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Comprehensive Risk and Environmental Analyses of High-Performance Water Based Mud

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Dedications

To my dear mother and family…

My friends…

To everyone how was part of the success…

-Elmaki

To my beloved parents…

My wonderful sisters, Chaima and Maria…

My brother Youssef…

My dear friends…

Your unwavering support and encouragement have been my greatest strength every step of the way.

-Kenza

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Comprehensive Risk and Environmental Analyses of High-Performance Water Based Mud

Abstract: - Drilling operation is a crucial stage in the oil production process. Similar to other fields, the petroleum sector faces significant challenges that require effective and sustainable solutions. Among these solutions, especially concerning drilling fluids, we find High-Performance Water-Based Mud (HPWBM), presented as an alternative to oil-based mud used in most drilling operations. Despite its proven efficacy in drilling, it is essential to assess this type of mud regarding its risks and environmental impacts. Therefore, this study aims to develop a comprehensive assessment of the risks associated with HPWBM in terms of well stability, human health, and environmental impacts. The assessment encompasses all activities and stages related to drilling mud, from preparation, circulation, analysis, and maintenance to disposal. To achieve this, various methodologies and risk analysis techniques were employed: HAZOP, HARC, and SERIECH software, along with environmental impact assessments. The results of the risk assessment indicate that the most significant risk occurs with continuous direct contact with the mud or its chemical components, leading to potential health effects. Regarding well stability, the analysis results show that HPWBM requires continuous monitoring of its properties to ensure effectiveness. In terms of environmental impacts, HPWBM has minimal environmental impact, except for water resource depletion due to its water-based composition. Therefore, HPWBM can be considered a more sustainable and environmentally friendly solution, with the necessity of adhering to safety measures and ensuring continuous monitoring of its properties during drilling operations to maintain its high performance.

Keywords: HPWBM, Drilling mud, Risk assessment, Environmental analyses**.**

تحليـــــل المخاطـــــر والتأثيرات البيئيـــــة للطيـــن الحفر ذو الأساس المائي عـــــالي الأداء

ملخـص: - يُعد التنقيب عن البترول مرحلة أساسية في عملية إنتاج النفط، وكغيره من المجالات، يواجه قطاع البترول تحديات كبيرة تتطلب إيجاد حلول فعالة ومستدامة. ومن بين هذه الحلول، خاصة فيما يتعلق بموائع الحفر، نجد طين الحفر ذو الأساس المائي عالي الأداء (HPWBM)، الذي قُدّم كبديل لطين الحفر ذو الأساس الزيتي المستخدم في معظم عمليات الحفر. ورغم ثبوت فعاليته العالية في عملية الحفر، فإنه من الضروري دراسة هذا النوع من الطين من ناحية المخاطر على صحة الإنسان وتأثيراته البيئية. ولذا تهدف هذه الدراسة إلى وضع تقييم شامل للمخاطر المتعلقة بـ HPWBM من حيث مدى استقرار البئر وتأثيراته على صحة العمال والبيئية. حيث يشمل التقييم جميع النشاطات والمراحل المتعلقة بطين الحفر بداية من عملية التحضير. الحفر، التحليل والصيانة حتى نهاية استخدام. وللقيام بذلك، تم استخدام عدة منهجيات وطرق لتحليل المخاطر، HAZOP وHARC وبرنامج SERIECH، وكذلك تقييم التأثيرات البيئية. أظهرت نتائج تقييم المخاطر أن أكبر خطر يكون عند الاتصال المباشر بين المائع أو أحد مكوناته الكيميائية باستمرار، مما قد يؤدي إلى تأثيرات صحية. أما من ناحية مدى استقرار البئر، فقد أظهرت نتائج التحليل أن HPWBM يتطلب مراقبة خصائصه بشكل مستمر لضمان فعاليته. بالنسبة للتأثيرات البيئية، فإن HPWBM ليس لديه تأثير بيئي كبير، باستثناء استنفاذ الموارد المائية بسبب ان مكونه الأساسي هو الماء. وبالتالي، يمكن القول إن HPWBM يمكن اعتماده كحل أكثر استدامة وأقل تأثيراً على البيئة، مع ضرورة الالتزام بتطبيق معايير السلامة الضرورية والحرص على مراقبة خصائصه أثناء عملية الحفر لضمان ادائه العالي.

كلمـات دلاليـة: موائع الحفر، طين الحفر ذو الاساس المائي عالي الأدائ, تحليل المخاطر, التحليل البيئي.

Analyses Complètes des Risques et de l'Environnement des Boues à Base d'Eau à Haute Performance

Résumé

L'opération de forage est une étape cruciale dans le processus de production pétrolière. Comme d'autres domaines, le secteur pétrolier est confronté à des difficultés importantes qui requièrent des solutions efficaces et durables. Parmi ces solutions, notamment en ce qui concerne les fluides de forage, on trouve la boue à base d'eau à haute performance (HPWBM), présentée comme une alternative à la boue à base de pétrole utilisée dans la plupart des opérations de forage. En dépit de son efficacité prouvée dans le forage, il est essentiel d'évaluer ce type de boue en ce qui concerne ses risques et ses impacts sur l'environnement. C'est pourquoi cette étude vise à développer une évaluation compréhensive des risques associés à l'HPWBM en termes de stabilité des puits, de santé humaine et d'impacts sur l'environnement. L'évaluation englobe toutes les activités et étapes liées aux boues de forage, depuis la préparation, la circulation, l'analyse et l'entretien jusqu'à l'élimination. Pour ce faire, diverses méthodologies et techniques d'analyse des risques ont été utilisées : HAZOP, HARC et SERIECH, ainsi que des évaluations de l'impact sur l'environnement. Les résultats de l'évaluation des risques indiquent que le risque le plus important est lié au contact direct et continu avec la boue ou ses composants chimiques, ce qui peut avoir des effets sur la santé. En ce qui concerne la stabilité des puits, les résultats de l'analyse montrent que l'HPWBM nécessite une surveillance continue de ses propriétés pour garantir son efficacité. En ce qui concerne les impacts sur l'environnement, la boue à base d'eau à haute performance a un impact minimal sur l'environnement, à l'exception de l'épuisement des ressources en eau en raison de sa composition à base d'eau. Par conséquent, le HPWBM est considéré comme une solution plus durable et plus respectueuse de l'environnement, avec la nécessité de respecter des mesures de sécurité et d'assurer une surveillance continue de ses propriétés pendant les opérations de forage afin de maintenir ses performances élevées.

Mots-clés : HPWBM, boue de forage, évaluation des risques, analyses environnementales.

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Acronyms

CHS	Clay Hydration Suppressant
ECD	Equivalent Circulated Density
ECD	Equivalent Circulation Density
ENAFOR	Entreprise Nationale de Forage
ENT	Ear, Nose, and Throat
ETA	Event Tree Analyses
HARC	Hazard Analyses and Risk Control
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HPWBM	High Performance Water Based Mud
HSE	Health Safety Environment
INRS	Institut National de Recherche et de Sécurité
LGS	Low Gravity Solides
LOPA	Layer Of Protection Analyses
LOTO	Lockout Tagout
OBF	Oil Based Fluids
OBM	Oil Based Mud
PHA	Preliminary Hazard Anlyses
PPE	Personal Protective Equipement
PTW	Permit To Work
QRA	Quantative Risk Assessment
ROP	Rate Of Penetration
SBF	Synthetic Based Fluids
SDS	Safety Data Sheet
SEIRICH	Système d'Evaluation et d'Information sur les Risques Chimiques
WBF	Water Based drilling Fluids
WBM	Water Based Mud

General Introduction

The oil and gas industry are a complex, multi-faceted field that encompasses a number of essential activities. It begins with the exploration of potential reserves and extends to the drilling, production, refining and distribution of these precious resources. Among these activities, drilling is particularly vital because it marks the point at which theoretical exploration is transformed into practical extraction.

The principle behind this process is to create wellbore in the earth's strata in order to explore for and extract oil and natural gas and it comprises several stages, including drilling, circulation and casing.

In the drilling operations, there is always a need to discover and research new technologies to improve well operations and maximize the efficiency of the process, in one way or another, by controlling the type and properties of drilling fluids.

Drilling mud is designed to facilitate the drilling process by achieving a number of goals, such as maintaining the stability of the wellbore against formation pressure, transport cuttings generated by the drill bit to the surface, lubricating and cooling the drill bit and drill string etc.

One of the new technologies is the improvement of water-based mud performance by adding chemical additives that target issues such as reduced lubrication, which leads to increased friction and bit wear, and the hydration and swelling of shale formations. This enhanced formulation is known as High Performance Water-Based Mud (HPWBM).

Considering all new technologies and proposed solutions from the perspective of Health, Safety, and Environment (HSE) is crucial due to the significant impact these factors have in any industry. Ensuring that a proposed solution does not negatively impact human health, equipment, processes, or the environment is vital for sustainable development. Given the intricate interconnection between these aspects, they must be prioritized in the development and evaluation of new technologies.

As High-Performance Water-Based Mud is a recent innovation in the field of petroleum exploration, it is necessary to evaluate it from the standpoint of HSE. This includes assessing the effectiveness of this type of mud in performing the required tasks while maintaining worker health and ensuring the smooth operation of the drilling process. Additionally, it is.

essential to determine whether this type of mud truly represents a more sustainable and less harmful solution for the environment

From this perspective, this study aims to provide a comprehensive analysis of the risks and environmental impacts associated with HPWBM. The goal is to identify potential risks that workers might face during all stages of drilling, from the preparation of the mud to its circulation, testing, maintenance, and disposal. The study will also examine all possible accident scenarios, evaluate the risks accurately, and propose necessary measures to either reduce the likelihood of occurrence or mitigate the severity of the risks, ensuring that operations can be carried out safely.

Furthermore, the study aims to assess the stability of the well during drilling with HPWBM, considering any changes in its properties, and to identify potential causes and their likely outcomes. Preventive measures will then be proposed to ensure the smooth operation of the drilling process.

To cover all necessary aspects, the study also aims to evaluate the environmental impacts related to HPWBM. This comprehensive environmental analysis will help determine the feasibility of replacing other types of drilling mud, such as oil-based muds with significant environmental impacts, with HPWBM as a viable alternative. It will also identify any weaknesses that need to be addressed to ensure that HPWBM has minimal environmental impacts.

This thesis manuscript consists of four detailed chapters:

Chapter 1: Provides a comprehensive overview of essential concepts in drilling, focusing on defining drilling processes, rotary drilling systems, and the critical role of drilling fluids. This chapter elaborates on the functions and types of drilling fluids, with a specific emphasis on High Performance Water-Based Mud.

Chapter 2: Introduces fundamental concepts of risk management processes and environmental analysis. It starts by defining basic terms related to risk assessment and explains the systematic steps of risk management. Additionally, this chapter offers an in-depth overview of environmental analysis techniques.

Chapter 3: Covers the application of various methods to evaluate the risks associated with HPWBM. This includes a thorough examination of the risks during both the fabrication and circulation processes of the mud. Furthermore, the chapter includes an evaluation of well stability, providing insights into how HPWBM impacts the structural integrity of wells during drilling operations.

Chapter 4: Evaluates the environmental impacts of HPWBM, discussing the significant challenge of its non-recyclability and the resulting environmental concerns. This chapter also provides a detailed overview of relevant Algerian regulations, examining how they address the environmental challenges posed by drilling fluids.

Finally, this thesis is closed with a general conclusion describing the main results of this research work.

Chapter 1

Introduction to Drilling and Drilling Fluids

1.1 Introduction

In the exploration and production of oil and gas, drilling stands as a fundamental operation, serving as the initial step in accessing subsurface reservoirs. This chapter provides a comprehensive overview of essential concepts in drilling, focusing on defining drilling processes, rotary drilling systems, and the critical role of drilling fluids, including their functions and types, with a specific emphasis on High Performance Water-Based Mud (HPWBM).

1.2 Definition of Drilling

Drilling operation is a complex process that involves boring a wellbore to extract oil or gas. The process of drilling involves several stages including boring, circulation, and casing. For this operation, drilling rig is installed, and an integrated system including the equipment such as mud tanks and pumps, derrick, drill string, power generation equipment (Balilehvand, 2023), while rotary drilling is the most common technique used to create boreholes for the exploration and exploitation of earth resources, such as oil and natural gas. The essential components of a rotary drilling system consist of a rotary table or a top drive at the surface to rotate the drill string, a drill bit at the wellbore bottom to excavate the rock, and a drill string to transmit the rotational energy from the surface to the drill bit (I. Kessai, 2020).

1.3 Rotary drilling Systems

Rotary drilling systems are designed to make a link between the surface of the earth and the deposit that may contain gas and oil reserves. This connection is carried out in the form of a hole from the surface to a certain depth (I. Kessai, 2020).

Although drilling rigs differ greatly in outward appearance and method of deployment, all rotary rigs have the same basic drilling equipment. The main component parts of a rotary rig are:

- Power system
- Hoisting system
- Rotary system
- Well control system
- Circulating system

— **Hoisting System** serves the crucial function of lowering or raising drill strings, casing string, and other subsurface equipment into or out of the hole. Its principal components include the derrick and substructure, crown block, travelling block, draw works, and drilling line.

- **Rotary System** is designed to rotate the drill string during drilling operations. Its principal components consist of the rotary table, Kelly or Top Drive, Kelly Bushing, and Master Bushing.
- **Power System** stands as a cornerstone in drilling operations, powering the machinery that drives the main components of the rigs. This system encompasses draw works, pumps, the rotary table, and the engines of various auxiliary facilities.
- **Well Control System** is indispensable for preventing the uncontrolled flow of formation fluids from the wellbore, ensuring operational safety and integrity
- **Circulating System** plays a significant role in removing rock cuttings from the hole as drilling progresses (Jadeer, 2021).

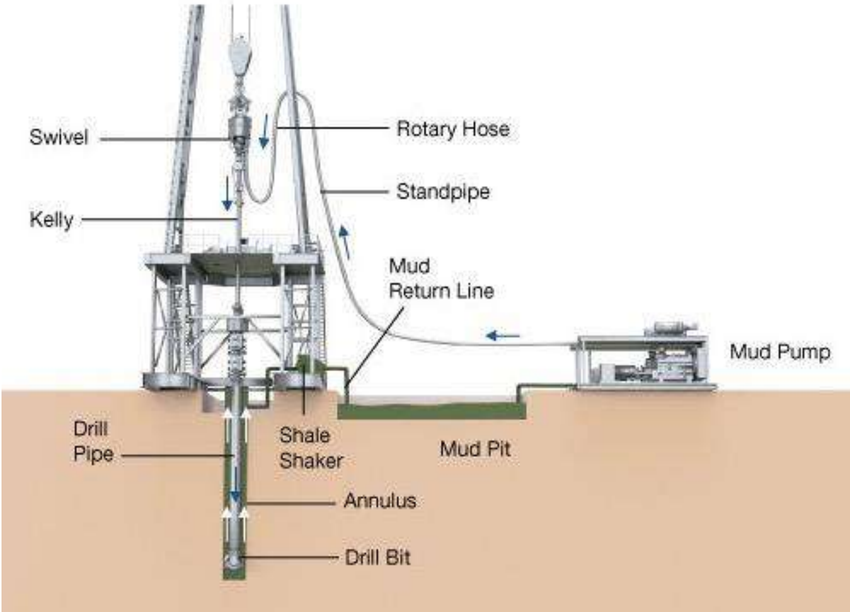


Figure 1-1 :Drilling Mud Circulation System *(*Petroleumonline, 2024*)*

1.4 Drilling Fluids

Drilling fluids are any fluids which are circulated through a well in order to remove cuttings from a wellbore. The fluid is pumped down the drill string, through the nozzles of the bit, and returns back up the annulus between the drill string and the wellbore walls, carrying the cuttings produced by the bit action to the surface. The main function is to clean the hole while drilling but the drilling fluid also serves to cool the bit, provide power to the mud motor and measuring-while-drilling tool, support the walls of the hole and control the well pressure.

