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Inherent Safety in Offshore Drilling Operations

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Abstract*: *Inherent safety (IS) is a proactive approach for safety management during process plant design and operation. It has been proven that, considering the lifetime costs of a process and its operation, an inherently safer approach is an environmentally friendly and cost-optimal option. IS can be incorporated at any stage of design and operation. However, application of IS is highly effective at the early design stage. In this work, incorporation of IS in designing offshore oil and gas (O&G) drilling operations is successfully done to achieve risk reduction. Some of offshore hazards/concerns including highly flammable substances, possible harsh weather conditions, toxic gas i.e. hydrogen sulphide and congested platforms and rigs layout are challenging to overcome especially during emergency responses. Based on this knowledge, we intend to exploit the versatility of the principles of IS for the purpose of achieving risk reduction in relation to offshore O&G drilling operations. As for hazard identification, HAZID is chosen while relevant IS principles – "substitution", "moderation" and "simplification" are recommended for risk reduction efforts.

Index Terms*: *Drilling operations, Inherent Safety, HAZID, Safety Management.

I. INTRODUCTION

The concept of inherent safety (IS) is becoming more common in offshore oil & gas (O&G) industry. In offshore, the hazardous materials and operations are in more proximity with the personnel working on board due to space limitation. Hence, the safety of personnel is a big concern to the design engineer. However, the incorporation of safety elements in the design is more of conventional safety rather than IS safety implementation. Inherent safety and conventional safety can be explained by the phrase of *"prevention is better than cure*". IS principles are preventive measures while conventional safety is implementation of corrective or active safety actions. In the past, the offshore O&G industry was focusing on active safety systems like shutting down plant and deluge systems to control the hazards [1]. However, after Piper Alpha disaster in 1988, the O&G industry started to change their perspective towards safety. The design is now concentrating on inherent safety.

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This is because, the active systems are only activated after the accident happens. Should the system fail, this leads to uncontrollable disaster and cause high number of injuries and casualties.Nevertheless, the challenge of IS is to remove or reduce these hazards at the early design stage. Hence, IS is incorporated at the fundamental, which leads to safer and better design of the offshore platform. This is, in contrast to conventional safety design which normally resorting to 'add on' safety features.

Recently, many experts proposed IS as the options for risk management in drilling activities. However, unlike methods of Hazard and Operability Studies (HAZOP) and quantitative risk assessment (QRA), IS is only applied to some parts of offshore O&G process design and operations thus far.

Procedural, passive and active risk reduction strategies are often relied upon, but these have yet to achieve optimal risk reduction due to inadequacies in procedures or the degradable, physical safety systems. Inherent safety, which is a subset of green chemistry and engineering [2], is known to be a more robust and cost-effective risk reduction option applicable at any stage in design or operation [3].

II. INHERENT SAFETY CONCEPTS

A. Inherent Safety Principles

Table-I below shows IS principles and their definitions. The design of offshore platform that incorporates IS principles will lead to safer, cost effective and environmentally friendly.

Table- I: Inherent Safety Principles and Definitions

Inherent Safety Principles	*Definitions*
Elimination	Eliminate the chemical or the process route that contain hazardous material
Substitution	The use of a safer material in place of a more hazardous one.
Minimization	Reduction of quantities of hazardous chemicals in the plant.
Moderation	Use of a hazardous chemical under less severe conditions such as lower pressure or temperature.
Simplification	Simpler plants are safer than complex plants as they provide fewer opportunities for error and contain less equipment that can fail

Fig. 1 shows IS principles hierarchy. The most effective principle is "Elimination" which it will reduce the likelihood and severity of drilling activities. Hence, should this principle to be implemented, the risk reduction magnitude is rather huge compared to other principles. In this work, the design of drilling facilities is to be assessed.

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The suitable IS principles are recommended at several aspects. For instance, designing drilling rig, selecting drilling fluid and drilling string. These are critical elements in designing any drilling facilities which normally lies the hazard.

