TORQUE AND DRAG MEASUREMENT: A COMPARISON BETWEEN CONVENTIONAL, SLIM HOLE AND CASING DRILLING METHODS IN A DEVIATED WELL

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ABSTRACT

Different locations and field conditions require various drilling methods to produce oil and gas. Three major operational methods are identified to be slim holes, conventional and casing drilling. Despite many affecting parameters, torque and drag are two highlighted factors for the determination of the best drilling method. Torque and drag play a significant role in the feasibility of drilling and its final costs. In this study, the influence of the torque and drag are investigated for the determination of optimum drilling type in consideration of the same S-shape well trajectory for all cases. Consequently, slim hole drilling showed minimum torque and drag value which meant that this method can be a good choice. Furthermore, casing drilling displayed maximum torque and drag in this study resulting in high sensitivity to the high degree of deviation. On the other hand, due to the constant weight of casing while drilling, this method showed a smooth increasing trend in terms of drag force while slim hole and conventional drilling showed significant changes in different parts of well trajectory. The number of build and drop sections significantly affect the amount of torque loss, while up to 50% to 70% of torque loss was observed in the drop or build section.

***Keywords*:** *torque, drag, directional drilling, slim hole, casing while drilling, well trajectory*

INTRODUCTION

Drilling well encounters different problems such as geomechanical problems [1-3]. Deviated wells, meanwhile, are experiencing more problems compared to other types of the well and incurring huge costs. Currently, directional drilling is essential in the development of offshore and onshore fields, but it remains a challenging task [4-8]. The utilization of this method allows access to inaccessible fields such as drilling an offshore field from shore or drilling a well into a residential field from far away. While directional drilling has many advantages, it is plagued by difficulties brought by torque and drag such as the limitation of drilling length. In some circumstances, torque and drag might lead to the collapse of the drill pipe, thus wasting energy and money. On the other hand, high dogleg severity and long horizontal departure cause high torque and drag lost in the drilling system. To overcome these problems, various types of drilling and completion are used; three of the more interesting types of the well will be explained here.

Conventional (rotary) drilling is one of the most popular methods used in the industry. Directional drilling has changed the landscape of the oil and gas industry. Drilling of relief wells using directional drilling technology as early as 1931 is mentioned in the literature [9]. Drilling non-vertical wells has opened up a world of possibilities in accessing reservoirs that would not have been possible with conventional methods. Directional drilling also makes it possible to avoid zones and formations where drilling would be troublesome and allows for increased production by exposing long non-vertical pay zones sections. This method drills a well with conventional equipment in accordance with conditions and is completed as an open or cased hole

Casing Drilling is a process in which a well is drilled and cased simultaneously. This innovative technology has been successfully spractised for the past decade. The original purpose of developing Casing Drilling was to eliminate Non-Productive Time (NPT) associated with tripping drill pipe and running casing. However, during the early implementation of the technology, other benefits were observed while drilling with large diameter casing [10]-[11]. Casing drilling can significantly improve drilling performance as it drills across pressure transitions. Overcoming pressure transition issues helped solved the lost circulation and well control problem. The elimination of at least one problem makes this process more economical. For example, casing while drilling knows as a preferred method in the formation with high shale content [12]-[13]. Nevertheless, the disadvantages of casing drilling include the usage of specialized equipment. Perhaps the detrimental effect remains as it is limited to the application in directional drilling. This is due to the restriction in its flexibility as the diameter of the casing is larger than the drill pipe. In addition to that, high dogleg severity can cause failure in the drilling process [11], [14].

Slim Hole drilling is a method that is used by the mining industries but also in the petroleum industries because of its cost-saving ability [15]. This is attributed to the money saved on the casing, rig site, disposal cost, environmental impact, cutting down the volumes of muds, cement, etc. [15[-[17]. Additionally, slim hole drilling is welcomed to the geothermal systems due to its advantages [18]-[19]. The major concern in using the slim hole drilling method is drill string failure associated with the use of small diameter tubing. The reduction in the size of the slim hole drill pipe can significantly reduce torque transmission capability. Kick detection, tool joint failure, decreasing penetration are the other disadvantages of this method [15-17], [20].

As mentioned before, the success of the drilling process can be affected by the presence of torque and drag, especially in deep and complex wells. For instance, high torque and drag forces prevent the reach of drilling target in extended reach drilling [21]. The forces that affect various drilling methods are explained as below:

Drag force is the difference between free rotating weight and the force required to move the pipe up or down the drill hole. Drag force is used to overcome the axial friction in the well. This is a phenomenon associated with deviated wells [21]-[24].

