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RESEARCH PAPER

Study of Torque, Drag and Hydraulics of a Deviated Drilled Well using Drilling Office Software

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Abstract

Rotational drilling was a revolution in drilling technology. It made the drilling process more efficient and faster and more depth of well could be achieved through rotation method. Besides all of its advantages, the rotation approach induced some problems like pipe sticking and downhole cleaning to the drilling procedure. Hole cleaning and reduction of torque and drag seems to be vital in inclined and horizontal ones due to its complexity and inclination. In this manuscript, hydraulic, torque and drag analysis were surveyed to investigate whether the path proposed for a well in the south of Iran is adequate or not. The required information was provided from associated drilling company and the proposed well trajectory used with hydraulic and drag data to run simulations via drilling office software. Effective axial load, Interaction of well and drill string, Comparison of stresses and von Mises graph were reported. Mentioned graphs showed the consistency of drilling project. The sensitivity of pressure drop to the pump flow rate and critical required rate to clean up annulus also reported pressure drop through the drilling system and required flow rate to clean up the bottom hole. In another word, obtained results of drag and hydraulic showed the consistency of trajectory.

Keywords:
Hydraulics,
Torque,
Drag analysis,
Drilling office,
Von Mise graphs

Introduction

From a technical point of view, the most desired path for drilling is a vertical one, but sometimes there is a problem with vertical drilling. Drilling operation in an offshore field is difficult, and it required to spend too much cost. So, branch wells in offshore drilling are much more common. Drilling path in the land could be inclined due to the existence of a road, city, lakes and other similar locations. In some cases, drilling crew opposes to dogleg and pipe sticking problem. In other conditions, they could not free the stuck point, and drilling pipe should be recovered. The remained stuff in the well is cemented and well will be inclined in upper points. Besides all of the mentioned restrictions, sometimes inclined and horizontal drilling is used to

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increase the face of production as an enhanced oil recovery (EOR) method. Horizontal drilling is necessary for steam-assisted-gravity-drainage (SAGD) method as it requires two parallel horizontal wells [1].

Ogunrinde [2] and his coworkers developed a model for optimizing hydraulic for efficient hole cleaning in deviated and horizontal wells. By comparing his model and data fields, he suggested to carry out proper drill string design to have the flow rate required for cleaning inclined and horizontal wells.

Too many researchers have investigated these parameters as determining factors of successfulness of a drilling project. Some of the important ones will be reported. The inclination of well induces some extra parameters and problems to the drilling operations and it requires much more accuracy in mud logging. Pipe sticking and dogleg, instability of formation and irregular pathway are some of the problems in drilling a well that is more probable in inclined ones.

Lian and his coworkers [3] proposed a model to investigate dynamic parameters in horizontal drilling in a gas well. They also did some experiments to validate numerical methods obtained by finite element approach. According to their researches, the change of weight on bit (WOB) is a typical sine curve, and the frequency of WOB increases linearly with rotary speed. Moreover, the frequency of WOB is approximately equal to the rotation frequency of the drill string. According to the similarity principle, the recommended rotary speed range is 37.5 -50 rpm in the horizontal gas drilling of the given well structure.

Zhu and his coworkers [4] designed a new ultra-high torque double-shoulder drill-pipe tool joint for extended reach wells. First, they established a 3D numerical simulation model for this type of joint that is called the XSJ joint. Then, orthogonal optimization was performed on its key structural parameters using the orthogonal optimization method. Finally, the bearing performance and fatigue performance of this tool joint and the API tool joint were calculated and compared using the Simulator Abaqus fe-safe software., the XSJ joint is better, and its tensile strength, torsion strength, bending strength and compression strength increase by 10.65%, 62.5%, 2.75%, and 52%, respectively in comparison with the API tool joint. Related tension-compression fatigue life, bending fatigue life, torsion fatigue life and composite fatigue life increase by 1.19 times, 1.74 times, 550 times and 28.79%, respectively.

