Enhancing Offshore Drilling Efficiency through Multilevel Flow Modeling of MPD Operations

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Abstract: Exploiting all forms of energy must be coupled with the preservation of human safety and the environment. Despite the energy reserves beneath the ocean depths, challenging obstacles confront offshore drilling operations, notably the high pressure beneath the well. To comprehend this process better, we turned to modeling the managed pressure drilling (MPD) using multilevel flow modeling (MFM). These models provide a robust framework enabling us to understand and analyze the intricacies of this complex process. Our use of these models allows us to examine the causes and effects associated with various aspects of this process. All of this enables us to drill safely for the well, achieving our primary goal in this context.

Keywords: Offshore Drilling, Managed Pressure Drilling,Multilevel Flow Modeling

1. INTRODUCTION

In the context of the rapid developments occurring worldwide across various fields, there is an urgent need to increase our energy supplies[1], whether from traditional sources like fossil fuels or renewable energy sources. This need becomes particularly evident in light of the economic and social challenges our world faces. Consequently, the global community continually strives to explore and develop new and diverse energy sources to meet growing human demands and achieve sustainable development[2].

In this crucial context, our focus shifts towards studying how to precisely control offshore drilling operations, a topic of utmost importance, especially in countries endowed with significant resources. The exploitation of these resources presents a vital opportunity to stimulate economic growth and promote sustainable development, but it also carries substantial responsibilities for environmental and safety preservation[3],[4].

Given our awareness of the significant risks associated with underwater oil and gas well blowouts due to high pressures at ocean depths, achieving precise control over these operations becomes increasingly critical. This paper delves into this vital subject matter in an advanced manner, employing multi-level

modeling as a powerful tool to gain a deep understanding of how this complex system operates and regulates well pressures with utmost precision. Subsequently, the data is analyzed to comprehend the causes and consequences [5] associated with both high and low levels in the operational elements.. All of this is accomplished using cutting-edge techniques such as Workbench paving the way for the sustainable and secure exploitation of these vital resources in our future.

2. OFFSHORE DRILLING

Offshore drilling is the extraction of petroleum and gas from vast underwater reserves using platforms situated in the middle of the sea. These platforms differ from solid ground and depend on factors such as depth and location. The process commences with drilling operations and concludes with extraction procedures. This process entails various risks, including natural, environmental, and safety factors. Therefore, offshore drilling is considered a significant challenge that demands attention and expertise[6],[7]. Additionally, controlling the well's pressure is of utmost importance to ensure the successful completion of offshore drilling operations[8].

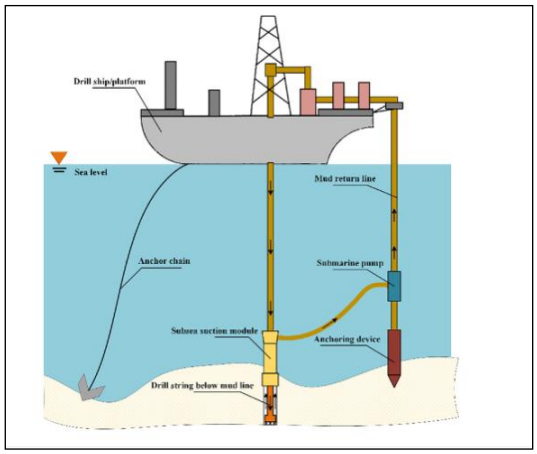


Fig. 1 Offshore drilling operation**[9]**

A. Managed drilling pressure

Well pressure control plays a crucial role in ensuring the safety of drilling operations. Geological conditions dictate that subsurface pressure surpasses surface pressure levels. This control process centers around the use of drilling mud a mixture of fluids introduced into the drill hole.[10] Drilling mud serves a dual purpose, maintaining pressure until it reaches the drill bit. At the drill bit, a valve facilitates fluid flow into the annular space while preventing any backflow. This annular space, positioned between the wellbore and the drill bit, acts as a protective buffer, overseeing pressure regulation and safeguarding against potential collapses. Further control is achieved through additional pumps that manage the flow of mud into this space.Once an adequate amount of mud accumulates, a valve directs it to a storage facility for thorough analysis, recycling, and eventual reuse in subsequent well control operations[8][11].

