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Critical Aspects of Pressure Relief Valve System used in Managed Pressure Drilling Applications

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Abstract

Managed Pressure Drilling (MPD) operations present unique challenges that necessitate a robust and reliable Pressure Relief Valve (PRV) system. The primary purpose of the PRV is to protect the formation as well as the MPD surface equipment from being over pressured. The relief valve achieves this by bypassing the normal fluid flow path of MPD system, thereby relieving the excess pressure in the system through a dedicated line.

In case a PRV is activated during MPD operations, the loss of surface back pressure increases the likelihood of taking a kick from the active formation. If the PRV is not activated, an excessive increase in surface pressure increases the chance of formation fracture, which can lead to losses and a secondary kick. As a result, the configuration of PRV's have a significant influence on the MPD system design.

This paper explores the critical aspects of PRV system design and operation, especially in deepwater MPD environments. Key design considerations such as pressure ratings, flow capacity, material selection, and control mechanisms are discussed, emphasizing their impact on system performance and safety. The paper highlights the importance of PRV system reliability and safety, emphasizing the need for rigorous testing, maintenance, and redundancy. Recent advancements in PRV technology are also explored to demonstrate their potential for improving MPD operations safety. Procedures showing the PRV system testing and verifications are presented. The paper concludes with an outline of future requirements and research directions for PRV systems with a focus on enhancing safety, efficiency, and environmental sustainability.

Introduction

Managed Pressure Drilling (MPD) has emerged as a vital technique in deepwater environments, addressing the challenges of high-pressure, high-temperature (HPHT) conditions and narrow drilling windows. Deepwater drilling operations often involve unpredictable pressure regimes and require precise control of annular pressure profiles to ensure wellbore stability and safety. MPD achieves this by enabling real-time adjustments to surface back pressure, thereby maintaining a constant bottomhole pressure (CBHP) and preventing influx or losses. The ability to proactively manage pressure helps mitigate well control incidents, enhances operational efficiency, and reduces non-productive time (NPT) (Denney, 2012). The integration of MPD systems into deepwater rigs has been shown to improve drilling efficiency and safety. For instance, the implementation of an integrated MPD control system on a deepwater drilling rig increased the accuracy of pressure control, leading to safer and more efficient operations (Carpenter, 2019).

However, incorporating MPD into the drilling process introduces additional complexity, especially in deepwater operations. The use of a Rotating Control Device (RCD) and the closed-loop annulus system significantly alter the pressure dynamics within the wellbore. This modification inherently increases the risk of overpressure conditions in the wellbore and marine riser, necessitating robust protective measures. These measures must account for the specific pressure limitations of each component, including the marine riser, which typically has a maximum pressure rating that must not be exceeded to maintain structural integrity and operational safety (Kulkarni, 2024).

In deepwater MPD operations, the challenges are magnified due to the extended length of the marine riser and the interplay of multiple pressure factors, including formation pressures, hydrostatic pressures, and applied surface back pressure. Overpressure incidents in this context could lead to catastrophic outcomes, such as riser burst or well control events. For instance, the Deepwater Horizon incident underscored the critical need for stringent pressure management and system reliability in offshore drilling (USCG, 2011).

MPD systems are not immune to software glitches, procedural inconsistencies, or human errors. These issues can result in unintended operational consequences, such as incorrect pressure settings, equipment malfunctions, or delayed responses to pressure anomalies. For example, a malfunctioning

MPD control system could fail to manage a surge in pressure, potentially leading to equipment damage.

Role and importance of PRVs in MPD systems

Pressure Relief Valves are critical components in MPD systems, especially in deepwater drilling operations. Their primary function is to protect the wellbore and surface equipment from overpressure scenarios by diverting excess pressure through a dedicated line, thereby preventing equipment failure or formation damage. The activation of a PRV relieves system pressure; however, it also results in the loss of surface back pressure, which can increase the risk of a formation kick due to the reduced bottomhole pressure. Conversely, failure to activate a PRV during an overpressure event can lead to formation fracture and fluid losses. Therefore, the configuration and performance of PRVs significantly influence well control and overall drilling safety (Benyeogor, 2019).

Optimizing PRV design and configuration is essential to balance the trade-offs between mitigating overpressure and maintaining sufficient back pressure to prevent kicks. This optimization enhances the safety and efficiency of deepwater MPD operations.

Objectives of this study

This study aims to evaluate PRV systems within deepwater MPD operations, focusing on their design, performance, and role in mitigating overpressure scenarios. The key objectives include:

- Highlight the importance of PRVs in protecting wellbore integrity and surface equipment from overpressure conditions.
- Discuss the complexities introduced by deepwater MPD systems, including the interaction of annular pressure, marine riser and rotating control device limitations, and the risks of formation kicks or losses due to PRV activation or failure.
- Discuss the importance of selecting correct PRV configurations to effectively manage pressure, ensure system stability, and improve overall drilling efficiency while mitigating well control risks.

PRV Guidelines – Industry Standards.

The design and operation of MPD systems are governed by industry standards and guidelines provided by organizations like API, DNV and ABS. The section of the paper examines the different guidelines detailed in their documentation.

