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SELECTION OF SAFETY EQUIPMENT BASED ON WELLHEAD MAXIMUM ANTICIPATED SURFACE PRESSURE CALCULATION

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Abstract: A study conducted at well TT–01/H (fictitious name for confidentiality purposes) in Vojvodina evaluates the efficiency and selection of pressure control safety equipment at the wellhead. Expected pressures at various depths and geological formations were analyzed, enabling precise equipment selection. Utilized equipment, including dual ram blowout preventers, exhibited high leak resistance and effectiveness in managing adverse scenarios such as fluid influx and gas channeling. Equipment testing procedures, conducted according to API standards, encompassed low–pressure and high–pressure tests, confirming operational readiness and equipment reliability. Simulations indicated that higher mud density reduces maximum expected pressures at the wellhead, contributing to system stability. Identified coupling issues were addressed with additional sealing measures, enhancing system integrity. Research findings affirm that suitable and regularly tested safety equipment is crucial for drilling safety and efficiency, with recommendations for maintenance improvement and further research aimed at optimizing safety strategies and monitoring technologies for well conditions.
Keywords: well, safety equipment, expected pressures, ram preventer, fluid influx (blowout), mud density, gas

1. INTRODUCTION

During drilling through rock layers, pressure increases with depth and is controlled by drilling mud, which creates a hydrostatic column. In cases where layers containing trapped gas or high–pressure fluids are breached, if the pressure exceeds the hydrostatic pressure of the mud column, a blowout occurs [1]. Oil and gas drilling carries significant risks due to high pressures, temperatures, and the flammability of hydrocarbons, while the unpredictability of rock formations can lead to dangerous pressure imbalances. Incorrect data or estimates of pore pressures can lead to poor well design and hazardous conditions, including fluid influx or blowout [2]. Safety equipment (Blowout Preventer, BOP) contains well fluids, regulates their volume, and seals the well for safety. Fundamental components of this system, such as annular and ram preventers, utilize hydraulic mechanisms for sealing and include connections that integrate the safety equipment with the wellhead. Failures, inadequate pressure calculations, or improper testing of the BOP can have serious consequences [3]. Catastrophic incidents, like the 2010 Deepwater Horizon platform explosion, demonstrated that BOP failure to shear the drill pipe and seal the well could be caused by the pipe's position close to the wellbore wall, outside the range of the rams [4]. This has driven the industry to enhance the reliability and safety of BOP systems [3], including more precise pressure calculations and proper testing. Safety equipment, as a secondary mechanism, manages high pressures and uncontrolled blowouts during drilling, complementing the hydrostatic pressure of the drilling mud [5, 13]. Therefore, the BOP serves as a critical safety measure predominantly used during exploration, development, and production activities in oil and gas fields [5, 6]. Its absence, deterioration, or malfunction allows an initial incident to escalate into a major accident with catastrophic outcomes [6]. Safety in well operations, such as well TT–01/H in Vojvodina, requires careful planning and testing of safety equipment to prevent the risks of uncontrolled fluid flow. Equipment selection must consider formation pressures, geological characteristics, and hydraulic conditions of the well for stable and safe operations. The research aims to improve procedures for selecting and testing safety equipment, emphasizing the evaluation of its effectiveness during various drilling stages.

2. THEORETICAL RESEARCH

Blowout

Blowouts or spills are the uncontrolled release of fluids such as crude oil and natural gas from a well during the exploitation of oil and gas fields, often caused by high formation pressures [9], when the bottom hole pressure becomes lower than the pore pressure, which can lead to a dangerous blowout [10]. These incidents pose significant hazards due to the potential for large fires and the release of toxic gases such as hydrogen sulfide [9]. In response to a blowout, the drilling crew typically employs a blowout preventer to seal the well [11] and introduces higher–density mud to stabilize pressure, allowing for controlled circulation and removal of the intruding fluids.

