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Automating Influx Management Envelope (IME) Generation Through Cloud-Based Solutions

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Abstract

This study focuses on automating the generation of Influx Management Envelopes (IME) for MPD through a digital cloud-based solution, aiming to simplify the process for routine application in drilling operations. The integration of digital cloud-based solutions and parallel computing enhances the efficiency of IME generation by parameterizing various influx scenarios. Utilizing a transient multiphase flow engine, the study establishes kick tolerance thresholds for safe influx volume determination. The analysis includes assessing associated risks during kick circulation using MPD system. Parallel computing ensures faster computations and improved scalability. The combined approach integrates simulation results into an operational envelope for safer decision-making. The study emphasizes the importance of applying and enforcing company well control policies, integrating corporate rules into every simulation for adherence to established guidelines and maintain a consistent and standardized approach to well control practices. Collaborative workflows are highlighted as essential, fostering seamless teamwork, communication, and coordination. The integration of a collaborative framework enables effective sharing of expertise and contributes significantly to a comprehensive understanding of drilling operations. Additionally, the capability to review and approve simulations within this environment enhances accountability, quality control, and adherence to industry best practices in MPD.

Introduction

Managed Pressure Drilling (MPD) transforms traditional well control methods by incorporating a dynamic, continuous circulation system to handle reservoir influxes. This innovative approach allows for real-time adjustments to the Surface Back Pressure (SBP), ensuring a balance between the influx and outflow rates to maintain steady control over the well (Liu et al. 2023, Yuan et al. 2023). Traditionally, the switch from MPD to conventional well control is directed by an MPD Operating Matrix. This matrix generally imposes a cautious limit on the maximum volume of an influx that can be managed with MPD equipment. While designed to ensure safety, this conservative strategy can sometimes overlook the complex dynamics involved in handling influxes safely and may not fully capitalize on the sophisticated capabilities of MPD systems.

Culen et al. (2016), advocating a more analytical methodology by introducing the Influx Management Envelope (IME). The IME considers both the volume of the influx and its kick intensity, creating a framework for managing well control scenarios during MPD operation. By applying the IME, the MPD system's potential to circulate influx volumes is unlocked, which is especially crucial for drilling within ultra-narrow margin environments where traditional safety buffers are minimal. Nevertheless, formulating an IME necessitates intricate well control simulations and in-depth engineering analysis, as noted by Bacon et al. (2015). This complexity poses significant challenges at the wellsite, particularly during dynamic drilling operations. Current IME software often requires extensive computational resources and time-consuming iterations, making the application difficult to implement. Manual steps involved in calculating the IME limits increase the risk of human error and inconsistencies. Moreover, integrating IME calculations with ongoing operations can be challenging because these tools often do not align well with operational workflows. Handling large volumes of data can be difficult due to inadequate data management features. Additionally, the user interfaces of existing tools can be complex, necessitating specialized training, which can be a barrier to effective use. Scalability issues further limit performance, especially in complex or large-scale operations. Addressing these drawbacks requires developing more intuitive and automated IME tools that enhance data integration, user interface design, and computational efficiency.

The digital cloud-based solution we are proposing can solve the required calculations at once by automation and parallelization. New engine technology will be a key enabler for removing manual work and the ability to automate the workflow. Without this automation, it would not be possible to release the significant efficiency gain achieved by parallelization. Running all calculations in parallel and presenting the results in an easy to evaluate graphical map, will reduce the time consumption for running this workflow to less than 10 % of previous practices. The core of our digital cloud-based solution is a new multiphase flow engine solution that is consistent between single and multiphase periods. This remove required manual steps from previous solutions. Consistency also means that more can be calculated in parallel leveraging from the power of simulation clusters running in cloud.

The user will be guided with postprocessed solutions and easy to analyze graphics. The savings will not be huge for one iteration, but MPD operations are complicated, and it is typical to require additional sensitivities and iterations. And with additional iterations, the time savings will be even bigger. The automated IME generation will represent a step change in efficiency through automation, parallelization and smart postprocessing. New engine features will cut significant parts of the previous workflow and result in a workflow that can be completed much faster than before. This will not only improve efficiency but also operational quality as the automated procedure will have new areas of use within operations.

The objective of the present study is to integrate cloud-based solutions and parallel computing to enhance the efficiency of generating IME, utilizing a commercial multiphase flow engine. First, the manual IME generation workflow is presented, followed by a case study. Then, the cloud-based solution is introduced, detailing its implementation and benefits. Finally, the paper discusses future work and potential improvements, summarizing the key findings and their implications for the industry.