The drilling fluids are complex mixtures formed from solids, liquids, chemicals, and sometimes even gases (Kalkan, 2019).

1.5 Drilling Fluids Functions

Functions of drilling fluids are crucial for safe and efficient well construction. The key functions are:

- **Removal of Cuttings:** Drilling fluids transport rock fragments (cuttings) generated by the drill bit to the surface for disposal. This prevents them from accumulating in the wellbore, which could hinder drilling progress and potentially cause wellbore instability.
- **Wellbore Pressure Control:** Drilling fluids exert hydrostatic pressure on the wellbore walls, counteracting formation pressures and preventing unwanted fluids (formation fluids) from entering the wellbore. This helps maintain well control and prevents blowouts.
- **Wellbore Stability:** Drilling fluids can interact with the formation rock to prevent sloughing and collapse of the wellbore walls. Clays in the drilling fluid can form a thin filter cake on the wellbore wall, minimizing fluid invasion into the formation and stabilizing the wellbore.
- **Cooling and Lubrication:** Drilling fluids cool and lubricate the drill bit and drill string, reducing friction and heat generation. This extends tool life, minimizes wear and tear, and improves drilling efficiency.
- **Suspension and Transport:** Drilling fluids suspend weighting materials (e.g., barite) to maintain the desired hydrostatic pressure. They also help suspend drilled cuttings while circulating, preventing them from settling and potentially causing problems during drilling or well completion.
- **Formation Evaluation:** Drilling fluids can play a role in formation evaluation by carrying formation cuttings to the surface for analysis. Additionally, some drilling fluids can be formulated to minimize formation damage, allowing for more accurate evaluation of the formation's potential (Ben Mahmoud, 2022; Parate, 2021).

1.6 Drilling Fluids Properties

The large number of functions performed by the drilling fluid that require minimum properties of the fluids can be maintained. The most critical properties are density, viscosity, chemical composition, and fluid loss control.

1.6.1 Density

Considering the density as the first parameter of Drilling fluids. For the desired densities greater or lower than one, Water Based Mud (WBM) or Oil Based Mud (OBM) can be used, respectively. Generally, for both WBM and OBM, mud density can be increased by adding various soluble materials or solids. Other undesirable solids issued from geologically drilled formations cannot be removed easily but can be reduced to finer particles, which may have some adverse effects on properties of fluid. So, these phenomena need to be avoided and we do it by using high speed shale shakers (Parate, 2021).

1.6.2 Viscosity

Considering the viscosity as the second parameter of Drilling fluids. It is defined as the internal friction generated by a fluid when a force is applied to flow. The internal friction is a result of the interaction between the molecules of a liquid and it is related to a shear stress. As the resistance of shear stress increases, viscosity also increases. The standard viscosity measurements do not define flow nature within shear rate ranges imposed at the pits, bit, annulus. The viscosity at the bit affects the rate of penetration, which can be better when viscosity is lower. The viscosity in the annulus affects efficiency of cleaning holes and the viscosity in the pits influences the effectiveness of solids separation techniques. Numerous chemical agents are added to the formulation in order to reach specific purposes which are sometimes contradictory. For example, mud has to be more viscous in order to lift the cuttings to the surface, but on the other hand, viscosity must not be very high in order to minimize friction pressure loss (Parate, 2021).

1.6.3 Plastic viscosity

Plastic viscosity is essentially described as the resistance of a fluid to flow (Agwu, 2021). It can be defined as the resistance offered by a fluid to flow freely. This resistance is a result of friction between the liquid undergoing deformation under shear stress and the solids and liquids present in the drilling mud. PV is an important rheological characteristic that affects properties of drilling fluid (Trenchlesspedia, 2023).

PV should be as low as possible for fast drilling and is best achieved by minimizing colloidal solids. YP must be high enough to carry cuttings out of the hole, but not so large as to create excessive pump pressure when starting mud flow. YP is adjusted by judicious choices of mud treatments. The direct-indicating rotational rheometer was specifically designed to apply the Bingham plastic fluid model (SLB, 2024).

Plastic viscosity depends upon 4 things:

1. Liquid Phase Viscosity
2. Size of Particles
3. Shape of Particles
4. Number of Particles (Leon Robinson, 2020).

1.6.4 March funnel Viscosity

Marsh Funnel viscosity (reported in seconds) is frequently used for monitoring the relative change in the consistency (i.e., relative viscosity) of the drilling fluids. This test is quick, simple and requires very little equipment. Using power law rheological model, estimated the effective viscosity of drilling fluids from Marsh Funnel readings (Guria, 2013).

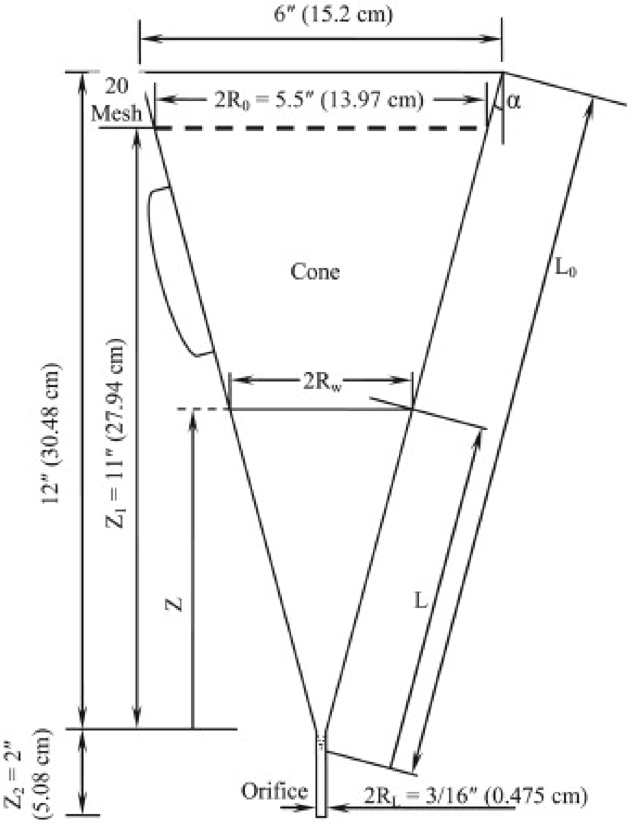


Figure 1-2 : Schematic representation of standard Marsh Funnel *(*Guria, 2013*)*.

1.6.5 Fluid loss

Considering the fluid loss as the last parameter of Drilling fluids. It is defined as the volume of the drilling mud which is passed into the formation through the filter cake obtained during drilling. It can be prevented by blending the mud with additives. A large number of factors affected by the fluid-loss properties of a drilling fluid, including time, temperature, compressibility, nature, amount and size of solids present in the drilling mud (Parate, 2021).

1.6.6 Yield point

The yield point is the resistance to initial flow and represents the stress required to start the fluid movement. If the applied stress is below the yield stress, then the fluid will display strain recovery when the stress is removed. This resistance is due to electrical charges located on or near the surface of the particles. Higher yield point leads to larger frictional pressure losses and an increase in the equivalent circulation density (ECD) (Agwu, 2021).

Yield point is a function of electrochemical behavior or effect of long chain polymers. An increase in plastic viscosity usually means that drilled solids are increasing in the drilling fluid. An increase in yield point could indicate some chemical contamination or degradation of chemicals used to maintain the yield point. PV indicates solids problems. YP indicates chemical problems. (Leon Robinson, 2020)

1.7 Drilling Fluids Types

Drilling fluid systems are comprised of a blend of liquid, solid, and occasionally gaseous elements. They are classified into gas, aqueous, or nonaqueous systems depending on their predominant phase. These systems are carefully tailored by incorporating various components to adjust specific properties like viscosity and density. The subsequent sections will delve into the primary classifications of drilling fluid.

1.7.1 Oil-Based Fluids (OBF)

Oil-based fluids (OBFs) are used for formulated with diesel, mineral oil, or low-toxicity linear olefins and paraffins. The olefins and paraffins are referred to as "synthetics" and they are derived from distillation of crude oil and some are chemically synthesised from smaller molecules. Internal brine or water phase electrical stability is monitored for strength of the emulsion is maintained at or near a predetermined value. The emulsion should be stable such that it incorporates additional water volume if a downhole water flow is encountered. Oil based mud has a special advantage for their unmatched performance for drilling. The good rheological properties such as temperature of 500∘F, has special advantage in OBM and is more inhibitive than water base mud such as effective against all types of corrosion and permits density less than 7.5 ppg. Reduction in production damage, gauge hole in evaporate formations, and resistance to chemical contamination are additional advantages.

1.7.2 Synthetic-Based Fluids (SBF)

Synthetic-based fluids, also known as non-aqueous drilling fluids, consist of a continuous phase of synthetic materials such as mineral oils, biodegradable esters, or olefins. While more expensive than water-based fluids, synthetic-based fluids offer superior borehole control, thermal stability, lubricity, and penetration rates. These characteristics can help operators save money in the long run by enhancing drilling efficiency and reducing operational risks. Synthetic-based drilling fluids are particularly beneficial in challenging drilling environments where water-based fluids may not be as effective.

1.7.3 Water-Based Fluids (WBF)

Water-based drilling fluids are the most diverse type of drilling fluid and are commonly used in various drilling operations. These fluids range in composition from simple blends of water and clay to more complex inhibitions. In recent years, there has been a focus on improving the inhibition thermal apposition of water-based systems to compete with non-aqueous fluids used in challenging drilling environments. Water-based drilling fluids are preferred in sensitive locations due to cost and environmental implications, as they are considered environmentally superior alternatives to oil-based fluids. They are known for their ability to cycle drilled cuttings to the surface, suspend cuttings during drilling halts, and provide lubrication to the drill bit, making the drilling process easier (Parate, 2021).

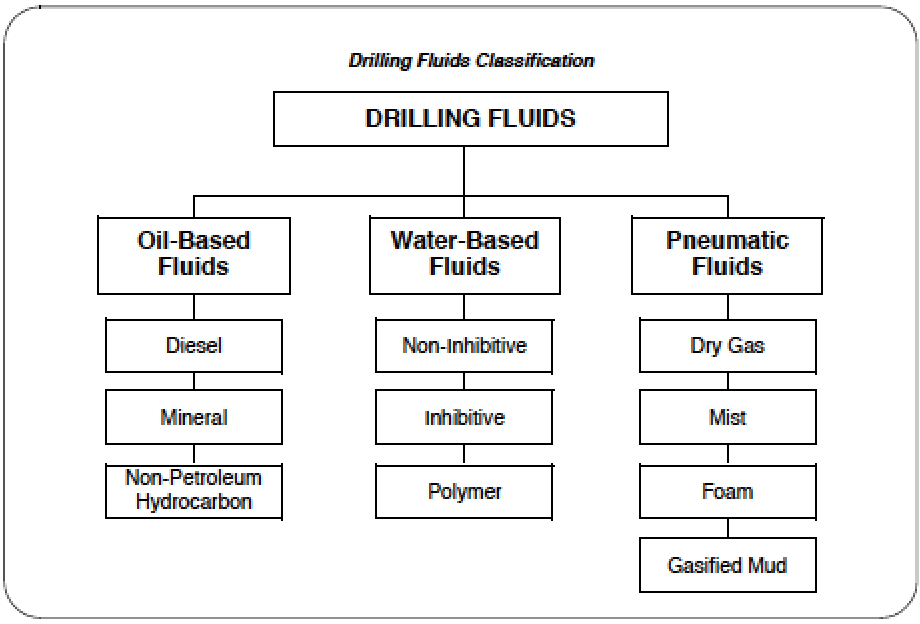


Figure 1-3: Drilling Fluids Classification *(Parate, 2021)*

1.8 High Performance Water-Based Mud (HPWBM)

The High-Performance Water-Based Mud (HPWBM) is a specialized drilling fluid system engineered with a unique composition of additives and components to optimize drilling operations while meeting stringent environmental standards. This innovative mud system is characterized by its low-salinity formulation, which not only enhances drilling performance but also minimizes environmental impact. The HPWBM is designed to provide superior wellbore stability, improve rates-of-penetration, reduce bit balling, and mitigate torque and drag issues commonly encountered during drilling activities.

The HPWBM furthermore uses a clay hydration suppressant (CHS) to stabilize highly reactive clays through a mechanism of cation exchange. The CHS inhibits reactive clays from hydrating and becoming plastic, which provides a secondary benefit of reducing the tendency towards bit balling. Its exceptional performance in the field has surpassed expectations based on laboratory analysis, setting new industry benchmarks and establishing it as the preferred fluid choice for challenging drilling operations, such as those in the West Urdaneta Field of Lake Maracaibo (Montilva, 2007).

1.9 Conclusion

This chapter presents a comprehensive overview of drilling and drilling fluids, with a specific focus on rotary drilling. It explores the details of the five primary drilling systems, namely power, hoisting, circulating, rotating, and well control, explaining their respective components and functions. The significance of drilling fluids is highlighted, particularly in tasks such as cuttings removal, pressure control, and ensuring wellbore stability. Additionally, the chapter examines various properties of drilling mud, such as density and viscosity. By laying down this groundwork, the chapter sets the stage for a deeper exploration of drilling practices and the role of drilling fluids in subsequent sections.

Chapter 2

Risk Assessment and Environmental Analysis

2.1 Introduction

Chapter "2" introduces fundamental concepts of risk management processes and environmental analysis. In risk management, terms like risk and hazard are defined: risk represents the likelihood and consequences of an event, while a hazard is a potential source of harm. Risk analysis involves identifying, assessing, and prioritizing risks, followed by risk assessment to evaluate their likelihood and severity. Risk acceptance acknowledges certain risks, while risk mitigation aims to reduce or eliminate them. Various methods exist for risk analysis and evaluation. Environmental analysis involves assessing environmental aspects, identifying impacts, and implementing measures to minimize adverse effects. This chapter provides a basic understanding of these concepts, setting the stage for further exploration.

2.2 Terms and definitions

2.2.1 Definition of Hazard

A hazard is the potential of a substance, activity or process to cause harm. Hazards take many forms including, for example, chemicals, electricity and the use of a ladder. A hazard can be ranked relative to other hazards or to a possible level of danger (Phil Hughes, 2009).