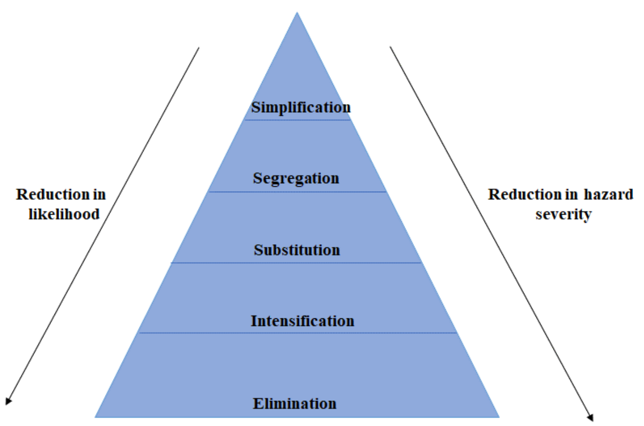

Fig. 1. Hierarchy control of IS principles.

Previous research showed that process and structural failure incidents account for almost 70% of incidents in offshore facilities [4].

The main hurdles to adopting IS are (i) the lack of awareness of the concept, especially by designers and project leaders (ii) lack of understanding on the IS principles and how these can be applied (iii) difficulty in securing time at the early stages of project (feasibility studies) to consider safety aspects; and (iv) insufficient knowledge on IS principles which relevant to regulations.

In this work, the application of IS in drilling activities will be shown. Some identified hazards are eliminated and substituted with less hazardous design characteristics.

B. Inherent Safety in Preliminary Process Design

The possibility for implementing IS in a process decreases as the design proceeds as more engineering and financial decisions have been made. Fig. 2 shows that it is easier to execute IS principles in the process configuration at the conceptual stage rather than in the later phases of process design [5]. Incorporation of IS at this stage will not only save a lot of time and money; it will also increase the opportunity to select less hazardous substance and equipment. Ultimately, less expensive safety modifications are needed, and fewer safety equipment add-ons are required to the final process design.

In the early design phases the available information on products, byproducts and raw materials, capacity, main process equipment and a rough range of process conditions e.g. temperature and pressure are limited. Therefore, hazard identification can only be done partially. However, any changes or modifications due to safety reasons, will be most profitable since nothing has been built or ordered yet and thus no expensive modifications are needed. Hence, implementation of IS considered as the best stage to execute IS.

C. Inherent Safety and Accident

Accident is an event that happens by chance and without apparent or deliberate cause. Accident is also an event that can contribute to serious injury, loss of property, material and environment or even the worst is casualty.

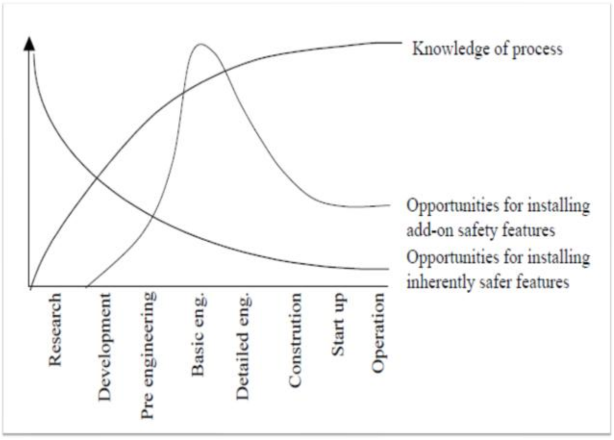

Fig. 2. Opportunities of Installing Inherent Safety Features is at the Early Stage of Project Development. [6]

The O&G industry throughout the world is commonly acknowledged for highly hazardous industry due to its nature and operating environment. Additionally, [7] demonstrated that the industry is one of the businesses that has a high hazard factor and working environment that can caused fatalities and wounds. Iraq, for instance, an oil rich nation, is far from free from accidents. It was reported from an individual correspondence, in 2009, the O&G counted for 332 mishaps, 35 deadly work wounds and 335 non-fatal work wounds [8].

It is important to understand inherent safety and safety are easily distinguished. The very famous Bhopal plant was said a safe plant if built and operated correctly. However, [9] highlighted that the plant was inherently unsafe as the reaction route selected produced large amount of toxic intermediate product - methyl isocyanate (MIC). After all, there is an alternative 'reaction route' from the same Bhopal's feedstock, which does not produce MIC. In this case, alternative route is an inherently safer option as opposed to Bhopal's.

Bhopal is one of major onshore events that caused many casualties. On top of that, there are major offshore events such as Titanic accident in 1912, Santa Barbara in 1969, Alexander L. Kielland (North Sea, Norway) in 1980, Piper Alpha offshore disaster in 1988 and the accident that affects the environment badly is Deepwater Horizon/Macondo accident in 2010.

