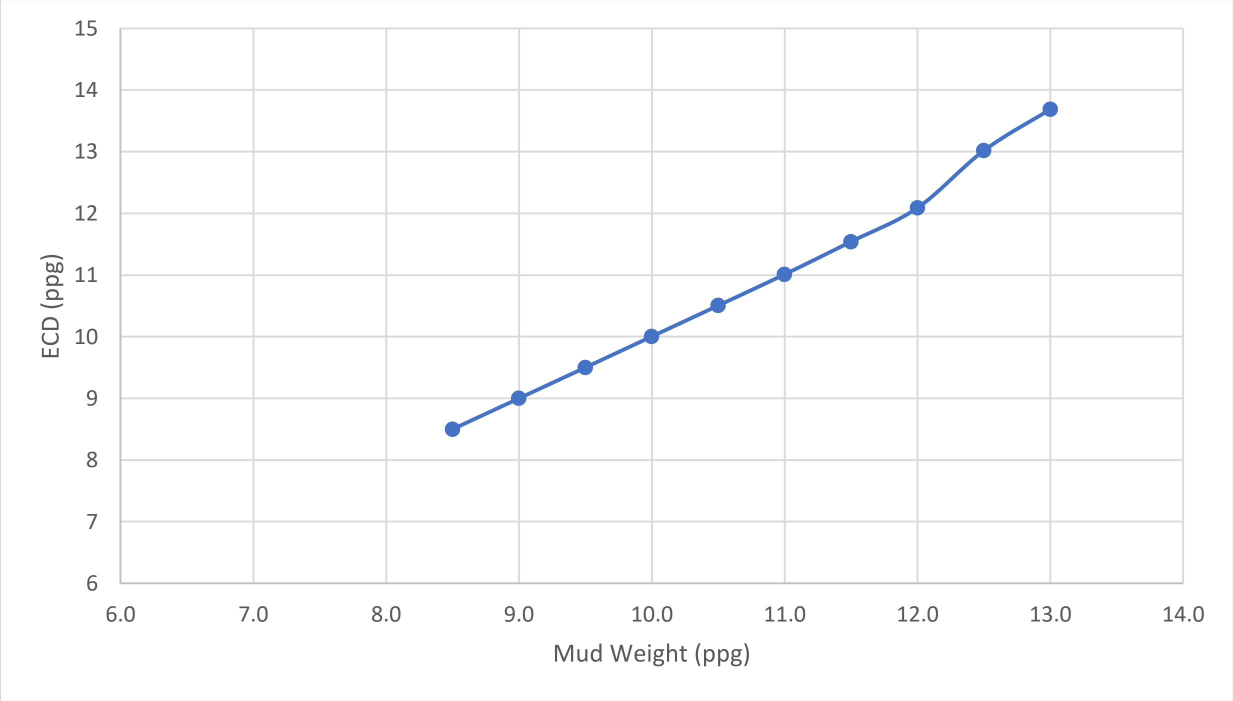

Figure 4.1.2 The relationship between mud weight and Equivalent Circulating Density (ECD).

Higher mud weight results in a higher ECD, which, in turn, affects the pressure exerted on the wellbore walls. Proper control of mud weight is essential to maintain wellbore stability and prevent issues like well kicks or formation damage.

4.1.3 Relationship Between Hole Size and Annular Velocity

The relationship between hole size and annular velocity is a critical parameter in drilling operations. It is presented in Table 4.1.3:

Table 4.1.3: Table showing the relationship between hole size and annular velocity

dh (in)	**dp (in)**	**ann_vel (ft/min)**
8.5	**5**	**259.26**
8.75	**5**	**237.56**
11	**5**	**127.60**
12.25	**5**	**97.95**
15	**5**	**61.25**
17	**5**	**46.40**
17.5	**5**	**43.56**
22	**5**	**26.69**

24.26	**5**	**21.74**
28	**5**	**16.14**

Table 4.1.3 illustrates a non-linear relationship between hole size and annular velocity. As the hole size increases, there is a corresponding decrease in annular velocity (Figure 4.6.3). This relationship has implications for wellbore stability and hydraulic performance.

