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Prediction of Trip, Connection, and Total Times for Top Drive and Kelly Drilling Rig Systems

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Abstract

It is essential, in any drilling operation, to minimize trip time and connection time in order to achieve the minimum drilling cost possible. It is generally assumed, for the calculation of cost per foot of drilling purposes, that the trip time is one hour for 1,000 feet. Connection time, on the other hand, varies according to the drilling system deployed. A top drive system allows reducing connection time by two thirds of the number of connections required by a kelly system which means less cost. However, top drive rigs come with higher rental rates than the rotary drive system. In this study we develop correlations for estimating drilling trip time, connection time and total time for both the top drive and kelly drive drilling systems. For this purpose, drilling data from the drilling daily reports of ten drilled wells in three different Libyan oil fields were gathered. Six wells were drilled using kelly system, and the remainder wells were drilled through the top drive system. The results indicate that the correlations can be adequately used to calculate the trip time, connection time and total time. This, in turn, allows predicting the total cost of drilling a well and also which type of drilling system yields less cost; the top drive or the kelly drive.

Keywords: Trip time; connection time; total time; drilling costs; top drive; rotary drive systems.

1. Introduction

Although oil and gas drilling has been taking place for over 100 years, the technological advances in recent years along with increasing extraction of unconventional oil and gas resources has revived interest and investment in the drilling industry over the past few years. The technologies are more integrated to enable faster and more accurate drilling in deep-water and ultra-deep-water and help secure oil and gas wells in the most demanding and challenging environments. These technologies allow a more rapid analysis of rock formations and a more accurate data acquisition from geological areas being explored. Various technologies are used to drill horizontal and directional wells that enable extraction of hydrocarbons from more difficult and unconventional resources. [?]

One of the relatively recent drilling technologies is the top drive drilling system, recognized as one of the most significant advancements in drilling technology since the introduction of the kelly system. When compared to conventional kelly drilling rigs, those equipped with top drive systems, regardless whether the prime mover for rotating the drill pipe is electric or hydraulic, consistently drill faster with far less instances of stuck drill pipe. In addition, drilling with a top drive allows operators to reach areas and types of formations that would not be accessible with conventional kelly drilling. Extended reach and horizontal drilling have brought about dramatic increases in production rates from specific fields, and these types of wells can only be drilled with top drives. These benefits, along with improved well control and better hole conditioning, all contribute to the in-

disputable financial justification for the top drive. It is obvious that over the last decade that the top drive system of drillings has become the predominant method of drilling offshore wells. At present we are also experiencing that, the critical parts of onshore wells are drilled with top drive though this requires experienced drilling personnel to maintain the system and solve any anticipated or unanticipated problems [2][3].

Several studies have compared connection times between top drive and kelly drive rig systems during the drilling processes [2][5]. As top drive system allows rotating full stand and thereby connections are reduced by two thirds of the number of connections required by a kelly system, all studies have concluded that top drive system is faster, more efficient and therefore less costly than the conventional kelly drive rig system. This applies to difficult to drill moderately deviated wells, easy to drill deviated or non-deviated wells and highly deviated wells [2].

Estimating drilling trip and connection times are very important because they directly affect the total cost of drilling a well. Trip time refers to time required to removing the drillstring from the hole to change a portion of the downhole assembly and then lowering the drillstring back to the hole bottom. Trip times are usually spent on changing dull bits. While connection time refers to time required to adding and connecting pipes to the drillstring in order to continue drilling and achive new depths.

The purpose of the work is to develop correlations to predict trip time and connection time for both top drive and kelly drive systems.

2. Material and Methods

Drilling data from the drilling daily reports of ten wells, drilled in three different Libyan oil fields, were collected and fully reviewed and analyzed. Six wells were drilled using kelly drive system and the other four wells were drilled by top drive system. Records from one kelly well was left out as test data for validation of the models. Therefore, the models were developed based on the nine remaining wells. Tables 1 and 2 below contain summary of some of the extracted data from wells drilled by the top drive and kelly systems, respectively.

Table 2.1: Some of top drive data used in the study

Well #	Well Type	Field	Interval	Hole Size, inch				
				26	17 1/2	12 1/4	8 1/2	6
A7	Vert.	NC89	Connection time, hr	2	34.5	40.8	18	23
			Tripping time, hr	5.5	98.5	202	180.5	234.5
			Footage, ft	562	4776	7202	1375	1381
6R2	Vert.	C59	Connection time, hr	4	10	36	16.5	
			Tripping time, hr	19	45	107	249	
			Footage, ft	564	2447	6466	1783	
O1	Vert.	NC98	Connection time, hr	3.5	42.5	24.5	32.5	33.5
			Tripping time, hr	21.5	109	124	166	688.5
			Footage, ft	984	6693	5106	1575	2047
2H17	Horiz.	C59	Connection time, hr	5	21.5	51.5	8.4	42.8
			Tripping time, hr	17	31.5	78.5	68.5	285
			Footage, ft	590	2220	6470	836	2910

