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Safety and risk analysis of managed pressure drilling operation using Bayesian network

Majeed Abimbola [a,b], Faisal Khan [a,b,*], Nima Khakzad [a], Stephen Butt [b]

[a] *Safety and Risk Engineering Group, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada*
[b] *Oil and Gas Engineering, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada*

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ABSTRACT

The exploration and development of oil and gas resources located in extreme and harsh offshore environments are characterized with high safety risk and drilling cost. Some of these resources would be either uneconomical if extracted using conventional overbalanced drilling due to increased drilling problems and prolonged non-productive time, or too risky to adopt underbalanced drilling technique. Seeking new ways to reduce drilling cost and minimize risks has led to the development of managed pressure drilling techniques. Managed pressure drilling methods address the drawbacks of conventional overbalanced and underbalanced drilling techniques. As managed pressure drilling techniques are evolving, there are many unanswered questions related to safety and operating pressure regime. This study investigates the safety and operational issues of constant bottom-hole pressure drilling technique which is used in managed pressure drilling compared to conventional overbalanced drilling. The study first uses bow-tie models to map safety challenges and operating pressure regimes in constant bottom-hole pressure drilling technique. Due to the difficulties in modeling dependencies and updating the belief on the operational data, the bow-ties are mapped into Bayesian networks. The Bayesian networks are thoroughly analyzed to assess the safety critical elements of constant bottom-hole pressure drilling techniques and their safe operating pressure regime.

1. Introduction

In the quest to reduce Non-Productive Time (NPT) and drilling cost in fractured and narrow mud pressure window environments, a set of drilling techniques known as Managed Pressure Drilling (MPD) has been developed. MPD is defined by the International Association of Drilling Contractors (IADC) subcommittee on underbalanced operation and managed pressure drilling (Minerals Management Service, 2008) as "an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore." MPD is an adaptive drilling process such that the drilling plan is adjusted in conformance to the changing wellbore conditions. In fact, MPD is an overbalanced technique; hence, it supposedly avoids the flow of formation fluid into the wellbore. It is a closed-loop system which prevents the well from being open to the atmosphere through using a rotating control device (RCD). The closed-system allows the casing back pressure to be adjusted precisely with a drilling choke when it is applicable to augment the hydrostatic pressure of the drilling fluid (Smith and Patel, 2012). An added benefit of the closed-loop circulation is that potentially dangerous gases are prevented from escaping on the rig, a drawback of conventional drilling. MPD techniques are used to reduce NPT resulting from correcting drilling problems; extend casing points; increase the rate of penetration; safely drill in fractured and cavernous formations with total lost return; limit loss of circulation; and eliminate lost circulation – kick sequence (Haghshenas et al., 2008).

Uneconomical conventional overbalanced drilling of reserves could be rendered economical when drilled with MPD techniques.

Abbreviations: BHP, Bottom Hole Pressure; BN, Bayesian Network; BT, bow-tie; CBHP, Constant Bottom Hole Pressure; CCS, Continuous Circulation System; COBD, Conventional Over-balanced Drilling; CPT, Conditional Probability Table; DAG, Directed Acyclic Graph; DAPC, Dynamic Annular Pressure Control; DGD, Dual Gradient Drilling; ECD, Equivalent Circulating Density; ET, event tree; FG, Fracture Gradient; FIT, Formation Integrity Test; FT, fault tree; IADC, International Association of Drilling Contractors; ICU, Intelligent Control Unit; LHS, Left Hand Side; LOT, Leak off Test; MODU, Mobile Offshore Drilling Unit; MPD, Managed Pressure Drilling; NPT, non productive time; PMCD, Pressurized Mud Cap Drilling; PP, Pore Pressure; PWD, Pressure measurement While Drilling; QRA, Quantitative Risk Analysis; RHS, Right Hand Side; RCD, rotating control device.

* Corresponding author at: Safety and Risk Engineering Group, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada.

E-mail addresses: mabimbola@mun.ca (M. Abimbola), fikhan@mun.ca (F. Khan), nkhakzadrostami@mun.ca (N. Khakzad), sdbutt@mun.ca (S. Butt).

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Further, offshore environments that are too risky to apply underbalanced drilling due to comparatively lower hydrostatic pressure than formation pore pressure could be drilled safer with MPD techniques.

Generally, a drilling operation comprises several sub-operations and/or stages. These sub-operations include: drilling ahead, tripping, static condition, casing and cementing (Arild et al., 2009). During drilling ahead, the formation is disintegrated by the cutting action of the drill bit. The drilling fluid carries the cuttings up to the surface as drilling progresses. This sub-operation constitutes the major portion of the productive time of the drilling operations. A well (Fig. 1) is drilled in a form resembling an inverted telescope with the larger size at the top. First, the conductor hole is drilled very shallow so that the conductor casing can be installed to stabilize earth near the top of the well and facilitate the drilling of the surface hole. The surface hole is drilled to the base of the fresh water zone or aquifer for the surface casing to establish a seal across the fresh water zone or aquifer when cemented. This may be followed by an intermediate hole for the intermediate casing to help stabilize the formations and isolate abnormally pressured zones. Lastly, the production hole for the production casing is drilled across the productive interval of the formation.