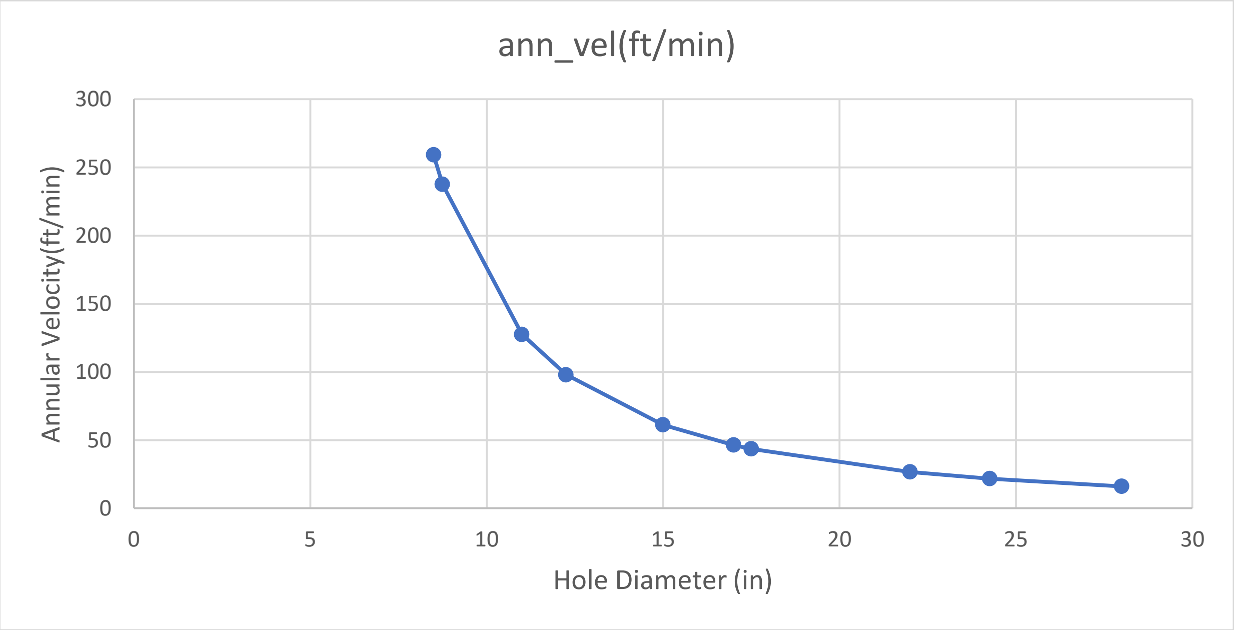

Figure 4.1.3 The relationship between hole size and annular velocity

A larger hole size results in reduced annular velocity, which affects the efficiency of cuttings transport and the hydraulic cleaning of the wellbore.

4.2 PUMP ANALYSIS

4.2.1 The relationship between pump flow rate (Q) and rotary speed (N)

The relationship between pump flow rate (Q) and rotary speed (N) is a critical factor in drilling operations. Our experimental findings reveal a direct proportionality between pump flow rate (Q) and rotary speed (N2), highlighting its practical implications.

Table 4.2.1 Table showing the relationship between pump flow rate (Q) and rotary speed (N)

Q	MW	Nozzle area	cd	ΔP	HHP
500	9.2	0.38656	0.95	1417.454	413.493
500	10.5	0.38656	0.95	1617.746	471.9214
500	11	0.38656	0.95	1694.782	494.3938
500	11.5	0.38656	0.95	1771.818	516.8663
500	12	0.38656	0.95	1848.853	539.3387
500	12.5	0.38656	0.95	1925.889	561.8111
500	13	0.38656	0.95	2002.924	584.2836

As the rotary speed increases, there is a corresponding increase in the pump's flow rate, maintaining a constant value of 0.0045 bbl/d for other parameters (figure

4.2.1). This relationship between pump flow rate and rotary speed has several noteworthy implications for drilling operations:

Operators can optimize drilling processes by adjusting rotary speed to control mud circulation and ensure efficient cuttings transport.

Precise control of pump flow rate through rotary speed adjustments plays a vital role in maintaining wellbore stability and mitigating the risk of formation damage or lost circulation.

Understanding the direct proportionality between pump flow rate and rotary speed assists operators in selecting mud pumps with the desired capacity for specific drilling projects.

The optimization of pump flow rates through rotary speed adjustments can lead to energy savings and a reduction in the environmental footprint of drilling operations.