Trip times and connection times were clearly recorded for further analysis. It must be noted that time lost due to any unexpected problems is excluded from the analysis. Average trip times and connection times, for each hole section, are plotted versus average depths achieved during drilling that particular section. As it can be seen from the tables, hole sections are of 26, $17\frac{1}{2}$, $12\frac{1}{4}$, $8\frac{1}{2}$, and 6 inch. The sum of connection time and trip time is the total time or total handling time. In some studies [7] total time is the same as trip time which indicate that the connection time is included with the trip time. A direct relationship between connection time and depth was found and a logarithmic relationship between trip time and depth was found.

Linear regression was used as a statistical tool to analyze the relationship between different drilling times (trip, connection and total) and depth. Linear regression is a statistical method used to summarize and study relationships between two continuous or quantitative variables. In this study, one variable, denoted time, is regarded as the predictor, explanatory, or independent variable. The other variable, denoted depth is regarded as the response, outcome, or dependent variable.

3. Results and Discussion

Figure 3.1 shows the relationship between connection time versus depth for the top drive system at an R^2 (statistical measure of how close the data are to the fitted regression line) value of 90.09 %. Equation (3.1) is a logarithmic relationship

Table 3.1: Some of kelly drive data used in the study

Well #	Well Type	Field	Interval	Hole Size, inch				
				26	17 1/2	12 1/4	8 1/2	6
F4	Vert.	NC98	Connection time, hr	2	39.5	40.5	32.5	7.5
			Tripping time, hr	31	71.5	142	203.5	155.5
			Footage, ft	522	4699	7309	2106	736
6R1	Vert.	C59	Connection time, hr	5.5	25	73.5	14.5	
			Tripping time, hr	25	44.5	154	97	
			Footage, ft	635	2428	6900	1231	
A61	Vert.	NC98	Connection time, hr	5	74	48.5	29.5	3.5
			Tripping time, hr	26	117	283.5	166	41
			Footage, ft	806	6737	5054	2045	339
2H15	Horiz.	C59	Connection time, hr	5	21.5	51.5	8	40.5
			Tripping time, hr	22	39.5	129.5	46.5	349.5
			Footage, ft	552	2439	5703	1442	2061
P2	Vert.	NC98	Connection time, hr	4	27	62	5	59.5
			Tripping time, hr	13.5	55	110	216	712
			Footage, ft	519	4597	5796	971	2616

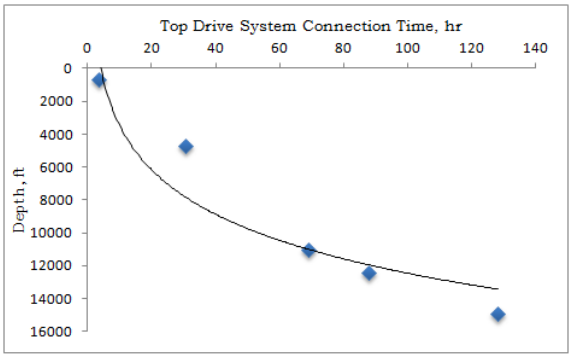

Figure 3.1: Connection time versus depth for the top drive system

between connection time and depth for the top drive system.

$$ConnectionTime = e^{0.000255Depth+1.4235} \quad (3.1)$$

Table 3 shows the actual average connection time, average depth, connection time calculated from Equation 3.1 and percent of relative error of the top drive system.
Figure 3.2 shows the relationship between connection times versus depth for the kelly drive system at an R^2 value of 88.60 %.
Equation (3.2) is a logarithmic relationship between connection time and depth for the kelly system.

$$ConnectionTime = e^{0.000267Depth+1.4235} \quad (3.2)$$

Table 3.2: Top drive system connection times comparison

Connection Time, hr	Depth, ft	Calculated Time, hr	% Relative Error
3.625	675	4.9314	26.4916
30.75	4709	13.7948	122.9093
68.95	11020	68.9650	0.02183
87.8	12412	98.3589	10.7351
128	14909	185.9160	31.1517

