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Development of a trip time for bit exchange simulator for drilling time estimation

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ABSTRACT

The development of geothermal power generation technologies for applications in non-volcanic areas, based on artificial reservoir creation, has prompted numerous studies on the efficient and economic execution of costly deep subsurface drilling operations. However, the difficulties in predicting the duration and cost of boring work with acceptable reliability make the efficient and organized management of drilling operations very difficult. The trip time for drill bit (i.e., the time taken to withdraw the drill stem to replace bits worn-out, followed by its re-entry into the borehole) that is required because of the abrasion and replacement of bits has a large impact on drilling time and performance. Therefore, a methodology for predicting the time required for a trip for bit exchange at a given depth will enable reliable drilling time and cost estimation for better drilling production management. This study divided the abrasion condition of roller bits into eight steps and used bit life expectancy time for developing a simulation algorithm for Trip Time for Bit Exchange (TTBE). A methodology that can classify the depth of drilling well based on the characteristics of the formation and drilling parameters has also been suggested based on the Bourgoyne and Young model to forecast drilling rates and the extent of bit abrasion.

1. Introduction

Geothermal energy has recently been gaining much attention because of growing concerns about the exhaustion of fossil fuel energy resources and environmental protection on a global scale. Geothermal energy sources can generate continuous and consistent amounts of electricity, unaffected by the weather. In particular, with the development of Engineered Geothermal Systems (EGSs), geothermal resources can be developed in non-volcanic regions. It is expected that 200 GW of geothermal power generation will be available worldwide by 2050 (Tanaka, 2011). In Korea, the 'MW Geothermal Generation Commercialization Technology Development' that has been carried out with the support of the Ministry of Trade, Industry and Energy as a five year plan from December 2010, it has set its goal on constructing and operating the MWe CDP (Commercial Demonstration Plant) in the Pohang region for the first time in Asia (Yoon et al., 2011).

Technologies for EGSs require drilling to depths of several kilometers to access high-temperature underground thermal sources in non-volcanic areas. Drilling accounts for approximately 50%–70% of the total expense of EGS projects. The drilling activity itself, excluding other processes such as casing and cementing, accounts for 25%–40% of the total drilling costs, and more than 40% of the total construction time. Therefore, drilling constitutes a major element in the planning and management of an EGS project (Schlumberger Business Consulting, 2008). As a result, efforts are continuously being made to develop more efficient and cost-effective drilling technologies.

Studies related to the optimization of drilling performance have been conducted since 1950s. From 1950s to 1970s, the principal goal of drilling research was the prediction and management of drilling control factors such as Rate Of Penetration (ROP), Weight On Bit (WOB), and Revolutions Per Minute (RPM) of the bit (Fig. 1). As one of the best known studies in drilling, Maurer (1962) suggested theoretical functions to optimize ROP of roller-cone bits into bored rocks by adjusting variables related to WOB, RPM, bit diameter, and rock strength, and by analyzing the drilling fluids and their contents (Maurer, 1962). Galle and Woods (1963) suggested a methodology for constructing a graph that would lead to an optimal combination of WOB and RPM during drilling, and thus allows estimates of drilling costs (Galle and Woods, 1963). Later, Bourgoyne and Young (1974) developed a numerical model that could calculate ROP as a function of eight factors, which included rock strength, bit abrasion, RPMs, WOB, consolidation of the formation, and pressure differences on the lower portion of the drill

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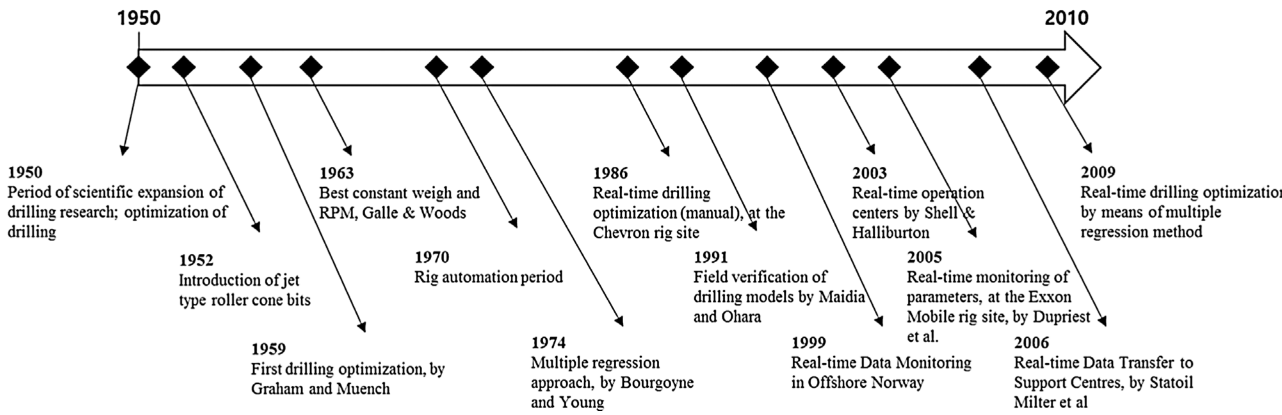

Fig. 1. Research on drilling optimization (Eren, 2010).