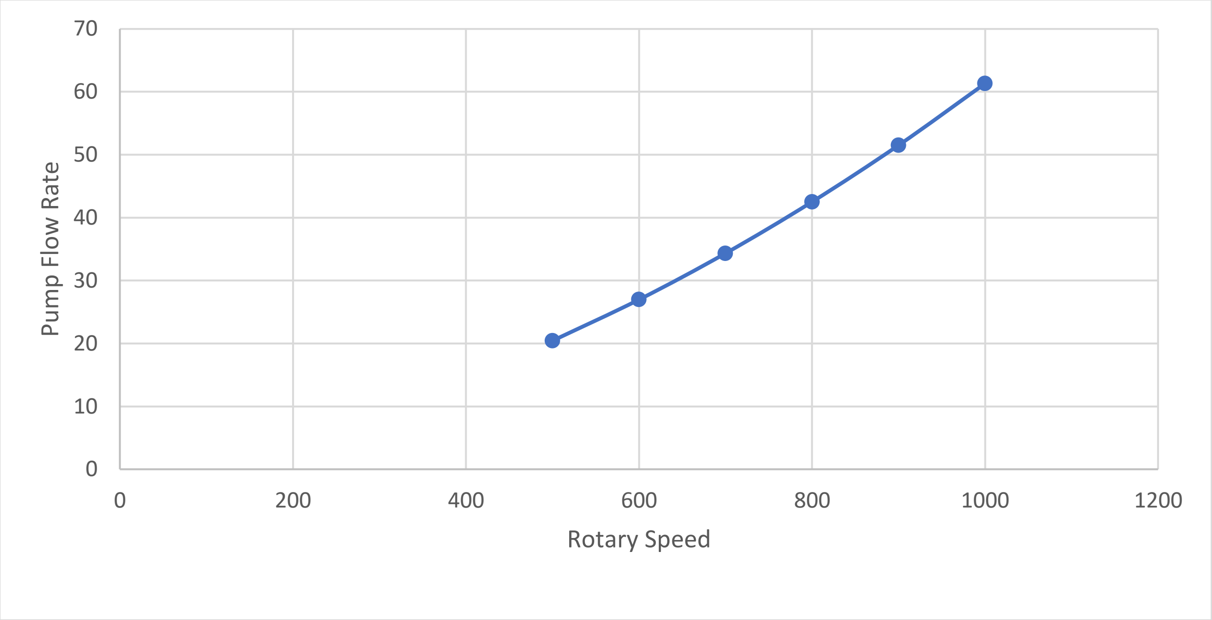

Figure 4.2.1 Figure showing the relationship between pump flow rate (Q) and rotary speed (N)

4.2.2 Relationship Between Pump Displacement and Rotor Diameter

The analysis of the relationship between pump displacement (Vo) and rotor diameter (D) is crucial for evaluating surface facilities in drilling operations. The data from Table 4.2.2 illustrates this relationship:

Table 4.2.2: Table showing the relationship between pump displacement (Vo) and rotor diameter (D)

Rotor Diameter(in)	E(in)	Ps(ft)	Pump Displacement(cuft)
10	2.87	200	160.72
12	2.87	200	192.86

13	**2.87**	**200**	**208.94**
14	**2.87**	**200**	**225.01**
15	**2.87**	**200**	**241.08**

The dataset shown in table 4.2.2 reveals a consistent linear pattern. As rotor diameter increases, there is a corresponding growth in pump displacement as shown in figure 4.2.2. Larger rotor diameters are associated with greater pump displacement, which has practical implications for drilling operations.