2.2.2 Definition of Risk

A risk is the likelihood of a substance, activity or process to cause harm. Risk (or strictly the level of risk) is also linked to the severity of its consequences. A risk can be reduced and the hazard controlled by good management (Srinivas, 2019)

2.3 Risk Management Process

Risk management is a process that aims to reduce the harmful effects of an activity through conscious action to anticipate unwanted events and plan to avoid them. Risk management can be thought a process of measuring or evaluating risk and then designing strategies for risk management. Overall, the strategies used include transferring risk to other sectors, avoiding risk, reducing the negative effects of risk and accepting a part or all of the consequences of a particular risk (Samimi, 2020)

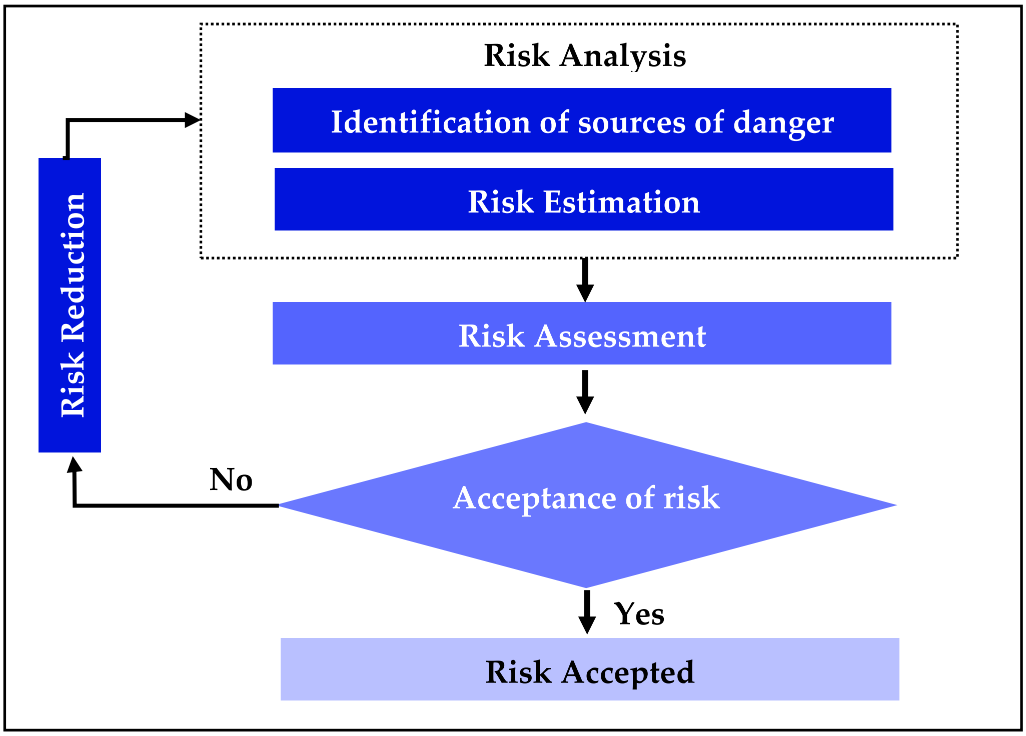


Figure 2-1 Risk Management Process (ISO 31000, 2018)

2.3.1 Risk Analysis

The analysis of risks occupies a central place in the risk management process. This step serves to define the system or installation to be studied by collecting all the necessary information and data. In this section, a three-level description, structural, functional and temporal, is indispensable in order to conduct an effective analysis and achieve the desired objectives in terms of risk management. (Misra, 2016) Firstly, the main sources of danger and accident scenarios must be listed and identified. The complexity of certain systems studied requires the use of analysis tools helping to identify dangers. Examples include HAZID (Hazard Identification), HAZOP (Hazard and Operability Study), PHA (Preliminary Hazard Analysis) and others. These analysis tools also make it possible to identify the various safety barriers existing in the system studied. Once the hazard is identified, the associated risk must be estimated. The estimation can be qualitative, semi-quantitative and/or quantitative in terms of the probability of its occurrence and the severity of its consequences on people, property and the environment (Phil Hughes, 2009).

2.3.2 Risk Assessment

After estimating the risk, it must be compared to the acceptability criteria previously established by the company concerned. This evaluation makes it possible to make a decision on the acceptability or unacceptability of each risk (Misra, 2016). The objective of risk assessment is to recognize the relative significance of some risks compared to others (Habegger, 2009).

2.3.3 Risk Acceptance

The acceptability of a risk is based on its two parameters. The level of quantified risk will be positioned in an evaluation matrix and according to the acceptability criteria retained whether the acceptability or non-acceptability of the risk is judged. If the risk is deemed acceptable, the management process will be completed and the judged risk will be monitored. Otherwise, the process continues by moving to the reduction stage (Babu & Veluthambi, 2016)

The figure (Figure 2-2) bellow shows the matrix used by SLB company.

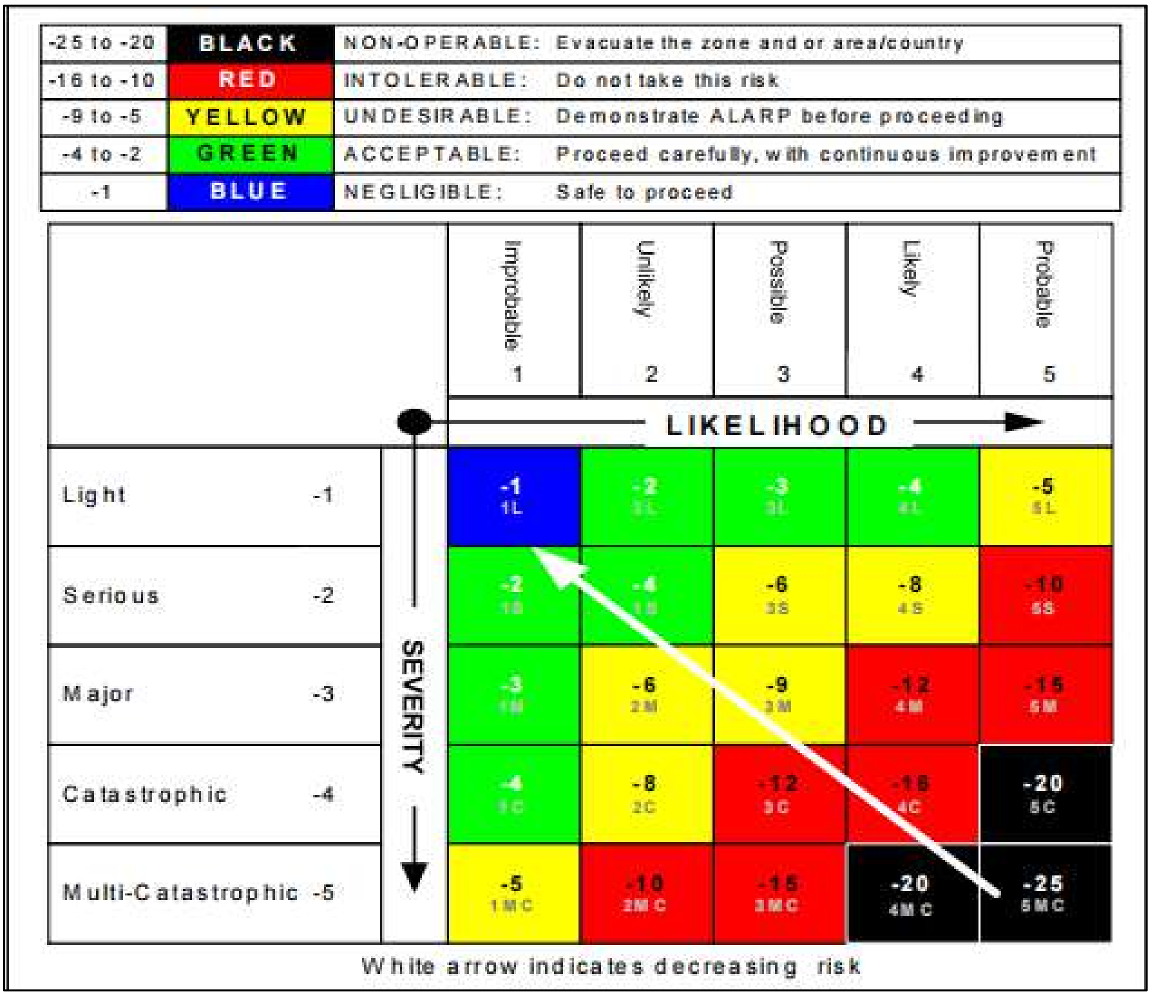


Figure 2-2: SLB Risk Evaluation Matrix

2.3.4 Risk Reduction

This step consists of implementing the various prevention and protection measures and barriers in order to reduce the intensity of the dangerous phenomenon (potential reduction of danger, mitigation of consequences) and reduce its probability of occurrence (Phil Hughes, 2009). In addition to technical and equipment reliability improvements, prevention also involves better consideration of risk factors linked to the organization and people. The choice of preventive actions to be undertaken is made by comparing the costs of their implementation with the costs of the risk consequences, taking into account their probability of occurrence. Regular monitoring of the evolution of risks is recommended in the risk management approach in order to control and ensure the relevance of the preventive actions undertaken and to correct the planned measures (Misra, 2016).

2.4 Risk Analysis and Evaluation Methods

In this section, we will provide a concise overview of the primary methodologies employed in the process of risk analysis. These methodologies will be categorized into three main groups: qualitative methods, semi-quantitative methods, and quantitative methods.

2.4.1 Qualitative methods

Qualitative risk analysis serves as a foundational step preceding any further analysis. It facilitates a comprehensive comprehension and systematic understanding of the system under study and its constituent elements. For effective qualitative risk assessment, this approach does not solely depend on numerical data but instead draws upon pertinent observations regarding the system's state, particularly emphasizing feedback and expert judgments. This methodology necessitates a profound understanding of the various parameters and factors associated with the system under examination. In certain hazard assessments, a well-executed and justified qualitative approach may suffice to attain the desired objectives (Coleman & Marks, 2019).

Many qualitative risk analysis and assessment tools exist, among which we find the PHA and HAZOP.

2.4.2 Semi-Quantitative Methods

Semi-quantitative risk analysis represents an intermediate approach that diverges from both purely qualitative and purely quantitative methods. It strives to mitigate the inherent subjectivity of qualitative data by enhancing precision and accuracy, while also addressing the potential limitations in data robustness associated with quantitative approaches (David C. Simmons, 2017).

A multitude of analysis and evaluation tools with a semi-quantitative nature have been devised such as LOPA (Layre of Protection Analyses).

2.4.3 Quantitative Methods

Quantitative risk analysis stands out as the predominant approach for informed risk decision-making. It revolves around characterizing various risk analysis parameters through probabilistic measurements.

The acquisition of these measurements typically involves mathematical manipulation, incorporating data pertaining to the evaluated parameters as well as other quantitative information. In applying this approach, meticulous consideration must be given to the data sources, their reliability, and their relevance to the specific cases under examination, as any oversight could jeopardize the integrity of the study (Macpherson, 2018).

The Event Tree Analysis (ETA) and Quantitative Risk Assessment (QRA) epitomize this category of methodologies.

2.5 Environmental Analyses

2.6 Terms and Definitions

2.6.1 Environment

Abiotic and biotic natural resources such as air, atmosphere, water, soil and subsoil, fauna and flora including genetic heritage, interactions between these resources as well as natural sites, landscapes and monuments (Law No. 03-10 , 2003).

2.6.2 Pollution

Any direct or indirect modification of the environment caused by any act that results in, or is likely to result in, a situation detrimental to human health, safety or well-being, or to the flora, fauna, air, atmosphere, water, soil and collective or individual property (Law No. 03-10 , 2003).

2.6.3 Impact

An Environmental Impact represents all the modifications to the environment engendered by an activity. These modifications can be positive or negative from an environmental perception perspective. In order to assess an Environmental Impact, it is necessary to characterize it, but also to know the surrounding environment, and in particular its "sensitivity". An Environmental Impact can have a positive effect: if treated water is discharged, it may be of better quality than that which was drawn. It can be direct (greenhouse gas emissions from the combustion of fossil fuels), indirect (use of chemicals that are only dangerous when mixed or when "contaminated" products are consumed), or both (production of waste that has a direct impact on the collection chain, but which can also be polluting) (ISO 14001, 2015).

2.6.4 Aspect

Anything that happens within organization that interacts with the environment, which means it and has a potential environmental impact. This encompasses both negative and positive interactions with the environment. It is an element of an organization's activities, products or services that may impact, or does impact, the environment. An environmental impact is a result of an environmental aspect (ISO 14001, 2015).

Table 2-1: Difference between impact and the environmental aspect (Thenthoughtor, 2024*)*

Activity, Service	Environmental Aspect	Environmental Impact
Car washing	Using water	Impact to natural resources
Heating	Emission from boiler	Air pollution
Storage of fuel in above-or underground tank	Potential for leakage or spill	Contamination of soil and groundwater

2.6.5 Environmental Analysis

Environmental analysis is based on the identification of legal requirements, environmental aspects and impacts. In particular, it must take into account impacts on the environment, including air, water, landscape, soil and subsoil, resources used (via energy consumption, for example), waste production, noise emissions, and natural and technological risks (Dalloz, 2023).

Environmental analysis consists of an analysis of an organization's activities, products and services that are likely to have an impact on the environment. This analysis must enable the organization to identify which of its activities, products and services have, or may have, significant environmental impacts, and in relation to which it can envisage improvement.

The relevance of the analysis is crucial to the effectiveness of the environmental management system. The organization must not lose sight of the fact that this approach must itself be part of a continuous improvement process. This process must demonstrate the organization's ability to keep this analysis up to date, particularly when changes or developments are likely to occur in the processes, products or equipment used by the organization. (ISO 14001, 2015).

An overall environmental analysis method can be divided into 4 stages:

1. Identify the activities of the organism and the surrounding environment
2. Determine the significant environmental aspects and impacts.
3. Identify and evaluate environmental aspects and impacts from a life-cycle perspective
4. Define risks and opportunities related to environmental aspects and impacts (Dalloz, 2023).

2.7 Conclusion

This chapter has introduced essential concepts of risk management processes and environmental analysis. By defining terms like risk, hazard, and environmental aspects, it has provided a foundational understanding of identifying, assessing, and mitigating risks, as well as analyzing environmental impacts. These insights underline the importance of proactive risk management and good environmental management in a variety of contexts, laying the foundations for effective strategies to ensure operational integrity and environmental sustainability.

Chapter 3

Comprehensive Risk Assessment of High-Performance Water-Based Mud

3.1 Introduction

Chapter 3 delves into the comprehensive risk assessment of High-Performance Water-Based Mud (HPWBM), encompassing both its fabrication and circulation processes. This chapter meticulously examines the various risks associated with HPWBM, employing advanced methodologies and tools to identify hazards and mitigate potential dangers throughout its lifecycle. Through the utilization of SEIRICH software, Hazard Analysis and Risk Control (HARC) methodology, and Hazard and Operability (HAZOP) analysis, the aim is to provide a thorough understanding of the safety considerations involved in HPWBM usage.

3.2 Methodological Framework

To achieve a comprehensive risk analysis encompassing all facets from mud formulation, worker exposure during circulation, to well stability during mud circulation, we underwent three main steps, each employing specific methods and sourcing data from relevant companies. Initially, we assessed the chemical risks of products used in HPWBM fabrication using the SEIRICH software, obtaining data from MI-SWACO Company. Subsequently, we evaluated risks associated with activities involving mud contact, utilizing the HARC (Hazard Analysis and Risk Control) method developed by SLB company, applied at the ENF 61 rig of ENAFOR company. Finally, we employed the HAZOP methodology to assess well stability during mud circulation at the same ENF 61 rig. Figure 3-1 below summarizes all the steps, data sources, and methods used.

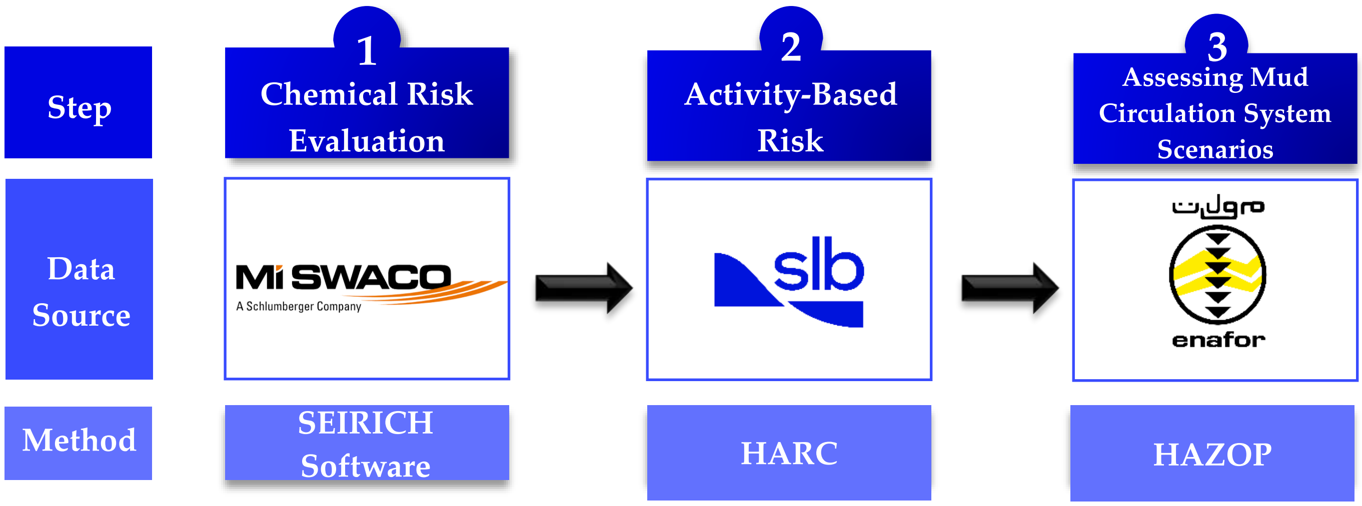


Figure 3-1 Methodological Framework.