Safety Equipment and Its Core Components

Safety equipment, mounted on the wellhead during drilling or completion operations, is crucial for pressure control and well protection in the event of a loss of control, allowing for the cutting of the drill pipe and sealing of the well [12]. The safety equipment is designed to withstand high pressures and fluid influx from the reservoir during drilling [14]. The functionality of the preventer is essential for protecting human lives, the environment, and the well's integrity, considering their temporary nature in drilling operations, which requires regular maintenance, including disassembly, inspection, replacement or repair of parts, and reassembly [13]. The safety of personnel and equipment during drilling largely depends on the quality and proper selection of safety equipment installed at the wellhead. This equipment includes [7, 8]:

- preventer assembly,
- wellhead,
- valves, and
- API flanges

Safety Mechanism (Preventer Assembly)

The safety mechanism consists of the following devices [7, 8, 15]:

- preventer
- koomey unit
- choke and kill lines

Blowout Preventers (BOPs)

Blowout preventers are crucial devices installed at the wellhead to prevent formation fluids from entering the annulus between the casing and the drill string, which can cause high pressures [7, 8, 11, 14, 24]. In high–pressure well situations, activating the preventers, either hydraulically or manually, is critical to prevent hazardous blowouts that can damage equipment and jeopardize worker safety. BOPs are tailored to the well depth and expected pressures during drilling, varying in closure mechanisms such as ram–type models, pipe rams that seal around the drill pipe, or universal preventers with rubber seals [7, 8, 11, 14]. Preventers must quickly close the well within less than 60 seconds after fluid entry, using hydraulic controls and a Koomey system for management [8].

Ram Blowout Preventer (Ram BOP)

Ram blowout preventers are designed to close the space around the drill pipes or the full bore of the wellbore when the drilling tool is removed [1,7,11,23]. A ram blowout preventer consists of a steel block made from cast steel, four cylinders with heads, pistons, and auxiliary pistons that stabilize the preventer's rams [7]. Ram BOPs can be single or double ram. Single versions typically contain either pipe rams or inserts to seal around the drill pipes [1,7,8,11,23]. Some preventers combine full–bore rams with pipe rams to reduce the height of the derrick, avoiding the need to install two separate preventers on top of the well [7,8]. Ram BOPs are the last resort for pressure control in emergency situations, although their activation can cause severe damage to the drilling equipment, resulting in high repair costs [16]. The high strength of the drill pipe material places greater demands on the cutting capacity of shear rams, which are crucial for the successful sealing of the well in the oil and gas industry [9].

Annular Blowout Preventer (Annular BOP)

Annular blowout preventers use a rubber sealing element to hermetically seal the space between the drilling equipment and the casing in the wellbore, relying on the elastic properties of the rubber to reliably seal various sizes of drilling equipment, thereby reducing the need for different preventers in varying situations [7,8,12]. Although it is possible to close an annular preventer on an open hole, such practice significantly reduces the durability of the sealing element and is therefore not recommended except in situations of absolute necessity [16]. Rubber is widely accepted for use in sealing and shock absorption due to its highly elastic and incompressible characteristics [17]. However, it is often observed that annular preventers are not as effective as ram preventers in maintaining a seal on an open hole [18].

— Control System (Koomey Unit)

The control system of the safety equipment is a crucial component of the overall system [19]. It functions by detecting the onset of potentially hazardous situations and automatically responding to prevent accidents [20]. The Koomey unit enables safe management of well blowout preventers through nitrogen–charged accumulators for power, pressure regulators, open and close valves, hydraulic oil reservoirs, and triplex pumps. This system allows the activation of preventers under pressure using electrical or pneumatic triplex pumps, while the oil pressure is regulated through pressure control valves [7, 8].

— Choke and Kill Lines

Choke and kill lines connect to the wellhead or blowout preventers via two series–connected valves, with a choke manifold equipped with adjustable chokes and a pressure gauge installed at the end of these lines. It is crucial that the lines have smooth bends to avoid damage, and the adjustable chokes must be easily accessible for manual or remote operation, especially in deep wells [7, 8]. All preventers are equipped with connections for choke and kill lines, essential for regulating well pressure. The choke line is used to inject heavy, high–density fluid to balance pressure during a blowout, while the kill line is used to relieve excess pressure. These lines also enable the performance of circulation tests with drilling fluid and other related activities, while auxiliary lines may include additional functions such as mud boosting, air injection, and hydraulic power supply [4]. The placement of the lines on the safety equipment is adapted to the designed specifications, where the choke line typically has two outlets, while the kill line has one outlet connected to the safety equipment. These lines are connected together on the surface to a manifold, allowing flexible operation as either choke or kill lines, contributing to additional safety and redundancy in the well control system [16].