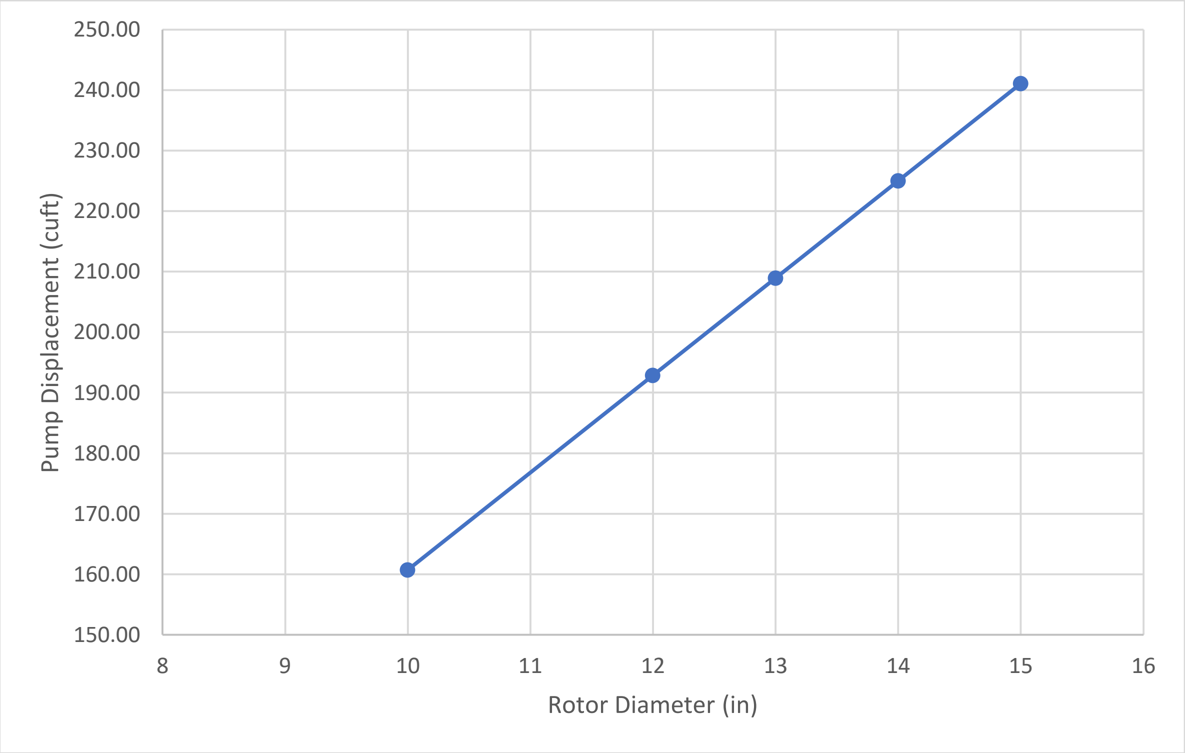

Figure 4.2.2: Figure showing the relationship between pump displacement (Vo) and rotor diameter (D)

This relationship informs the selection of mud pumps for surface facilities. Choosing mud pumps with adequate displacement capacity ensures effective management of drilling fluid volume, optimizing equipment for efficiency and reliability.

Additionally, precise control of pump displacement based on rotor diameter plays a pivotal role in well control. It facilitates cuttings transport and maintains wellbore stability throughout drilling, contributing to safety and cost-effectiveness.

4.2.3 Relationship between Mud weight, Bit Nozzle Pressure Loss and Horsepower Required

The analysis of the relationship between mud weight (MW), bit nozzle pressure loss (ΔP), and horsepower required (HHP) offers valuable insights into drilling operations. The data in Table 4.2.3 illustrates this relationship.

Table 4.2.3: Table showing the relationship between mud weight (MW), bit nozzle pressure loss (∆P), and horsepower required (HHP)

Q	MW	Area of nozzle	cd	∆P	HHP
500	**9.2**	**0.38656**	**0.95**	**1417.454**	**413.493**
500	**10.5**	**0.38656**	**0.95**	**1617.746**	**471.9214**
500	**11**	**0.38656**	**0.95**	**1694.782**	**494.3938**
500	**11.5**	**0.38656**	**0.95**	**1771.818**	**516.8663**
500	**12**	**0.38656**	**0.95**	**1848.853**	**539.3387**
500	**12.5**	**0.38656**	**0.95**	**1925.889**	**561.8111**
500	**13**	**0.38656**	**0.95**	**2002.924**	**584.2836**

As mud weight (MW) increases from 9.2 ppg to 13 ppg, there is a corresponding increase in bit nozzle pressure loss (Figure 4.2.3). This trend suggests that denser mud weights result in higher nozzle pressure losses. The rise in nozzle pressure losses with higher mud weight is accompanied by an increase in horsepower required (HHP). This indicates that drilling with denser mud requires more power to maintain the desired nozzle pressure and fluid circulation.

