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Risk analysis of deepwater drilling operations using Bayesian network

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ABSTRACT

Deepwater drilling is one of the high-risk operations in the oil and gas sector due to large uncertainties and extreme operating conditions. In the last few decades Managed Pressure Drilling Operations (MPD) and Underbalanced Drilling (UBD) have become increasingly used as alternatives to conventional drilling operations such as Overbalanced Drilling (OVD) technology. These newer techniques provide several advantages however the blowout risk during these operations is still not fully understood. Blowout is regarded as one of the most catastrophic events in offshore drilling operations; therefore implementation and maintenance of safety measures is essential to maintain risk below the acceptance criteria. This study is aimed at applying the Bayesian Network (BN) to conduct a dynamic safety analysis of deepwater MPD and UBD operations. It investigates different risk factors associated with MPD and UBD technologies, which could lead to a blowout accident. Blowout accident scenarios are investigated and the BNs are developed for MPD and UBD technologies in order to predict the probability of blowout occurrence. The main objective of this paper is to understand MPD and UBD technologies, to identify hazardous events during MPD and UBD operations, to perform failure analysis (modelling) of blowout events and to evaluate plus compare risk. Importance factor analysis in drilling operations is performed to assess contribution of each root cause to the potential accident; the results show that UBD has a higher occurrence probability of kick and blowout compared to MPD technology. The Rotating Control Devices (RCD) failure in MPD technology and increase in flow-through annulus in UBD technology are the most critical situations for kick and blowout.

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1. Introduction

Oil and gas drilling operations has accounted for the highest rate of critical incidents compared to other domains in the petroleum industry (Vandenbussche et al., 2012). Safety during drilling operations is the most important aspect to be considered. The transient, intersecting, continuous and complex characters of drilling operations determine the variety of risk. In addition, the associated risk is extremely difficult to control (Januarilham, 2012). Blowouts are the most undesired and feared incidents during drilling operations (Khakzad et al., 2013a). Kick is another major problem in drilling operations. When a kick is not controlled properly, it escalates to a blowout and offshore blowouts can lead to devastating consequences. A recent example is the Deepwater Horizon accident in 2010. The gas blowout-induced explosion killed 11 workers and injured another 17 of the 126 on board. The deepwater Horizon rig sank about 36 h after the explosion; the riser and drill pipe bent, wrinkled, and broke at the top of the blowout preventer, releasing millions of barrels of oil into the sea for 87 days (Rathnayaka et al., 2012). The Deepwater Horizon accident is the largest blowout catastrophe on record in deepwater oil drilling history and it further led to the maximum oil spill in the history of the oil and gas industry (Cai et al., 2013).

Deepwater reservoir fields often have high pressure, high temperature and are remotely located. High reservoir pressure and temperature provide a narrow window between pore pressure and fracture pressure to operate. This may cause potential issues which include but are not limited to: loss of circulation of drilling fluids, controlling hole deviations, sticking and torqueing pipes, twist off, bridging, and incentive for kick and blowout (Rathnayaka et al.,

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2012). In recent years, offshore drilling operations have extended further offshore into deeper water and more remote locations. Researchers and engineers must therefore focus on better technology with specialized tools in order to overcome the challenges associated with drilling and well control. Further, Blowout is one of the most feared critical incidents, which can occur during drilling operations. The occurrence of blowout cannot be stopped completely but preventative measures can be used to reduce the probability of occurrence and also the severity of the consequences (O.O.S.O.T.O.E.T. Group, 2011; Khakzad Rostami, 2012).

Risk analysis is an effective tool for developing strategies which prevent accidents and for devising mitigation measures. Quantitative risk and reliability analysis techniques have been widely used to reduce the probability of failure in offshore drilling operations. Some of these techniques include: fault tree, event tree, reliability block diagram, reliability graphs and the Markov chain (Siu, 1994). The application of Bayesian Network (BN) in conducting quantitative risk assessment in the offshore oil and gas industry is relatively new. However, in recent times, BN is being used more often in the fault tree and bow-tie analysis (Khakzad et al., 2013a; Cai et al., 2013; Khakzad Rostami, 2012; Abimbola et al., 2015). BN analysis is becoming a popular probabilistic inference technique for reasoning under uncertainty. The BN analysis can model multi-state variables, common causes of failure and conditional dependencies. Further, BN makes it possible to perform probability updating and sequential learning (Khakzad et al., 2013a; Khakzad Rostami, 2012; Khakzad et al., 2012). Hence, BN analysis is not static which has advantages that overcome the limitations of other risk assessment techniques. It can also model conditional dependencies amongst other risk assessment techniques such as fault tree, event tree, and bow-tie (Khakzad et al., 2013a; Khakzad Rostami, 2012). Dynamic safety methodologies are attractive approaches to tackle systems with complex dynamics (with behaviour highly dependent on the values of the process parameters). It is important to consider a dynamic safety analysis instead of conventional safety analysis in the oil and gas industry because this methodology can produce consistent results and conditional dependencies which are possibly missed during the application of conventional methods (Podofillini and Dang, 2012).