Literature Review

The advancement of MPD systems and the development of the IME have significantly improved well control practices, as evidenced by multiple scholarly contributions. Gabaldon et al. (2014) initiated the discussion by highlighting MPD's ability to dynamically manage unwanted influxes without resorting to traditional shut-in procedures, marking a fundamental shift from conventional well control methods. Culen et al. (2016) further refined this approach by introducing the IME, a method to define the safe operational limits for managing influxes, providing a more precise decision-making tool compared to traditional MPD matrices. Patil et al. (2018) advanced this methodology by considering various operational factors, such as shoe strengths, shut-in scenarios, circulation rates, mud compressibility, and Mud Gas Separator capacities, to shape the IME more accurately.

Subsequent studies expanded on these concepts to enhance the IME's practical application and accuracy. Gabaldon et al. (2019) conducted a detailed parametric sensitivity analysis to refine the IME limits based on data and lessons learned from offshore applications, emphasizing the importance of adjusting the IME for specific operational contexts. Gabaldon et al. (2020) extended this work by incorporating realistic equations of state for gases and developing a conceptual IME plot with color-coded operational zones, thus providing a clearer framework for decision-making during MPD operations. Berg et al. (2020) contributed by addressing the limitations of earlier IME models, proposing a new approach that integrates real-fluid behavior and avoids simplifying assumptions, thereby improving the accuracy of peak circulating pressure and maximum weak-point pressure calculations. This progression illustrates the trend towards more sophisticated and adaptable MPD systems that integrate data and advanced simulations to better manage complex scenarios, such as ultra-deepwater operations, as suggested by Gabaldon et al. (2022).

Despite these advancements, a significant gap remains in the manual steps and iterations required to apply the IME. The current process often relies on offline analysis and manual adjustments, which can introduce delays and potential human error. A cloud-based solution, as demonstrated by Yuan et al. (2019) and Gomez et al. (2021), could automate data collection, analysis, and application of the IME, enabling continuous updates and immediate, accurate decision-making. This solution integrates well data with advanced algorithms and simulations on cloud platforms, enhancing collaboration and process efficiency. Vij et al. (2023) and Morrison et al. (2023) further emphasize the benefits of digital transformation in well planning, including reduced planning times, improved data accuracy, and streamlined workflows. Medina et al. (2023) illustrates how digital platforms facilitate the integration of various engineering tasks, automate repetitive processes, and enable real-time collaboration among teams. To implement such a solution successfully, robust data infrastructure, seamless integration with existing drilling systems, high-speed internet connectivity, cybersecurity measures, and personnel training are essential. This approach promises to enhance the safety and efficiency of MPD operations, bridging the gap between current manual practices and the potential for fully automated well control management.

Manual IME Generation Workflow

The IME generation workflow, as detailed by Culen et al. (2016), is designed to enhance the decision-making process in MPD operations by providing a more precise and data-driven approach compared to traditional well control matrices. The IME uses kick tolerance calculations to correlate kick size, initial shut-in pressure, and peak surface and weak-point pressures while circulating gas to the surface. This approach allows for the creation of a "kick envelope," which defines the limits within which kicks can be safely managed using MPD without transitioning to conventional well control. The workflow involves calculating the maximum surface pressure encountered during kick circulation as a function of initial surface pressure and kick volume. By plotting these values on an IME plot, operators can determine whether a given kick can be managed with MPD systems.

The manual workflow of the IME generation presented in this study involves the calculations of MPD hydraulics and well control using a commercial multiphase flow software. In this study, a reference depth, also known as anchor point, is defined where the pressure at this position is maintained constant by automatically computing the choke pressure while circulating the kick. This function ensures both a stable wellbore pressure profile and safe circulation of the kick to the surface within the boundaries of the primary wellbore barrier. The workflow of IME can be broken down into several key steps:

Initial Setup for Dynamic Hydraulics Module

(1) Enter survey data input, including measured depth, inclination, azimuth, vertical depth, etc. (2) Enter pore pressure and fracture pressure data; (3) Define wellbore geometry, including casing, drill string geometries; (4) Input temperature profiles and mud properties for the simulation.

Run Initial Simulation

Run a batch simulation and assume encountering unexpected pore pressure and taking a kick at a specific depth.

Data Transfer Between Modules

(1) Transfer the simulation results (e.g., pressure, temperature profiles) between Dynamic Hydraulics and Dynamic Well Control; (2) Adjust the Equivalent Circulating Density (ECD) in Dynamic Well Control to match the ECD from Dynamic Hydraulics. This can be done by modifying the mud reference temperature or density; (3) Set reference depth (Constant well position at the top of reservoir) as circulation mode and set the constant well pressure by applying a safety margin above the reservoir pressure.