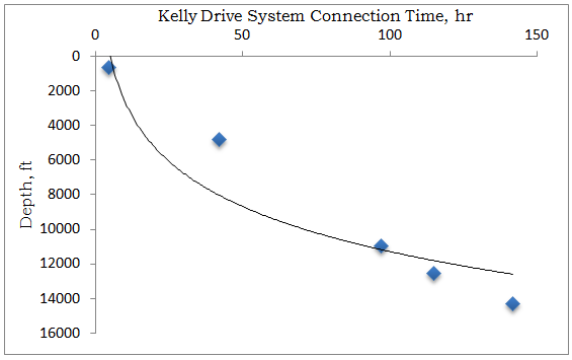

Figure 3.2: Connection time versus depth for the kelly system

Table 4 shows the actual average connection time, average depth, connection time calculated from Equation 3.2 and percent of relative error of the kelly system.
Figure 3.3 below shows trip time versus depth for the top the drive system at an R^2 value of 96.48%.
Equation (3.3) is the logarithmic relationship between trip time and depth for the top drive system obtained from Figure 3.3.

$$TripTime = e^{0.00026Depth+2.756} \quad (3.3)$$

Table 5 shows the actual average trip time, average depth, trip time calculated from Equation 3.3 and percent of relative error of the top drive system.
Figure 3.4 below shows trip time versus depth for the kelly drive system at an R^2 value of 97.92 %.
Equation (3.3) is the logarithmic relationship between trip time and depth for the top drive system

Table 3.3: Kelly drive system connection times comparison

Connection Time, hr	Depth, ft	Calculated Time, hr	% Relative Error
4.3	606.8	4.881	11.9178
41.7	4786.8	14.903	179.8057
96.9	10939	77.035	25.7861
114.8	12498	116.806	1.7178
141.6	14262	187.077	24.2959

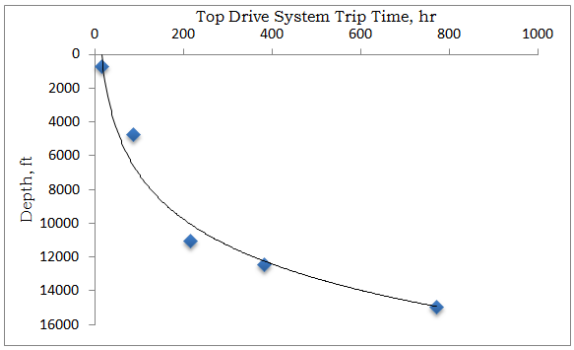

Figure 3.3: Trip time versus depth for the top drive system

Table 3.4: Top drive system trip times comparison

Connection Time, hr	Depth, ft	Calculated Time, hr	% Relative Error
15.75	675	18.755	16.0257
86.75	4709	53.535	62.0428
214.6	11020	276.220	22.2994
380.6	12412	396.701	4.0526
770.2	14909	759.256	1.4369

obtained from Figure 3.4.

$$TripTime = e^{0.00024Depth+3.081} \tag{3.4}$$

Table 6 shows the actual average trip time, average depth, trip time calculated from Equation 3.3 and percent of relative error of the kelly drive system.

Figure 3.5 shows total time (connection time plus trip time) versus depth for the top the drive system at an R^2 value of 95.74 %. Equation (3.5) is the logarithmic relationship between total time and depth for the top drive system obtained from Figure 3.5.

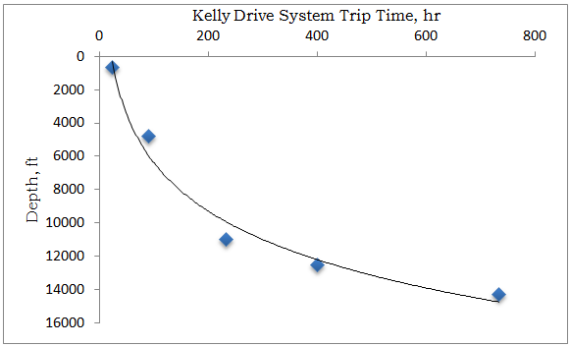

Figure 3.4: Trip time versus depth for the kelly system

Table 3.5: Top drive system trip times comparison

Connection Time, hr	Depth, ft	Calculated Time, hr	% Relative Error
23.5	606.8	25.194	6.7262
89	4786.8	68.705	29.5380
230.8	10939.2	300.788	23.2683
398.6	12498.2	437.277	8.8450
732.6	14262.2	667.767	9.7125

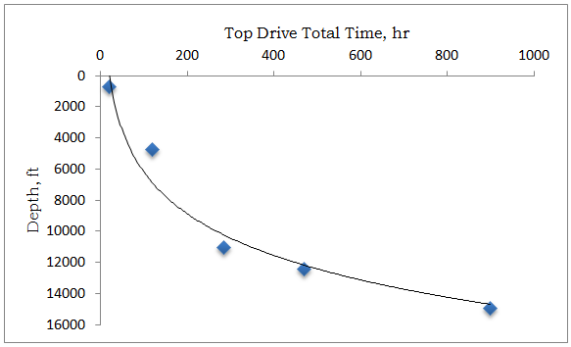

Figure 3.5: Total time versus depth for the top drive system

$$TotalTime = e^{0.000258Depth+3.0} \tag{3.5}$$

Figure 3.6 shows total time versus depth for the kelly drive system at an R^2 value of 97.18 %. Equation (3.6) is the logarithmic relationship between total time and depth for the top drive system obtained from Figure 3.6.

$$TotalTime = e^{0.0002398Depth+3.334} \tag{3.6}$$

Table 7 shows the top drive total actual time, average depth, total calculated time from Equation 3.5, error and absolute error. Average error is -21.06 and standard devation is 45.63. Average absolute error is 0.2031.