— Wellhead

The wellhead is mounted directly onto the casing string and has several key roles. First, it serves as a platform for installing blowout preventers (BOP) and pressure control devices at the top of the well. It also allows for the suspension of the next casing string after cementing the previous one. Most importantly, it ensures a hermetic seal of the annular space between the installed casing strings [7, 8, 21, 22]. The selection of a specific wellhead design is adapted to the well's configuration and the expected pressure at the wellhead [7, 8].

— Valves

Wellhead valves, available in various designs, are mounted using API flanges or threads integrated into the wellhead body. Their internal diameter must be equal to or larger than the opening in the wellhead flange to avoid flow constriction and pressure drop at the outlet. Additionally, the valves are adapted to the working pressure of the wellhead onto which they are mounted [7, 8].

— API Flanges

Wellheads with lower operating pressures typically use valves connected via Longitudinal Pipe Threads. For wellheads that must withstand higher operating pressures, valves are mounted using API flanges tailored to the specific pressure of the wellhead. The use of flanges provides flexibility and reduces the risk of damage due to vibrations at the joints [8].

3. MATERIAL AND METHODS

Research focuses on the selection and testing of safety equipment for well TT–01/H to protect against uncontrolled fluid flow and blowouts. The main goal is to ensure stability and reliability throughout all drilling phases, with an analysis of formation pressures and hydraulic characteristics of the well. The research aims to find optimal solutions and tests necessary for selecting safety equipment to conduct drilling safely and efficiently.

The study focuses on analyzing expected formation pressures and identifying suitable safety equipment for different drilling phases. Additionally, the research addresses reviewing methods for selecting safety equipment in accordance with industry standards, tailored to specific well requirements.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Research methodology includes analyzing technical documentation of the well, field performance testing of safety equipment, and computational simulations to assess maximum expected pressures. Research techniques involve fluid influx simulations and pressure testing, with verification using instruments such as test plugs and cup testers.

For research purposes, calculation of maximum expected pressure was limited to the third and fourth drilling phases, as initial drilling phases typically involve lower pressures. These phases differ by including greater drilling depths and higher formation pressures, necessitating detailed calculations for selecting appropriate safety equipment.

Discussion of the research focuses on confirming that selected equipment meets specifications and can effectively respond to operational challenges of the well. Issues with integrity of some joints were identified and resolved through additional sealing.

This approach enables systematic planning and selection of safety equipment for well TT–01/H, aiming to reduce incident risks during drilling and enhance operational safety.

4. RESULTS AND DISCUSSION

Main approaches for selecting safety equipment

To determine the maximum expected surface pressure, we apply basic methods that take into account specific conditions in the well. This can be the situation when the well is completely filled with gas or when gas occupies 80% of the borehole volume.

Markings of safety equipment

The markings of safety equipment components on the wellhead play a crucial role in identifying and understanding the functionality of the blowout preventer assembly.

- An annular preventer is marked with the letter A,
- A rotating preventer with the letter G,
- While a single ram preventer may be marked as R (for pipe rams) or as R (for blind rams),
- A double ram preventer is designated as Rd,
- Whereas the side outlet cross with choke and kill lines is denoted by the letter S,
- Additionally, components rated for a working pressure of 68.95 bar are marked with the letter K, providing clear guidelines for the installation and use of each of these key safety components on the wellhead.

The sequence of marking the components of the blowout preventer assembly, with the specified markings, is done from the lowest point of the wellhead to the highest point. The blowout preventer assembly is fully defined by the following markings:

"5K 346.08 – SRR"

The provided example of marking the safety equipment at the wellhead defines the working pressure of the preventer as 344.75 bar, the bore size of the preventer as 346.08mm ($13^{5/8}$"), and indicates that the assembly includes a side outlet cross and two single ram preventers (with pipe rams and blind rams).