Van Puymbroeck [5] surveyed hydro-mechanical hole cleaning devices to increase drilling efficiency. Mentioned devices provide drilling with safer equivalent circulating density margins and reduce time spent on hole cleaning operations. It was reported that hydrocleaning is effective in highly deviated and horizontal wellbores.

Mitchell and his coworkers [6] proposed a novel method of torque and drag predication in a way that includes bending moment and shear forces to the conventional torque/drag one. The model carried just an error of 2% at its maximum.

Mirhaj and his coworkers [7] presented a new robust model that takes the pipe bending stiffness into account despite assuming constant curvature trajectory for the wellbore without using the finite element method (FEM) calculations. According to the proposed model, the effect of shear forces and stiffness for torque and drag calculations is small and using time-consuming FEM is not necessary even for wellbores with high dogleg severity (DLS).

Sun [8] and his coworkers proposed a new model to optimize placement of the friction reducers located on the drill pipe to reduce torque and drag on the drill pipe.

Zhu [9] and his coworkers used ABAQUS FEM Explicit solver package to develop the dynamic FEM model to describe torque and drag of highly deviated wells. They developed the model based on the kinetic energy equation. Some of the assumptions are: the drill string is simplified to homogeneous beam with a circular cross-section, constant rotation at the top, rock is assumed to be anisotropic material, and rock nonlinearity is simulated by Drucker–Prager elastic-plastic model and borehole wall has large rigidity, and its cross section is usually in a circular form.

Besides all of the mentioned attempts, new endeavors have been done to make drilling more intelligent. Automated modern casings enable monitoring of torque and drag through sensors placed on the casing is one of them. Raw data sensed by sensors sent to the acquisition system at the surface and calculate values via high frequency acquired data. Picking-up, slacking-off and rotating off-bottom hook loads could be monitored via mentioned systems, automatically [10].

Simmons [11] proposed a technique to couple several drilling parameters to optimize the rate of penetration and increase drilling efficiency. Factors of Formation Drillability, bit selection, circulating system hydraulics weight on the bit, bit revolutions per Minute, drilling fluid type and properties taken account into the proposed technique.

Torque and drag, as well as hydraulics of drilling, are some of the vital characteristics of directional and horizontal drilling projects. Drag is measured as the difference between the static weight of the drill string and the tripping weight. A difference between the torque applied to the rig floor and the torque available at the bit occurs owing to friction [12].

Johancsik [13] and his coworkers proposed a new model to predict the torque and drag of directional drilling. Related data were gathered using novel torque and hook load indicators that were portable. Sliding friction is calculated by multiplying the sidewall contact force by a friction coefficient, considered to be the main cause of torque and drag.

To reduce torque and drag in the penetration of a smooth and straight well, new technology has been proposed that is based on a reduction of friction factor. The mentioned technology consists of extended-gauge bit design with a matched steerable motor system [14].

Gaynor [15] and his coworker compared the effects of large-scale tortuosity and micro ones by studying more than 100 wells drilled conventionally and over 20 wells drilled by slick bore drilling system. They concluded that wells without spiral are of lower torque and drag. Besides, their data indicates that the spiral is caused mainly by using short gauge bits.

Another important case that should be cared is to use proper hydraulic power and mud with suitable characteristics like viscosity, yield strength, and density to clean up the bottom hole successfully. Providing such a performance make well more stable and could obstacle pipe sticking. Various models have been proposed to determine slip velocity of cuttings to verify whether hydraulic of the system is sufficient to recover the cuttings or not. Larsen's model is one of the proposed methods that are responsible for determining the critical flow rate for cleaning up inclined wells with 55-90 degree. Larsen method is showed following [16,17]:

$$V_{min} = V_{cut} + V_{slip} \tag{1}$$

$$V_{cut} = \frac{ROP}{36(1 - \left(\frac{D_{pipe}}{D_{hole}}\right)^2)(0.64 + \frac{18.16}{ROP})} \tag{2}$$