3.3 Chemical Risk Evaluation

In order to evaluate the chemical risks associated with HPWBM used in the drilling operation of HTF-18 well, Section 16'', using Nabors NDIL-283 rig sold to SONATRACH Company and completed by MI-SWACO (MI Algeria SPA). In this evaluation, we used SEIRICH software and collected the necessary data from the company, which includes the drilling fluid proposal presented by MI-SWACO to SONATRACH, the safety data sheet (SDS) for each product and product bulletins that describe the chemical and physical properties of the products. The evaluation was conducted during four basic steps:

1. Definition of areas of use and inventory of labeled products and chemical agents emitted, to characterize their dangers.
2. Prioritization of potential risks to classify products requiring detailed assessment.
3. Evaluation of residual risks taking into account the physicochemical properties of the product, the context of use and collective and individual protective equipment.
4. Planning preventive actions to reduce risks.

3.3.1 Presentation of SEIRICH Software

A tool helps to assess and prevent chemical risks and take into account the risks to health, safety and the environment developed by INRS on 2005.

The methodology includes several steps implemented as functionalities: inventorying of products and emitted substances, ranking of products and emitted substances according to their risk level, chemical risk assessment adapted to the user's degree of expertise, technical and legal advice adapted to the context, follow-up for prevention actions. (Seirich, 2024)

3.3.2 Application of SEIRICH Software

3.3.2.1 Definition of product use areas and inventory

At the outset of our chemical risk assessment, a novel operational entity, MI-SWACO, was established. Subsequently, a dedicated unit for the rig HTF-18 well was formed, directly linked with the drilling mud team. This unit encompasses all essential tasks for HPWBM preparation, encompassing drilling fluid additives, fluid loss control, pH modifier, viscosifier, and weighting agents, as illustrated in Figure 3-1.

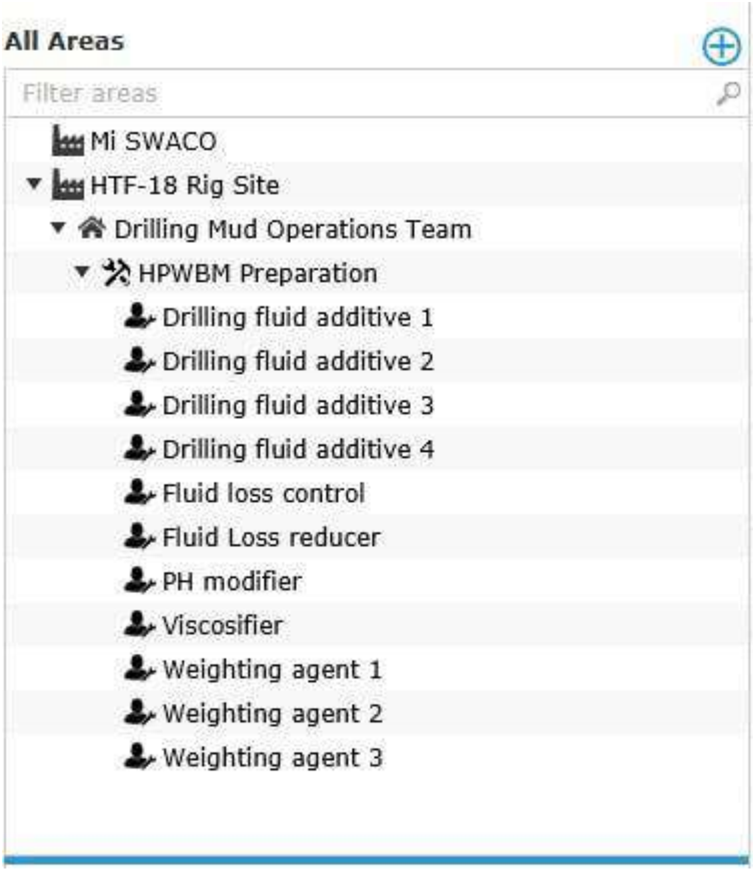


Figure 3-2 Definition of product use areas.

The chemical products inventory is a crucial process of chemical risk assessment, focusing on three categories of information for each product, which we have compiled from various documents that we have obtained:

Product identification:

- Name: The full names of the products.
- Supplier: Indication of the product supplier, if available.
- SDS (Safety Data Sheet): Possibility of saving the SDS in electronic format in SEIRICH.
- Other Information: Include additional details such as photos to aid recognition.

Product Hazards:

- Hazard Statements: Entering information from the label and SDS to identify hazards associated with the product.
- Pictograms: Addition of relevant pictograms for quick visualization of dangers.
- Safety advice: Inclusion of safety advice to inform about safety measures.

Consumption:

- Quantity Used: Recording of the quantity of each product used in the Chemistry Unit.

- Potential Exposure Indicator: Entering consumption serves as a key indicator to assess the level of potential exposure.
- Global or Zone Entry: Depending on the level of the user, consumption can be entered globally or by zone, in accordance with the prioritization of potential risks described in the second step of the process.

Figure 3-2 shows the products inventory in SEIRICH:

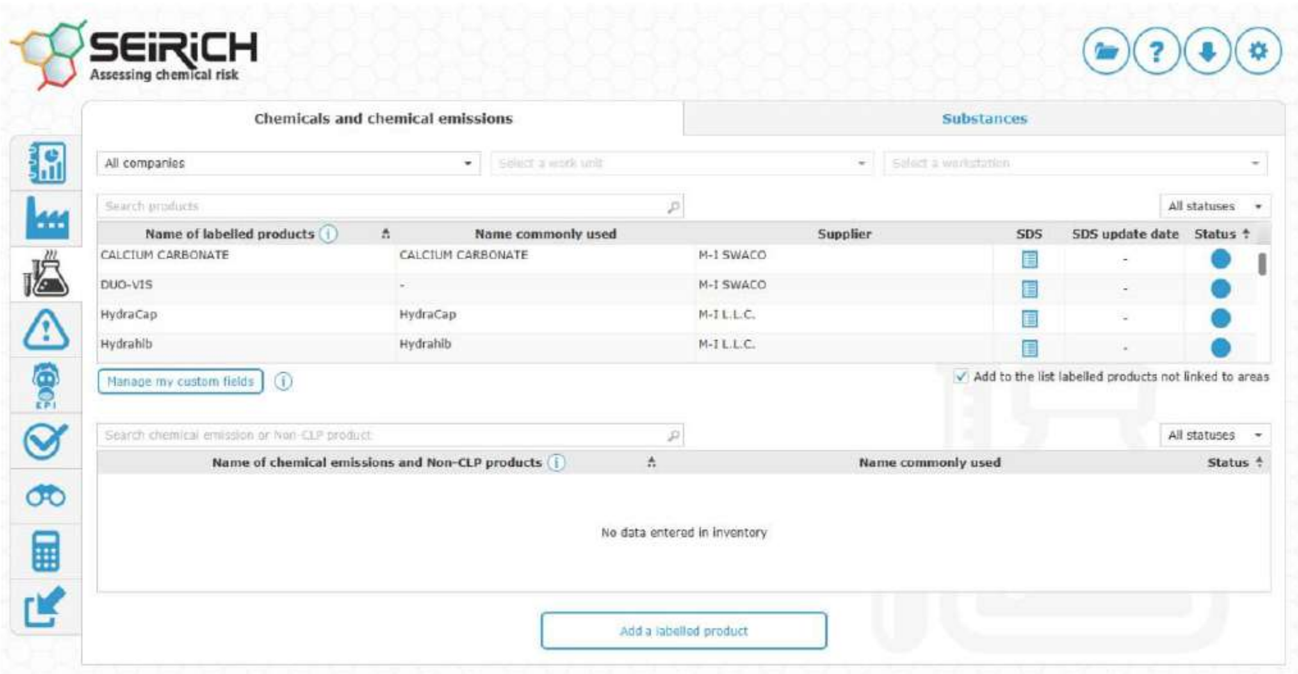


Figure 3-3 *HPWBM Product inventory.*

3.3.2.2 Prioritization of potential risks

Due to the substantial diversity of products and raw materials used within the establishment, the second step in our approach consists of prioritizing potential risks. This step aims to establish priorities for further assessments or actions by first addressing the most significant potential risks.

The prioritization of products, identified during the inventory, is based on the inherent dangers and the quantities used within drilling. This prioritization process is segmented into three distinct categories: health impact, potential for combustion, and environmental impacts as it is shows in Table 3-3.

Table 3-1: Prioritization of Potential Risks.

Prioritization

Health

Fire

Environment

Labelled products

CALCIUM CARBONATE	CALCIUM CARBONATE	CALCIUM CARBONATE
Barite	Barite	Barite
SODA ASH	SODA ASH	SODA ASH
HydraCap	HydraCap	HydraCap
Ultrafree	Ultrafree	Ultrafree
Hydrahib	Hydrahib	Hydrahib
DUO-VIS	DUO-VIS	DUO-VIS
LUBE-167	LUBE-167	LUBE-167
M-I PAC	M-I PAC	M-I PAC
POLY-SAL HT	POLY-SAL HT	POLY-SAL HT
POTASSIUM CHLORIDE	POTASSIUM CHLORIDE	POTASSIUM CHLORIDE

This prioritization of priorities linked to potential risks in SEIRICH is associated with a color code:

Green: moderate priority

Orange: high priority

Red: very high priority

The prioritization analysis of products indicates that CALCIUM CARBONATE and SODA ASH pose the highest health risk (very high), with other substances presenting a high-risk level, except for BARITE, which carries a moderate risk. In terms of fire hazard, HYDRACAP and ULTRAFREE are the most concerning, while the remaining substances pose a moderate risk. Regarding environmental impacts, the majority of products pose a moderate risk, although HYDRAHIB is identified as having a high-risk level.

3.3.2.3 Assessment of Residual Risks

The third step of our approach revolves around the assessment of residual risks. This phase involves a thorough risk assessment, taking into consideration impacts on health (inhalation, skin/eye) and safety (fire/explosion). This approach requires the collection of a more exhaustive set of information compared to the prioritization phase, particularly with regard to the conditions for implementing the various products.

The analysis of residual risk is based on observation of actual work and operating conditions. This phase requires a complete description of the characteristics of the different tasks performed by operators within a workstation. Estimating the residual risk associated with a specific task takes into account several factors, including:

— The dangers of chemical products.
— The physicochemical properties of the products, including their physical state and their volatility.
— The implementation conditions, such as the process used, temperature, skin exposure scenario, daily quantity, duration of tasks, etc.
— Collective protection means, including ventilation and storage procedures.
— The means of individual protection put in place.

From this detailed information, the risk inherent in each task is assessed for each specific combination (workstation/task/product). This approach allows a precise assessment of residual risks, thus promoting the implementation of adequate prevention and protection measures.

The level of residual risk is reflected in SEIRICH by a color code as it shows in Table 3-2:

- Green: moderate risk
- Orange: high risk
- Red: very high risk

Table 3-2: Assessment of Residual Risks.

Residual Risk

Inhalation

Skin - Eye

Fire

Labelled products

Inhalation	Skin - Eye	Fire
Weighting agent 2 - CALCIUM CARBONATE	PH modifier - SODA ASH	Drilling fluid additive 1 - HydraCap
PH modifier - SODA ASH	Weighting agent 2 - CALCIUM CARBONATE	Drilling fluid additive 3 - Hydrahib
Drilling fluid additive 1 - HydraCap	Drilling fluid additive 1 - HydraCap	Drilling fluid additive 4 - POTASSIUM CHLORIDE
Drilling fluid additive 3 - Hydrahib	Drilling fluid additive 2 - Ultrafree	Fluid loss control - M-I PAC
Viscosifier - DUO-VIS	Drilling fluid additive 3 - Hydrahib	Fluid Loss reducer - POLY-SAL HT
Drilling fluid additive 4 - POTASSIUM CHLORIDE	Drilling fluid additive 4 - POTASSIUM CHLORIDE	PH modifier - SODA ASH
Fluid loss control - M-I PAC	Fluid loss control - M-I PAC	Viscosifier - DUO-VIS
Fluid Loss reducer - POLY-SAL HT	Fluid Loss reducer - POLY-SAL HT	Weighting agent 1 - LUBE-167
Weighting agent 1 - LUBE-167	Viscosifier - DUO-VIS	Weighting agent 2 - CALCIUM CARBONATE
Weighting agent 3 - Barite	Weighting agent 1 - LUBE-167	Weighting agent 3 - Barite
Drilling fluid additive 2 - Ultrafree	Weighting agent 3 - Barite	Drilling fluid additive 2 - Ultrafree

Following the risk assessment and alignment of each product with its corresponding workstation and associated tasks, the findings are detailed in the health section: For inhalation risks, CALCIUM CARBONATE (Weighting agent 2) exhibits a high residual risk, while SODA ASH (pH modifier) poses a very high risk for skin/eye contact. Additionally, products such as CALCIUM CARBONATE (Weighting agent), HYDRACAP (Drilling fluid additive), ULTRAFREE (Drilling fluid additive), HYDRAHIB (Drilling fluid additive), POTASSIUM CHLORIDE (Drilling fluid additive), M-I PAC (Fluid loss control), POLY-SAL HT (Fluid Loss reducer), DUO-VIS (Viscosifier), and LUBE-167 (Weighting agent) are identified as high-risk contributors. Conversely, BARITE (Weighting agent) presents a moderate residual risk. In the fire section, all products are categorized with a moderate residual risk.

3.3.2.4 Action Plan

The fourth step in our chemical risk management process concerns the establishment of an action plan. The objective of chemical risk prevention goes beyond assessment alone; it aims to translate the results of the evaluation into tangible actions to be implemented in the company, with a view to improving the health, safety and working conditions of employees.

The proposed actions are listed in Table 3-3

Table 3-3: Action Plan

Action Name	Description
Storage Conditions	Store in a cool, dry place away from heat and moisture.
Storage Conditions	Store Ultrafree in its original containers or compatible containers tightly sealed to prevent contamination and degradation. Keep the product away from incompatible materials such as oxidizers or acids.
Safety Measures	Ensure proper labeling, provide PPE for handling, and implement spill containment measures.
Inventory Management	Track quantities of Soda Ash stored, including incoming shipments and usage. Regularly inspect containers for signs of damage or deterioration, and update inventory records accordingly.
Safety Measures	Label containers clearly with product name, hazard information, and handling precautions. Provide appropriate PPE for handling, such as gloves and safety goggles, as specified in the SDS. Implement spill containment measures and provide spill cleanup materials nearby.

Storage Area	Designate a dedicated area with proper ventilation and temperature control. Ensure the storage area is away from sources of heat, flames, or direct sunlight.
Storage Area	Designate a covered area with limited exposure to moisture and humidity
Storage Conditions	Store Soda Ash in its original containers or compatible containers tightly sealed to prevent contamination and degradation. Keep the product away from incompatible materials such as acids or oxidizers.
Storage Conditions	Store Hydrahib in its original containers or compatible containers tightly sealed to prevent contamination and degradation.
Storage Conditions	Store Potassium Chloride in its original containers or compatible containers tightly sealed to prevent contamination and degradation. Keep the product away from incompatible materials such as strong acids or oxidizers.
Storage Conditions	Store M-I PAC in its original containers or compatible containers tightly sealed to prevent contamination and degradation. Keep the product away from incompatible materials such as strong acids or oxidizers.