Over-Pressurization Protection

API 92M and 92S provide general guidance on the installation of PRVs for the MPD system as outlined below:

- A pressure relief discharge tank may be necessary to ensure safe discharge of fluids. It should have appropriate sizing, level control and provisions for integrating with the rig circulation system.
- Consider potential hydrocarbon presence and ensure downstream venting and overpressure protection.
- Pressure relief lines should have a low risk of obstruction and open-ended wherever possible.
- If valves are present, they must be locked open during operations.
- The lines should be flushed with clean fluid or air regularly to prevent plugging.

MPD Riser Components (API 92S)

For the deepwater MPD operations, the above Tension Ring (ATR) MPD riser and Below Tension Ring (BTR) MPD system should both have provisions for installing suitably rated PRVs for riser overpressure protection.

When planning MPD operations, a PRV philosophy should address the following:

- The well structure,
- The riser system,
- Surface piping and equipment.
- Formation Protection and Piping Considerations
- A formation protection pressure relief system should prevent over pressurization while maintaining wellbore pressure.

Discharge piping design must account for:

- Area classification and vertical displacement
- Potential for line plugging
- Volume measurement
- Relief device sizing
- Intervention procedures
- Fluid stream composition including potential for hydrocarbons
- Remote monitoring and activation indication are recommended for real-time oversight

According to the ABS Guide – Classification of Drilling Systems, components and systems exposed to pressures exceeding their design need to be safeguarded with appropriate pressure protection devices (not pressure regulators).

Equipment design must account for all potential pressure sources, including formation pressure, pumps, static heads, and thermal effects, when selecting overpressure protection. Pressure relief devices will be reviewed per the design parameters. MPD systems should incorporate appropriate overpressure protection devices, such as pressure relief valves (PRVs), to ensure safety and reliability when components face pressures exceeding their design limits. These safeguards are essential for preventing equipment failure and protecting system integrity during drilling operations (ABS-Guide-Drilling-Systems, 2021)

Key considerations for MPD overpressure protection include the placement of relief valves upstream of the choke manifold for components at risk of overpressure. For rigs with subsea BOP stacks, all components between the BOP and MPD choke must also be safeguarded by PRVs. The location and implementation of these devices must be justified through rigorous risk assessments to address potential failure scenarios effectively. PRVs and associated discharge piping must meet stringent design and testing standards, including API Spec 6A PSL 3, API RP 14C safety principles, and API Recommended Practice 520 for relieving capacity. The relieving capacity must accommodate the maximum output of the drilling mud pumps or be supported by well-specific calculations. These calculations should account for various operational and emergency scenarios, such as handling gas in the riser, ensuring adequate protection across all operational modes.

According to API 92S, installing a PRV at a specification break[1] between high- and low-pressure rated equipment is a common requirement. This is done to protect the lower-rated components from over-pressure events. Depending on the system configuration, multiple PRVs may be required in the MPD system to ensure adequate pressure protection (API-92S, 2023).

According to an ABS guide for classification and certification of MPD system, the following requirements apply to PRVs utilized in MPD operations (ABS-Guide, 2017):

- Each PRV should be installed at the highest feasible point and in such a way that debris does not accumulate on the PRV's inlet.
- In case of a rig power failure, the PRV is to remain functional until MPD operations can be suspended, and the well is fully secured. The PRV system must have a reliable backup power supply.
- A redundant PRV must be installed upstream of the choke manifold, equipped with an independent power source and control system.
- A remote indication of the activation or status of each PRV must be provided.
- All PRVs must reset to their pre-release settings after a pressure-release event to maintain system pressure integrity.

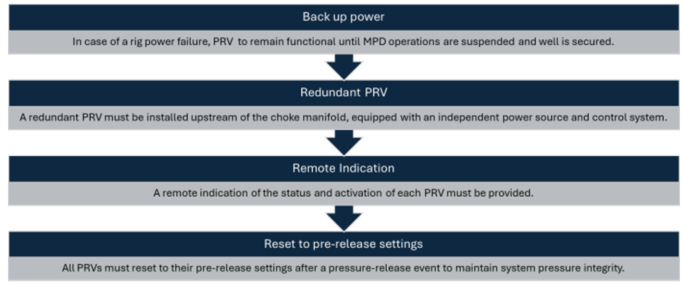

Figure 1 Key requirements of PRV in MPD operations

Pressure Relief Valve (PRV) Installation

The design philosophy for MPD systems prioritizes operational safety and environmental protection. MPD systems must divert discharged fluids to secure locations, considering the type and volume of fluid. In scenarios where a dedicated PRV discharge tank is used, the system must include features such as remote monitoring, volume measurement, appropriate venting, and connectivity to the rig's mud system. In emergencies, provisions must exist to redirect fluid flow to overboard lines or other safe locations upstream of the choke manifold.

PRVs must be installed at the highest feasible location to minimize the risk of debris accumulation, and all systems must remain operational during power outages, ensuring continued functionality until operations are safely suspended, and the well is secured. To enhance system redundancy, a secondary PRV with an independent power supply must be positioned upstream of the choke manifold. Additional requirements include remote activation status indicators and the ability of PRVs to reset to their original settings post-activation (ABS-Guide, 2017)

Discharge piping associated with PRVs is subject to stringent criteria. They must be free from obstructions and capable of safely discharging pressure at all times. Special considerations include mitigating the risk of line plugging, ensuring accessibility for maintenance, and accommodating the specific characteristics of the discharged fluid stream. Discharge piping must also incorporate flushing capabilities and minimize resistance (ABS-Guide, 2017)

A buffer manifold, or a functionally equivalent piping, located upstream of the choke manifold is to be provided to direct the well fluids to the rig's shakers, rig's choke manifold, rig's gas buster, overboard lines, or to the MPD choke manifold (ABS-Guide, 2017).