Initial Setup for Dynamic Well Control Module

(1) Define initial values for influx volumes (e.g., 2, 5, 10, 15, 20, 25, and 30 barrels); (2) Set an initial guess for kick intensity (e.g., 0.3 ppg).

Running Initial Simulation

(1) Initiate a simulation with the predefined input parameters and monitor for the pit alarm level, which indicates the detection of an influx; (2) Extract the reservoir and wellbore pressure data from the simulation to calculate the underbalance pressure.

Adjust Surface Backpressure (SBP)

(1) Calculate the initial SBP required to stop the influx from the underbalance pressure and a safety margin; (2) Adjust the SBP in the simulation; (3) Continue the simulation with the adjusted SBP.

Simulate Well Control Procedures

(1) Active "reference depth" mode; (2) Monitor the pressure window at the casing shoe to ensure it remains within safe limits; (3) Increase the reservoir pressure (kick intensity) by the pressure window to determine the maximum SBP; (4) Re-run the simulation to check if the increased reservoir pressure can be managed without exceeding the weak point pressure.

Influx Circulation and Backpressure Determination

(1) Reduce pump rates to a safe level and circulation of influx while monitoring gas front position; (2) Calculate connection backpressure by adding annular friction pressure loss to the circulating backpressure.

IME Plotting

(1) Use the collected data to plot the IME; (2) Highlight regions where the influx can be safely managed using MPD equipment and where secondary barriers are needed; (3) Color-coding of the IME graph for easy identification of safe and unsafe regions.

Validation and Testing

(1) Test the workflow with various scenarios to ensure robustness and reliability; (2) Validate the results against field data to ensure accuracy; (3) Continuously refine the algorithms based on feedback and new data to improve accuracy and efficiency.