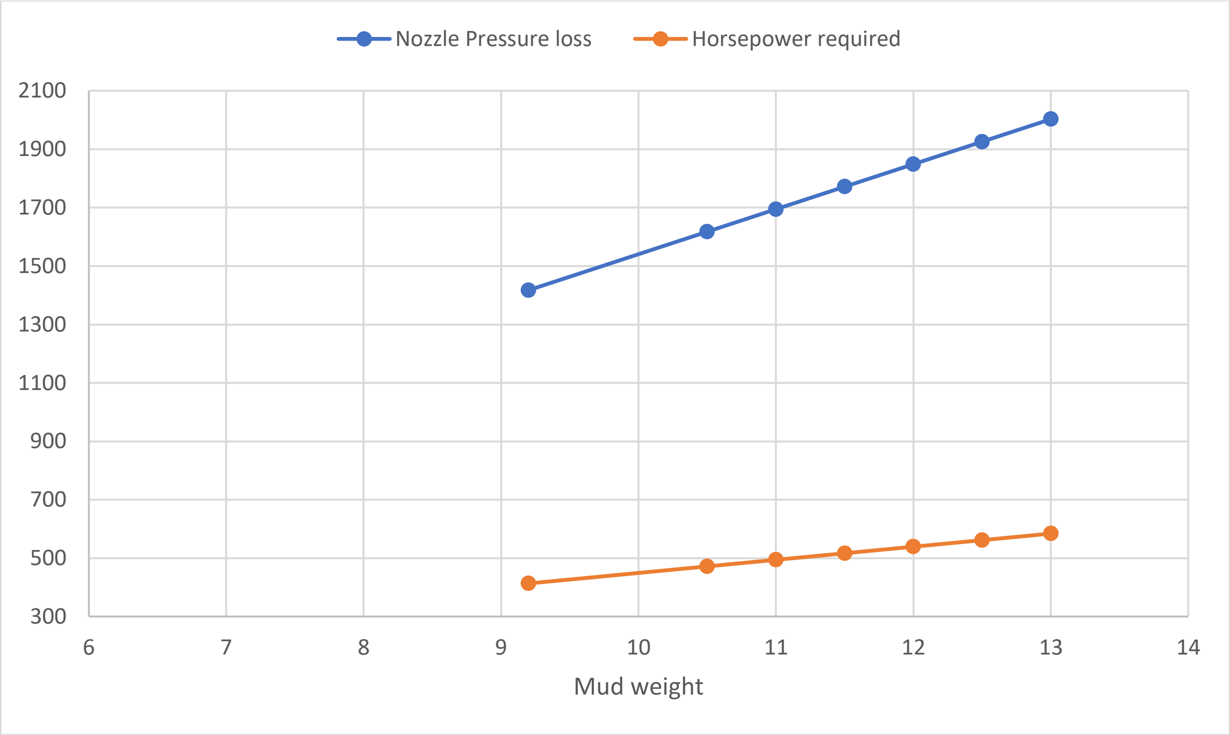

Figure 4.2.3: Figure showing the relationship between mud weight (MW), bit nozzle pressure loss (ΔP), and horsepower required (HHP)

Understanding the relationship between mud weight, bit nozzle pressure loss, and horsepower required is crucial for drilling engineers and operators. Denser mud weights may necessitate adjustments in drilling parameters and equipment to accommodate higher nozzle pressure losses and power requirements. Precise control of mud weight is essential to maintain efficient drilling operations while minimizing unnecessary power consumption. This analysis highlights the practical implications of controlling mud weight for wellbore stability, equipment selection, and overall drilling efficiency.

4.3 CUTTINGS ANALYSIS

4.3.1 Volume of Cuttings Generated per Foot of Hole Drilled

The relationship between porosity and the volume of cuttings generated per foot of hole drilled is a critical aspect of drilling operations. The data in Table 4.3.1 presents this relationship:

Table 4.3.1: Table showing the relationship between porosity and the volume of cuttings generated per foot of hole

dh (in)	Porosity (%)	Vol_cut/ft (bbl/ft)
8.5	14	0.060
8.5	27	0.051
8.5	48	0.036

The dataset reveals a clear correlation between porosity and the volume of cuttings generated. As porosity increases, there is a corresponding decrease in the volume of cuttings per foot of hole drilled (figure 4.3.1). This trend has significant implications for drilling efficiency and cuttings management.

Higher porosity in the rock formations results in greater space for the cuttings to disperse and settle. As a result, the volume of cuttings generated per foot of hole drilled decreases, indicating that porous formations tend to produce fewer cuttings.