Slip velocity could as expressed as:

$$V_{slip} = 0.00516\mu_a + 3.006 \qquad \mu_a < 53cp \tag{3}$$

$$V_{slip} = 0.002554(\mu_a - 53) + 3.82 \qquad \mu_a < 53cp \tag{4}$$

Based on mud density, cutting size and well angle three correction factor multiplied by the calculated slip velocities:

$$C_{mw} = 1 - 0.0333(\rho_m - 8.7) \qquad \rho_m > 8.7 \tag{5}$$

$$C_{mw} = 1 \qquad \rho_m < 8.7 \tag{6}$$

The angle of the inclination correction factor is:

$$C_{ang} = 0.034\theta - 0.000233\theta^2 - 0.213 \quad (7)$$

And cutting average size correction factor is expressed as:

$$C_{size} = -1.0D_{50\ cut}4 + 1.286 \quad (8)$$

Finally, slip velocity is given by:

$$V_{slip} = V_{uncor}.C_{mw}.C_{ang}.C_{size} \quad (9)$$

In contrast to Larsen's model, Moore's method is just able to predict slip velocity of cuttings in vertical wells. Eq. 10 express Moore related formula [6].

$$V_{sl} = 1.89\sqrt{\left(\frac{d_s}{f}\right).\left(\frac{\rho_s - \rho_f}{\rho_f}\right)} \quad (10)$$

Ahmed and Takach [18] experimented the sweep efficiency of fiber sweep by comparing sweep efficiency of fiber sweep (0.47% Xanthan Gum and 0.04% synthetic fiber) and the base fluid (0.47% Xanthan Gum). They concluded that fiber-containing sweeps cleaning efficiency is better than the base fluid. Besides, they reported that the addition of fiber to the sweep fluid reduces pressure loss under turbulent flow conditions.

Wang and Salehi [19] determined an optimal network model and input parameter impact on the proposed model to optimize drilling hydraulics. Afterward, they used 180-200 data points from the field data for the simulation that was selected from 3 wells. Results demonstrated that the proposed model has predicted accurate pump pressure and matched concisely with the field data.

Meng and his coworkers [20]. proposed a new model to optimize drilling hydraulics based on drilling data of several wells in the Tarim basin in China. They used an iterative method to calculate bit specific hydraulics horsepower and pressure loss under each flow rate to obtain the flow rate. Also, the rate of penetration was taken into accounts. Finally, they established a new systematic drilling hydraulics optimization that is applicable for all of the common rheological methods like power law and plastic Bingham model.

As mentioned in the literature, in some cases, researchers tried to propose novel models to predict the drag and torque of the drill pipe to choose the most proper design of the trajectory path of drilling. Besides, some are engaged with designing new patterns and devices to provide more strength on drill pipe during the performance. In this study, we will investigate the proposed pathway of an inclined well in south pars with drilling office software. Torque and drag parameters will be taken in to account beside of hydraulic parameters. In this manuscript, we will survey a drilling trajectory path in a gas field in the south of Iran, based on torque, drag and hydraulic system by drilling office software.

Process and Software

Common considerations to design well trajectory

Before starting a discussion about the characteristics of the gas field and input data of the well, we will discuss the logic of choosing such a curved trajectory for drilling. The most important consideration in designing a pathway for a trajectory well is practicality. Regardless of considering such a critical aspect, every drilling operation will suffer a high amount of cost or even may fail. For example, the angle of an inclined well should not be high in the primary steps of penetration due to the low flexibility of dense primary casing. Another consideration is to avoid drilling in a sliding manner for a long time in the formations that probability of pipe sticking is high. Absolutely, after each pack of sections drilling with slide, penetration must continue normally with rotation from above.

From an economic point of view, a designer should try to use low-cost casings in the well. Besides, the trajectory should be designed with casing or another type of completion tube must be of lower length. Drilling depth must be in its shortest possible way. Wellhead location and the target point in the reservoir is predetermined, but it is an art of a drilling supervisor to drill in the most economical approach.