Deepwater Horizon/Macondo disaster killed 11 rig workers and vomited four million barrels of oil into the Gulf of Mexico. It was leased by British Petroleum plc (BP) to drill an exploration well. Nevertheless, the drilling operation from the ultra-deep-water offshore drilling rig ended by a major explosion and 87-days of oil spill.

III. OFFHORE DRILLING

A. Drilling Operations

Offshore O&G operations can be segmented into three distinct areas which are (i) drilling, (ii) production and (iii) pipelines. These areas require specific safety management issues and management approaches. Drilling operation is an art of making holes.

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It is programmed during the oil and gas exploration phase and it needs the management of space and time as drilling is a dynamic operation. It is a process that cuts and makes holes on the rocks using drilling bits to create a well for oil and natural gas production. The steps in drilling operations include (i) boring process (ii) mud circulation operation (iii) casing installation (iv) completion and (v) production [10].

Drilling equipment known as drill string comprises a set of components with specific functions alongside other vital equipment. Drill string can be simple for modest well and complex for sophisticated wells. For instance, drill string that requires to have additional functions such as the ability to monitor position, collect formation information, regulate formation pressure and used as directional tool is a complex drill string design.

Furthermore, drilling rigs move from one station to another within a few days before moving on to the next potential well adds the burden on safety and emergency response. Hence, drilling operations can be troublesome as there are several vessels in a non-spacious area. Normally, drilling involves many parties from contracting companies. It involved dozens of contracting companies performing their specific tasks at the very same time. Communication and cooperation can be a hurdle especially during emergencies.

Additionally, drilling for oil and gas is an uncertain operation. Many unknown variables to be considered and some remained unknown even after drilling operation is complete. Hence, extra safety precautions are essential during drilling operation without compromising the cost and human resource matters.

B. Types of Hazard in Drilling Operations

1) Physical hazard

Vibration and noise can be both autonomously posture critical wellbeing dangers (e.g. from bore floors, sack rooms, generators). The average method, where noise can't be relieved or by means of engineering controls, has been to set up noise control zones requiring the utilization of hearing security, in view of territory noise estimations. A few controllers require region estimations to be utilized for examination between establishments. Configuration controls on commotion levels have been region based, as a major aspect of advantage respectability upkeep [10].

2) Chemical Hazard

Distributed presentation information from precise testing of unsafe operators on upstream activities are constrained or distributed a few years prior. Since benzene is a characteristic part of raw petroleum and flammable gas, a couple of studies have revealed information on benzene introduction. Substances, for example, hydrogen sulfide (H_2S), are typically very much controlled through fixed frameworks, allow to work frameworks, gas cleansing, region and individual observing, preparing, crisis designs, and so on. Previously, the organization of penetrating 'mud' had significant harmfulness for both the people and the earth [11]. Be that as it may, the piece has altered throughout the years, with a general pattern to materials of lower lethality. Other potential poisonous and suspected cancer-causing specialists r blends exist, for example, mineral oil fog and vapor, asbestos filaments, formaldehyde, tetrachloroethylene, welding/cutting exhaust, acids, coatings, and so on.

IV. METHODOLOGY

A. HAZID study

HAZID study is a qualitative analysis carried out using process flow diagrams (PFD) and piping and instrumentation diagram (P&ID) to identify specific hazards. The discussion normally focusses on the consequences of the identified hazard, particularly safety and environmental consequences namely as fire, explosion, toxic release and oil spill. Major accidents previously encourage some consideration of IS into the design in order to rule out or minimize the hazard via IS principles.

This technique is suitable for early identification of hazards and threats and can be applied at the conceptual or detailed design stage. Early identification and assessment of hazards provides essential input to project development decisions at a time when a change of design has a minimal cost penalty [12].

Table II shows the objectives of HAZID which are to be achieved in this work.

Table- II: Objectives of HAZID

No.	*Objectives of HAZID*
1.	Identify hazards to the host facilities due to design and evaluate potential consequences should the hazards be realized.
2.	Establish safeguards to manage hazards; identify areas where further understanding of safeguard effectiveness is needed.
3.	Make recommendations to reduce the likelihood of hazard occurrence or mitigate the potential consequences.

Fig. 3 shows the flowchart of HAZID studies. In this work, a base case is the field development plan (FDP) design by [13] is considered. Relevant guidewords are used in order to perform HAZID studies. Then, hazards are identified as well as to assess the threat and cause. Finally, the safety controls are recommended to prevent the hazards.