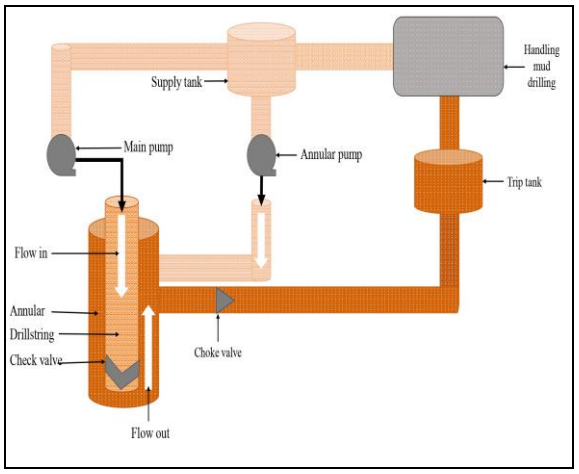


Fig. 2 Managed Pressure Drilling

3. MULTILEVEL FLOW MODELING

A. Definition

Multilevel Flow Modeling (MFM) is a graphical modeling methodology. It finds its practical application in representing and elucidating the intricate and complex systems that are prevalent in various industrial plants. [5] MFM goes beyond being just a graphical representation tool. It serves as a comprehensive analytical instrument, enabling an in-depth understanding of processes. This understanding is conveyed through the creation of clear and easily understandable graphical representations. Within MFM, a hierarchical approach is employed. It is rooted in the concept of flow functions, which are used to systematically divide complex systems into well-defined subsystems. This hierarchical structure not only aids in comprehending the functions of individual components but also greatly simplifies the process of analyzing the causes, consequences, and intricate interconnections that exist among these components.[12] The symbols utilized in MFM are depicted **Fig.3** [13].

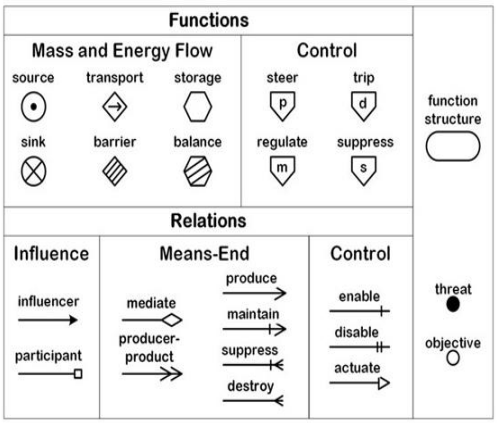


Fig. 3 Elements of MFM

B. MFM Workbench tool

To facilitate the modeling process, a set of MFM Workbench tools has been developed by Kairos Technologies. These tools encompass a range of symbols specifically designed to streamline the modeling process. The screenshot of the workbench, as depicted in **Fig. 4**, serves as a visual representation of these tools in action. These resources are invaluable for users looking to efficiently create and work with Multi-Functional Models (MFMs) within the MFM Workbench environment [14].

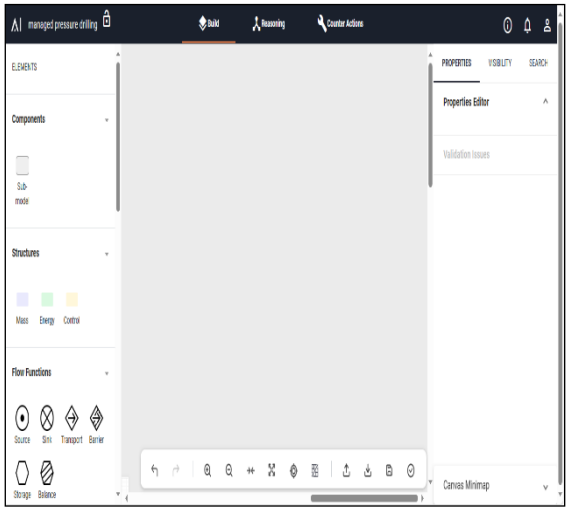


Fig. 5 MFM Workbench Tool

After creating the model, you can engage in reasoning to understand the causal relationships leading to the desired goal. Within this process, there are three variables: "normal," "high," and "low." These variables help you discern the cause-and-effect dynamics within the model. The color scheme used to represent these relationships is illustrated in the accompanying **Fig. 6**[15].