Torque is a quantity of force taken to rotate the drill string. The torque is used to overcome the rotational friction in the well and on the bit. Torque will be lost along a drill string which leads to less torque available in the bit for destroying rock. A perfect vertical well has almost zero torque loss with negligible loss due to viscous drag from mud [21]-]24].

Generally, high torque and high drag occur together but these forces are not the only forces affecting the drill strings. Torque and drag from any source tend to be more troublesome in directional holes. In very deep and highly deviated wells, overcoming torque and drag is critical to the success of well completion. The analysis of these two forces on the drill pipe has two main benefits. Firstly, deep and highly deviated wells can be planned to minimize torque and drag. The use of torque and drag as criteria to select the most appropriate well path will help ensure successful drilling operations to total depth. Secondly, more complete knowledge of drill string loading allows improvements to be done on the drilling techniques. Therefore, this study aims to investigate torque and drag forces in different types of drilling methods. The results of this study can help the researcher and industry to choose the best drilling method.

METHODOLOGY

Drilling a directional well is more complex than vertical well because of the azimuth and inclination of the well. In this study, a directional well is divided into two sections. The first section refers to the straight section of the well and the second one refers to the curved section of the well. Each section will be analyzed separately and finally, the summation of the forces of each section equates to the force that is acting on the drill string.

Straight section

Drag force acting on the straight section of the drill string is calculated as:

$$F_n = \sum_{i=2}^{n} \{\beta w \Delta L \times (\cos \alpha \pm \mu \sin \alpha)\} \quad (1)$$

where F_n is the drag force, β is the buoyancy factor, w is the weight of drill pipe per unit length, ΔL is the length of the element, μ is the friction factor, and α is inclination angle.

When the friction coefficient equals to zero, the equation shows the static weight of the drill string in a straight section for different drilling operations.

Also, the sign "+" indicates that the pipe is pulled upward and the sign "–" indicates that the pipe is lowered downward.

The torque acting on the drill string is defined as:

$$T_n = \sum_{i=2}^{n} \{\beta w \Delta L r \sin \alpha \times \mu\} \quad (2)$$

where T_n is torque, β is buoyancy factor, w is the weight of drill pipe per unit length, ΔL is the length of the element, μ is friction factor, α is inclination angle, and r is tool joint radius.

The above equation shows torque loss along the drill pipe and can be considered independent of the direction of rotation.

As it is in a vertical section, inclination equal to zero as no torque loss is present due to the negligible value of the normal force. Inclination equal to 90 degrees as it is in the horizontal section, maximum torque loss will occur due to maximum normal force.

Curved section

Drag forces that act on the curved section of the drill string is calculated as:

$$F_n = \sum_{i=2}^{n} \left\{ F_{i-1} \times e^{\pm \mu_i r_i |\theta_i|} + \beta_i w_i \Delta L_i \times \left[\frac{\sin \alpha_i - \sin \alpha_{i-1}}{\alpha_i - \alpha_{i-1}} \right] \right\} \quad (3)$$

where F_{i-1} is the drag force in the *i*–1 step, and θ_i is dog leg severity.

And Torque loss in the curved section defined as curved section defined as:

$$T_n = \sum_{i=2}^{n} F_{i-1} \mu_i r_i |\theta_i| \quad (4)$$

The buoyancy factor effect is clear and must be calculated for each element as different kinds of mud are used in the well controlling process. However, it can be considered a constant value along the well. An average value of the buoyancy factor can be presented as a good estimation of a buoyancy factor throughout a well [22], [25]. Also, the friction factor varies in the different sections of the drill string. It is obvious that the friction factor in the curved section is more than the straight section of the well. The friction factor is also affected by the type of drilling fluid and cutting. However, a constant value of friction factor can be identified in real data to find the best value of friction factor that can be allocated to the entire element [22], [26].

While complex wells are drilled for various purposes, most wells are typically planned around one of three potential geometries: build and hold, build and drop, and deep build/kick-off [27]. The case that will be discussed here is a two dimensional S-shaped well. Figure 1 showed an S-shaped well that is drilled in a vertical plane.

The total length is 2111 m. The well is filled with 1.3 S.G. drilling mud and the coefficient of friction is estimated to be 0.2. The bottom hole assembly (BHA) starts just below the drop-off section and it is vertical. In this case, there is no change in azimuth and the dogleg equal to the change in inclination.

