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Dynamic safety risk analysis of offshore drilling

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ABSTRACT

The exploration and production of oil and gas involve the drilling of wells using either one or a combination of three drilling techniques based on drilling fluid density: conventional overbalanced drilling, managed pressure drilling and underbalanced drilling. The conventional overbalanced drilling involves drilling of wells with mud which exerts higher hydrostatic bottom-hole pressure than the formation pore pressure. Unlike the conventional overbalanced drilling, underbalanced drilling involves designing the hydrostatic pressure of the drilling fluid to be lower than the pore pressure of the formation being drilled. During circulation, the equivalent circulating density is used to determine the bottom-hole pressure conditions. Due to lower hydrostatic pressure, underbalanced drilling portends higher safety risk than its alternatives of conventional overbalanced drilling and managed pressure drilling. The safety risk includes frequent kicks from the well and subsequent blowout with potential threat to human, equipments and the environment.

Safety assessment and efficient control of well is critical to ensure a safe drilling operation. Traditionally, safety assessment is done using static failure probabilities of drilling components which failed to represent a specific case. However, in this present study, a dynamic safety assessment approach for is presented. This approach is based on Bow-tie analysis and real time barriers failure probability assessment of offshore drilling operations involving subsurface Blowout Preventer. The Bow-tie model is used to represent the potential accident scenarios, their causes and the associated consequences. Real time predictive models for the failure probabilities of key barriers are developed and used in conducting dynamic risk assessment of the drilling operations. Using real time observed data, potential accident probabilities and associated risks are updated and used for safety assessment. This methodology can be integrated into a real time risk monitoring device for field application during drilling operations.

1. Introduction

The exploration and production of oil and gas involve the drilling of wells. Wells are drilled using either one or a combination of three drilling techniques based on drilling fluid density: conventional overbalanced drilling (COBD), managed pressure drilling (MPD), and underbalanced drilling (UBD) (Rehm, 2012). In COBD, the hydrostatic pressure of the drilling fluid (mud) column in the well is higher than the pore pressure of the formation. It involves the use of water based mud, oil based mud or synthetic drilling fluid which contains weighting materials to keep the bottom-hole pressure (BHP) above the formation pore pressure. This technique is relatively economical as it requires the least expertise and easiest well control as heavy mud is used; however, it is susceptible to lost circulation, reduced rate of penetration (ROP) and formation damage which affects reservoir productivity (Bennion, Thomas, Bietz, & Bennion, 1998).

On the other hand, in UBD, the effective circulating bottom-hole pressure of the drilling fluid is intentionally designed to be lower than the pressure of the formation being drilled. This technique leads to a reduction in the possibility of lost circulation and formation damage; an increase in reservoir productivity (to as much as 60% more than COBD (Gough & Graham, 2008)), ROP, bit life; an elimination of the need for costly mud systems and disposal of exotic mud with the use of water and light fluids; a minimization of differential pipe sticking, extensive and expensive completion and stimulation operations; and enables flow testing while drilling. However, it is susceptible to wellbore instability; suffers from an inability to use conventional measurement while drilling (MWD) technology; increases the cost of drilling due to the use of more equipment than conventional overbalanced drilling; requires highly skilled personnel as well control is complicated; and a carefully developed well plan is required (Bennion, Lunan, &

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Saponja, 1998; Leading Edge Advantage, 2002). This drilling method is often characterized as high risk drilling.

MPD, a derivative of UBD, has been defined by the International Association of Drilling Contractors (IADC) (Minerals Management Service, 2008) as "an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular pressure profile accordingly." It reduces lost circulation and formation damage, while increasing ROP. However, more equipment, higher expertise for well control and higher risks are involved than conventional overbalanced drilling (Haghshenas, Paknejad, Reihm, & Schubert, 2008).

The choice of drilling technique is determined by the formation pressure (abnormally, normally or sub-normally pressured), nature of reservoir fluid (gas, condensate or black oil), type of well (exploratory, development, re-entry), formation geology (fractured or unconsolidated reservoirs), accessibility (onshore or offshore), economics, equipment availability, government policies or regulations and associated risks. Since most formation and reservoir properties are characterized with high uncertainty – exploratory and development drilling operations are associated with various forms of risks which have led to major rig accidents in the past: Ocean Ranger rig accident, in February, 1982, Deepwater Horizon drilling rig explosion, in April, 2010, Vermillion Oil Rig 380 explosion, in September, 2010 and Chevron Nigeria limited oil rig explosion, in January, 2012 (Arnold & Itkin LLP, 2014).