Types of PRVs used in MPD operations

For MPD operations, the most common types of PRVs are

- Mechanical PRV
- Software Based PRV

– Pressure Relief Choke

Mechanical PRVs

Mechanical PRVs are traditional safety devices designed to release excess pressure from the drilling system when a pre-set pressure threshold is exceeded. They operate purely based on mechanical principles without reliance on electronic systems or software. Mechanical PRVs typically use a spring-loaded or weighted mechanism to maintain a seal under normal conditions. When the system pressure surpasses the set point, the valve opens, venting excess pressure until normal conditions are restored. Commonly used in drilling operations, and surface equipment and are used in situations requiring immediate mechanical response without dependency on electronic systems (API-520, 2000).

Mechanical spring-loaded PRVs are the most commonly used mechanical pressure relief devices. They function using a spring force opposing system pressure to control valve opening and closing.

Design & Function:

- Self-actuated, spring-loaded valve designed to open at a predetermined pressure to relieve excess pressure from the system.
- Comprises an inlet nozzle, movable disc, and compression spring.
- Under normal conditions, the spring force keeps the valve closed.
- When system pressure exceeds the setpoint, the force exerted by the fluid overcomes the spring force, causing the valve to open.

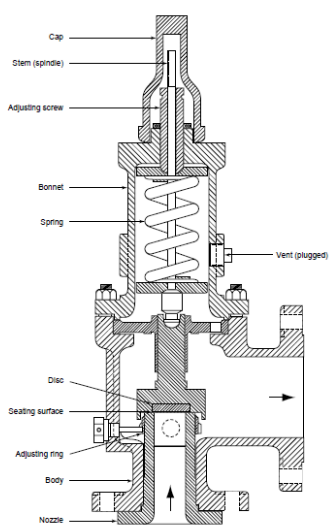

Figure 2 Mechanical Pressure Valve with Single Acting Ring for Blowdown Control, Source (API-520, 2000)

Figure 2 depicts a spring-loaded PRV with different components described below.

- Cap – Covers the adjusting screw to prevent accidental changes.
- Stem (Spindle) – Connects the adjusting screw to the spring and helps control movement.
- Adjusting Screw – Used to set the desired pressure at which the valve opens.
- Bonnet – Encases the spring and moving components.
- Spring – Provides the necessary force to keep the valve closed until the set pressure is exceeded.
- Vent (Plugged) – Can be used for venting or secondary pressure control.
- Disc – Acts as the sealing element that lifts to release excess pressure.
- Seating Surface – Contact area where the disc seals the valve under normal conditions.
- Adjusting Ring – Fine-tunes the valve's opening characteristics.
- Body – Houses all components and connects to the piping system.
- Nozzle – Directs fluid flow out when pressure exceeds the setpoint.

Valves used for gas and vapor service are known as safety valves, which operate with a pop-action opening mechanism. In contrast, relief valves, designed for liquid service, open gradually. Both types of function are based on a force balance mechanism, where spring force opposes the fluid pressure.

Blowdown is defined as the pressure difference between the setpoint (opening pressure) and the reseating pressure (the point at which the valve closes). The valve re-seats when the inlet pressure drops sufficiently below the set pressure, allowing the spring force to push the disc back into place. Adjusting rings are used to fine-tune the blowdown characteristics.

Software Based Pressure Control System

- Pressure relieving
- Pressure controlling/throttling (i.e. Pressure relief choke)
- Pressure relieving with a minimum/closing pressure
- Dynamic and static set points pressure relief and minimum closing pressure

Pressure Relief Choke

The Pressure Relief Choke (PRC) serves as an adjustable flow restriction device, enabling controlled pressure relief through the adjustment of the choke position. Unlike traditional PRVs, the Pressure Relief Choke allows for graduated pressure release, which is beneficial in managing large or rapid influxes.

Key benefits are adjustability which provides operators with the ability to adjust pressure relief rates, offering greater control over wellbore pressure.

The PRC is used in conjunction with other MPD equipment to enhance pressure management capabilities.

PRV Design

Detailed calculations must be carried out to ensure that the PRVs planned for an operation can effectively manage the pressures and flow rates expected in the system. These calculations typically include:

- PRV Sizing
- Line Size (Friction Pressures)
- Line Pressure Rating

PRV sizing

Properly sized PRVs safeguard against equipment failure by allowing controlled discharge of fluids, ensuring operational safety and compliance with industry standards. API Standard 520 outlines the methodology for determining the required relieving capacity for PRVs. Specifically for liquid service, it emphasizes key parameters like flow rate, fluid properties, and operational pressures to calculate the required discharge area (A), ensuring a PRV operates effectively under expected conditions.