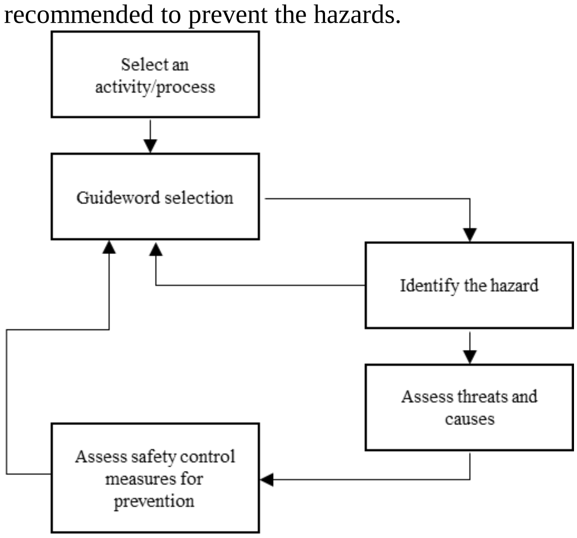

Fig. 3. Flowchart of HAZID.

Table- III: HAZID Studies Analysis

Guide word	*Event Nature*	*Cause*	*Consequence*	*Control Measures*	*Inherent Safety Principle*
Overpressure	Blowout	Uncontrolled pressure on wellbore	Catastrophic event ie. fire, explosion, oil spill	Installation of BOP during well intervention/ drilling operation with safety shutdown valve (SSV) and subsurface safety valve (SSSV) during normal operation	Simplification
		External impact	Fire hazard, environmental impact, release of toxics	Installation of SSSV with fail close design	Simplification
	Collapse	High differential pressure between casing and formation at depth ±1250m	Wellbore caving in and cause drilling problem	Use a higher mud weight to balance the wellbore pressure/ add fibre to the cement	Substitution
	Stuck Pipe	Swelling behind the bore at intermediate and surface casing	Pipe will remain on wellbore	Install drilling steerable system on the drilling string design	Substitution
	Lost of Circulation	High differential pressure	The mud will enter the formation Disturb formation characteristic	Eliminate the hazard by adding moderate amount of Potassium Chloride, KCl	Moderation

V. RESULT AND DISCUSSIONS

A. Analysis from HAZID Studies

Table-III shows a sample of HAZID studies analysis obtained in this work. The guideword of "Overpressure" shows various IS principles are recommended to achieve safer design than the original FDP design by [13]. Note that the possible IS principles suggested are "simplification", "moderation" and "substitution". Even though "elimination" is the top priority of IS principle, there is no room for its implementation in this case study. This is due to stringent requirement of "elimination" principle which is impossible to be used here. Similar HAZID studies on other guidewords have been performed too. However, only results from guideword "Overpressure" are shown in this paper.

B. Inherent Safety Principles Implementation

In analysing the potential of IS implementation, a few elements in drilling operations are studied. Among others are, drilling rig design, drilling fluid, drilling bit and drilling string.

1) Drilling Rig Selection

In assessing the drilling rig selected in [13], it is found that the data available is insufficient. Hence, the possible hazard identified during for this drilling rig is climate change. Since, weather issue is a non-modifiable, IS implementation for this element is not possible.

2) Drilling Fluid Design

Based on [13], the well is shaly-sand formation. Hence, the proposed drilling fluid is water-based mud (WBM) that is using seawater with high viscosity sweeps (gel mud). However, considering the overpressure event the drilling fluid is modified with Partial Hydrolyzed Polyacrylamide (PHA) additive. In order to achieve IS, the Potassium Chloride (KCl) is also added as additive because [13] stated that KCl helps to prevent clay, shale formation from swelling.

Table- IV: Proposed Drilling Fluid [11]

Casing	*Depth, m TVD*	*Size*	*Mud Design*
Conductor	0-600m	20''	Seawater
Intermediate	0 – 1350m	13 3/8''	Seawater + Hi-Viscosity (gel mud)
Production	0-1480m	9 5/8''	Seawater + Hi-Viscosity (gel mud)

Other than that, lost circulation material (LCM) can be used to stop or slow mud loss. LCM is added into the proposed drilling fluid. LCM includes soft granules, insoluble salts and flakes. Fig. 4 show that effect of LCM on filter cake, it will hold the filter cake and prevent any problem to happen. This material does not disturb any properties for the proposed drilling fluid. LCM is claimed to be effective not only reduce the losses but also for preventing them [14].