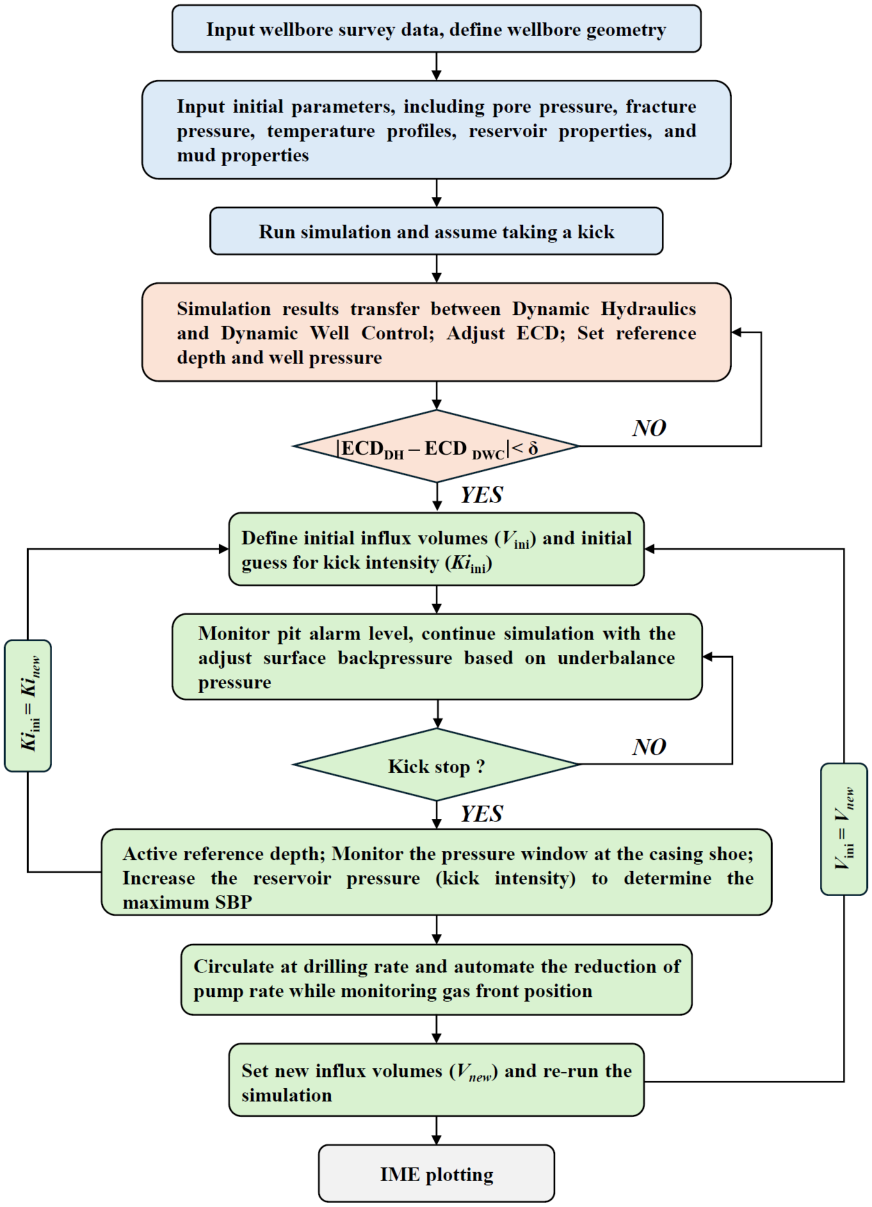

Figure. 1—Manual IME workflow.

Case Study

Simulations were performed in a 13 5/8″ hole section with an initial bit depth of 10141 ft. The well is drilled with oil-based mud (OBM) at 792.5 gpm. Other simulation parameters are summarized in Table 1.

Table 1—Simulation parameters.

Simulation Parameters	Value	Simulation Parameters	Value
Casing ID	12.374 in	Rotation speed	90 rpm
Drillpipe OD	5.5 in	Torque	3688 lbf-ft
Initial bit depth	10141 ft	Rate of penetration	66 ft/hr
Wellbore inclination	0o	Pump rate	792.5 gpm
Mud weight	13.27 ppg	Permeability	300 md
Mud type	OBM	Porosity	30%
SBP during drilling	140 psi	Surface temperature	87 oF

Assume drilling hits an unexpected high reservoir pressure and gas kick occurs at depth of 10436 ft, the current ECD at the bit depth is 13.68 ppg and the wellbore temperature profile is shown in Fig. 2.

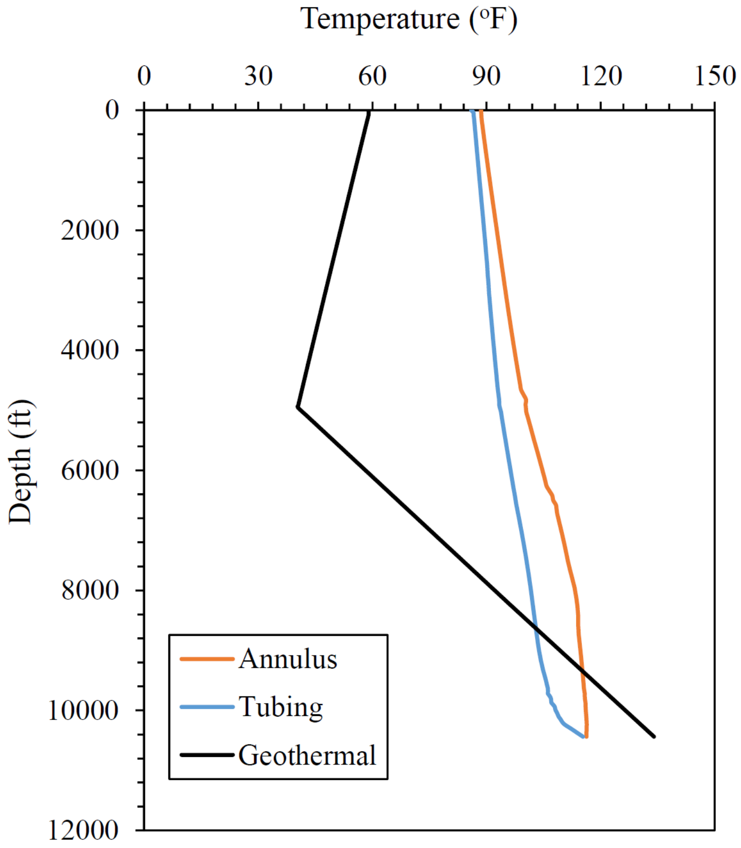

Figure. 2—Temperature profile.

At this point, the simulation of MPD hydraulics is completed and the data is transmitted to MPD well control, ensuring that the bit depth and ECD are matched to the hydraulics. Next step is to set the kick size and initial guess of KI until the maximum KI is determined, following the procedures in the above section. For instance, a 30 bbl influx at 0.385 ppg KI (7535 psi) can be suppressed by applying 487 psi SBP. A safety margin of 50 psi is included in the control SBP.