The required discharge area (A) for a PRV is calculated using the following equation (API-520, 2000):

$$A = \frac{Q}{(38 \times K_d \times K_W \times K_V)} \times \sqrt{\frac{G}{(P_1 - P_2)}}$$

Variables:

- A= Required discharge area (in²)
- Q = Flow rate (gallons per minute, gpm)
- K_d = Coefficient of discharge (dimensionless)
- K_w = Capacity correction factor (dimensionless)
- Kv = Viscosity correction factor (dimensionless)
- G = Specific gravity of the fluid (dimensionless)
- P_1 = Set pressure plus allowable overpressure (psi)
- P_2 = Backpressure (psi)

Kw = correction factor due to back pressure.
P_B = back pressure, in psig.
P_S = set pressure, in psig

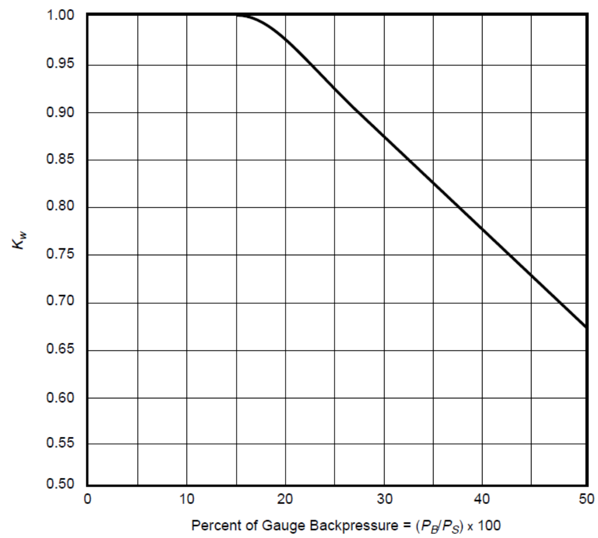

Figure 3 Curve used to determine K_w as a function of the ratio of P_B/P_S

Example Calculations

To illustrate the PRV sizing methodology, the following example calculations with 10 ppg and 12.8 ppg mud and maximum flow rate of 1200 gpm, a set pressure of 1,100 psi and a back pressure of 80 psi on the choke has been considered.

Key Input parameters

- Mud weight 1(G) = 10 ppg (1.20 sg)
- Mud weight 2 (G) = 12.08 ppg (1.45 sg)
- Maximum flow rate (Q) = 1,200 gpm
- Set pressure (P_{set}) = 1,100 psi
- Allowable overpressure = 10% of P_{set}
- Backpressure (P_2) = 80 psi
- $P_1 = Set\ Pressure \times (1 + Overpressure)$
- $P_1 = 1{,}100 \times (1 + 0.1) = 1{,}210\ psi$
- $\Delta P = P_1 - P_2 = 1{,}210\ psi - 80\ psi = 1{,}130\ psi$

PRV Characteristics

- Coefficient of Discharge (K_d): 0.65 (assume 3in PRV)
- Capacity Correction Factor (K_w): 1.0 (assumes small backpressure effect)
- Viscosity Correction Factor (Kv): 1.0 (since Re > 16,000)

$$A = \frac{Q}{(38 \times K_d \times K_W \times K_V)} \times \sqrt{\frac{G}{\Delta P}}$$

$$A = \frac{1200}{(38 \times 0.65 \times 1 \times 1)} \times \sqrt{\frac{1.2}{1130}}$$

$A = 1.58\ in^2$ for mud weight 1 = 10 ppg (1.2 sg)

$A = 1.74\ in^2$ for mud weight 2 = 12.08 ppg (1.45 sg)

For the given illustration, a 10 ppg mud with a maximum flow rate of 1200 gpm would require a PRV with a minimum discharge area or trim of 1.58 in². Similarly, for a 12.08 ppg mud under the same flow rate and conditions, the required PRV discharge area would be 1.74 in².

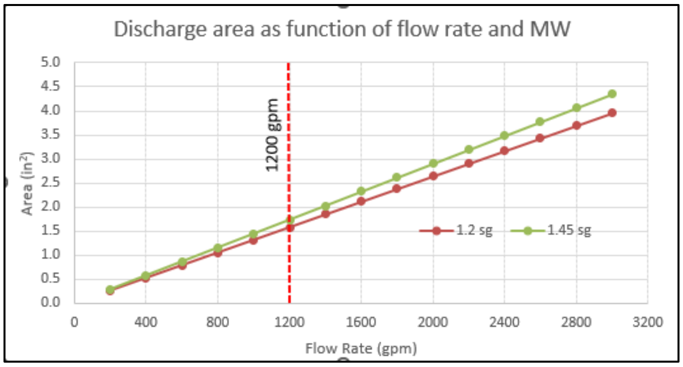

Figure 4 Discharge area as a function of flow rate and mud weight

Line Size (Friction Pressures)

Friction pressure is the pressure loss due to fluid movement through the discharge lines. If the discharge line is undersized, friction pressure can rise sharply, resulting in:

- Excessive backpressure on the PRV.
- Reduced discharge capacity, potentially compromising safety.
- Risk of PRV malfunction due to backpressure exceeding the set point.