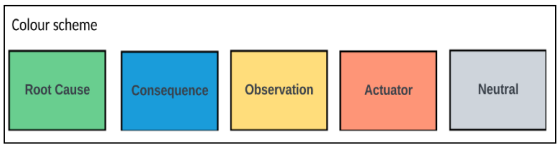


Fig. 7Color scheme in MFM reasoning

4. APPLICATION OF MFM IN MPD

In this section, we will take an overview of how we model our system using the Multilevel Flow Modeling methodology. This model is represented in **Fig.8**and includes an explanation for each of the subsystems that comprise it.

A. Drilling Operation (DO) - Energy Structure Subsystem

This critical subsystem initiates and manages the drilling operation.

In this operation, the Source (SDO) is the starting point, kickstarting the entire process.
Representing the drilling string, the Transport (Dst) stands for the drilling string, a vital component that connects various elements downhole.
The Target (tar) is pivotal, as it channels energy into bit drilling. It plays a transformative role by converting rotational energy into the mechanical power required for drilling.
The Transport (Btd) represents the actual bit drilling process, the heart of the drilling operation. Meanwhile, Storage (WB) represents the wellbore, which functions as a reservoir for the drilling process. The Transport (Dl) phase signifies the physical drilling action, where the bit penetrates the Earth's surface to create a well.
Finally, the Sink (Wl) represents the well itself, the ultimate goal of the drilling operation. It's where resources like oil and gas are extracted.

B. Mud Drilling (MD) - Mass Flow Subsystem:

In this subsystem, the focus shifts to mass flow, particularly the movement of drilling fluids.

The Source (MP) denotes the main pump, responsible for generating the force required to move drilling fluids throughout the system.

The Transport (fin) represents the mass flow of drilling fluids within the drill string, which is essentially the hollow pipe extending down into the well.

Storage (Dst) serves as a temporary holding reservoir for these fluids, ensuring a continuous supply during drilling. The Barrier (CeV), or check valve, is a crucial control component that regulates the mass flow by allowing fluid movement in one direction only. The Sink (An) represents the annulus, which is the region between the drill string and the wellbore where drilling fluid is managed, circulated, and controlled.

C. Mud Drilling in the Annulus (MS)– Mass Flow Subsystem:

This subsystem mirrors the mass flow focus, but within the annulus, which is the area surrounding the drill string.

The Source (AP) acts as the annulus pump, responsible for maintaining fluid circulation within this space. Transport (fain) signifies the mass flow of drilling fluids within the annulus, where fluids are circulated for cooling and pressure management.

Storage (An) serves as the storage unit for annular fluids, ensuring a constant supply when needed.

Transport (faout) represents the outflow of drilling fluids from the annulus, which is then further controlled by the balance (CoV) or choke valve. Transport (FCO) depicts the outflow of fluids after passing through the choke valve, while Storage (TTn) is the trip tank used to monitor the volume andhelping detect changes of drilling fluid.

Transport (fTout) represents the final outflow of drilling fluids,and Sink (DMH) drilling mud handling involves recycling mud for use as feedback in the annular system.

D. Mud Feedback (FDMH) Subsystem:

In this final subsystem, we continue to focus on the mass flow of drilling mud.
Transport (FDH) signifies the outflow of mud from the handling mud. Storage (STn) serves as a supply tank for mud, ensuring a continuous source of drilling fluid.
Transport (FMDin) represents the inflow of mud drilling materials back into the system, which ultimately returns to the Source (AP), completing the cycle of mud flow management.