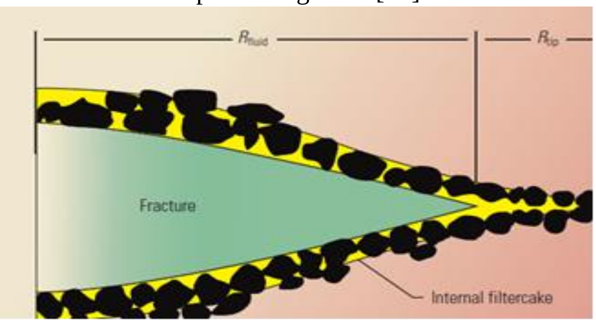

Fig. 4. Effect of LCM on filter cake. [14]

Drilling Bit Selection

A traditional milled tooth tricone drill bit has been proposed for its economical factor and rate of penetration (ROP). It is also suitable for the shally-sand formation. Nevertheless, there a several problems can be encountered especially for the formation. Tricone drilling bit wears easily so it can cause bit to be stuck on the formation.

In order to overcome this, IS principles are to be considered in this design. Hence, the use of polycrystalline diamond compact (PDC) bit is proposed. PDC contains a cutter that enhance the performance of drill bits. This will make drilling process is dynamically stable across a wide range of demanding vertical and directional drilling applications [15]. Polycrystalline diamond cutter is a unique material possessing high strength, hardness and toughness. This makes it ideal for numerous material removal (cutting) processes. Table-V shows the proposed design for drill bit.

Table- V: Proposed Drilling Bit [13]

Depth, (ft.)	*Drill Bit Size, (inch)*	*Type*
0 – 2,550	24	Milled tooth tricone
2,550 – 4,350	17.5	Milled tooth tricone
4,350 – 4,800	12.25	Milled tooth tricone

Fig. 5 showed is a sample of the traditional milled tooth tricone. Every bit has a different kind of teeth based on the rock formation. Fig. 6 showed is a sample of PDC drill bit. PDC contains diamond that known as the hardest material on earth. This hardness gives it superior properties for cutting any other material. Directional control is maintained in real time. Communication to and from the tool is maintained by mud pulses. Course adjustments are accomplished by a special stabilizer sub with articulating vanes that can change bottom hole assembly on the fly [16]. That is what makes it steerable, the directional driller can follow a planned well track with almost zero deviation.

3) Drilling String Selection

For drill string design selection, [15] stated that the drill string specification is technically safer unless for margin of pull for drill pipe for production section. The margin of pull (MOP) design factor is 1.33 which is approximately to safety factor of 1.3. There is some issue can be happened if problem not encountered. The issue can happen is difficulty to pull the drill string when achieve production target depth.

Other than that, well-2 and well-3 have the highest dogleg severity which is 3.18º/ft and 3.41º/ft respectively. Even though the value is lower but the chance for unnecessary trip or dogleg severity. Rotary steerable systems (RSS) are a relatively innovation. Directional control is maintained in real time. Communication to and from the tool is maintained by mud pulses. Course adjustments are accomplished by a special stabilizer sub with articulating vanes that can click open or closed to change bottom hole assembly on the fly [16]. That is what makes it steerable, the directional driller can follow a planned well track with almost zero deviation. The RSS is expensive but keeps the bit on bottom longer and it is cost-effective.

Fig. 5. Milled tooth tricone. [15]

Fig.6. PDC drill bit. [15]

VI. CONCLUSION

Inherent safety (IS) can be applied to all design aspects and O&G industry is not excluded. In this work, a typical offshore installation is studied to explore the potential application or implementation of IS principles. From HAZID, it was found that the installation can be designed safer with the incorporation of IS principles. Relevant IS principles for drilling operations are substitution, simplification and moderation. The integration of these principles is expected to minimize unsafe actions and conditions. On top of that, inherently safer technologies are proposed to achieve safer, cost-effective and environmental-friendly drilling facilities such as the use of substituted drilling fluid (WBM with PHA and KCl additives), PDC drilling bit as opposed to milled tooth tricine type, and rotary steerable systems (RSS) drilling string.

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