Selection of safety equipment at wellhead TT–01/H

The location of well TT–01/H is approximately 580 meters northeast of the nearest drilled well TT–01. The coordinates of the well are:

- Y = 5 076 577,00,
- X = 7 455 504,00 i
- Z = 79,20

Expected formation pressures

Based on previously conducted geological surveys of the "TT" exploration area, as well as data obtained from drilling the contour–exploration well TT–04 and exploratory wells TT–02, TT–03, and TT–05, the following development of formation pressures can be expected at exploration well TT–01/H:

- From 0m to 1425m, formation pressures at hydrostatic levels.
- From 1425m to 1931m, formation pressures 20% above hydrostatic levels.**

Input data

Well input data:

- Total well depth: 1931m

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

- Fluid influx density (surface column): 0,23$\frac{kg}{dm^3}$

SURFACE COLUMN

- Installation depth of the column: 1133m
- Fracture gradient at column depth: 1,75$\frac{kg}{dm^3}$
- Mud density: 1,16$\frac{kg}{dm^3}$

PRODUCTION COLUMN

- Installation depth of the column: 1884m
- Fracture gradient at column depth: 1,8$\frac{kg}{dm^3}$
- Mud density: 1,16$\frac{kg}{dm^3}$

LINER COLUMN

- Installation depth of the column: 1931m
- Fracture gradient at column depth: 1,802$\frac{kg}{dm^3}$
- Mud density: 1,16$\frac{kg}{dm^3}$

Selection of safety equipment for Phase III of drilling

For the third drilling phase, the data is as follows:

- Final well depth: Z=1931m
- Depth of the layer with maximum formation pressure: Z_s=1890m
- Maximum formation pressure at a depth of 1884m: p_{sl}=190bar
- Installation depth of the last casing: H_k=1884m
- Formation fracture gradient at the casing hanger: G_{fk}=1,80$\frac{kg}{dm^3}$
- Average density of gas layer fluid: ρ_{fg}=0.10$\frac{kg}{dm^3}$
- Mud density for continued drilling: ρ_{is}=1,16$\frac{kg}{dm^3}$

With this information, we can use equations (1) and (2) to calculate the maximum pressure expected when the well is fully filled with gas: [8]

$$p_{us\ max} = p_{sl} - 0{,}0981 * Z_s * \rho_{fg} \quad (1)$$

$$p_{us\ max} = 0{,}0981 * H_k * (G_{fk} - \rho_{fg}) \quad (2)$$

$$p_{us\ max} = 190 - 0{,}0981 * 1890 * 0{,}10 = 172bar$$

$$p_{us\ max} = 0{,}0981 * 1884 * (1{,}80 - 0{,}10) = 315bar$$

The operating pressure of the wellhead safety equipment (wellhead, valves, and flanges) must exceed operating pressures of 172 and 315 bar, which is the specification for the 5K (345 bar) safety equipment. In a situation where the wellbore is filled with gas up to 80%, the maximum pressure is calculated using formula (5). To calculate the maximum pressure, we first need to determine the length of the mud column in the wellbore according to formula (3): [8]

$$X = Z * 0{,}20 \quad (3)$$

$$X = 1931 * 0{,}20 = 386{,}2m$$

Then the length of the gas column in the casing string according to formula (4):

$$Y = H_k - X \quad (4)$$

$$Y = 1884 - 386{,}2 = 1497{,}8m$$

To finally calculate the maximum expected pressure: [8]

$$P_{us\ max} = p_{sl} - 0{,}0981 * \left[G_{fk} * H_k - \left(X * \rho_{is} + Y * \rho_{fg}\right)\right] \quad (5)$$

$$P_{us\ max} = 0{,}0981 * [1{,}80 * 1884 - (386{,}2 * 1{,}16 + 1497{,}8 * 0{,}10)] = 274bar$$

The safety equipment at the wellhead, such as the blowout preventer, valves, and API flanges, must have a working pressure greater than 274 bar. This implies that in this scenario as well, safety equipment classified as 5K (345 bar) should be used.