E. Control Subsystem C1 - Control Wellbore:

This subsystem is dedicated to managing and stabilizing the pressure and flow conditions within the wellbore, the geological formation where drilling operations take place.
Pressure Stabilization (CWB): The Control Wellbore (CWB) component is responsible for maintaining consistent pressure levels within the wellbore. It achieves this by carefully regulating the flow and pressure with the assistance of the main pump (MP) and annulus pump (AP). By controlling the pressure, CWB ensures that the wellbore remains in a safe and optimal state for drilling operations.
Control Maintain (CP): Control pressure (CP) serves as the central control unit for the wellbore. It oversees the operation of various components within the wellbore, ensuring they work in tandem to maintain the required pressure and flow conditions. Additionally, CP establishes a vital connection with both the main pump (MP) and annulus pump (AP), forming a feedback loop that allows for real-time adjustments. This closed-loop control mechanism guarantees that wellbore conditions remain within the specified parameters, enhancing the safety and efficiency of drilling.

F. Control Subsystem C2 - Control Annulus:

The Control Annulus subsystem focuses on monitoring and regulating pressure and fluid flow within the annulus, the space between the drill string and the wellbore.
Pressure Maintenance (CAn): Control Annulus (CAn) is responsible for maintaining precise pressure levels within the annulus. It accomplishes this by meticulously controlling the choke valve (CoV).
CAn ensures that pressure remains stable, preventing undesirable fluctuations that could impact drilling operations.

Controlled Choke Valve (CCoV) is tasked with dynamically regulating this valve. By making real-time adjustments to the choke valve, CCoV maintains a stable and controlled pressure environment within the annulus.

G. Interactions

Product Production (FMDin to AP): Efficiently recycles drilling mud from FMDin to the Annulus Pump (AP) for continued drilling operations.
Pressure Regulation (Flow in Choke Valve to Sink Annulus): Ensures precise pressure control within the annulus for safe drilling.

Maintain wellbore (Sink Annular to Storage Wellbore): Facilitates the flow of drilling fluids into storage for efficient resource management.
Pressure Control (Wellbore to Target Control Well): Maintains optimal pressure levels within the wellbore for safe and effective drilling.

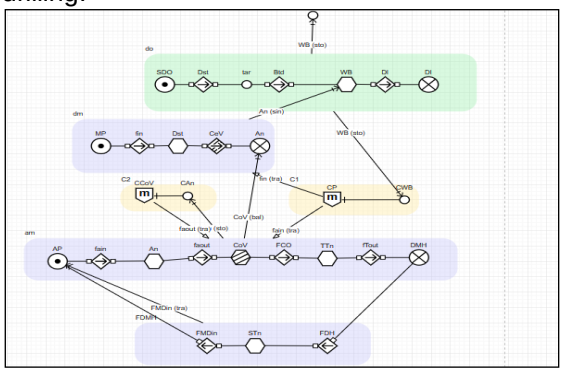


Fig. 9. The model of managed pressure drilling using MFM

5. REASONING

In the following section, we delve into the dynamic world of system reasoning, where we explore the cause-and-effect relationships that underpin the intricate operations of our managed pressure drilling system. [12] Through this analysis, we gain valuable insights into how various components interact to influence crucial factors like wellbore pressure and annular pressure. Understanding these relationships is paramount to ensuring the safe and efficient execution of drilling operations.

an increase in wellbore pressure is caused by the action of controlling pressure (CP) **Fig.10** The consequence of this action is that it affects the targets, which are to control the wellbore pressure (CWB) and control the well (WC) **Fig. 11.**