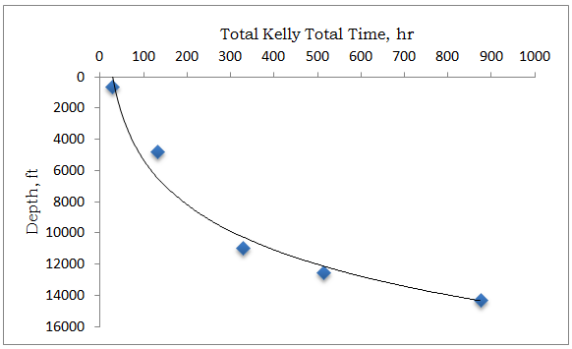

Figure 3.6: Total time versus depth for the kelly drive system

Table 3.6: Top drive system total actual and calculated time

Total Time, hr	Ave. Depth, ft	Calculated Total Time, hr	Error	ABS Error
19.4	675	24.0399	-4.6649	0.2407
117.5	4709	68.1961	49.3038	0.4196
283.6	11020	348.4873	-64.9123	0.2289
468.5	12412	499.4255	-31.0005	0.0661
898.2	14909	952.2209	-54.0543	0.0601

Table 3.7: Kelly drive system total actual and calculated time

Total Time, hr	Ave. Depth, ft	Calculated Total Time, hr	Error	ABS Error
27.8	606.8	32.4406	-4.6406	0.1669
130.7	4786.8	88.3966	42.3033	0.3236
327.7	10939.2	386.5515	-58.8515	0.1795
513.4	12498.2	561.7938	-48.3938	0.0942
874.2	14262.2	857.6351	16.6148	0.0190

Table 8 shows the kelly drive total actual time, average depth, total calculated time from Equation 3.5, error and abslute error. Average error is 10.56 and standard devation is 42.81. Average absolute error is 0.1566.
Correlations were further validated and tested against data obtained from the left out well. Table 9 shows the depth and total of the kelly drive testing well, total calculated time from Equation 3.6, error and absolute error. Average error is 8.92 and standard devotion is 17.23. Average absolute error is 0.3394.
It is evident from the table that correlations provide relatively accurate results compared to actual drilling measurements. Therefore, the correlations developed, with the high R^2 values and low errors, can be used to estimate trip, connection and total times during drilling a well. As the total time for drilling a well becomes known, the entire cost of the drilling process may be estimated. Moreover, the developed correlations assist on deciding which type of drilling system must be implemented, the top drive or kelly system. A rig of a drilling system that achieves the target depth at less time is the preferred choice. However, the daily rental rate of the rig must be taken into consideration. Applying Equation (3.5), to the same depth of 4244 feet and assuming the well had been drilled by the top drive system, yields a total time of 60.47 hours. The smaller value of total time is consistent with the literature [2][5] which clearly demonstrate that top drive rigs can achieve depths faster than the conventional kelly rigs.

Table 3.8: Comparison between validation well and correlations

Total Time, hr	Ave. Depth, ft	Calculated Total Time, hr	Error	ABS Error
18.5	103	28.7487	-10.2487	0.3564
71	2230	47.8790	23.1209	0.4829
91.5	4244	77.6074	13.8925	0.1790

4. Conclusion

On the bases of the current study, the following conclusions can be withdrawn:

1. Correlations that can be used to predict connection time, trip time and total time for both top drive and kelly drive systems were developed at high R^2 values close to 100 %.
2. Correlations were tested against actual drilling data that were intentionally excluded from correlations development process for the purpose of models' verification. The outcome of the testing and verification was encouraging.
3. The accuracy of the developed correlations is within an acceptable the range.
4. Correlations can be used to estimate the total time required for pipe handling (connection and trip times) which is of great significance as it assists in estimating the total cost of drilling a well.
5. Correlations also assist on deciding which type of drilling system must be implemented; the top drive or Kelly drive.

5. Recommendation

A relatively small number of wells were considered in the study. Therefore, it is recommended to expand the current study, by adding new wells, in order to increase the reliability of analysis and outcomes achieved.

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