Table 1 shows the drill string specification for the three mentioned methods. In conventional drilling, the drill string consists of 161 m of 8 inches drill collars and 1950 m of 5 inches drill pipe. The drill collar radius is 0.1 m, and the drill string connection radius is 0.09 m. In slim hole drilling, the drill string consists of 161 m of 4 ⅞ inches drill collars and 1950 m of 2 ⅞ inches drill pipe. The drill collar radius is 0.062 m, and the drill string connection radius is 0.061 m. In casing drilling, the drill string consists of 6.625 inches casing. The casing radius is 0.168 m [28].

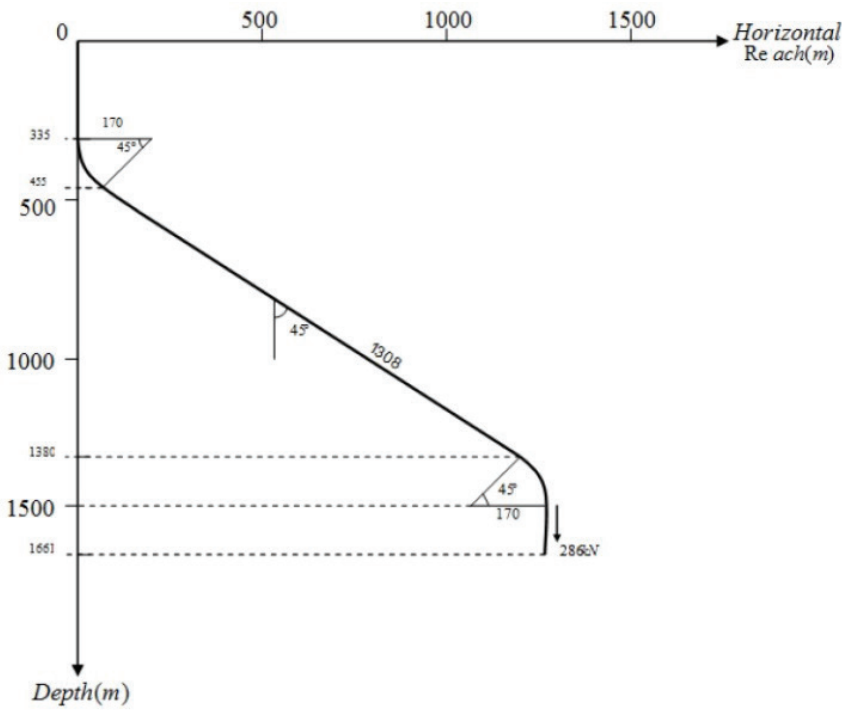

Figure 1 An S-shaped well trajectory [22]

Table 1 Specification of drilling string

Drilling Method	Conventional Drilling	Slim Hole	Casing Drilling
Drill Pipe Length (m)	1950	1950	-
Drill Pipe Radius (inches)	5	2 7/8	-
Drill Pipe Weight (kN/m)	0.285	0.152	-
Drill Collar Length (m)	161	161	-
Drill Collar Radius (inches)	8	4 7/8	-
Drill Collar Weight (kN/m)	2.13	0.728	-
Casing Length (m)	-	-	2111
Casing Radius (inches)	-	-	6.625
Casing Weight (kN/m)	-	-	0.467

RESULTS AND DISCUSSION

Drag force for static weight, hoisting, and lowering modes in each case are shown in Figure 2, Figure 3, and Figure 4, respectively. The results of the drag force in the conventional well are presented in Figure 2. The conventional drilling method is considered as a base method for future comparison. The results showed a general increasing trend from the bottom hole to the surface. This increasing trend is significant between the target point and the end of the drop section. Also, in this section, drag force changes showed the same value for static weight, hoisting, and lowering modes. In the drop section, there are three different behaviors of drag force for different static weight, hoisting, and lowering modes. The value of drag force changes in the drop section is lower than the drag force changes in the build section, especially for hoisting mode. The drag force varied in the range of 490 to 840 kN in the different modes.