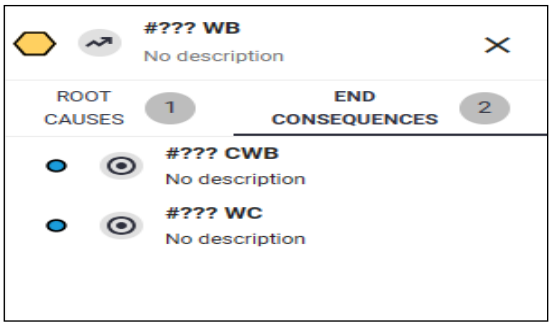


Fig. 12. Reasoning for high wellbore pressure

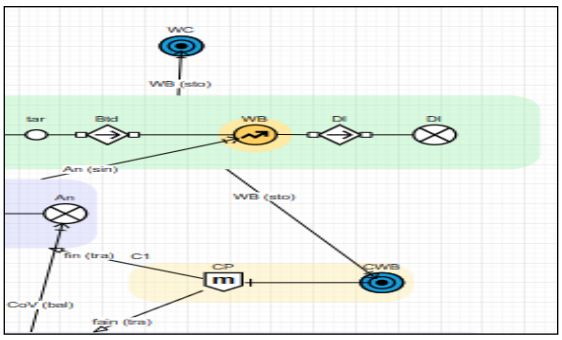


Fig. 13. Consequences of high wellbore pressure

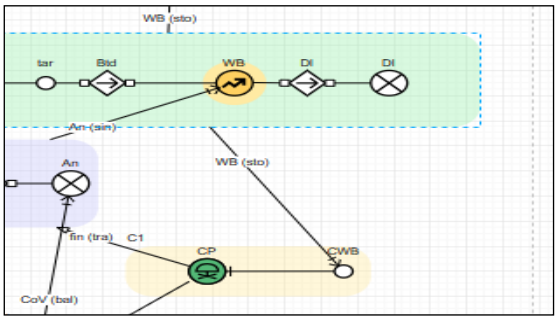


Fig. 14. Causes of high wellbore pressure

an increase or decrease in pressure control can negatively impact the ability to reach the targeted goals. If the pressure deviates from the required level in pressure control, it can be an obstacle to achieving the goals of Control Wellbore (CWB) and Control Pressure in the well (WC)**Fig. 15**.

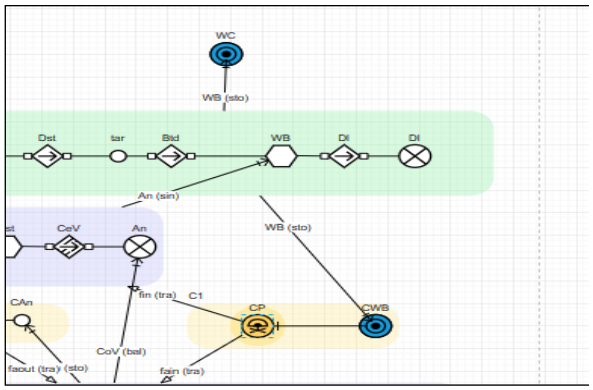
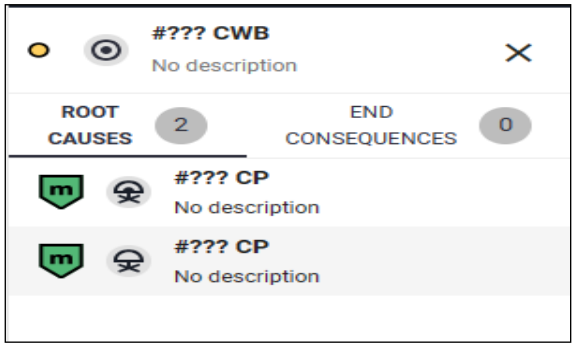


Fig. 16. Consequences of high control pressure



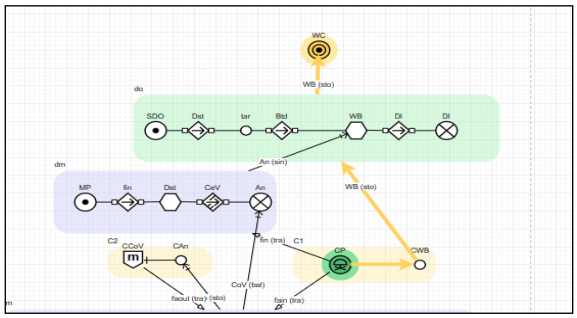


Fig. 17. Causes of false control well

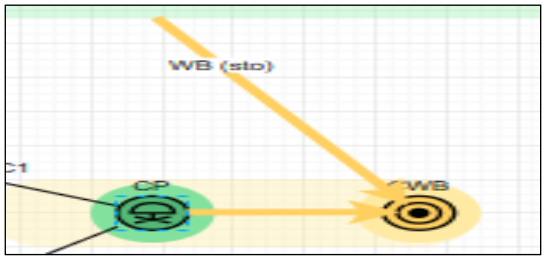


Fig. 18. Causes of false control wellbore

an increase in annular pressure is caused by the action of controlling the choke valve (CCoV) **Fig.19** The consequence of this action is that it affects the target, which is to control annular pressure (CAn) **Fig. 20**.