On the other hand, an oversized discharge line may lead to unnecessary costs and installation challenges without offering significant operational advantages. The friction pressure in the discharge line is dependent on:

- Flow Rate: Higher flow rates result in greater frictional losses.
- Fluid Properties: Viscosity and density of the drilling fluid or gas impact friction losses. High-viscosity fluids, such as drilling mud, can increase pressure losses.
- Line Length: Longer discharge lines increase the cumulative friction pressure.
- Pipe Diameter: Smaller diameters increase friction pressure, while bigger diameters decrease it.
- Roughness of the Line Material: Surface roughness of the pipe influences the friction factor

Line Pressure Rating

The pressure rating of a discharge line connected to a PRV is a critical design parameter. This rating ensures that the discharge line can safely handle the maximum pressure that may arise during PRV activation without causing line failure. Properly rated lines are essential for system safety, compliance with regulations, and operational reliability.

PRV Philosophy

A PRV philosophy for MPD operations outlines the procedure, and equipment configurations necessary to ensure the safe and efficient use of PRVs within an MPD system. This philosophy ensures that the system operates within its design limits, manages unplanned pressure events, and provides redundancy to enhance well control and equipment protection. Below are key components of a PRV philosophy for MPD operation.

A typical PRV philosophy should include a comprehensive list of all PRVs installed within the system, along with a detailed outline of their design and operational parameters. The design parameters are illustrated below.

Designed For

PRVs are designed to protect equipment, personnel, and the environment by preventing overpressure conditions that could lead to catastrophic failures. The design considers factors such as pressure ratings, fluid properties, temperature ranges, and compliance with industry standards and regulations.

Set Point

The set point defines the pressure at which the Pressure Relief Valve (PRV) is activated to release excess pressure from the system. This parameter is critical for ensuring the system operates within safe pressure limits. The set point is determined based on the maximum allowable working pressure (MAWP) and the specific operating conditions of the system.

Type

PRVs are available in different types, including spring-loaded and pilot operated. The type of PRV selected depends on the application requirements, such as the desired responsiveness, pressure range, and environmental conditions. Spring-loaded valves are commonly used for straightforward applications, while pilot-operated valves are suited for high-pressure and high-capacity system

Adjustability

Adjustability refers to the capability to modify the set point of the PRV within a specific range. Adjustable PRVs offer flexibility for varying operating conditions, enabling fine-tuning of the system pressure to match changes in process parameters. This feature is particularly useful in dynamic environments where pressure requirements may vary over time.

Reset Method

PRVs can have either manual or automatic reset mechanisms.

- Manual Reset: Requires operator intervention to close the valve and return it to its original state after activation.
- Automatic Reset: Automatically closes the valve once the system pressure returns to safe levels, ensuring quicker restoration of normal operations.

Discharge Point

The discharge point defines where the fluid or gas relieved by the PRV is directed. Proper discharge point selection is vital to ensure safe handling of the relieved material. For example, discharge can be routed to flare systems, collection tanks, or safe areas, depending on the nature of the fluid and environmental regulations.

Alarm Capability

Alarm capability indicates whether the PRV is equipped with sensors or switches to provide alerts when the valve activates. This feature enhances safety by notifying operators of overpressure events, enabling prompt action to address the underlying cause.

Manual Activation

Some PRVs offer a manual activation feature, allowing operators to trigger the valve as needed. This capability is beneficial for testing the valve's functionality or intentionally relieving pressure during maintenance or specific operational scenarios.

Example PRV Philosophy

The table in **Appendix 2** illustrates an example of PRV philosophy with design and operational parameters.

PRV Discharge Location

Selecting the appropriate discharge location for a PRV system is essential for maintaining safe and efficient fluid management. Depending on operational needs, PRV discharge can be directed through different pathways. This section outlines commonly considered industry discharge locations, along with their advantages and disadvantages.

Dedicated Discharge overboard lines

Dedicated Overboard lines, as shown in Figure 5, provide a direct route for discharging the excess pressure overboard. They efficiently vent gases away from the rig, reducing hazards on the rig. However, these lines are expensive to install and maintain, and accidental discharges can cause environmental damage. Despite the costs, overboard lines remain a reliable choice for PRV discharge lines.

Note that the figure represents one specific MPD equipment configuration with a metering manifold downstream of the MPD choke manifold; MPD configurations can vary significantly, such as with a Coriolis Meter upstream, the use of an Active Control Device (ACD) instead of a RCD, and other design variations depending on MPD operational requirements.

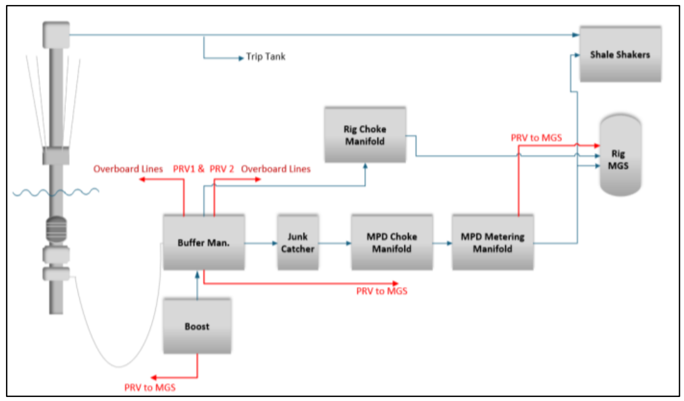

Figure 5 Illustration of Primary PRVs having discharge location overboard

Table 1 Advantages and disadvantages of PRVs having discharge location overboard lines

Discharge Location	Advantages	Disadvantages
Overboard lines	Safe method for people and equipment	Expensive
	Most direct route overboard	Accidental discharges can cause environmental issues
	Gas is routed safely off the rig	

PRV Discharge to Shale Shaker

Discharge lines to shale shaker as shown in figure 6, provide a simple fully open-ended pipe run to the rig's shale shaker.