Managed Pressure Drilling (MPD) and Under Pressure Drilling (UBD) are regarded as the drilling solutions for the world's remaining hydrocarbon resources. Hydrocarbon resources are more challenging to drill than those drilled in the past using conventional drilling technologies such as Overbalanced drilling (OVD) operations (Kok and Tercan, 2012). MPD technology has provided a cost effective option by reducing drilling-related excessive costs typically associated with conventional offshore drilling. Further, MPD uses more modern technology which makes drilling operations safer with regard to well-control problems (Cai et al., 2013; Kok and Tercan, 2012). On the other hand, UBD provides many advantages such as: reduced formation damage, reduced lost circulation, increased rate of penetration, reduced drilling time, reduced differential sticking, and extended bit life. The UBD technology can provide a rapid indication of productive reservoir zones and it has the potential for dynamic flow testing while drilling, making it safer to operate (Engevik, 2007; Fossli et al., 2006; Rohani, 2012). Hannegan and Wanzer, 2004 made a comparison between UBD technology well-control considerations over the OVD technology. He also recommended that future comparison analysis be done between MPD and UBD technology because current comparisons are not yet fully understood. There is also other recently published research available (Engevik, 2007) which presents risk assessment of drilling operations. Abimbola et al., 2015, 2014 reported the recent comparison of safety in constant bottomhole pressure (CBHP), as a technique used in MPD and OVD operations using BN (Abimbola et al., 2015, 2014).

This paper is aimed at conducting dynamic safety analysis for offshore MPD and UBD operations using BN analysis. The purpose of conducting this safety assessment is to develop better understanding of MPD and UBD drilling technologies which are regarded as the future solution for drilling operations. Blowout scenarios for MPD and UBD are analysed using BN analysis as a case study. A brief description of MPD, UBD, BN modelling and its application on predictive failure analysis, are presented in subsequent sections.

2. Managed pressure drilling (MPD) technology

The detection of inflow from formation fluids is one of the primary safety aspects of drilling operations. Even with a closed wellbore, and with the use of MPD technology, kick detection and the subsequent well-control procedures must remain in place. MPD technology has safer well-control procedures for kick detection and for kick-control strategies; however, the possibility of kicks in MPD cannot be overlooked. MPD is regarded as a better solution than UBD for kick detection and kick control as it controls the annular pressure profile during the drilling operation. Further, MPD is also used to control bottomhole pressure; it can therefore be regarded as a primary well-control barrier because the pressure in the well is controlled in the first place so as to prevent an influx of formation fluids into the wellbore (Abimbola et al., 2015; Schubert, 2012). Moreover, MPD utilizes both a compressible fluid system and specialized equipment to more precisely control the annular pressure profile throughout the wellbore. In MPD technology, a Rotating Control Device (RCD) is employed to close the wellbore which makes drilling operations safer. This technique is not possible in other conventional drilling operations (Abimbola et al., 2014; Schubert, 2012). MPD is also used to reduce the hydrostatic pressure and avoid mud losses; it uses the lower mud weight to reduce hydrostatic pressure. It is important to remember that reduction of mud weight can sometime cause serious well-control problems such as differential sticking, lost circulation, kick and blowout. Hence timely inspection and the application of preventative measures are used to reduce these problems.

Most of the challenges in shallow and deeper water wells, such as barriers to economically drillable wells and a litany of other drilling-related issues, have well control implications either directly or indirectly (Neapolitan, 2004). MPD is the term given when the use of UBD technology and its specialized equipment is deployed for the purpose of overcoming a number of drilling related barriers or problems commonly encountered when drilling overbalanced (Neapolitan, 2004; Råen, 2012). This study illustrates that offshore practice of MPD has the potential to enhance well control in this process, with an enhanced ability to avoid and control kick and underground blowouts by utilising the specialized equipment (Neapolitan, 2004). Fig. 1 shows the schematic of MPD. In Fig. 1 an RCD is installed on the top of the annular preventer to close the wellbore around the drill pipe. The outlet of the RCD is split between the main return flow line and the MPD choke manifold. Backpressure can be applied to the well at anytime by use of the MPD manifold. In MPD technology the secondary safety barriers, i.e. the blowout preventer (BOP) and the rig choke manifold, remain ready for operation in case they need to be utilized (Schubert, 2012).

3. Underbalanced drilling (UBD) technology

UBD is the drilling process in which the wellbore pressure is intentionally designed to be lower than the pressure of the formation being drilled (Khakzad et al., 2013a; Neapolitan, 2004). This underbalanced pressure condition allows the reservoir fluids to

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