The technical drawing of the safety equipment for Phase III drilling is depicted in Figure 1.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

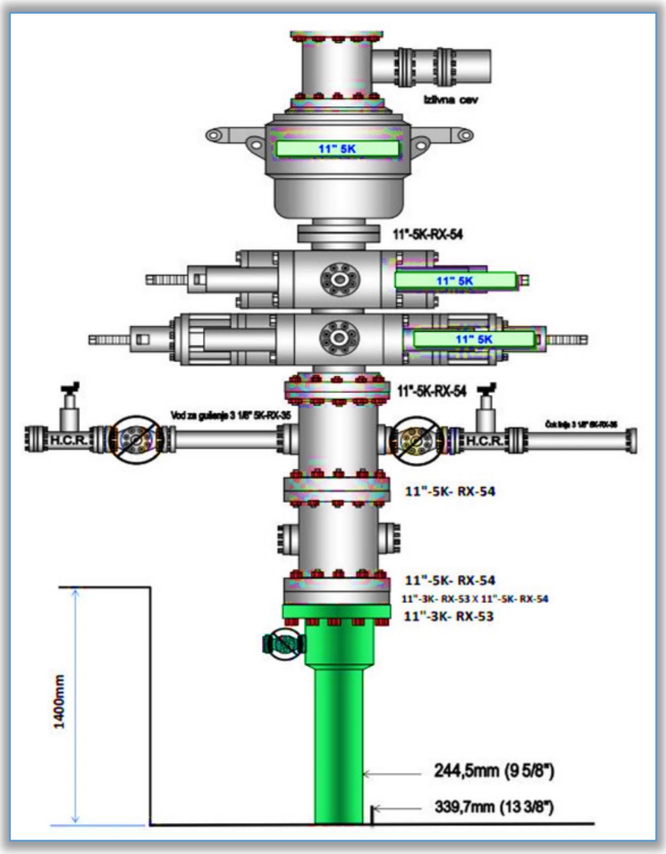

Figure 1. Schematic representation of the wellhead with installed safety equipment for Phase III drilling [25]

Selection of safety equipment for the IV drilling phase.

- Final well depth: Z=1931m
- Depth of the layer with maximum formation pressure: Z_s=1931m
- Maximum formation pressure at a depth of 1931m: p_{sl}=197bar
- Installation depth of the last casing: H_k=1931m
- Formation fracture gradient at the casing hanger: G_{fk}=1,802$\frac{kg}{dm^3}$
- Average density of gas layer fluid: ρ_{fg}=0.20$\frac{kg}{dm^3}$
- Mud density for continued drilling: ρ_{is}=1,16$\frac{kg}{dm^3}$

With this information, we can use equations (1) and (2) to calculate the maximum pressure expected when the well is fully filled with gas:

$$P_{us\ max} = 197 - 0{,}0981 * 1931 * 0{,}20 = 160bar$$
$$P_{us\ max} = 0{,}0981 * 1931 * (1{,}802 - 0{,}20) = 304bar$$

The operating pressure of the wellhead safety equipment (blowout preventer, valves, and flanges) must exceed the operating pressures of 160 and 304 bars, hence we apply safety equipment configurations rated at 5K (345 bars).

In a situation where the wellbore is filled with gas up to 80%, the maximum pressure is calculated using formula (5). To calculate the maximum pressure, we first need to determine the length of the mud column in the wellbore according to formula (3):

$$X = 1931 * 0{,}20 = 386{,}2m$$

Then the length of the gas column in the casing string according to formula (4):

$$Y = 1931 - 386.2 = 1544{,}8m$$

To finally calculate the maximum expected pressure:

$$P_{us\ max} = 0{,}0981 * [1{,}802 * 1931 - (386{,}2 * 1{,}16 + 1544{,}8 * 0{,}20)] = 279bar$$

The safety equipment at the top of the well, such as the wellhead, valves, and API flanges, must have an operating pressure greater than 279 bars. This means that in this situation as well, equipment with a classification of 5K (345 bar) should be used.