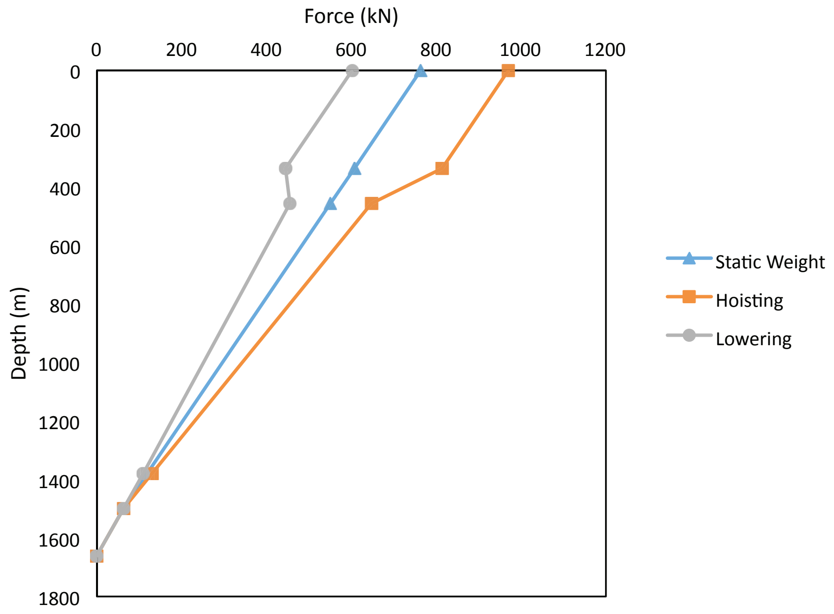

Figure 2 Drag force in conventional well

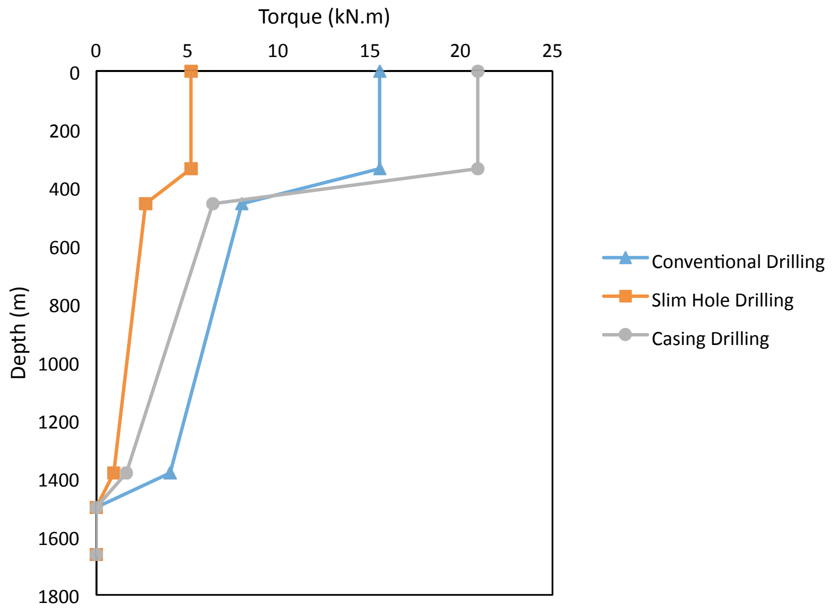

Figure 3 Drag force in casing drilling

Figure 3 showed the results of the casing while drilling method. In this method, the use of casing instead of drill pipe and drill collar led to the increment of weight. The casing has more weight in compression with the drill pipe and less weight in compression with drill collar but this weight is constant during the drilling process albeit the increment in total weight compared to the conventional method. This weight increment resulted in the subsequent increment of drag force.

As seen in Figure 3, the drag force showed a general increasing trend. Minimal drag force changes are seen between the target point and end of the drop section for the three different modes. In the drop section, the changes are negligible as static weight, hoisting, and lowering modes showed similar values. The changes of drag force are significant in the build section which indicated that potential failure is high in this section. The drag force varied in the range of 600 to 970 kN in the different modes.

In the results shown in Figure 4 showed for the slim hole case, due to the usage of drill pipe and drill collar with a smaller diameter compared to the conventional method, the weight of drill string has reduced significantly resulting in the reduction of drag force. It is observed that using a smaller drill pipe in the slim hole method resulted in drag force reduction but had also diminished its pressure tolerance.

As seen in Figure 4, 40% (in the lowering mode) and 25% (in the hoisting mode) of drag force changes happened between the target point and end of the drop section. The drag force changes are small in comparison with the build section. The drag force varied in the range of 250 to 420 kN in the different modes.