The well pressure (Fig. 3a) decreases initially as gas influx enters the wellbore and then keeps constant throughout the circulation of influx out of the well. Pressure at casing shoe is not exceeded the fracture pressure with a safety margin of 50 psi and then kept constant once the influx has passed the shoe (Fig. 3b). The choke pressure is automated adjusted to ensure a constant BHP and the pump pressure is reduced to avoid exceeding the mud gas separator capacity, as shown in Fig 3 (c) and (d).

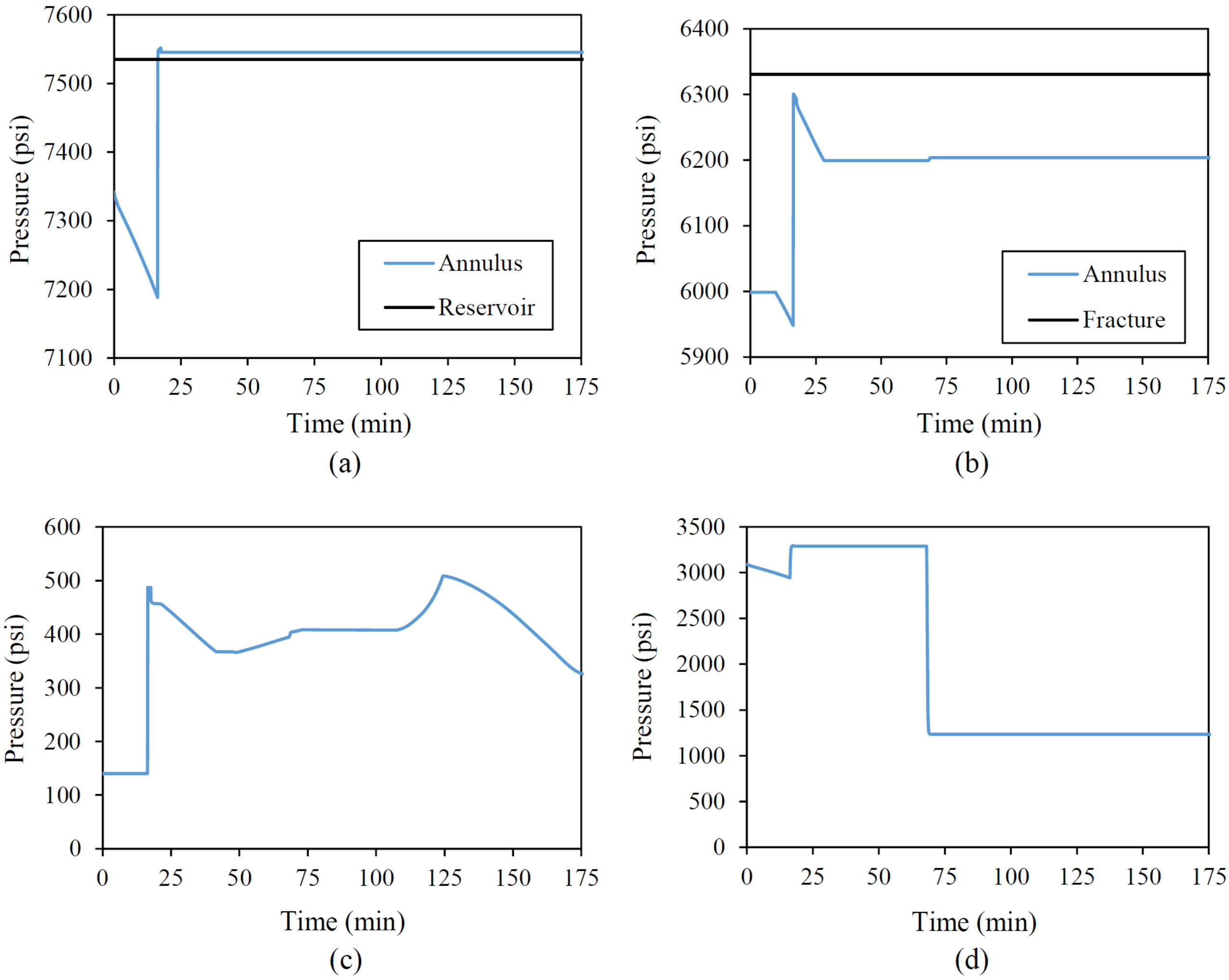

Figure. 3—Pressure behavior. (a) Well pressure, (b) pressure at casing shoe, (c) choke pressure, and (d) pump pressure).