The technical drawing of the safety equipment for the IV phase of drilling is shown in Figure 2.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

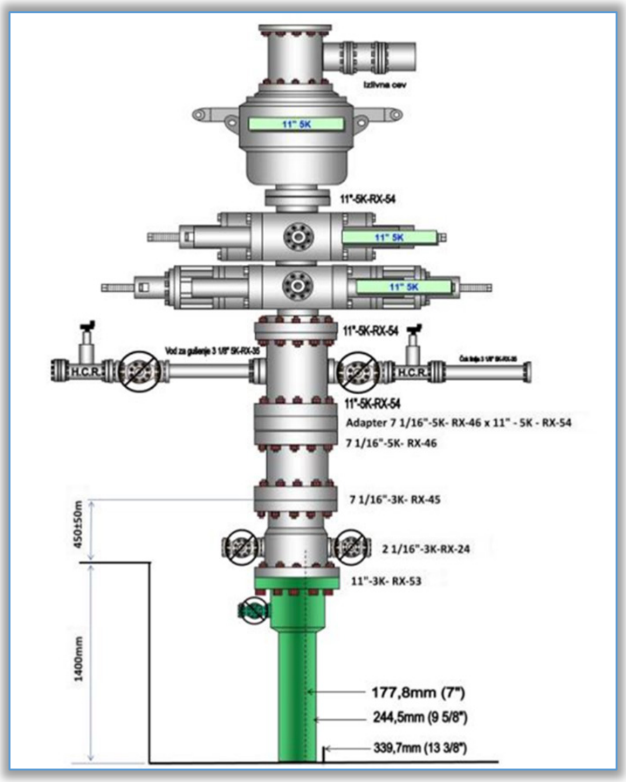

Figure 2. Schematic representation of the wellhead with installed safety equipment for the IV phase of drilling [25]

The upcoming Table 1 will illustrate the arrangement of the safety equipment at the wellhead for both drilling phases. It clearly presents all key elements and their positions, enabling a clear and straightforward analysis of the installed safety systems at the well.

Table 1. Tabular representation of the wellhead with installed safety equipment for both phases. [25]

Protective casing string	Wellhead equipment	Pressure testing of safety equipment after assembly, [bar]	Identification	Standard	Quantity	Allowable working pressure, [bar]
1	2	3	4	5	6	7
Surface	Flange connection	105	$9^{5/8}$″ x 11″ 3M RX–54	API	1	207
	Brezone adapter	105	11″ 3M RX–53 x 11″ 5M RX–54	API	1	207
	BOP equipment	105	Drilling flange 11″–5M RX–54	API	2	345
		105	Ram BOP 11″–5M RX–54	API	2	345
		105	Spherical BOP 11″–5M RX–54	API	1	345
		105	Rigid kill fluid 2″ 5M	API	1	345
		105	Manual valves $3^{1/8}$″–5M RX–35	API	2	345
		105	HCR valve $3^{1/8}$″–5M RX–35	API	2	345
		105	Chok line 3″ 5M	API	1	345
Production	Introduction Flange	150	$9^{5/8}$″ x 11″ 3M RX–53	API	1	207
	Casing Flange	150	11″ 3M RX–53 x $7^{1/6}$″ 3M RX–45	API	1	207
	Flange Adapter	150	$7^{1/16}$″ 3M RX–45 x $7^{1/16}$″ 5M RX–46	API	1	207
	Brezone Adapter	150	$7^{1/16}$″ 5M RX–46 x 11″ 5M RX–54	API	1	345
	BOP equipment	150	Drilling flange 11″–5M RX–54	API	1	345
		150	Ram BOP 11″–5M RX–54	API	2	345
		150	Spherical BOP 11″–5M RX–54	API	1	345
		150	Rigid kill fluid 2″ 5M	API	2	345
		150	Manual valves $3^{1/8}$″–5M RX–35	API	2	345
		150	HCR valve $3^{1/8}$″–5M RX–35	API	2	345
		150	Chok line 3″ 5M	API	1	345
Production Liner column	Introduction Flange	150	$9^{5/8}$″ x 11″ 3M RX–53	API	1	207
	Casing Flange	150	11″ 3M RX–53 x $7^{1/6}$″ 3M RX–45	API	1	207
	Pressure Control Devices	150	$7^{1/16}$″ x 3M RX–45	API	1	207