Also, there are common considerations to design well trajectory of oil and gas well, but there is not unique process to design for each of the trajectories, and each well path has its specified well design. There are some restrictions related to the wellhead location and geology of under-surveyed gas field.

There are a lot of wells located in the region and they are all starting from a jacket, so the density of the wells in the field is too high. Besides, the soft bed of the sea makes setting the conductive casing more difficult. So, it is reasonable to drill the first 200 meters of the well vertically. From the end of the vertical section, directional drilling begins and it continues to approximately 10-30 meters on the top of the Jahrom formation. Drilling in Jahrom formation is of many difficulties due to the mud lost in the formation. Drilling opposes the full loss of mud and it makes difficulties in the driving casing and pipe sticking will be more probable. So, penetration should be straight with the constant angle and with rotation from the surface to avoid pipe sticking. It continues to 10-30 meters below the Ilam formation. The new section starts from the end of the last hold section to the upper 100 meters of Hith formation. Final directional drilling happens in this section. Details of well section information and torque and drag input data of drilling are reported in Tables S1 and S2 in the supplementary information, respectively.

Results and Discussions

First of all, we should enter the data of field, jacket, well, borehole and target point. Besides, bottom hole assembling, bit size, casing, and other data should be entered into the software.

Analysis of torque and drag

Torque and drag analysis of holes surveyed with Torque and Drag module of drilling office. Effective axial load, sinusoidal buckling limit, and helical buckling limit parameters are sketched with respect to depth via software.

Types of stresses on drill string are shown in Fig. 1 The effective axial load is shown by the red line. The drill string is in tension when the mentioned line is in positive half, and it is in compression wherever located in negative half. It is important to put the drill string in tension to avoid buckling in the sting that is probable in compressed strings. Beside of red line, there are two other lines that are the indication of the sinusoidal and helical limit of buckling. As the weight on the bit is increased, compressive loads are induced into the collars, with the highest compressive load just above the bit and decreasing to zero at the neutral point. By increasing the weight, the drill collars or drill pipe buckles and contacts the wall of the hole. Increment of the well causes the string to buckles second time and contacts the borehole at two points. With still further increased the weight on the bit, the third and higher order of buckling occurs [21]. Sinusoidal and helical ones are referred to those buckling that their shapes resemble sinus function and helix respectively. The drilling tube buckles initially with a sinusoidal form. In the post-buckling state, the shape of the tube alters to be helical one [22]. From the point of view of the figure, buckling occurs certainly if the red stress line locates below two bucking limits.

In proposed well design, all of the drill string unless its bottom section is in tension and it is the reason why authors think that the proposed design is proper. It is unavoidable to put bottom hole assembling (BHA) in tension like other sections due to the weight of several hundreds of feet drill pipes over it.

Fig. 2 is a graph to indicate the interaction of well and drill string in 23 ½ holes. It could be deduced that most of the interactions between well and drill string are between 1000-1200 ft of drill depth. Fig. 3 is a graph of various yield stresses and von Mise graph. Yield stresses are defined by characteristics of the alloy used to manufacture the drill pipes. Von Mise line indicates the combination of axial, buckling and twist stresses on the drill string. To avoid collapsing of the drill string, it is vital to avoid von Mise line to reach over the yield strength. It is clear that von Mise line is far below the stress lines and it is another evidence for validation of the proposed design. Effective axial load, the interaction of well and drill string, and Comparison of stresses and von Mises graph with a measured depth of 16, 12 ¼, and 8 ½-inch holes are shown in Figs. S1-S9, respectively. Besides, single point of torque and drag analysis are reported in Table S3.