Although the arrangement is relatively inexpensive, there is potential for hydrocarbon gas or H2S discharge at shakers.

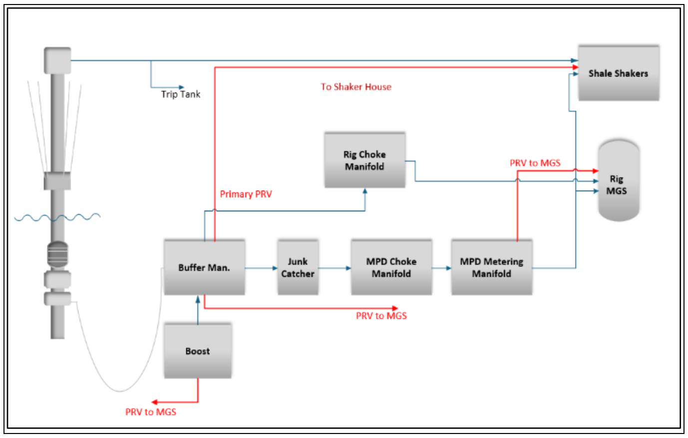

Figure 6 Illustration of Primary PRVs having discharge location overboard

Table 2 provides a comparison of advantages and disadvantages of this arrangement.

Table 2 PRV discharge location to shake shaker - Advantages and disadvantages

Discharge Location	Advantages	Disadvantages
To Shale Shakers	Simple fully open-ended pipe run	Potential for significant hydrocarbon gas release at shakers
	Relatively inexpensive	Potential for H2S discharge at shakers

PRV Discharge to Downstream of Choke Manifold

The configuration provides a discharge path downstream of the choke manifold, allowing fluids to be routed to the low pressure system in the event of PRV activation. However, due to the short pipe run and a partially restricted outlet, there is a risk of plugging downstream of the tee. The setup utilizes the MGS or shaker, but its effectiveness is dependent on the MGS flow capacity. There is a potential risk of hydrocarbon gas release at the shakers, posing safety concerns. Table 3 Provides a summary of advantages and disadvantages.

Table 3 PRV discharge to downstream of Choke Manifold – Advantages and Disadvantages

Discharge Location	Advantages	Disadvantages
Downstream of choke manifold	Short pipe run	Not fully open-ended - plugging may occur downstream of tee
	Inexpensive MGS or shaker routing	Dependent on MGS flow capabilities
		Risk of hydrocarbon gas release at shakers

PRV Discharge to Trip Tank or Dedicated Tank

The configuration utilizes a trip tank or dedicated tank, offering the possibility to use existing equipment. However, there are several risks associated with this setup. If the tank does not have sufficient volume available, there is a risk of overflow. The fully open-ended pipe run increases the potential for tank pressurization. Additionally, there is a possibility of hydrocarbon or H_2S gas release on the rig, posing significant safety hazards. Table 4 highlights the advantages and disadvantages

Table 4 PRV Discharge to trip tank or dedicated tank – Advantages and Disadvantages

Discharge Location	Advantages	Disadvantages
Trip tank or dedicated tank	Possibility to use existing equipment, which may save cost	Risk of tank overflow if sufficient volume is unavailable.
	Fully open-ended pipe run	Potential for tank pressurization.
		Possibility of hydrocarbon or H_2S gas release on the rig.

PRV Discharge to Mud Gas Separator

The MGS is utilized for handling PRV discharge, offering containment and gas separation capability. However, the effectiveness of the MGS is highly dependent on its flow capacity—if the incoming volume exceeds its design limits, result in the carryover or blow-by of hydrocarbon or H_2S gas at the shakers. The open-ended pipe run in the system may require the installation of a check valve to prevent unwanted backflow, ensuring safe and efficient gas management during PRV activation events. Proper system evaluation and flow control are essential to mitigate risks associated with high-pressure gas discharge. Table 5 highlights the advantages and disadvantages for MGS as a discharge location.

Table 5 PRV Discharge to MGS– Advantages and Disadvantages

Discharge Location	Advantages	Disadvantages
Mud Gas Separator	Provides containment with gas separation capability	Dependent on flow capacity of MGS
	Controlled (separated) gas is routed safely off the rig	Risk of hydrocarbon or H_2S carryover or blow-by at the shakers.
	Relatively open-ended pipe run (check valve would be required)	

PRV Testing

The function testing of PRV systems, particularly those with software-adjustable setpoints, is a critical process to ensure their reliability and effectiveness in mitigating overpressure events. The test results verify PRV functionality and compliance with industry standards such as API 92M and API 520.

This testing procedure systematically ensures that PRVs activate at their designated setpoints, reset correctly, and perform as expected without delays, thereby maintaining well control integrity.