Fig. 4 (a) shows the initial 30 bbl. gas influx and the pit gain decreases as the influx is circulated out (Fig. 4b) and well is overbalance. Fig. 5 displays the influx mass fraction along the wellbore from the circulation initiated, circulation, and circulating out of the well.

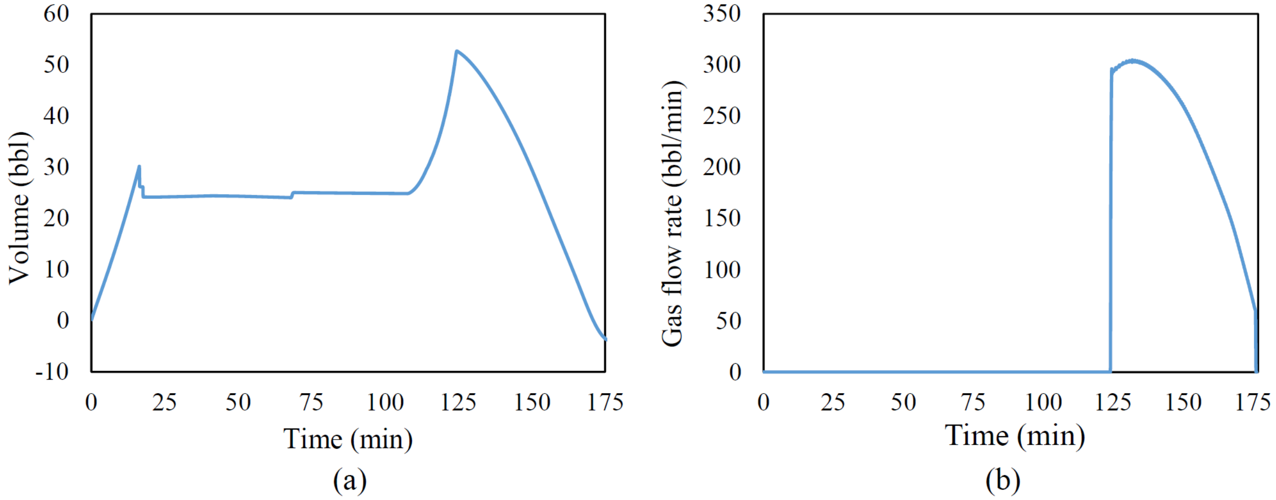

Figure. 4—(a) Pit gain, (b) gas flow rate out.

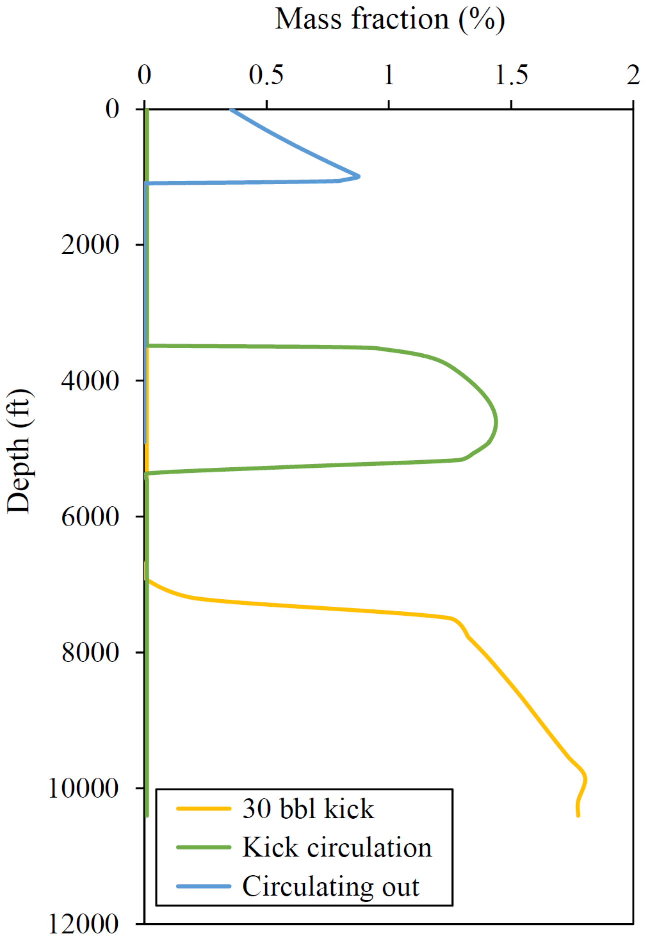

Figure. 5—Gas mass fraction.