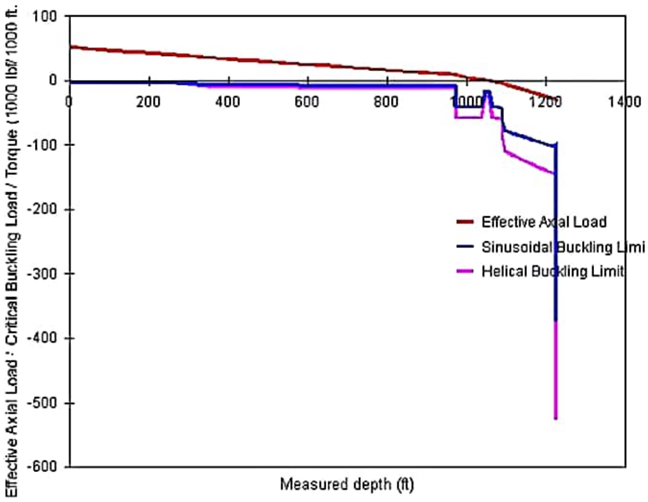

Fig. 1. Effective axial load in 23 ½ hole.

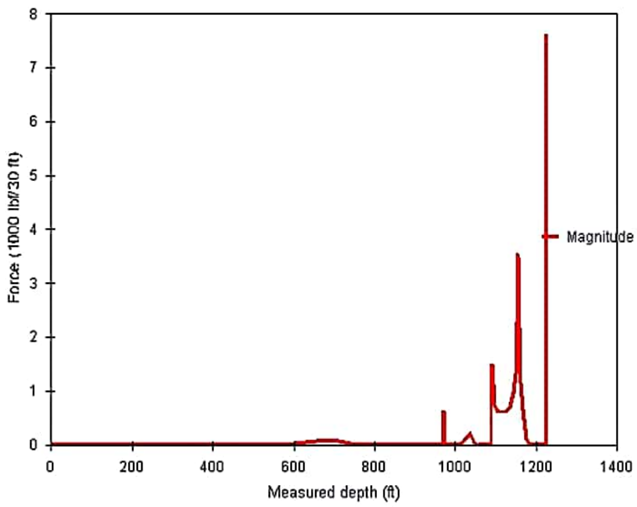

Fig. 2. Interaction of well and drill string in 23 ½ hole.

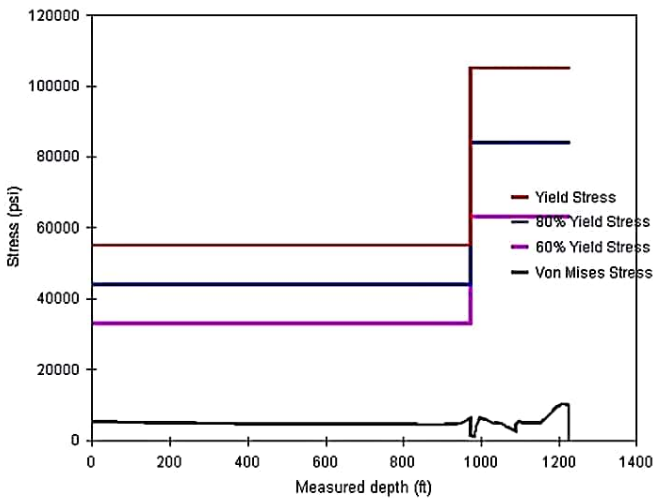

Fig. 3. Comparison of stresses and von Mises graph with measured depth in 23 ½.

Analysis of hydraulics of drilling

To investigate the hydraulic of drilling mud in drill pipes, bits, and casing, we could use the hydraulics module of drilling office. It was mentioned that flow rate, the velocity of mud and jet impact force of on the bits affect downhole cleaning, previously. To plan a proper road map and avoid well sticking, it is important to consider bit balling effect. It happens when the mud weight, viscosity, and flow rates are not sufficient to displace the cuttings. All of the data required to simulate hydraulics of drilling could be found in Table 1.

Table 1. Hydraulic input data and mud properties in each hole.