5. DISCUSSION

The discussion on the importance of safety equipment in oil and gas drilling represents a key point of research. Oil well drilling is a complex process that carries significant risks, including high pressures, unpredictable geological conditions, and potential blowouts. All these hazards necessitate the use of advanced safety equipment to ensure the protection of workers, the environment, and the well itself.

As a mining engineer, I believe that properly selected and maintained safety equipment, such as Blowout Preventer (BOP) systems, is crucial for the safety and stability of the well. My research focuses on the analysis of various components of safety equipment, including annular and ram preventers, control system technology, and their integration into the wellhead.

During my research, I have extensively studied different types of preventers and their specific functions in high–pressure situations. For example, ram preventers are used to seal around drill pipes or when the drilling tool is withdrawn, while annular preventers enable hermetic sealing between the drilling equipment and the casing. Although it is possible to close a universal preventer on an open well, such practice significantly reduces the durability of the sealing element and is therefore not recommended except in emergencies. Each of these systems plays a crucial role in responding to emergencies such as blowouts or influxes of high–pressure fluids.

Furthermore, technical specifications of the wellhead and the application of API flanges for safety valves have been explored, contributing to overall well safety. My research also emphasizes the importance of regular maintenance and testing of safety equipment to ensure their effectiveness and operational reliability throughout all drilling phases.

Finally, my work is not only theoretical but also includes practical aspects such as field performance testing of safety equipment and simulations to assess maximum expected pressures. This combination of theoretical knowledge and practical skills enables me to make informed decisions regarding the selection of safety equipment tailored to the specific requirements of each well.

In essence, research on safety equipment in oil and gas drilling is not just an academic interest but a vital contribution to enhancing industry safety and reducing risks. My goal is to continually improve standards and practices to ensure the safety of all participants in drilling operations and environmental protection.

6. CONCLUSION

Based on a detailed analysis of safety equipment for well TT–01/H, it is concluded that proper selection and testing are crucial to ensuring operational safety throughout all drilling phases. Oil and gas drilling carries significant risks due to high pressures and irregularities in rock formations, which can lead to dangerous pressure imbalances. Safety equipment such as BOP systems is crucial for pressure control and blowout prevention, as confirmed by case studies like Deepwater Horizon 2010. Therefore, careful planning, testing, and implementation of safety equipment are necessary to minimize risks of uncontrolled fluid flow and ensure stable well operation.

The importance of safety equipment is underscored by its role in protecting human lives, the environment, and well integrity. The preventer assembly, including ram and annular preventers, represents the core components of BOP systems activated during high–pressure scenarios to shut in the well. Proper functioning of this equipment requires regular maintenance and inspection to ensure its functionality and readiness for rapid response in emergencies.

Research methodology, which includes analysis of geological characteristics and hydraulic conditions of the well, is crucial for correctly sizing safety equipment according to the specific requirements of well TT–01/H. Pressure simulations and field tests contribute to verifying the effectiveness of selected equipment in pressure control during drilling. Further research focuses on continuously improving safety standards and technologies to enhance operational safety in the oil and gas industry.

In conclusion, proper selection, testing, and implementation of safety equipment are critical to preventing catastrophic accidents and maintaining stable and secure well operations. The industry continues to evolve to improve the reliability of BOP systems and reduce risks of uncontrolled fluid discharge, setting high standards for planning and implementing safety measures in future drilling projects.

Based on the results of this research, further development of strategies to enhance maintenance procedures and optimize safety equipment is recommended. Additional research could focus on innovative methods for detecting potential failures and integrating advanced technologies for simulation and monitoring of well conditions. Continued research in this area can contribute to further safety and efficiency in drilling, reducing operational risks, and better protection against uncontrolled fluid flow.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665