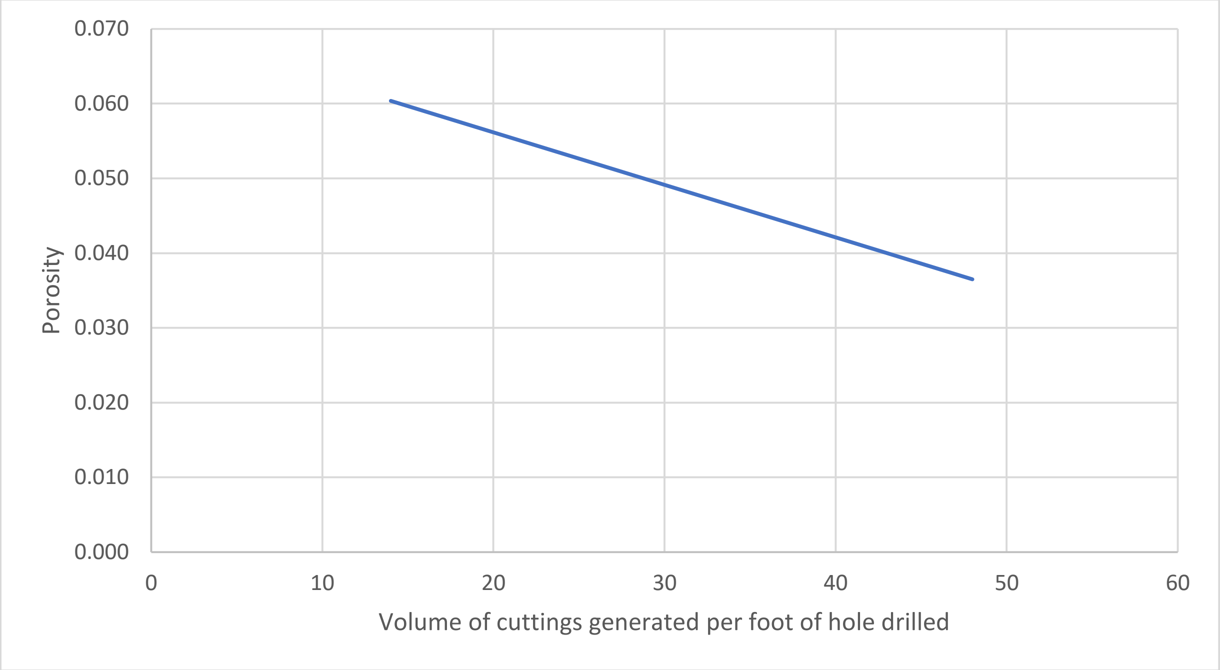

Figure 4.3.1: Figure showing the relationship between porosity and the volume of cuttings generated per foot of hole

This relationship underscores the importance of geologic knowledge and formation evaluation in drilling planning. Understanding the porosity of the rock formations encountered during drilling enables operators to anticipate and manage cuttings production effectively.

4.3.2 Volume of Solids Entering the Mud System While Drilling (Shale Shaker)

The relationship between the Rate of Penetration (ROP) and the volume of cuttings entering the mud system is a critical parameter in drilling operations. The data in Table 4.3.2 presents this relationship:

Table 4.3.2: Table showing relationship between the Rate of Penetration (ROP) and the volume of cuttings

Porosity (%)	dh (in)	ROP (ft/hr)	Vc (lb/hr)
25	26	62	30.55
36	28	98.3	47.93
48	32	164	84.87

The dataset in table 4.3.2 illustrates a direct relationship between the ROP and the volume of cuttings entering the mud system. As the ROP increases, the volume of cuttings per hour also increases (fig 4.3.2). This relationship has significant implications for cuttings management and wellbore stability.

A higher ROP often indicates more aggressive drilling and, consequently, an increased rate of cuttings generation. This can lead to challenges in maintaining wellbore stability and efficient cuttings removal.