Table 2 summarizes the combinations of influx volumes, maximum kick intensities, and the corresponding SBP to define the IME boundaries. Fig. (6) presents the IME for 13 5/8″ hole section based on maximum SBP that can safely kill the influx.

Table 2—Results of kick intensity and post-influx SBP.

KI (ppg)	Influx volume (bbl)	Post-Influx SBP (psi)
0.522	2	436
0.491	5	438
0.45	10	440
0.397	15	437
0.372	20	445
0.361	25	464
0.358	30	486

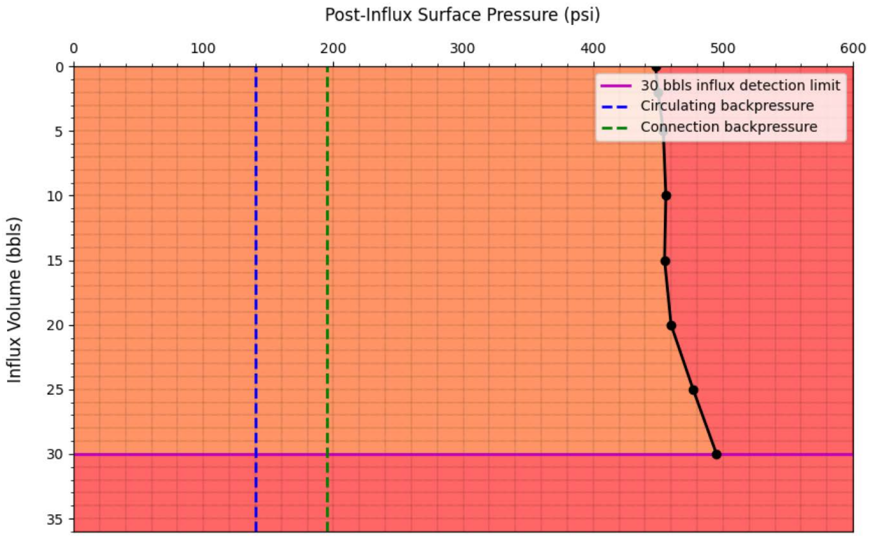

Figure. 6—IME for the 13 5/8″ hole section.

Cloud-Based Solution

Cloud-based solutions in well engineering are grounded in several core principles designed to optimize performance and collaboration. Central to these solutions is the centralization of data, which ensures that all relevant information is stored in a single, accessible repository. This eliminates data silos and enables real-time updates and access for all team members, fostering a collaborative environment. Another key principle is automation and standardization; by automating repetitive and time-consuming tasks, such as data entry and engineering calculations, cloud-based solutions reduce human error and allow engineers to focus on more critical, value-adding activities. Scalability and flexibility are also crucial, as cloud infrastructure can dynamically adjust to varying project demands, ensuring optimal resource utilization without the need for significant upfront investment in physical infrastructure. Additionally, improved decision-making capabilities are enabled through data analysis and visualization tools, providing actionable insights that enhance the precision and timeliness of decisions. Lastly, robust security and compliance measures are integral, protecting sensitive data and ensuring adherence to industry standards and regulations.

The cloud-based simulation platform is designed to be user-friendly and highly automated. Once logged in, the user interacts with the web interface to start a new simulation or retrieve past results. This interface sends a request to the system, which then coordinates the necessary tasks. It prepares and processes the drilling data provided by the user into a suitable format for the simulation. The system creates jobs for the simulation, which are managed by a job scheduler to ensure proper execution. The processed input data is automate transformed into a format that the dynamic multiphase flow simulation engine can use, and the simulation is run, generating results. Throughout the simulation, updates are collected and made available to the user. Once the simulation is complete, the results are stored in a database, and the final results are archived for future reference.

This platform uses a single multiphase flow simulation engine for both MPD hydraulics and well control processes, which is usually treated separately in common practices. The powerful simulation engine allows for the incorporation of advanced features during MPD, such as drilling cuttings. This will improve the accuracy of temperature profile and ECD predictions. It also employs parallel computing by setting a range of parameters, such as kick intensity and influx volumes, allowing multiple simulations to run concurrently for efficiency. Automation significantly reduces the manual workload on engineers by handling tasks such as data transformation, calculating post-influx SBP, iterating maximum KI, and adjusting pump rate, reducing the likelihood of human error and freeing engineers to focus on more complex tasks. Data logging and analysis are integral parts of the workflow. The system logs the results of each simulation run, including influx volume, kick intensity, and corresponding SBP, storing the data in a structured format for easy retrieval and analysis. This logged data helps identify trends and relationships between influx volume, kick intensity, and SBP. Additionally, the platform automates Integrated IME plotting, further enhancing efficiency and accuracy. The automate IME workflow is presented in Fig. 7. This comprehensive approach not only enhances well control but also optimizes resource allocation, reduces operational costs, and improves the safety and efficiency of well planning and execution.