3.4 Activity-Based Risk Assessment

To analyze and mitigate risks associated with handling High Performance Water Based Mud (HPWBM) during activities, we employ the Hazard Analysis and Risk Control (HARC) method developed by SLB. This approach allows for the identification of potential risks and the effective implementation of control measures. We applied this method to the ENF 61 Rig, owned by the ENAFOR company, to enhance safety protocols and minimize operational hazards. Utilizing various documents such as job descriptions, process descriptions, and accident reports, along with conducting interviews with onsite personnel including Rig manager, workers, HSE supervisor, doctor, mud engineers, mud loggers, and drillers, facilitated the application of this method.

3.4.1 Hazard Analysis and Risk Control

Hazard Analysis and Risk Control (HARC) is designed by SLB to analyze risk prior to performing activities and to define risk control measures in order to reduce the risk. This is supported by a number of supplementary Action plan risk management tools/techniques.

The HARC process is made up of the following main steps:

- Select key task/process;
- Define activities and hazards;
- Assess the potential risk;
- Develop risk controls.

3.4.2 Application of HARC Method

The application method involves assessing the likelihood and severity of undesirable events for each identified hazard, considering preventive and mitigating measures. Likelihood assessment is based on formal experience or knowledge of similar operations, while severity assessment involves evaluating a "realistic worst-case" consequence. The potential impact of hazards on various stakeholders, the process includes identifying hazards directly and indirectly related to each step or sequence of the operation or process. Preventive measures aim to reduce the likelihood of undesirable events, while mitigating measures focus on minimizing their severity after they occur. This comprehensive assessment is summarized in table 3-4.

Table 3 4-: The application of HARC method

Activity / Process	Potential Loss			Potential risk			Measurs	
	Hzarad category	**Hazard description and worst case with consequences with no prevention/metegation in place**	**Population Affected**	**Likelihood**	**Severity**	**Risk level**	**Prevention measurs to reduce Liklihood**	**Metigation measurs to reduce severity**
Fabrication	Mechanical lifting	Transporting additive containers from the storage area to the hoppers presents risks including workers being struck by forklifts due to the absence of a banksman, potentially resulting in serious injuries	Surface operaters	3	3	9	• Provide training to forklift drivers on safe driving procedures. • Ensure a qualified banksman is present during the lifting operation. • Barricade the area and maintain proper signage around the operation area. • Reduce the distance between the storage area and the hoppers. • Authorize access to the area only for authorized workers. • Provide a lifting plan before starting the operation to ensure safe handling of additive containers.	• Ensure proper Personal Protective Equipment (PPE) is worn. • Ensure the availability of a first aid kit and a trained first aider on site.

							• Conduct regular safety inspections to identify and address potential hazards in the operation area.	
	Mechanical lifting	Forklift overturning due to heavy load, leading to serious injuries.	Driver	3	3	9	• Check that the load is suitable for the capacity of the truck. • Draw up a lifting plan before starting work.	•Ensure proper Personal Protective Equipment (PPE) is worn. •Ensure the availability of a first aid kit and a trained first aider on site.
	Toxic/ Corrosive/ Chemicals Hazardous	Spreading dry additives into the air while pouring them into the hoppers can lead to inhalation, causing severe respiratory irritation and systemic toxicity.	Driver/ Surface Operaters	4	4	16	• Determine the wind directly before starting. • Inform the potentially affected worker of the SDS of the product and discuss it with the supervisor. • Ensure that the driver is qualified. • Limit worker exposure time during pouring tasks. • Utilize enclosed hoppers with dust control mechanisms. • Ensure proper isolation between the hoppers and the forklift truck, allowing only the hanging container to enter this area	•Ensure proper Personal Protective Equipment (PPE) is worn. •Provide workers with respiratory protection equipment such as masks or respirators. •Ensure the availability of a first aid kit and a trained first aider on site. •Provide access to emergency eyewash stations and showers near work areas for quick decontamination.

	Manuel Lifiting	During the addition of additives, the operator carrying them may sustain a back injury due to incorrect lifting methods.	Roughneck/ Derrickmen/ Operaters	3	4	9	• Provide proper training on correct lifting techniques. Implement ergonomic design principles for handling and transporting additives. • Use mechanical lifting aids to assist with heavy loads. • Ensure that additives are packaged in containers with handles or lifting points for safe handling. • Ensuring that workers are aware of the exact weight of the load. • Carrying the load with the help of another person. • Organizing work to reduce repetitive movements and handling efforts. • Regular medical examinations	•Ensure the availability of a first aid kit and a trained first aider on site.
Mud Circulation	Toxic/ Corrosive/ Chemicals Hazardous	Releasing mud vapor from shale shakers and tanks may lead to inhalation, resulting in potential health risks including intoxication, ENT diseases,	Drilling Team	2	2	4	• Conduct regular maintenance of equipment such as shale shakers and tanks to prevent leaks or malfunctions. • Provide comprehensive training to workers on proper operating procedures and the potential	•Provide workers with respiratory protection equipment. •Ensure proper Personal Protective Equipment (PPE) is worn.

		respiratory irritation, and respiratory diseases					health risks associated with exposure to mud vapor. • Avoid standing on top of tanks for a long time, especially during times of high temperature. • Regular medical examinations.	•Provide access to emergency eyewash stations and showers near work areas for quick decontamination.
	Toxic/ Corrosive/ Chemicals Hazardous	The failure in the mud saver during tripping, may expose workers to mud splashes which lead to skin irritation.	Roughneck/ Roustabouts	4	4	16	• Regular maintenance and inspection of mud saver. • Sensibilization of workers about the risks related to contacting with drilling mud.	•Prompt decontamination of skin after exposure to mud splashes. •Access to medical evaluation for workers experiencing skin irritation.
	Stepping/ Slipping/ falling	Slipping on the rig floor due to lack of cleaning and inattention can result in serious injuries.	Roughneck /Driller/ Assistant driller/ Roustabouts	4	4	16	• Ensure regular housekeeping to keep the work area clean free from obstacles. • Use mud saver during tripping to avoid mud leak.	•Ensure proper Personal Protective Equipment (PPE) is worn. •Ensure the availability of a first aid kit and a trained first aider on site.
	Noise/ Nuisance	Workers are consistently exposed to noise and nuisances throughout all areas of the rig, which can result	Drilling team	4	2	8	• Provide a noise map and ensure that is well communicated. • Periodic inspections and maintenance of technical equipment and installations.	•Ensure proper Personal Protective Equipment (PPE) is worn. •Appropriate personal protective equipment in good condition: earmuffs,

		in both auditory and non-auditory issues.					• Training and awareness-raising on the risks associated with noise and its consequences.	earplugs. maintain acoustic cover for noisy equipment
Testing	Stepping/ Slipping/ Falling	While taking samples for testing mud parameters, workers may fall due to poor housekeeping or inattention, resulting in serious injuries.	Mud Engineer/ Mud Logger /Derrickmen	3	3	9	• Ensure regular housekeeping to keep the work area clean and free from obstacles. • Reduce the number of workers in the bacs floor. • Maintaining a slip hazard warning signs. • Increasing the number of workers and distributing the workload.	• Ensure proper Personal Protective Equipment (PPE) is worn. • Ensure the availability of a first aid kit and a trained first aider on site.
	Toxic/ Corrosive/ Chemicals Hazardous	During testing of mud parameters involving high temperatures and chemicals, direct skin contact with samples may result in skin irritation and burns of varying degrees.	Mud Engineer/ Mud Logger	3	4	12	• Increasing awareness of laboratory chemical hazards. • Implement engineering controls such as splash guards or barriers to minimize the risk of direct skin contact with samples. • Ensure thorough training on safe handling procedures for chemicals and hot substances.	• Ensure proper Personal Protective Equipment (PPE) is worn (specific PPE latex gloves-lab coat goggles) • Establish emergency response protocols for immediate treatment in case of skin contact with hot or chemical-laden samples.

									• Provide access to emergency eyewash stations and showers near work areas for quick decontamination.
Cleaning	Toxic/ Corrosive/ Chemicals Hazardous	Failure to detect toxic gases (such as H2S, CO, CO2) in the tank during cleaning operations can result in fatalities.	Roustabouts	2	5	10	• Ensure the gas detector is calibrated. • Establish a PTW (confined space) work permit and ensure that it is well communicated to workers. • Guarantee the presence of an external supervisor. • Measures the percentage of gas before entering the tank. • Barricade the entrance of the zone and maintain warning signs. • Rotate inside workers every 20 minutes.	• Ensure proper Personal Protective Equipment (PPE) is worn (specific respiratory PPE) . • Ensure the presence of emergency procedures for gas inhalation. • Provide a tripod at the top of the tank.

	Machinery/ Equipment/ Hand tools	During mud tank cleaning without isolating electrical power, the agitator can accidentally activate, striking and potentially killing the worker.	Roustabouts	2	5	10	• Barricade the entrance of the zone and maintain warning signs. • Ensure proper electrical isolation through Lockout Tagout (LOTO) procedures. • Test the isolation of the agitator before entering the tank.	•Ensure proper Personal Protective Equipment (PPE) is worn. •Ensure the presence of emergency procedures for gas inhalation. •Provide a tripod at the top of the tank.
	Pressure	Cleaning surfaces, pumps, etc., with a high-pressure Karcher can lead to serious injuries and skin irritation due to potential splashes of mud hitting the worker.	Roustabouts/ Drilling team	3	3	9	• Maintain sufficient distance between the Kercher and the worker.	•Ensure proper Personal Protective Equipment (PPE) and specific PPE (face shield ….)

Following the analysis of activities related to drilling mud—encompassing its fabrication, circulation, testing, and cleaning—the results and risk evaluation for each potential scenario indicate that the majority of high-risk potentials stem from direct contact with the mud or its chemical components. These risks are prevalent across most activities, making the fabrication process particularly high-risk, especially during mud preparation or the addition of additives due to the significant probability of exposure to hazardous chemicals as it is clear in the bellow chart (Figure 3-4).

Figure 3-4: Risk level by activity/process.

Additionally, the analysis identified risks associated with mud circulation in the event of equipment failure or process malfunction, where workers could be exposed to the mud. During the testing phase, the highest risk arises from sample collection and testing, where engineers are directly exposed to the mud. In the cleaning phase, workers are exposed to various hazards, including chemical exposure, slipping, and pressure hazards which are summarized in the Figure 3.5.

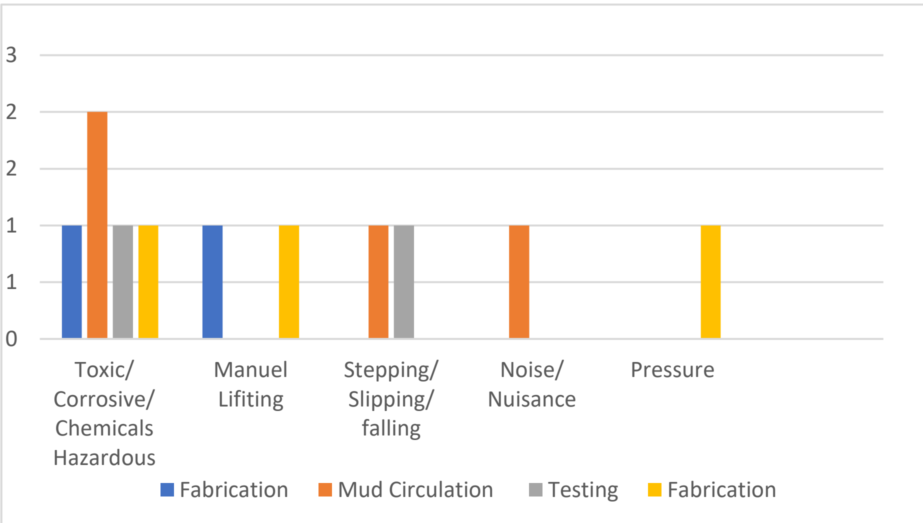


Figure 3-5: Hazard category by activity/ process.

The analysis highlights that roughnecks and roustabout are the most exposed to hazards due to their involvement in mud fabrication and additive incorporation, resulting in frequent contact with the mud As shown in the Figure 3-6 below.

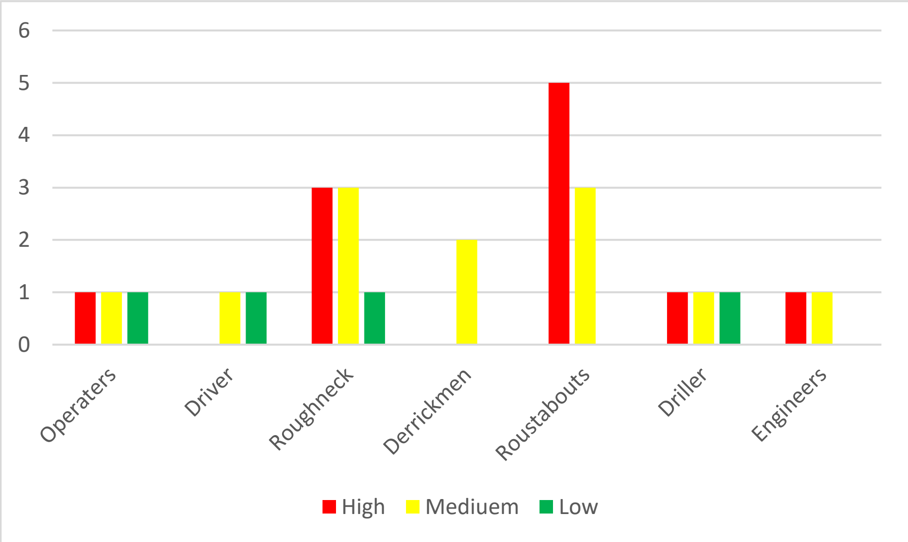


Figure 3-6: Risk level by population affected.

Based on the potential scenarios assessed, as well as the likelihood and severity of identified risks, we have proposed targeted prevention and mitigation measures to reduce the likelihood of occurrence and minimize the severity of these risks.

3.5 Assessing Mud Circulation System Scenarios

The aim of this study is to evaluate potential scenarios within the circulation system during drilling operations using HPWBM. We conducted a HAZOP analysis on the ENF 61 Rig, which was acquired by the ENAFOR company.