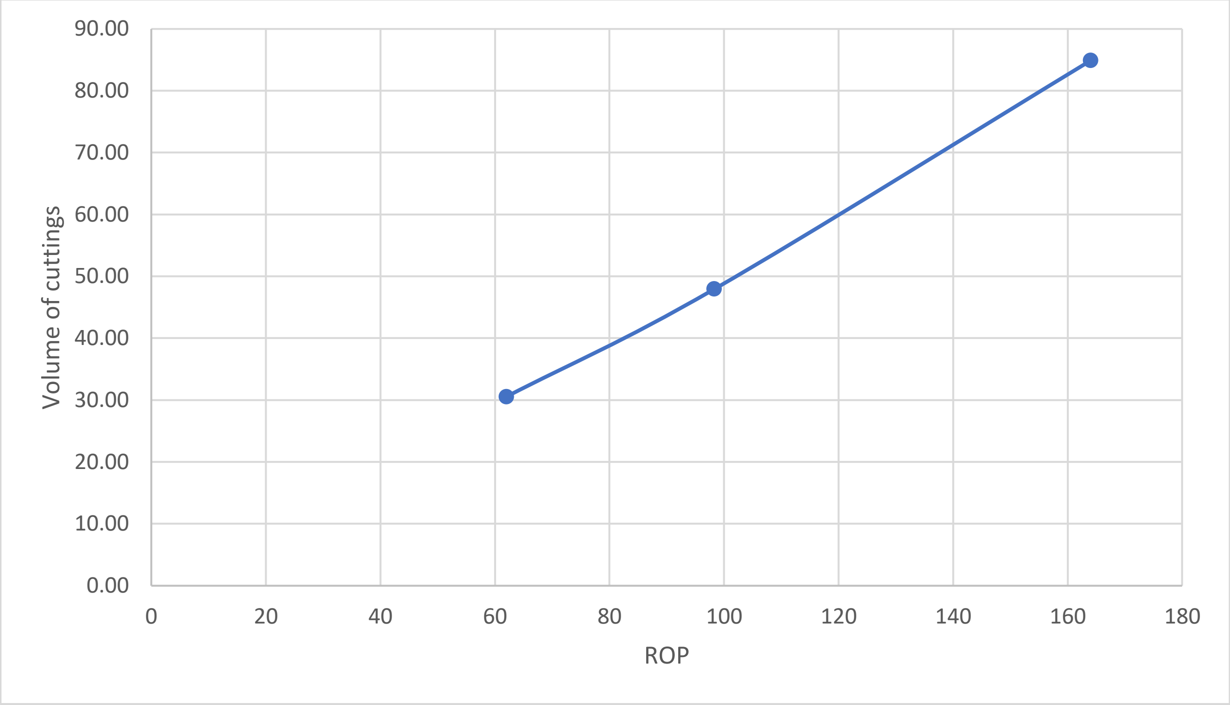

Figure 4.3.2: Figure showing relationship between the Rate of Penetration (ROP) and the volume of cuttings

Operators must carefully manage the balance between drilling speed (ROP) and the ability to control and remove the generated cuttings from the wellbore. Failure to do so can result in issues like lost circulation and wellbore instability.

4.4 HYDROCLONE ANALYSIS

Fig 4.4 provides a detailed analysis of how variations in slurry weight affect the drilling process. It presents data on the mass rate of discharged solids and the volume of liquid ejected for different slurry weights. This data was obtained through systematic experimentation, keeping other parameters constant.

4.4.1 Mass Rate of Discharged Solids

The mass rate of discharged solids is a critical parameter in drilling operations as it directly affects hole cleaning, drilling efficiency, and equipment wear. In Table 4.4.1, we observe the following trends:

- As slurry weight increases from 1 ib to 10 ppg, the mass rate of discharged solids increases from 4.54ib/hr to 45.38ib/hr. This trend suggests that denser slurry weights may result in lower volumes of solids being transported to the surface.
- The increase in mass rate of discharged solids with higher slurry weight can be attributed to increased suspension capacity, where denser mud can effectively suspend a larger volume of cuttings.

Table 4.4.1: Mass Rate of Discharged Solids

MW	Hd(%)	weight_of slurry	Vol_slurry(quarts)	Solid mass rate	v(gal/hr)
13	**34.85**	**10**	**2**	**45.38**	**39.09**
13	**34.85**	**8**	**1.6**	**36.30**	**31.27**
13	**34.85**	**5**	**1**	**22.69**	**19.54**
13	**34.85**	**2**	**0.4**	**9.08**	**7.82**
13	**34.85**	**1**	**0.2**	**4.54**	**3.91**

4.4.2 Volume of Liquid Ejected

The volume of liquid ejected is another crucial aspect of drilling operation. It impacts mud circulation, cuttings transport, and overall wellbore stability. In Table 4.4.1, we observe the following trends:

- With the decrease in slurry weight from 1Ib to 10 Ib, the volume of liquid ejected decreases from 39.09 gal/hr to 3.91gal/hr (Figure 4.4.1). This indicates that denser mud requires less liquid volume for effective cuttings transport.
- The increase in liquid volume ejected with higher slurry weight aligns with the trend observed in the mass rate of discharged solids. Denser mud suspends cuttings more efficiently, reducing the need for excess liquid.