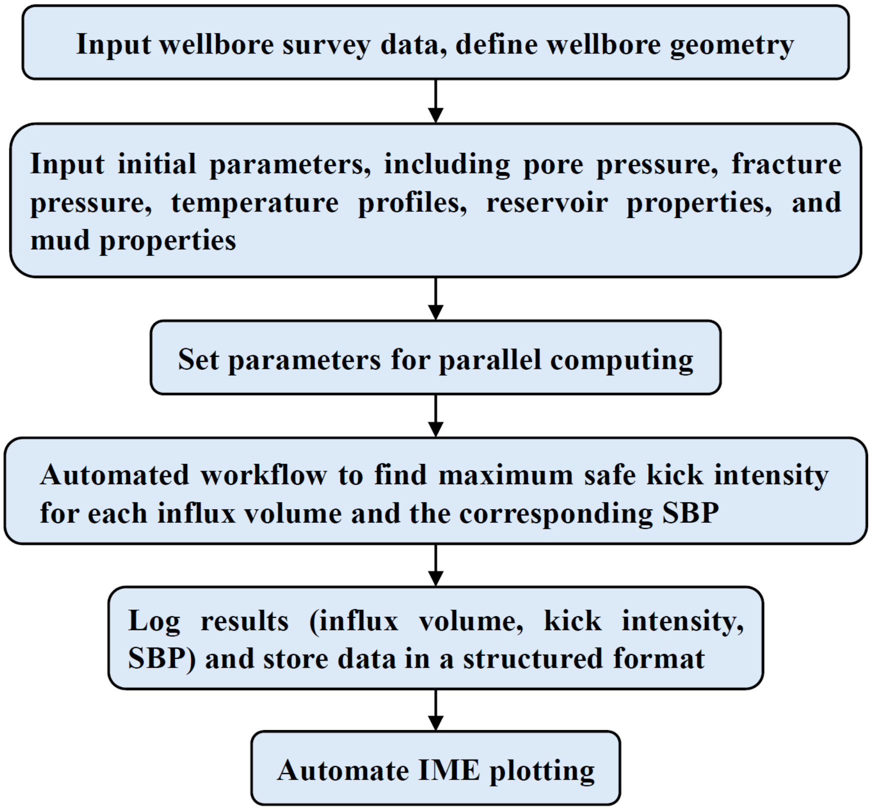

Figure. 7—Automate IME workflow.

Future Work

Applying field data to validate the performance and reliability of the automated IME generation system under various conditions will be crucial. Future work should also expand the engine's capabilities to simulate oil influx scenarios, providing a more comprehensive tool for managing different types of influxes. Incorporating models that simulate the performance and limitations of mud gas separators will enhance the system's accuracy in predicting and managing gas separation and handling capabilities.

Conclusion

The automation of IME generation through cloud-based solution represents a significant advancement in MPD operations. By integrating digital cloud-based technologies with parallel computing, this study has demonstrated a streamlined and efficient approach to handling complex well control scenarios. The adoption of a transient multiphase flow engine for kick tolerance thresholds and safe influx volume determination enhances operational safety and decision-making capabilities.

This innovative approach mitigates the challenges associated with traditional IME generation, such as extensive computational requirements, manual adjustments, and synchronization issues with data feeds. The cloud-based solution centralizes data, automates repetitive tasks, and leverages the power of parallel computing to perform multiple simulations concurrently. This results in significant time savings, reduced human error, and improved scalability and consistency in IME generation.

Unlike traditional methods that require separate handling of MPD hydraulics and well control scenarios, the new multiphase flow engine integrates both processes into a single cohesive framework. This integration ensures a consistent approach throughout the MPD IME generation process. Moreover, the new engine can improve the accuracy of downhole temperature and ECD predictions by incorporating advanced features such as drilling cuttings. This leads to more reliable simulations and better-informed decision-making.

The findings of this study underscore the potential of cloud-based solutions to transform MPD operations by offering a more intuitive and automated IME generation tool. This approach not only improves efficiency and operational quality but also opens new areas of use within drilling operations, ensuring a safer and more effective management of well control scenarios. Future work will focus on further refining the cloud-based platform, enhancing its features, and exploring additional applications to continue advancing the field of managed pressure drilling.

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