3.5.1 Hazard and Operability Study

HAZOP is a prevention measure for the loss of containment which may lead to a major accident. The process safety management directives call for a thorough HAZOP during the design phases. In operational phase, for any change which affects the process configuration, HAZOP shall be performed as a part of the Management of Change procedure. (Fabienne-Fariba Salimi, 2023)

HAZOP is essentially a qualitative procedure in which a small team consisting, e.g., of a process engineer, a control instrument expert, a risk analyst, and an operator, guided by an experienced chairman, examines a proposed design by generating questions about it in a systematic manner. For this purpose, a number of "guide-words" are used indicating potential deviations of a process parameter from the design intention. These deviation questions may reveal (often hidden) possible causes and the effects on process behavior, hence causes and effects of a possible fault. Commonly used guide-words are given in Table 3-1. The HAZOP study is function driven. Thus, potential safety and operability problems are identified and appropriate actions can be taken. A poorly operable process is usually also unsafe. (Pasman, 2020)

Guide-word + Parameter = Deviation

Table 3-5: Standard HAZOP guide-words and their generic meanings *(*Pasman, 2020*)*

Guide-word	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (less of, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution—another activity takes place
Where else	Applicable for flows, transfers, sources, and destinations
Before/after	The step (or some part of it) is affected out of sequence
Early/late sequence	The timing is different from the intention
Faster/slower	The step is done/not done with the right timing

Table 3-6: Examples of meaningful combinations of parameters and guide-words *(*Pasman, 2020*)*

Guide-word	Meaning
Flow	None; more of; less of; reverse; elsewhere; as well as
Temperature	Higher; lower
Pressure	Higher; lower, reverse
Level	Higher; lower; none
Mixing	Less; more; none
Reaction	Higher (rate of); lower (rate of); none; reverse; as well as/other than; part of
Phase	Other; reverse; as well as
Composition	Part of; as well as
Communication	None; part of; more of; less of; other, as well as

3.5.2 Application of HAZOP in the Circulation of HPWBM

The analysis involved the meticulous selection of various critical parameters such as viscosity, density, pressure, filtrate, level, and flow. By employing a range of guide-words, as outlined in Table 3-3, potential scenarios arising from deviations in these parameters were systematically identified. This thorough approach ensures a proactive stance in recognizing and addressing operational risks and to implement appropriate action plans and suitable safety measures

Table 37-: Application of HAZOP method

Parameter	Guide-word	Deviation	Possible Causes	Consequence	Detection	Safety Measures
Yield Point	More of	**More of yield point**	• Contamination by CO2, H2S gases, by contact with CaCo4 formation or by cement • Excessive treatment with viscosifiers_ • Increase the amount of low-gravity solids (LGS)	• Risk of formation • Fracturing due to increased hydrostatic pressure • $\boldsymbol{P_{hy} > P_f \rightarrow Loss}$	Measurement with Rheometer	• Using chemicals (thinner) to reduce the viscosity • Add fresh HPWBM • Mechanical treatment (removal of undesirable clays from the sludge) • Baryte recovery
	Less of	**Less of yield point**	At a considerable depth where the temperature is high the Yp will be proportional to this temperature • Contamination by fresh water • Treatment with viscosifiers	• Poor well cleaning • Risk of jamming to tool and drill string • Risk of formation fracturing due to the increase of ECD (Equivalent Circulated Density)		• Add viscosifiers products

Plastic & Marsh funnel Viscosity	More of	**More of Plastic & Marsh funnel Viscosity**	• Contamination by clay formation	• Increase the amount of low-gravity solids (LGS) • constraints (counterforce)	Measurement with Rheometer	• Mechanical treatment by mud cleaner and centrifugal • Add fresh HPWBM
	Lesss of	**Less of Plastic & Marsh funnel Viscosity**	• Contamination by fresh water	• Production column relief • Poor cleaning • Risk of packer jamming		• Add viscosifiers products
Density	More of	**More of Density**	• Increase the amount of cutting • Human error in mud preparation • Mud valves failure	• During drilling, there is a risk of loss (total loss, partial loss) • Risk of formation fracturing • Affects mud pump (pump failure) • Reduction of rate of penetration (ROP) • $P_{hy} > P_f \rightarrow Loss$	Measurement with Densimeter	• Reduce pumping rate of drilling pumps • Regular monitoring and control of density every 30 minutes • Maintenance of mechanical treatment circuit components • Periodic calibration of measuring instruments (densimeter) • Installation of a recording device, equipped with an alarm.

	Less of	**Less of Density**	• Contamination by CO_2, water or oil • Presence of Calcium chloride (LD2) in the formation • Human error in mud preparation • Mud valves failure	• Risk of well collapse • Risk of drilling tool jamming in case of mobile formations Increased pump torque • Having rotation problems • Possibility of splitting the drilling gear • In the case of unconsolidated formations, there is a possibility of having caving phenomena which lead to mechanical jamming.		• Mud weighting by using barite $BaSO_4$ and $CaCO_3$ Pumping of heavy mud • Add viscosifiers products
Hydrostatic Pressure	Higher	**Higher Hydrostatic Pressure**	• Increase in density and pumping flow • Surging effect when the drill string descends • Human error (control) caused by malfunction of measuring instruments (pressure gauge)	• Destruction of the formation • Loss of circulation • Contamination of the groundwater • Imbalance between hydrostatic pressure and formation pressure • $P_{hy} > P_f \rightarrow Loss$	Detect by the formula: Ph = DH/10.2 D: density H: column height	• Permanent monitoring of hydrostatic pressure and density • Calibration of measuring instruments • Periodic maintenance of pumps

	Lower	**Lower Hydrostatic Pressure**	• Mud loss at the formation level due to a drop in static level • Decrease in injected Mud density • Decrease in injected Mud flow rate (pump failure) • Surging effect • Filling defect	• Imbalance between hydrostatic pressure and formation pressure • Probability of a kick • Hole cleaning issue (open Hole) • Probability of rod sticking • $P_f > P_h \rightarrow kick$		• Continuous monitoring of hydrostatic pressure and density • Calibration of measuring instruments • Periodic maintenance of pumps
Filtrate	More of	**More of Filtrate**	• Reduction in the concentration of chemicals called reducers • Evaporation of mud at too deep levels • Contamination of mud with a liquid around the drilling bore	• Having a false interpretation of logging • Reservoir contamination • Packer jamming • Increase in differential pressure	API Filtrate	• Add filtrate less control agent to the mud

Flow	More of	**More of Flow**	• Increased pump delivery (pump failure) • False control caused either by human error or by failure of flow control instruments	• Increase in hydrostatic pressure • Erosion of soft or unconsolidated zones • Increased probability of mud loss at formation levels • $\boldsymbol{P_{hy} > P_f \rightarrow Loss}$	Flowmeter	• Regular maintenance of pumps • Regular flow control and measurement instruments • Regular inspection of all circuit equipment
	Less of	**Less of**	• Pump failures • Insufficient mud in tanks or mud loss • Human error (incorrect command) • Failure of measuring instruments	• Decrease in hydrostatic pressure • Reduced effective hole cleaning • Reduction in drilling speed		• Regular maintenance of pumps • Regular flow control and measurement instrument checks • Regular inspection of all circuit equipment

Level	Higher	**Higher Level**	• Gas, water, crude plugs • Contamination of tanks by water • Ineffective mud displacement • Leakage at tank level • Failure of mechanical treatment system	• Increase in wellbore fill-up • Increase in hydrostatic pressure It's an indication of a kick • $\boldsymbol{P_f > P_h \rightarrow kick}$	Level detector	• Regular maintenance and inspection of solid treatment elements and periodic cleaning of tanks • Regular level monitoring of tanks • Regular maintenance and inspection of tank level detectors Installation of tank level recorder equipped with alarm • Awareness training for workers on the significance of high and low level • Testing the mud circuit with water before starting drilling

	Lower	**Lower Level**	• Mud loss at mud tanks, pipelines, flexibles, valves • Mud loss at formation level (presence of caves and fissures in the formation) • Human error (valve control)	• Fill-up failure • Decrease in hydrostatic pressure which causes the possibility of a kick • $\boldsymbol{P_f > P_h \rightarrow kick}$		• Regular maintenance and inspection of solid treatment elements and periodic cleaning of tanks • Regular level monitoring of tanks • Regular maintenance and inspection of tank level detectors • Installation of tank level recorder equipped with an alarm • Awareness training for workers on the significance of high and low levels • Testing the mud circuit with water before starting drilling

In a HAZOP study of several causes and consequences linked to the evolution of the parameters of the mud circulation system inside the well, it was found that there is a correlation between all the parameters. If one parameter deviates from the normal value, it will influence all the other parameters. For example, an increase in density will automatically lead to an increase in hydrostatic pressure, which can cause fracturing (loss) within the formation or a blowout (kick) depending on the parameters. Therefore, the HPWBM needs to be monitored most of the time and tested regularly.

3.6 Conclusion

Chapter 3 has provided a detailed exploration of the comprehensive risk assessment surrounding High-Performance Water-Based Mud (HPWBM), covering both its production and circulation processes. Through the meticulous application of advanced methodologies such as SEIRICH software, Hazard Analysis and Risk Control (HARC) methodology, and Hazard and Operability (HAZOP) analysis, a thorough understanding of the associated hazards and potential dangers has been achieved. By identifying risks and implementing mitigation measures, this assessment serves as a crucial foundation for ensuring the safety of workers and the integrity of operations. Moving forward, the insights gained from this analysis will inform informed decision-making and robust risk management strategies to mitigate risks effectively.

Chapter 4

Environmental Analyses of High-Performance Water-Based Mud

4.1 Introduction

In this chapter, the focus shifts to the evaluation of the environmental impacts associated with the use and circulation HPWBM. By conducting a thorough environmental analysis, the aim is to identify and assess the potential adverse effects of HPWBM on various environmental aspects. This includes examining its impact on air quality, soil, water resources. It presents the findings and proposes strategies to mitigate any identified risks, thereby promoting sustainable practices within the oil and gas industry.

4.2 Evaluation of the Environmental Impacts of HPWBM

Evaluating environmental aspects, including the potential impacts of a company's activities, products, and services on the environment, is a fundamental step. This essential evaluation aims to identify and address any adverse impacts resulting from the use of HPWBM. therefore, we applied this method to the ENF 61 Rig, owned by the ENAFOR company. This proactive approach helps take specific measures to reduce the environmental impact of any identified risks, thereby promoting environmental sustainability and regulatory compliance within the HPWBM usage. The figure 4.1 shows the prosses steps used in order to conduct this evaluation.

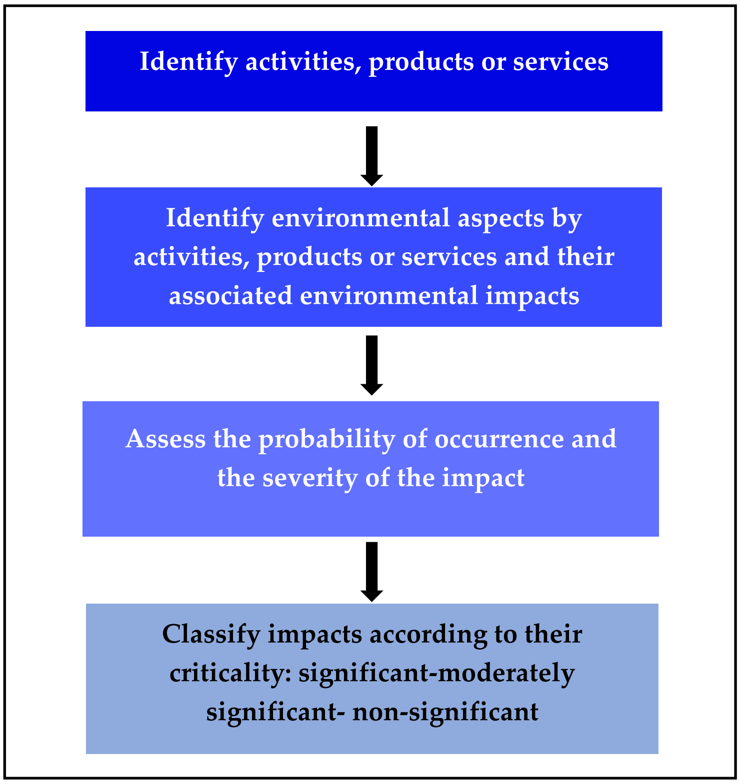


Figure 4-1 : Environmental Impacts Evaluation Process

4.2.1 Identification of environmental aspects and their associated impacts

For each activity, product, or service related to the use of HPWBM, environmental aspects are identified across different environmental domains (such as energy, air, natural resources, noise, waste, soil, and landscape):

- In normal operating state: start-up, stop and maintenance of facilities (including ordinary maintenance and programs)
- In abnormal toning state: non-flat operation or degrades starting and stopping conditions)
- In an emergency situation: incident, accident, one-off situation with a variable frequency of occurrence and presenting one or more degrees of gravity.

For each identified environmental aspect, an analysis of the operation is conducted to identify a wide range of potential environmental impacts, whether they are significant or not.

4.2.2 Rating and determination of significant environmental aspects/impacts

Two rating criteria have been defined to assess the criticality of the impact:

1. The probability of occurrence of the aspect / impact (P)

Table 4-1: Probability of occurrence of the aspect

Probability of occurrence of the aspect		
Probability	**Rating**	**Interpretation**
Very high	4	From once a day (usual)
High	3	From once a week (occasional)
Low	2	From once per month (rare)
Very low	1	Never or from once a year (very rare)

2. Severity of impact (G)

Table 4-2: Severity of impact

Severity of impact		
Probability	**Rating**	**Interpretation**
Very high	4	Non-biodegradable discharge or very low dilution, dispersion or very high collection of natural resources / very toxic, harmful effects on fauna, flora / very strong decrease in natural resources very significant degradation of environmental quality.
High	3	Low biodegradable discharge or low dilution, dispersion or high removal of natural resources / toxic effects, harmful to fauna, flora strong decrease of natural resources / strong degradation of the quality of the environment.
Low	2	Biodegradable release or good dilution, dispersion or low removal of natural resources / few toxic, harmful effects on fauna, flora / small decrease in natural resources / low degradation of the quality of the environment.
Very Low	1	Rapidly biodegradable or high dilution release, dispersion or very low removal of natural resources / no toxic, harmful effects on fauna, flora / very small decrease in natural resources / negligible degradation of the quality of the environment.

Calculation formula: **Criticality of the impact = P × G**

The impacts are divided into three categories according to the degree of criticality according to the matrix shown in Table 4.3

- Significant environmental impacts
- Moderately Significant environmental impacts
- Non-significant environmental impacts

Table 4-3: Enivronmental impacts evaluation matrix

Severity of impact	**4**	Very high	4	8	12	16
	3	High	3	6	9	12
	2	Low	2	4	6	8
	1	Very Low	1	2	3	4
			Very Low	Low	High	Very high
			1	**2**	**3**	**4**
			Probability of occurrence of the aspect			

The evaluation in **Table 4.4** below was conducted for the fabrication and circulation of HPWBM to provide a comprehensive view of its potential environmental impacts.

Table 4-4: Environemental impacts evaluation of HPWBM

Activity	State of operation	Aspect	Impact	Probability of occurrence of the aspect	Severity of impact	Criticality
Fabrication	Normal	Generation of plastic contaminated by chemicals	Olfactory nuisance Visual nuisance Ground clutter	4	3	12
	Normal	Generation of plastic not contaminated by chemicals	Olfactory nuisance Visual nuisance Ground clutter	3	1	3
	Emergency situation	Uncontrolled releases in case of fire or explosion	Air and soil pollution	1	2	2
	Normal	Generation of soiled rags	Olfactory nuisance Visual nuisance Ground clutter	3	3	9
	Normal	Generation of soiled gloves/shoes/clothes	Depletion of non-renewable natural resources	3	4	12
	Normal	Noise generation	Discomfort to local residents and neighbors	4	1	4
	Normal	Use of water	Depletion of groundwater resources	4	4	16
	Emergency situation	Spillage of drilling mud on the ground	Soil pollution Groundwater pollution	1	2	2
	Emergency situation	Spillage of chemicals on the ground	Soil pollution Groundwater pollution	1	3	3

Circulation	Normal	Industrial wastewater generation	Soil and Water pollution	1	3	3
	Normal	generation of chemically uncontaminated plastic	Olfactory nuisance Visual nuisance Ground clutter	3	4	12
	Normal	generation of plastic contaminated by chemicals	Olfactory nuisance Visual nuisance Ground clutter	1	2	2
	Emergency situation	uncontrolled releases in the case of fire or explosion	Soil and Water pollution	1	2	2
	Normal	generation of soiled rags	Olfactory nuisance Visual nuisance Ground clutter	3	3	9
	Normal	generation of contaminated gloves/shoes/clothes	Olfactory nuisance Visual nuisance Ground clutter	2	2	4
	Emergency situation	spillage of drilling mud on the ground	Soil pollution Groundwater pollution	1	4	4
	Emergency situation	spillage of chemicals on the ground	Soil pollution Groundwater pollution	1	3	3
	Normal	Noise generation	Discomfort to local residents and neighbors	4	1	4
	Normal	Water usage	Depletion of groundwater resources	2	2	4

The bellow chart (Figure 4-2) resumes the environmental impact evaluation by each activity

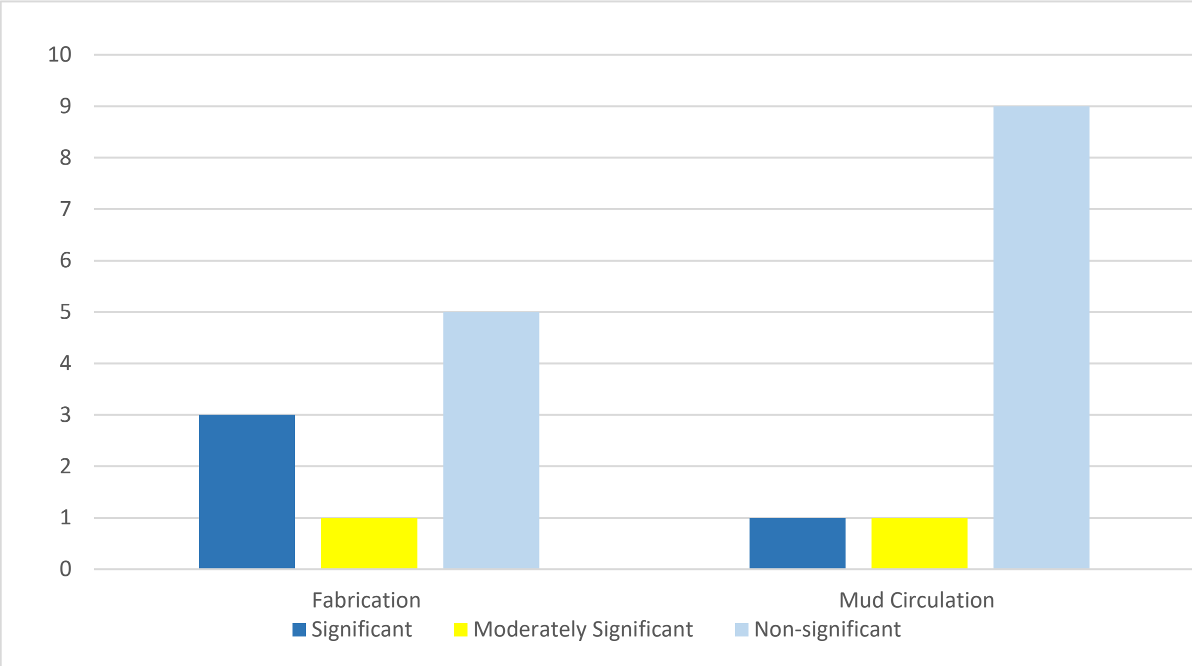


Figure 4-2: Impact criticality by activity.