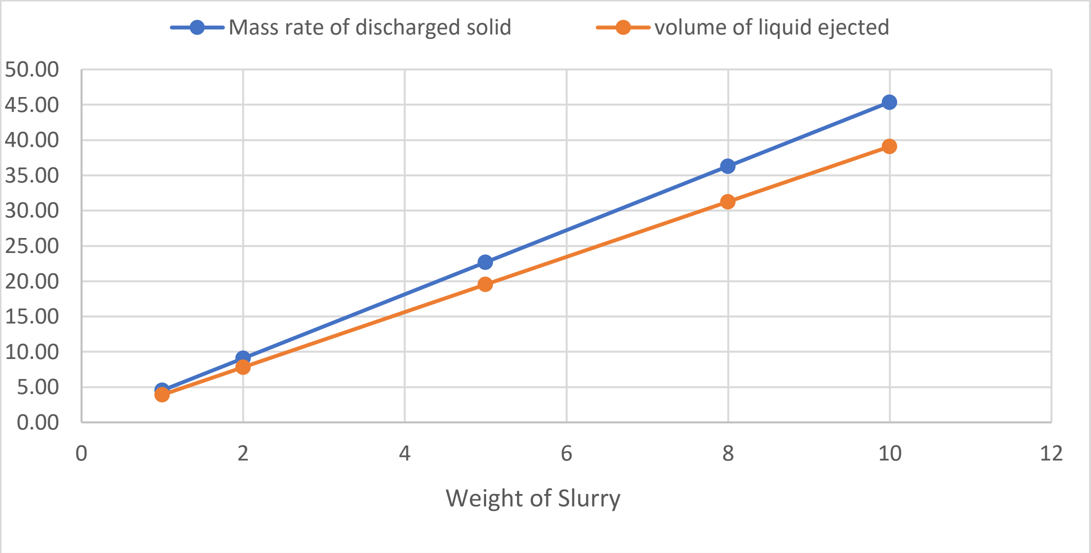

Figure 4.4.1 Volume of Liquid Ejected

CHAPTER FIVE

CONCLUSION AND RECOMMEDATION

5.1 CONCLUSION

Throughout our investigation, we've delved deep into the intricate web of parameters governing drilling operations, unearthing valuable insights crucial for surface facilities. Our analyses, spanning various aspects of drilling, offer a holistic view of how to finesse equipment selection, streamline processes, and maintain the integrity of drilling fluids.

1. **Pump Displacement and Rotor Diameter**: We unveiled the intimate connection between pump displacement and rotor diameter, recognizing its pivotal role in the sizing of mud pumps. This insight underscores the importance of selecting appropriately sized pumps to manage drilling fluid volume effectively and to ensure operational efficiency.
2. **Mud Weight and Bit Nozzle Pressure Loss**: Our exploration into mud weight, bit nozzle pressure loss, and the required horsepower elucidates the practical implications of mud weight control. It's evident that denser mud necessitates adjustments in drilling parameters and equipment to cope with higher nozzle pressure losses and power requirements, ultimately safeguarding wellbore stability and optimizing drilling operations.

3. **Solids Control Equipment Deployment**: A key revelation centers on the volume of cuttings generated per foot of hole drilled and the volume of cuttings entering the mud system. These parameters should serve as your guideposts for deploying solids control equipment. When these values exceed recommended thresholds, it's time to consider employing desilters and desanders to maintain drilling fluid cleanliness.
4. **Hydrocyclone Efficiency**: Our analysis of hydrocyclone (desilters and desanders) efficiency provides a valuable snapshot of their performance under varying drilling conditions. The critical takeaway is that these devices can significantly benefit from reduced mud flow rates and the use of finer screens, which enhance their cuttings removal efficiency.

5.2 RECOMMENDATION

Based on the outcomes of our rigorous evaluation, we propose the following recommendations:

1. **Mud Weight Control:** Drilling engineers and operators should maintain a vigilant stance towards mud weight, tailoring it to specific drilling conditions and wellbore stability requirements. Continual monitoring and adjustment of mud weight parameters ensure efficient drilling operations.

2. **Mud Pump Selection:** Selecting mud pumps with displacement capacities commensurate with drilling fluid volume demands is paramount. Engineers should leverage the relationship between pump displacement and rotor diameter to optimize drilling equipment and enhance well control measures.
3. **Pipe Diameter Consideration:** In multiphase flow systems, careful consideration of pipe diameter choices is essential to balance particle transport and energy conservation. Drilling operators must align pipe size with operational requirements for efficient drilling fluid circulation.
4. **Solids Control Deployment:** Drilling engineers should closely monitor cuttings generation and influx into the mud system. When these values exceed recommended thresholds, prompt deployment of solids control equipment, including desilters and desanders, is advised to maintain drilling fluid cleanliness and wellbore stability.

In summation, our evaluation of surface facilities during drilling underscores the paramount importance of informed decision-making in optimizing drilling processes. By adhering to these recommendations and leveraging the insights gained through our analysis, drilling operations can enhance efficiency, safety, and overall performance. Our study not only contributes to the body of knowledge in drilling engineering but also empowers practitioners to navigate drilling challenges effectively and achieve success in their projects.

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