Preparation & Safety Measures

The function testing of PRVs is conducted using the cementing unit, which is lined up to the MPD buffer manifold. Before initiating the test procedure, a pre-job safety meeting is conducted to brief all involved personnel, including the MPD Supervisor, Driller, Cementing Supervisor, and Subsea Team, on the testing process. The following preparatory steps are taken:

- **Valve Lineup Verification:** Ensuring proper valve configuration for safe and correct pressure application.
- **Safety Precautions:** Implementing all necessary safety measures to mitigate risks.
- **Communication Protocol:** Establishing clear roles and responsibilities for communication.

PRV Function Testing Procedure

The PRV setpoints are adjusted to a lower setpoint than the actual operational setpoint, typically with an activation pressure of 300 psi and a reset pressure of 200 psi, maintaining a differential of 100 psi.

Activation & Pressure Monitoring

- The cementing unit slowly increases pressure at a controlled flow rate of 0.25 bpm or less until the PRV activation pressure is reached.
- The MPD Supervisor monitors the MPD HMI system which displays “PRV pressure” to confirm that the PRV opens at the designated pressure, relieving excess pressure.
- As soon as pressure drops, confirming PRV activation, the cementing supervisor stops pumping to prevent excessive fluid discharge.

Final Report & Compliance

- The process is recorded by third party and the test results are reported to company representative, ensuring the PRV meets operational criteria. The test results are documented, including pressure readings, PRV response times, and any anomalies observed.
- This structured testing ensures that PRVs in deepwater MPD operations remain reliable, responsive, and fully functional, preventing well control incidents and maintaining drilling safety.

Conclusions

The study on PRV systems for deepwater MPD operations highlights the critical role of PRVs in maintaining well control, protecting the formation and equipment, as well as ensuring operational safety. Key findings include:

Enhanced Well Control and Safety:

PRVs are essential components in MPD systems, providing a critical line of defense against overpressure events. Properly configured PRVs, designed in accordance with industry standards such as API 92M and 92S, help prevent formation damage and equipment failures by releasing excess pressure in a controlled manner.

PRV Design and Configuration:

The performance of PRV systems is heavily influenced by their design and operational settings. Mechanical, software-based, and pressure relief choke systems each offer unique benefits and limitations. The selection of the appropriate PRV type must consider factors such as wellbore conditions, anticipated pressure ranges, and the system's overall design.

Operational Efficiency and System Integrity:

PRV activation directly impacts surface back pressure and can influence wellbore stability. The research underscores the importance of conducting regular tests, including function tests with simulated overpressure scenarios, to verify PRV performance. Ensuring accurate setpoints and proper discharge configurations enhances the overall efficiency and integrity of MPD operations.

Industry Standards and Best Practices:

Reviewing industry standards and recommended practices, including those from API, ABS, and IADC, is essential for the effective implementation of PRV systems. The paper provides practical insights into PRV sizing, installation, and maintenance practices that align with standards published by API to ensure consistent and reliable performance.

Future Direction:
As MPD technologies continue to evolve, ongoing research and collaboration within the industry will be essential. The development of advanced PRV designs with improved response times and reliability, along with enhanced training for drilling personnel, will contribute to safer and more efficient deepwater drilling operations.

In conclusion, the effective deployment of PRV systems in deepwater MPD applications requires a comprehensive understanding of pressure dynamics, system configuration, and industry standards. By adopting best practices and continuously evaluating PRV performance, operators can mitigate risks, enhance safety, and optimize MPD operations in challenging offshore environments.

Acknowledgments

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Nomenclature

MPD	Managed Pressure Drilling
PRV	Pressure Relief Valve
SBP	Surface Back Pressure
HPHT	High-Pressure High-Temperature
API	American Petroleum Institute
IADC	International Association of Drilling Contractors
ABS	American Bureau of Shipping
MGS	Mud Gas Separator
FIT	Formation Integrity Test
LOT	Leak-Off Test
BOP	Blowout Preventer
DB	Drill Bench
SPPT	Static Pore Pressure Test
PP	Pore Pressure
ATR	Above Tension Ring
BTR	Below Tension Ring
IRJ	Integrated Riser Joint
HMI	Human Machine Interface
PSL	Product Specification Level
Re	Reynolds Number
K_d	Coefficient of Discharge
K_w	Capacity Correction Factor
K_v	Viscosity Correction Factor
G	Specific Gravity
Q	Flow Rate
P_{set}	Set Pressure
P_{reset}	Reset Pressure
SPPT	Static Pore Pressure Test

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Appendix-1

Figure 7 illustrates an example of a PRV system used on a deepwater rig.

- PRV1 & PRV2: Located on the buffer manifold, these PRVs vent overboard and protect the riser, MPD flow line, and upstream MPD choke manifold. Their set points are determined by the lesser of the maximum allowable riser pressure or the upstream MPD component pressure.
- PRV3: Installed on the boost line and venting to the buffer tank, PRV3 prevents overpressure in the boost line by maintaining its pressure below its maximum rating.
- PRV4: Protects MPD high-pressure pipework from over pressurization due to choke and kill interactions.
- PRV5: Positioned in the return line, PRV5 vents to the MGS and ensures minimal backpressure on the return line to safeguard formation integrity.
- PRV6: Positioned downstream of the MPD choke manifold, PRV6 vents to the Mud-Gas Separator (MGS) and protects low-pressure pipework from overpressure, particularly in case of Coriolis meter plugging.
- PRC (Pressure Regulating Choke): Functions primarily to protect the formation while also providing backup pressure regulation in case of MPD choke plugging. It maintains a bias pressure over the Surface Back Pressure (SBP) set point and includes alarms to alert operators of activation.