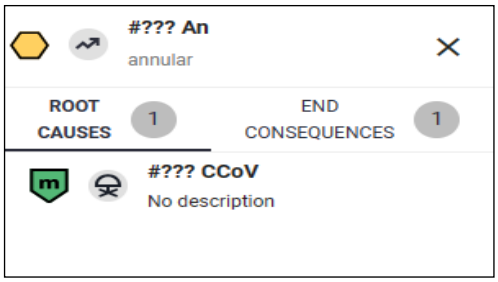


Fig. 21. Reasoning for high annular pressure

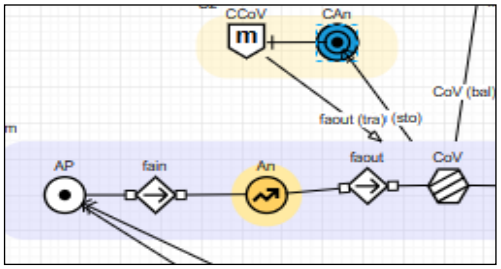


Fig. 22. Consequences of high annular pressure

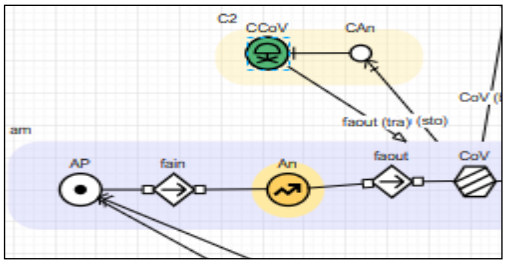


Fig. 23. Causes of high annular pressure

an increase or decrease in control choke valve also can negatively impact the ability to reach the targeted goals. If the pressure deviates from the required level in the choke valve, it can be an obstacle to achieving the goals of Control annular (CAn) **Fig. 24** .

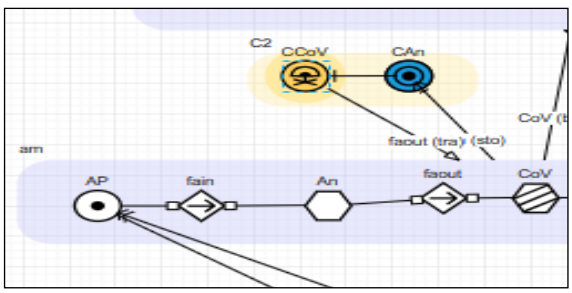


Fig. 25. Effect of Choke Valve Control on Annular Pressure

6. CONCLUSION

This study has provided a comprehensive exploration of the intricate world of managed pressure drilling (MPD) through the lens of multi-level flow modeling (MFM), elucidating the indispensable role of well pressure management in offshore drilling.

MPD, born of the necessity to contend with the formidable pressures lurking beneath the ocean's depths, harnesses the power of drilling mud and cutting-edge methodologies like Burke Punch to secure the stability and safety of wellbores. Multilevel Flow Modeling (MFM) has furnished us with a robust framework to grasp, scrutinize, and illustrate the labyrinthine interplay of components and processes that define these operations. The introduction of the MFM Workbench as an invaluable modeling tool, coupled with an in-depth examination of various subsystems within the MPD domain, has enriched our comprehension of this complex discipline.

The practical application of MFM in the context of MPD has unveiled a holistic representation and analysis of drilling processes, spotlighting the pivotal roles of critical components, including control wellbores and choke valves. The interdependencies among these constituents have underscored the intricate tapestry of causality that governs the triumphant execution of drilling endeavors.

In summation, this work has underscored the paramount significance of well pressure control in offshore drilling, accentuating the synergy between MPD and MFM as the pathway to elevate safety, efficiency, and sustainability in the exploitation of invaluable resources. By amalgamating leading-edge technologies with a profound comprehension of drilling dynamics, we lay the foundation for a future where energy requirements are met conscientiously and securely, thereby contributing to the realization of a sustainable energy landscape for generations to come.

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