Tripping operation involves the running of a drill string out of the well and then into the well to continue the drilling operation. This is done for example to replace a dull drill bit, make or break a drill string connection and to install or repair a bottom hole assembly. Moving the drill string out of the well can give rise to a swabbing effect in which the BHP would be reduced equivalent to the volume of the drill-string. On the contrary, when the drill string is running into the well, a surging effect would occur in which the BHP would increase equivalent to the volume of the drill string. Static condition is a stage in which there is no circulation of the mud and the drilling has been stopped in the well. The rig pump is off and the BHP is either balanced only by the hydrostatic pressure of the mud column or supplemented by some backpressure. Casing operation is the running of casings into an open hole. Each casing size is run in succession into the open hole. Casings include: conductor casing, surface casing, intermediate casing

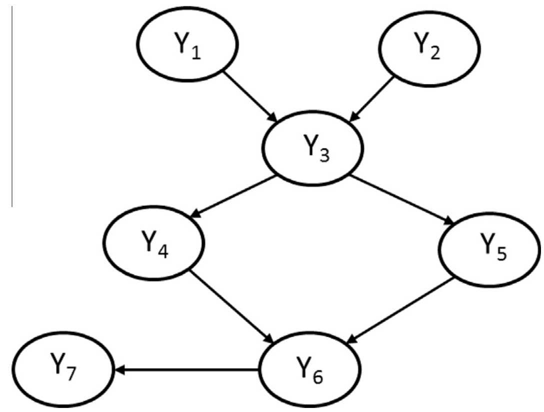

Fig. 2. A typical Bayesian network.

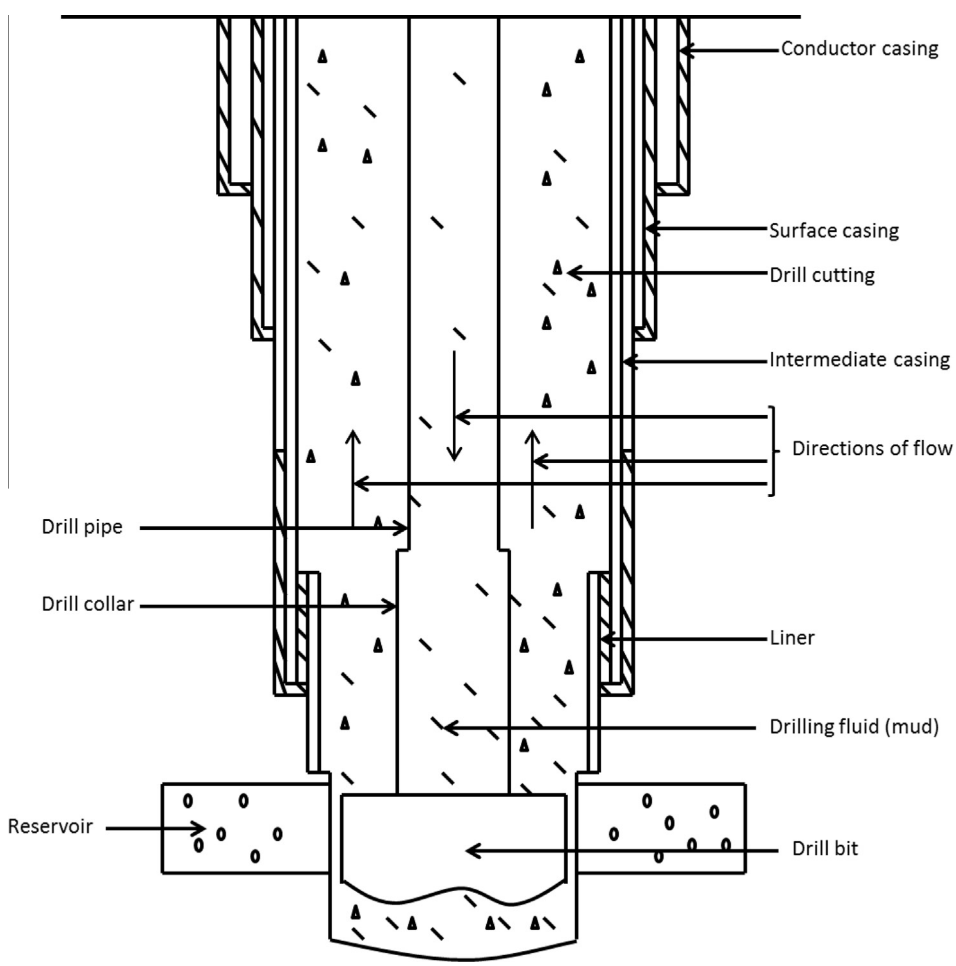

Fig. 1. A typical well profile.