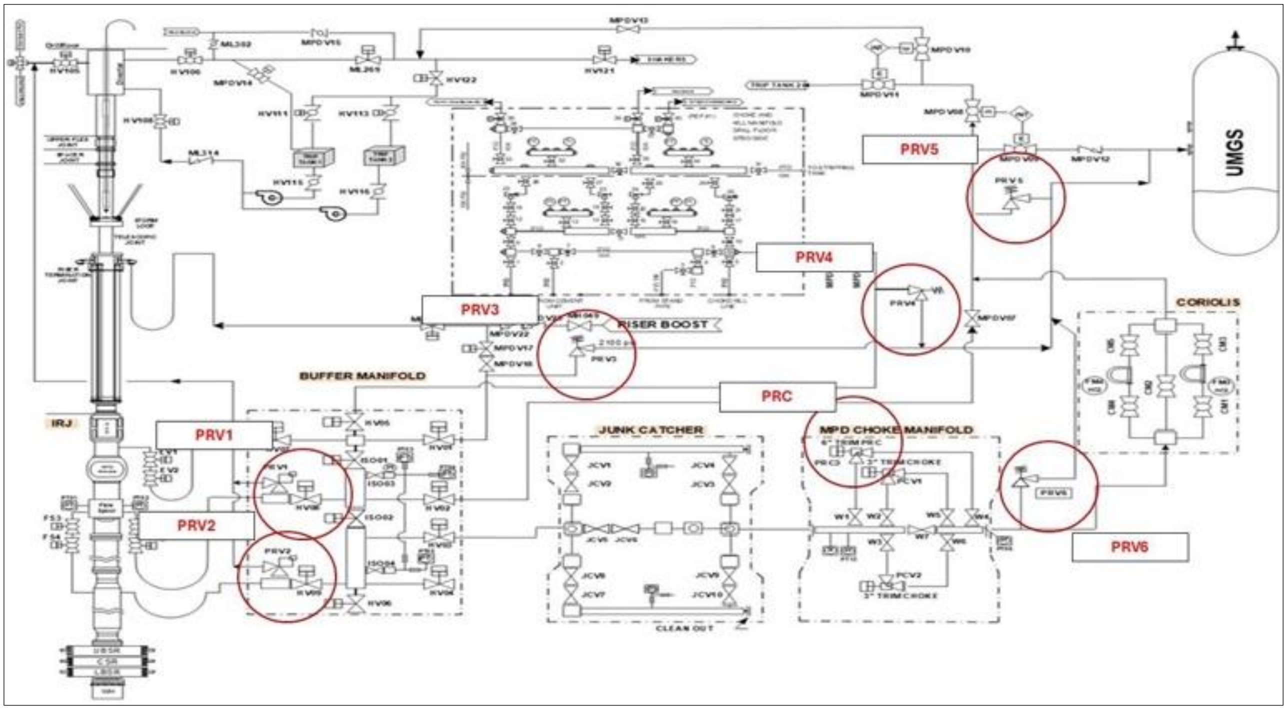

Figure 7 Example PRV Process Flow Diagram

Appendix-2

Appendix 2 presents an example PRV Philosophy. This is developed at the beginning of an MPD project.

Table 6 Example PRV Philosophy

	PRV1	PRV2	PRV3	PRV4	PRV5
	Primary Flowline	**Primary Flowline**	**IRJ Over Pressure Protection**	**MPD System SBP High Limit**	**PRV Booster Line**
Design for	Protects the formation	Protects MPD equipment, lines, and riser.	Protects riser equipment and hoses.	Protects the formation	Protects the Booster Line Pressure
Set Point	**LOWER OF:** • Set point: to 90% of the FIT/LOT[2]. **or** • 90% of IRJ OPP & PRV2 setting	Set point: 1400 psi	Set point: 1400 psi (manufacture pre-set value)	Set point: 100% of the FIT/LOT	Set point: to be set at 2000 psi + booster line friction at 400 gpm*
Type	Electronic Pressure Gauge with hydraulic actuation	Electronic Pressure Gauge with hydraulic actuation	Mechanical Type	Software feature of MPD Chokes actuation (fully open position)	Electronic Type
Adjustment	Adjustable from 0 up to 1400 psi (software hard coded)	Not adjustable (software hard coded to 1400 psi Max)	Not adjustable	Using MPD HMI.	Adjustable to any range
Reset Method	Auto reset to close position at 80% of set point value.	Auto reset to close position at 80% of set point value.	Auto reset to a close position after the pressure transducer (in 1 sec) detects pressure lower than 1400 psi	Manually reset using HMI Controls (MPD Software)	Automatically reset once pressure is relieved
Discharge Point	Discharge downstream of the MPD choke manifold, upstream diversion to MGS or Shakers.	Discharge line to overboard	Discharge line to overboard	Discharge upstream diversion to MGS or Gumbo Box.	Discharge to Pit System