The evaluation of the environmental impact of HPWBM confirms that its overall environmental impact is relatively low, primarily due to its fundamental component being water. This water-based composition is advantageous as it reduces the use of more harmful oil-based substances. Consequently, the most significant environmental impact identified is the depletion of groundwater resources, as large volumes of water are required for the mud's fabrication.

Most other aspects exhibit either non-significant or moderately significant impacts, with the exception of waste generation during fabrication, particularly plastic waste that may be contaminated or non-contaminated by chemicals. Moreover, because water is the primary constituent of HPWBM, any spillage or leakage of the mud on the ground does not pose a significant environmental impact.

4.3 Impact of HPWBM on CO_2 Emissions

Indeed, high-performance water-based mud (HPWBM) eliminates the need for diesel, thus reducing associated CO_2 emissions from transportation. However, the analysis highlights significant environmental concerns regarding CO_2 emissions in the industry. Each metric ton of CO_2 emitted during diesel combustion and transportation exacerbates the industry's environmental impact. The use of diesel for transportation, including trucks and other modes, significantly contributes to CO_2 emissions.

4.4 Environmental Implications of Non-Recyclable HPWBM

Unlike some other drilling fluids, HPWBM cannot be easily recycled or reused after drilling due to changes in its composition and properties during the drilling process. This inability to recycle HPWBM results in the generation of significant quantities of non-recyclable waste, posing implications for both drilling operations and environmental sustainability.

The disposal of this waste raises concerns regarding environmental contamination, as improper handling can lead to soil and water pollution, impacting ecosystems and human health. Moreover, the accumulation of non-recyclable waste adds to the environmental burden associated with drilling activities, exacerbating concerns about resource depletion and ecological degradation.

Furthermore, the management of non-recyclable waste incurs costs and logistical challenges for drilling companies. Disposal methods such as landfilling or incineration require financial resources and infrastructure, affecting operational efficiency and profitability. Additionally, regulatory compliance regarding waste disposal adds another layer of complexity to drilling operations.

Addressing the challenge of HPWBM non-recyclability requires innovative solutions and proactive measures from industry stakeholders. Developing alternative drilling fluid formulations with improved recyclability or exploring advanced waste treatment technologies are potential avenues to mitigate this environmental challenge. However, implementing such solutions may require investment in research and development, as well as collaboration among industry players to ensure their feasibility and effectiveness.

4.5 Algerian Regulatory Requirements:

The Algerian state is committed to enacting comprehensive legislation aimed at environmental protection and sustainable development. Recognizing the oil sector's pivotal role in the country, several key laws have been established to regulate the sector from an environmental standpoint. This study particularly highlights the following regulations:

Law No. 03-10 on Environmental Protection in the Context of Sustainable Development: Article 3 establishes the principles of this law, emphasizing the conservation of natural resources, the substitution of environmentally harmful materials with less harmful alternatives, and the integration of environmental protection and sustainable development into planning processes. Article 59 mandates the protection of natural resources from pollution, acknowledging their non-renewable nature. Furthermore, Article 69 focuses on safeguarding human health and the environment from chemical substances and preparations.

Law No. 01-19 on Waste Management, Control, and Elimination: Article 6 places full responsibility on waste producers to implement necessary measures for waste reduction and disposal, advocating the adoption and utilization of more environmentally friendly technologies.

Law No. 05-12 on Water: Article 43 requires the protection of aquatic ecosystems from any form of pollution that could degrade water quality.

Law No. 13-01 Amending and Supplementing Law No. 05-07 on Hydrocarbons: Article 18 mandates that institutions conduct comprehensive environmental impact assessments prior to commencing any activities. This includes describing preventive measures to mitigate the environmental impacts associated with their operations.

Collectively, Algerian legislation promotes proactive measures, technological solutions, and practices that aim to preserve natural resources and mitigate environmental impacts across various sectors. Consequently, High-Performance Water-Based Mud aligns with these legislative directives, as its application results in minimal environmental impact, as substantiated by this study. This compliance underscores HPWBM as a viable and sustainable alternative within the regulatory framework governing Algeria's oil sector.

4.6 Conclusion

The evaluation of HPWBM shows it has a relatively low environmental impact due to its water-based composition, reducing reliance on harmful oil-based substances. The main environmental concern is groundwater depletion from the large water volumes required for HPWBM fabrication. Other impacts, such as waste generation, are mostly non-significant or moderate. Continuous monitoring and proactive management are essential to minimize HPWBM's environmental footprint and promote sustainable practices in the oil and gas industry. Additionally, HPWBM aligns well with Algerian environmental regulations, supporting its use as a sustainable alternative in the sector.

General Conclusion

This work provides a comprehensive study of High-Performance Water-Based Mud (HPWBM) from the perspectives of health, safety, and environmental (HSE) impacts, which are critical factors in selecting drilling fluid. Given that drilling mud plays a fundamental role in the drilling process, it is essential to consider all aspects of its selection, including effects on human health, drilling operations, and the environment. This study addresses these considerations by employing various methodologies and software to analyze potential scenarios and impacts of HPWBM on human health, drilling operations, and the environment.

Initially, the theoretical framework related to the research topic was presented, defining key elements of drilling and focusing on drilling fluids, particularly HPWBM. Theoretical concepts for risk analysis and environmental impact assessment methods were also introduced.

In the practical part, the chemical effects of the components of HPWBM were evaluated using SEIRICH software. The results indicated some chemical hazards, such as skin, eye, or respiratory irritations, which necessitate specific preventive measures. A detailed action plan was proposed, outlining necessary steps and their implementation to mitigate these chemical risks. To provide a thorough analysis, risks associated with each stage of HPWBM use in drilling operations, from preparation to circulation, cleaning, and testing, were evaluated using the HARC methodology. This method allowed for the examination of various potential accident scenarios, risk assessments in terms of probability and severity, and the proposal of necessary preventive and protective measures. The study revealed that the highest risk occurs with direct and continuous contact with the drilling mud or its chemical components, particularly during preparation and cleaning stages. Workers on the drilling rig, especially roughnecks and roustabout, are the most exposed to these risks. Preventive measures were provided to reduce the likelihood and severity of these risks.

Following this, well stability and technical risks associated with drilling using HPWBM were examined through the HAZOP methodology, focusing on potential deviations in mud properties and their causes and consequences. This analysis demonstrated the interdependence of mud properties, where any change in one property affects others, potentially impacting pressure, leading to formation fractures or leaks. The findings underscored the need for continuous monitoring of HPWBM properties due to their sensitivity to changes during drilling operations.

Finally, the environmental impacts of HPWBM were assessed by examining all environmental aspects and their corresponding impacts at each stage of HPWBM preparation and circulation. The evaluation showed that HPWBM has relatively low environmental impacts compared to other types of drilling mud, such as oil-based mud. However, it does contribute to the depletion of natural resources, particularly water, as it is the primary component. The usage of HPWBM can also reduce CO2 emissions by avoiding transportation with trucks. From a legal perspective, it was demonstrated that Algerian law strongly encourages the adoption of environmentally friendly and sustainable technologies. Thus, HPWBM is legally compliant due to its low environmental impact.

This comprehensive analysis underscores the importance of considering HSE aspects when selecting drilling mud. HPWBM is found to be suitable in terms of health, safety, and environmental impact, with necessary preventive measures required, which are standard for any drilling operation. Future studies should include a detailed comparison of HPWBM with other drilling fluids regarding efficiency, cost, and HSE impacts to facilitate the selection process. Additionally, it is important to explore the challenges and opportunities associated with HPWBM to develop a strategic plan for its adoption as a viable alternative to existing drilling fluids.

Bibliography

Agwu, O. E. (2021). A critical review of drilling mud rheological models. *Petroleum Science and Engineering*.

Babu, R., & Veluthambi, K. (2016). *Risk Analysis Framework.* India: Centre for Environmental Risk Assessment (CERA).

Balilehvand, M. A. (2023). Process Safety and Environmental Protection . *European Federation of Chemical Engineering*, Vol. 170 Pages 392-402.

Ben Mahmoud, M. D. (2022). A comprehensive review of key performance indicators of drilling fluids. *Journal of Petroleum Science and Engineering, 213*. doi:10.1016

Coleman, M., & Marks, H. (2019). Qualitative and quantitative risk assessment. *Elsevier Science Ltd*, 289-297. doi: 10.1016/S0956-7135(99)00052-3

David C. Simmons, R. D. (2017). Qualitative and quantitative approaches to risk assessment. European Commission.

Fabienne-Fariba Salimi, L. U. (2023). *A New Approach to HAZOP of Complex Chemical Processes.*

Guria, C. (2013). Rheological analysis of drilling fluid using Marsh Funnel. *Journal of Petroleum Science and Engineering*, 62-69.

Habegger, B. (2009). *The International Handbook on Risk Analysis and Management.* (V. M. Andreas Wenger, Éd.) Switzerland: Center for Security Studies.

I. Kessai, S. B. (2020). Drill Bit Deformations in Rotary Drilling Systems under Large-Amplitude Stick-Slip Vibrations. *Applied Sciences* , Vol. 10 Issue 18 Pages 6523.

ISO 14001. (2015). *Environmental Management System EMS*.

ISO, I. O. (2018). ISO 31000: Risk management — Guidelines.

Jadeer, M. R.-S. (2021). Operations and Equipment of Well Drilling. *International Petroleum and Petrochemical Technology Conference 2021*, (pp. Springer Pages: 361-366).

Kalkan, A. W. (2019). Drilling Fluids; Types, Formation Choice and Environmental Impact. Vol. 8 Pages 66-71.

Law No. 03-10 . (2003 , July 19). *Environmental Protection within the Framework of Sustainable Development*.

Leon Robinson, S. B. (2020). *A Practical Handbook for Drilling Fluids Processing.* U.S: Gulf Professional Publishing.

Macpherson, A. (2018). A comparison of qualitative and quantitative risk analysis and assessments. *ALLAN MACPHERSON*.

Misra, K. B. (2016). Risk Analysis and Management: An Introduction. *Recherchgate*, 662-676. doi:10.1007/978-1-84800-131-2_41

Montilva, v. O. (2007). *AADE National Technical Conference and Exhibition.* Huston, Texas.

Parate, N. B. (2021). A review article on drilling fluids , types , properties and criterion for selection. *Journal of Emerging Technologies and Innovative Research (JETIR), 8*.

Pasman, W. J. (2020). *Methods in Chemical Process Safety.*

Phil Hughes, E. F. (2009). *Introduction to Health and Safety at Work.* Oxford: Elsevier Limited.

Prats, A. (2011). *Analyse environnementale/ Techniques de l'Ingénieur.* Paris.

Rappel de la méthode et perspective cycle. (2023). lefebvre Dalloz.

Samimi, A. (2020). Risk management in oil and gas refineries. *Progress in Chemical and Biochemical Research, 3*(2), 140-146.

Sciences, R. M. (2023). Investigations on the Stinger PDC cutter breaking granitoid under in-situ stress and hydrostatic pressure conditions.

seirich. (2024, 04 16). seirich: https://www.seirich.fr/seirich-web/comprendrelesrisqueschimiques.xhtml

SLB. (2024, 05 23). WWW.SLB.com: https://glossary.slb.com/terms/b/bingham_plastic_model

Srinivas, K. (2019). *Perspectives on Risk, Assessment and Management Paradigms* (éd. 3). (A. G. Hessami, Éd.) Intechopen. doi:10.5772/intechopen.80804

Thenthoughtor. (2024, 03 25). Récupéré sur Impact-and-environmental-aspect: https://thethoughtnow.com/impact-and-environmental-aspect/

Trenchlesspedia. (2023, July 5). https://trenchlesspedia.com/definition/4284/plastic-viscosity-pv-drilling-fluid

Appendix A: Companies Presentations

MI-SWACO

M-I SWACO became a Schlumberger company in 2010, It is a leading provider of drilling fluid solutions and technologies for the oil and gas industry worldwide. With a rich history dating back over 80 years, MI SWACO is renowned for its innovative products and services that optimize drilling operations, enhance efficiency, and maximize wellbore productivity. The company offers a comprehensive range of drilling fluid systems, additives, and equipment, along with expert engineering support and field services to address the diverse needs of drilling projects across various environments and challenges. MI SWACO's commitment to innovation, safety, and environmental stewardship positions it as a trusted partner for oil and gas operators seeking reliable and sustainable drilling solutions.

SLB company

SLB is the largest multinational oilfield services company. The story of this company begins with what truly means to be a technology innovator. The common sense of purpose unites 82,000 people representing 170 nationalities with products, sales and services in more than 120 countries. They supply the industry's most comprehensive range of products and services, from exploration through production, and integrated pore-to-pipeline solutions that optimize hydrocarbon recovery to deliver reservoir performance sustainably.

SLB was born of an idea—that if an electric field could be generated below ground, voltage measurements at the surface could be mapped to reveal subsurface structure under the name "Société de prospection électrique" in 1926 by two brothers Conrad & Marcel Schlumberger. Now it's a multinational company in many countries in the world specialist in petroleum services. Its main offices (Headquarters) are located in Houston, Paris, and La Hague with a research & development center in Clamart. Olivier Le Peuch is the Chief Executive Officer CEO of SLB company.

National Drilling Company (ENAFOR)

The National Drilling Company, abbreviated as "ENAFOR," established by Decree No. 81-170 of August 1, 1981, is a wholly-owned subsidiary of the SONATRACH holding company for oilfield services (SPP).

ENAFOR is tasked with conducting drilling operations on behalf of national and international operators for the exploration and exploitation of hydrocarbon deposits and/or aquifers, as well as the maintenance of oil or gas producing wells.

With over 45 years of experience in the oil drilling industry, ENAFOR excels in its field, earning it undeniable recognition both nationally and internationally. Operating on behalf of SONATRACH and its foreign economic operators, ENAFOR focuses its operational activities on the two main areas of drilling and work-over, in addition to oilfield maintenance activities and support services such as transportation and hospitality. ENAFOR's missions are aligned with the overall strategy of the SONATRACH group: to actively participate in the development and replenishment of energy reserves for current and future generations.

ENAFOR is a member of the International Association of Drilling Contractors (IADC).