The torque for all three cases is determined and a comparison is made in Figure 5. As seen in Figure 5,

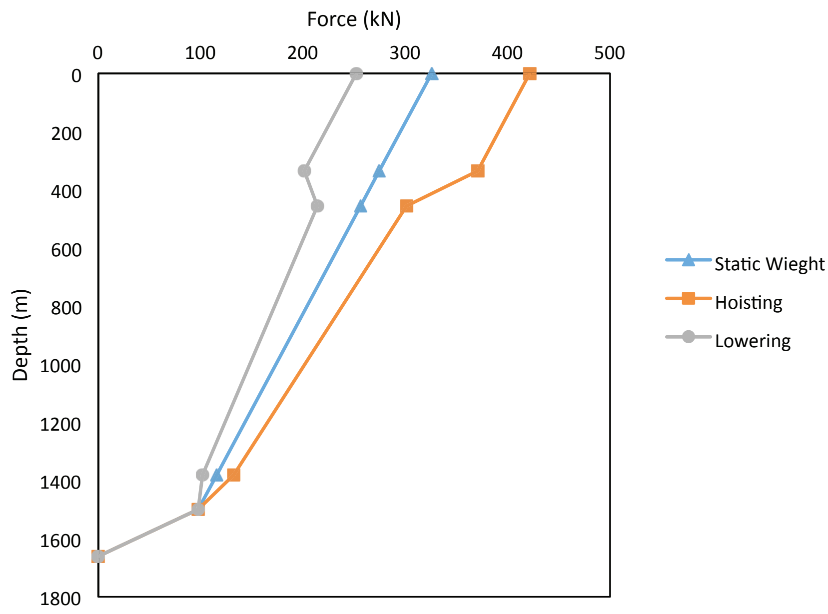

Figure 4 Drag force in the slim hole well

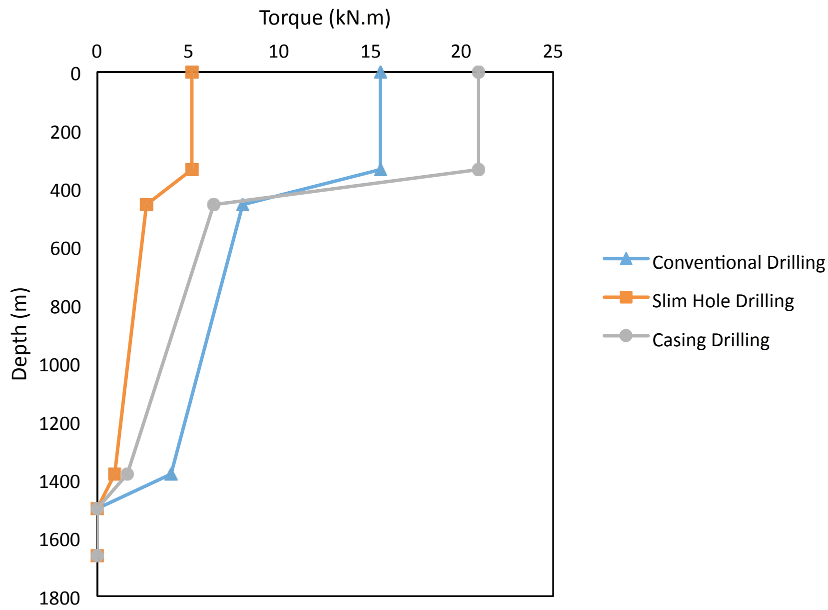

Figure 5 Torque comparison for conventional, slim hole and casing drilling

torque in the slim hole is less than the other holes leading to the decrement in drill string capability thus the possibility of failure is more likely. This has led to the limitation in the drilling length.

Casing drilling in first high dog leg severity behaved similarly to the slim hole. This section showed that the torque is less than the conventional method and it can be attributed to the lesser weight of casing compared to the drill collar. In addition to that, the lower torque in an inclined section is also attributed to the lesser weight of casing. The second high dog leg severity is caused by the lesser flexibility of casing compared to the drill pipe. Therefore, it has led to the significant increment of torque which is observed to be more than that of conventional drilling. The sharp increment in this section can cause failure in the drilling process.

CONCLUSION

Directional drilling has many advantages, but it is plagued by difficulties brought by torque and drag such as the limitation of drilling length. In this study, we investigated three different types of drilling from the perspective of torque and drag. The results showed that,

a. Slim hole with its specification can be effective and economical in this well trajectory but the length of well must be considered due to the instability of this method.
b. Casing drilling technology is one of the best recent drilling technologies. It can reduce the time and cost of drilling as well as reducing the across pressure transient risks. However, in directional drilling, this method showed weaknesses with the increasing rate of building angle.
c. Increasing in build or drop section number caused a significant increase in torque.
d. The weight of drilling string is important due to its high impact on drag force.

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