(Bourgoyne and Young, 1974). They suggested a methodology for calculating the optimal WOB, RPM, and the expected abrasion rate of the bit for given drilling conditions. The impact of the eight factors on ROP was calculated using a multiple regression model based on historical data obtained from the available sites. Bourgoyne and Young's method for calculating the penetration rate and optimizing the control of drilling elements has been adopted as a standard and reliable method for optimizing drilling efficiency (Bahari and Baradaran Seyed, 2007; Hasan et al., 2011; Irawan et al., 2012). Subsequently, with the rapid development of advanced IT technologies starting in 1980s, systems such as Measurement While Drilling (MWD), which is a real-time onsite interfacing technology and Logging While Drilling (LWD) have been developed. As shown in Fig. 1 many studies have been conducted on the development of real-time drilling performance optimization.

Previous research focused mainly on optimization of drilling parameters such as WOB, RPM, and ROP. However, reliability and design parameters for overall performance of drilling are difficult to predict, not only because of variations in ROP, but also because of lost circulation and other potential difficulties such as damage to drilling tools, pipes, the Bottom Hole Assembly (BHA), and malfunctioning of drilling equipment, as well as occasional replacement of drill bit caused by bit abrasion. They are the reasons of non-productive time of drilling process which need to be managed well to save the time and cost. Therefore, efforts have been made to increase productivity by studying the characteristics of non-productive activities considering the types of rigs, rock conditions, and mechanical properties such as bit wear mechanism which are the sources of non-productive drilling activities (Bär et al., 2013; Macini, 1996; Bär and Teodoriu, 2013). In particular, the withdrawal of the drill stem to replace worn-out or broken bits, followed by its re-entry into the borehole, a process referred to as a 'trip for bit exchange', requires approximately 22% of the total drilling period. Because of the large impacts of trip for bit exchange on project performance, especially during deep drilling to depths of several kilometers below the surface (as in EGSs), the trip for bit exchange must be optimized by considering both ROP and the recurrence interval of it (Polsky et al., 2009; Finger and Blankenship, 2010).

The timing of a trip for bit exchange due to abrasion is generally based on the intuitive judgment of the drilling engineers. In general, 96% of bit exchange occurs due to low ROP during drilling operation, 3% of it due to mandatory bit changes specified in the beginning of project, and 1% of it due to drilling troubles (Muchendu et al., 2014). Also, even if ROP is not low, bits are exchanged based on life expectancy considering the historical data on bearing breakdown and other factors such as operation time, drilling depths, and number of rotations (Arevalo, 2011; Schlumberger, 2011). In the case where the bit remains in the borehole until it is abraded to the maximum level to reduce the frequency of trip for bit exchange, ROP can become very low. If a trip is initiated when the amount of bit abrasion is low, to maintain a certain level of ROP, the drilling time increased due to the added trip will potentially increase the total time and cost of drilling. Therefore, an algorithm that can identify all the cases in which trips need to occur according to the possible scenarios for abrasion of the bit and ROP can rationally calculate the trip frequency by simulating all possible combinations of variables. With such algorithm, efficient drilling operation that optimizes both performance and cost can be planned.

2. Scope and methods of research

Generally, the project performance can be estimated from the time and expense required for the completion of the project. In the case of drilling, the lease of the rig and the wages constitute a large portion of the expense; therefore, reducing the duration of the well construction is one way to reduce the cost (Augustine et al., 2006; Kaiser, 2007; Hance, 2005; Yost et al., 2015). To optimize drilling operation in the planning phases of the project, it is necessary to predict ROP and the timing at which a trip for bit exchange is required in order to minimize delays and construction time. The penetration rate and the timing for the trip for bit exchange are both related to the abrasion of the bit. Because ROP decreases as the bit becomes abraded (Bourgoyne and Young, 1974), it is possible to assess the timing for the trip by predicting the bit abrasion rate for different trip frequencies, thus creating a replacement frequency standard. In this study, the type of bit is limited to roller bit because Bourgoyne and Young's model is confined to common roller bit such as steel tooth bit and insert bit. In this study, it is assumed that the trip for bit exchange is occurred mainly due to abrasion of bit tooth, and, therefore, partial breakdown or loss of cutting structure was not considered. Fig. 2 gives the details of the research methodology used in this study.

Firstly, the abrasion status value (0%–100%) for bit exchange needs to be determined. The International Association of Drilling Contractors uses eight abrasion status evaluation standards (IADC, 2000). Therefore this study adopted IADC's evaluation standards for the simulation as shown in Fig. 3.

The well needs to be partitioned into sections for the following reasons. According to Bourgoyne and Young's model, it is necessary to incorporate WOB, RPM, and ROP to calculate the amount of bit rotation time to reach a certain abrasion status. Also, the formation abrasiveness constant (τ_H), which assesses the effect of the formation on bit abrasion based on historical drilling data in similar environments, and the tooth wear parameter (J2), which correlates the drilling control variables WOB and RPM with the amount of bit abrasion, must be calculated. Because the values of these variables vary for different intervals of a geothermal well, the well is partitioned into sections with similar conditions for simulation.

After tooth abrasion status value for bit exchange is determined and