Geographical Location of ENAFOR Site #61:

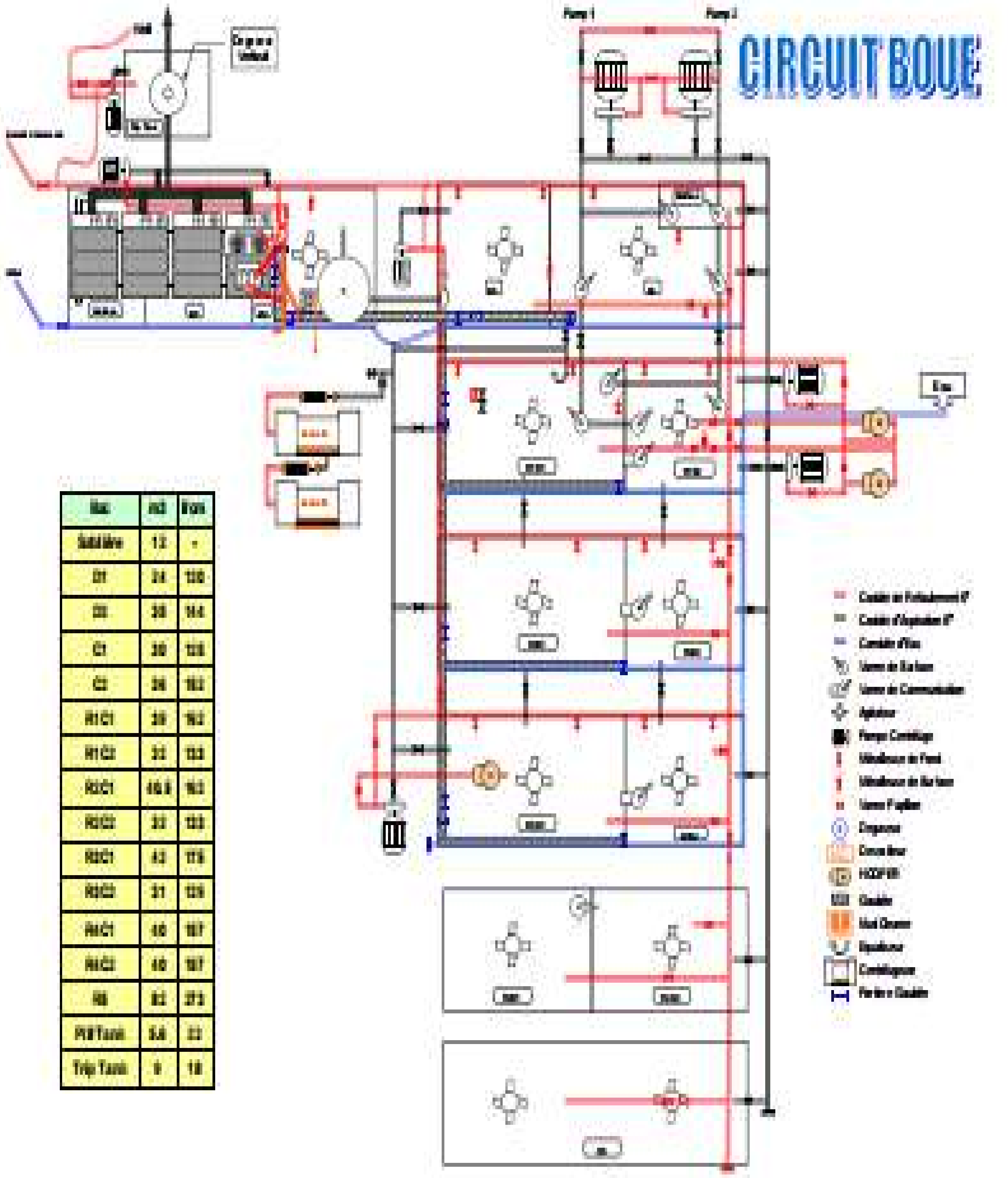
ENAFOR #61 is a drilling rig among the sites of the National Drilling Company. It commenced operations in 2016 and has since carried out maintenance operations for wells with high efficiency and minimal accidents or damages.

Currently, ENAFOR Site #61 is located 32 km south of the city of Hassi Messaoud. From Hassi Messaoud, take the road towards Ouargla until reaching junction 04 chemin 05 km, then turn right and follow the road towards the grouped camps (24, 25, 26, 33, 61) for a distance of 3 km. Continue on the road, passing by the CINA plant for 21 km. Then, turn left and travel 3 km to reach well OMG 612.

- Longitude: 6°02'40.0"
- Latitude: 31°54′58.0"

ENAFOR #61 operates on behalf of SONATRACH Production Division (HMD region). The workforce at this site consists of 97 individuals who work on a schedule of 4 weeks on duty followed by 4 weeks off duty.

Appendix B: Mud Circulation System



Appendix C: Charts Statistics

Risk level by activity/process

Risk level	Activity/Process			
	Fabrication	Mud Circulation	Testing	Cleaning
High	1	2	1	2
Mediuem	3	1	1	1
Low	0	1	0	0

Hazard category by activity/ process.

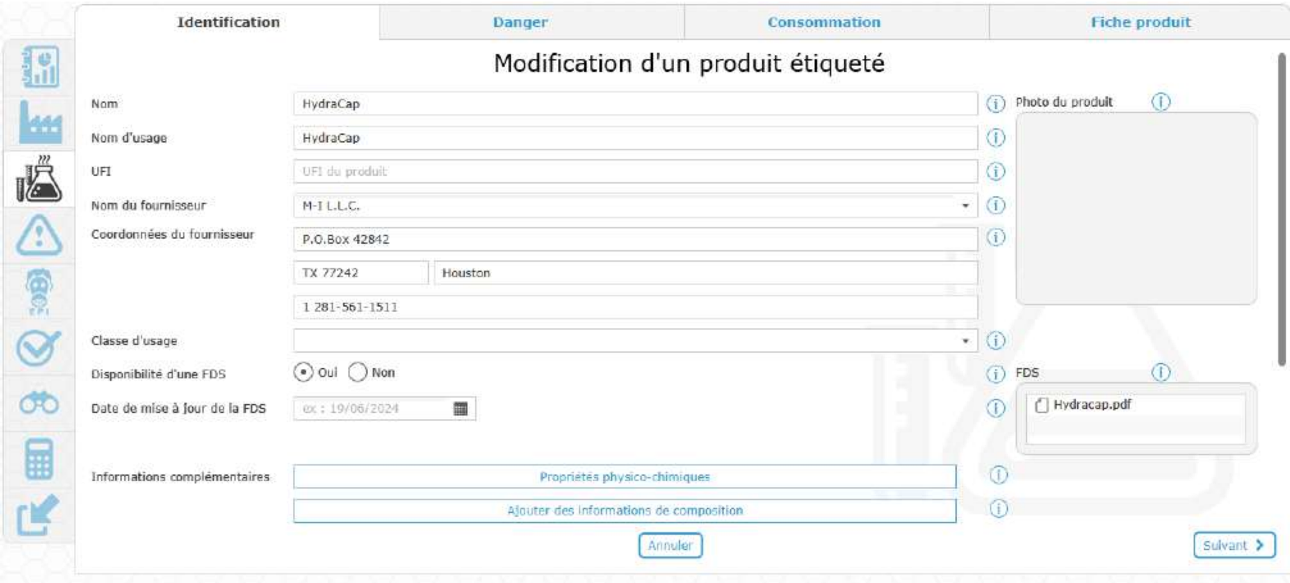
Activity/Process	Hzarad category					
	Mechanical lifting	Toxic/ Corrosive/ Chemicals Hazardous	Manuel Lifiting	Stepping/ Slipping/ falling	Noise/ Nuisance	Pressure
Fabrication	2	1	1	0	0	0
Mud Circulation	0	2	0	1	1	0
Testing	0	1	0	1	0	0
Fabrication	0	1	1	0	0	1

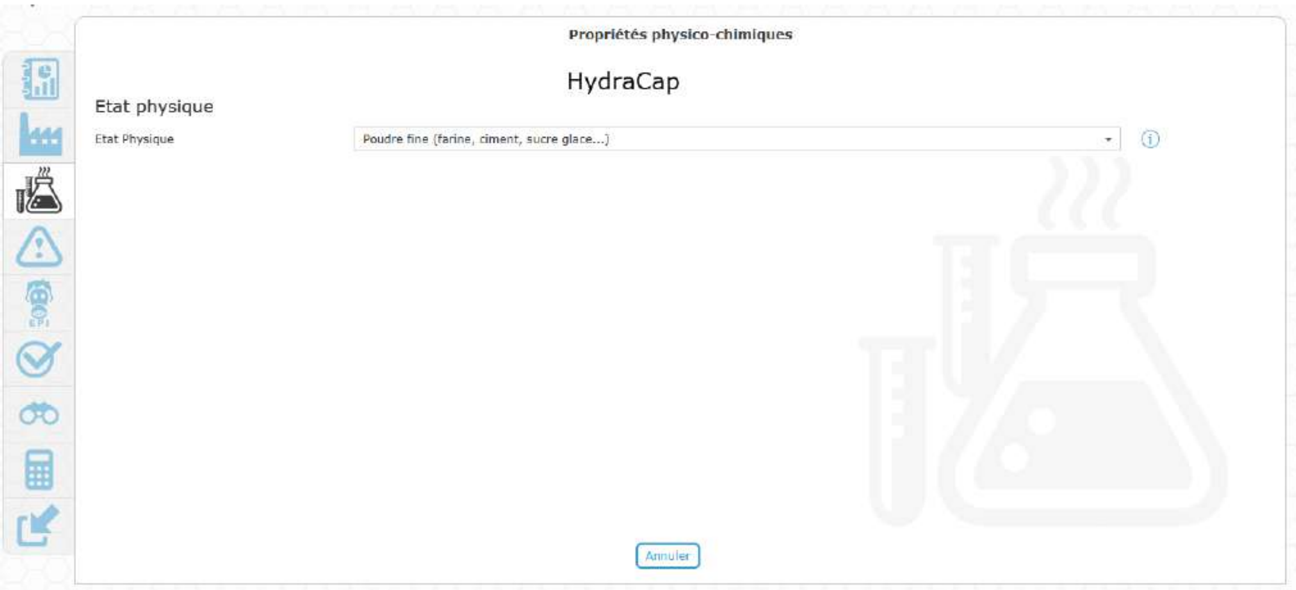
Risk level by population affected.

Risk level	Population Affected						
	Operaters	Driver	Roughneck	Derrickmen	Roustabouts	Driller	Engineers
High	1	0	3	0	5	1	1
Mediuem	1	1	3	2	3	1	1
Low	1	1	1	0	0	1	0

Impact criticality by activity.

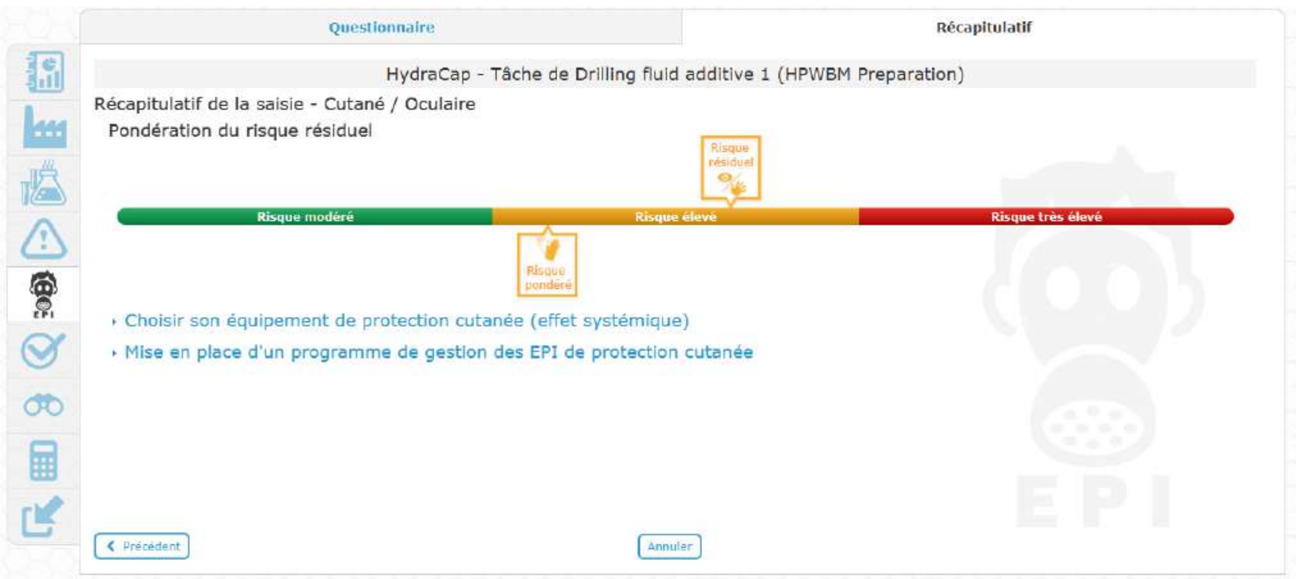
Criticality	Activity/Process	
	Fabrication	Mud Circulation
Significant	3	1
Moderately Significant	1	1
Non-significant	5	9


Identification
Danger
Consommation
Fiche produit
Modification d'un produit étiqueté
Nom
HydraCap
Photo du produit
Nom d'usage
HydraCap
UFI
UFI du produit
Nom du fournisseur
M-I L.L.C.
Coordonnées du fournisseur
P.O.Box 42842
TX 77242
Houston
1 281-561-1511
Classe d'usage
Disponibilité d'une FDS
Oui
Non
FDS
Date de mise à jour de la FDS
ex : 19/06/2024
Hydracap.pdf
Informations complémentaires
Propriétés physico-chimiques
Ajouter des informations de composition
Annuler
Suivant


Propriétés physico-chimiques
HydraCap
Etat physique
Etat Physique
Poudre fine (farine, ciment, sucre glace...)
Annuler


Identification
Danger
Consommation
Fiche produit
HydraCap
Nom d'usage : HydraCap
UFI :
Nom du fournisseur : M-I L.L.C.
Pictogrammes :
Date d'arrivée :
Date de fin d'utilisation :
Date de fin de présence :
Mentions de danger :
EUH210 - Fiche de données de sécurité disponible sur demande
H241 - Peut s'enflammer ou exploser sous l'effet de la chaleur/Peut s'enflammer ou exploser en cas d'échauffement
Zone
Santé
Incendie
Environnement
HPWBM P...
2.359t
Spécificités réglementaires
Le produit HydraCap possède la mention EUH210. Même s'il n'est pas classé dangereux, il contient des substances dangereuses en faibles quantités qui peuvent provoquer des effets néfastes pour les salariés (irritation, toxicité pour la reproduction, sensibilisation respiratoire...) et pour l'environnement. Pour en savoir plus : ED 6207, page 84
Précédent
Annuler
Exporter (.docx)


Choix du type EPI
Questionnaire
Récapitulatif
HydraCap - Tâche de Drilling fluid additive 1 (HPWBM Preparation)
Choix du type d'APR
Famille
Demi-masque équipé de filtre(s)
Description
Demi-masque équipé de filtre(s)
Classe
P3
Pondération du risque résiduel
Risque résiduel
Risque modéré
Risque élevé
Risque très élevé
Risque pondéré
Vérification de l'adéquation entre APR et conditions de travail
Vérification de la mise en place d'un programme de protection respiratoire
Précédent
Annuler


Questionnaire
Récapitulatif
HydraCap - Tâche de Drilling fluid additive 1 (HPWBM Preparation)
Récapitulatif de la saisie - Cutané / Oculaire
Pondération du risque résiduel
Risque résiduel
Risque modéré
Risque élevé
Risque très élevé
Risque pondéré
Choisir son équipement de protection cutanée (effet systémique)
Mise en place d'un programme de gestion des EPI de protection cutanée
Précédent
Annuler