As drilling is a hazardous operation, safety is one of the major concerns. Safety is often measured in terms of risk (Khan, 2001). Risk is defined as a measure of accident likelihood and the magnitude of loss (fatality, environmental damage and/or economic loss). Risk analysis involves the estimation of accident consequences and frequencies using engineering and mathematical techniques (Crowl & Louvar, 2002). Various techniques have been developed for quantitative risk analysis; the foremost among the conventional methods are fault tree and event tree analyses. The results of these analyses are used in risk assessment to evaluate the safety provided for preventing or mitigating the consequences of accidents. Conventional risk assessment techniques are known to be static; failing to capture the variation of risks as operation or changes in the operation take place (Khakzad, Khan, & Amyotte, 2012). Besides, conventional risk assessment techniques make use of generic failure data; making them to be non-case-specific and also, introduces uncertainty into the results. These limitations have led to the development of dynamic risk assessment method. Dynamic risk assessment method is meant to reassess risk in terms of updating initial failure probabilities of events (causes) and safety barriers as new information are made available during a specific operation. Two ways are currently used in revising prior failure probabilities: (i) Bayesian approaches through which new data in form of likelihood functions are used to update prior failure rates using Bayes' theorem (Meel & Seider, 2006; Kalantarnia, Khan, & Hawboldt, 2009; Kalantarnia, Khan, & Hawboldt, 2010; Khakzad, Khan, & Amyotte, 2012). (ii) Non-Bayesian updating approaches in which new data are supplied by real time monitoring of parameters, inspection of process equipments and use of physical reliability models (Ferdous, Khan, Sadiq, Amyotte, & Veitch, 2013; Khakzad, Khan, & Amyotte, 2012; Shalev & Tiran, 2007).

Underbalanced drilling is undertaken to maximize hydrocarbon recovery while minimizing drilling problems. However, it is associated with safety concerns as a result of the BHP being always less than the formation pore pressure which increases the possibility of kicks and blowout, thus, endangers personnel, facilities as well as the environment. There are a few studies on the risk analysis of overbalanced drilling (Anderson, 1998; Bercha, 1978; Khakzad, Khan, & Amyotte, 2013; Khakzad, Khakzad, & Khan, submitted for publication; Khakzad, Khan, & Palterinieri, 2014; Rathnayaka, Khan, & Amyotte, 2013; Skogdalen & Vinnem, 2012) and modeling of BOP systems (Fowler & Roche, 1994; Holland, 1991, 2001). The study of MPD and UBD is limited to Safety and Operability (SAFOP) analysis (Engevik, 2007).

The present study is aimed at conducting a dynamic quantitative risk assessment of drilling operations using advanced approach that can use real time data from the operation. The main objectives of this study are: (i) to develop a detailed quantitative risk analysis model that helps to assess and update the risk during drilling operation and (ii) to identify most vulnerable causes that have propensity to cause accident (blowout). Knowing these will help to design blowout prevention and mitigation measures. The study is focused on offshore application of three drilling techniques with subsurface blowout preventer (BOP). A brief description of drilling techniques and a description of dynamic risk methodology are presented in subsequent sections.

2. Drilling techniques

2.1. Conventional Overbalanced Drilling (COBD)

COBD involves drilling of a well with a drilling mud whose hydrostatic pressure is deliberately kept higher than the BHP. It is the basis of rotary drilling, thus, the commonest technique in the oil and gas industry. It is practiced because of its ease of well control, requiring the least planning, least expensive as the basic equipments of rotary drilling are used and the least number of crew members of all drilling techniques. The mud composition stabilizes the wellbore and is also compatible with all types of MWD tools; however, it has the least rate of penetration due to heavy mud used and could lead to lost circulation, stuck piping and formation damage (Adams, 1985; Bourgoyne, Millheim, Chenevert, & Young, 1986).

2.2. Underbalanced Drilling (UBD)

UBD includes drilling techniques employing appropriate equipment and controls to drill a well at a wellbore pressure less than the pore pressure in any part of the exposed formations in order to bring formation fluid to the surface (IADC) (Rehm, 2012). It is classified into two categories based on the type of drilling fluid: single phase fluids and two-phase (gaseous and compressible) fluids. The single phase fluid drilling comprises all underbalanced drilling techniques that do not use compressible gases as drilling fluid. It includes water, oil and additives such as glass beads. Two-phase fluid drilling, otherwise known as compressible fluid drilling, utilizes compressible fluids such as air, mist, foam and aerated mud (Leading Edge Advantage, 2002). Other forms of UBD are coiled tubing drilling, liner drilling and casing while drilling. In UBD operation, COBD equipments are used in addition to specialized facilities which include: rotating control device (RCD), snubbing unit, drill-string non-return valves, compressors for gas generation (if applicable) and dedicated choke manifold (Bennion, Lunan, & Saponja, 1998; Bennion, Thomas, Bietz, & Bennion, 1998; Gough & Graham, 2008; Hannegan & Wanzer, 2003; Leading Edge Advantage, 2002).

2.3. Managed Pressure Drilling (MPD)

MPD like UBD is a closed-loop fluid system requiring some of the UBD's specialized equipment: RCD, drill-string non-return valve and a dedicated choke manifold. It uses a single-phase drilling fluid to produce minimal friction losses. It is also described as near-balanced drilling as the mud hydrostatic pressure is kept close to the formation pore pressure, hence, it is called a constant bottom-hole pressure drilling technique. MPD unlike UBD avoids kicks