Input data	Hole size (in)			
	23 ½	**16**	**12 ¼**	**8 ½**
MW (lbm/gal)	8.7	9.4	11.6	11.5
Plastic viscosity (cp)	1	18	20	20
Yield point(lbf/ft^2)	22	24	22	22
Pump Flow rate (gal/min)	1100	900	750	550
Min-Max Flow (sensitivity)	700-1200	700-1200	400-800	300-700
Rate of penetration (ft/hr)	27	22	24	18
Cutting density (gr/cc)	2.71	2.68	2.83	2.7
Average diameter of cutting (in)	0.1	0.1	0.1	0.1
Max pump Pressure(psi)	4000	4000	4000	4000
Nozzles	3-18 (1/32") 3-22 (1/32")	3-14 (1/32") 3-18 (1/32")	3-16 (1/32") 3-18 (1/32")	3-15 (1/32") 6-12 (1/32")
Surface equipment	Type 3	Type 3	Type 3	Type 3
Air gap Water depth Sea water density	98.4 ft 203.4 ft 8.8 lbm/gal	98.4 ft 203.4 ft 8.8 lbm/gal	98.4 ft 203.4 ft 8.8 lbm/gal	98.4 ft 203.4 ft 8.8 lbm/gal
Rheology	Power low PV-YP	Power low PV-YP	Power low PV-YP	Power low PV-YP

1100 gal/min considered to be the proper flow rate of drilling mud n 23 ½-hole. In a similar way, the proper flow rate for 16, 12 ¼ and 8-holes was chosen to be 900, 750 and 550 gal/min respectively. Besides, count and size of bit nozzles were chosen in a way providing the appropriate performance to downhole well cleaning. Three 18 and three 22 nozzles were suggested for 23 ½-hole. According to the drilling office software pressure drop related to the bit, surface and total pressure drop are 280 and 23 and 347 psia respectively. Besides, the jet impact force on the drill bit was calculated 941 lb. Fig. 4 shows the sensitivity analysis the minimum flow rate required to clean up the well. It is clear that the increment of the penetration rate increases the required flow rate. Fig. 5 is a report of pressure drop versus pump flow rate in 23 ½ inch hole.

Volumetric hydraulic data and pressure drop in different sections of holes are reported in Table 2 and 3**,** respectively. Critical transport rate at different holes is reported in Table 4. More efficiency will be obtained by an increment of a fraction of total pressure drop in the drill bit. So according to results in Table 3, 23 ½, and 16 are of more efficiency due to more pressure drop fraction in the drill bit. It is common to use equipment that reduces the pressure drop in the path before the bit. The sensitivity of pressure drop to the pump flow rate in standpipe and surface equipment and Relationship between critically required rates to clean up annulus versus the rate of penetration 16, 12 ¼, and 8 ½-inch hole are reported in Figs. S10-S15. Besides, corresponded hydraulic results of circulation system are shown in Tables S4-S6.

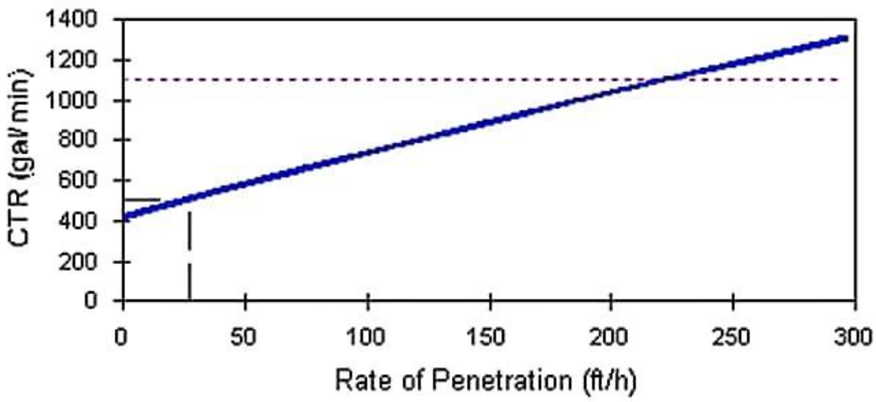

Fig. 4. The relationship between critical required rate to clean up annulus versus the rate of penetration in 23 ½.

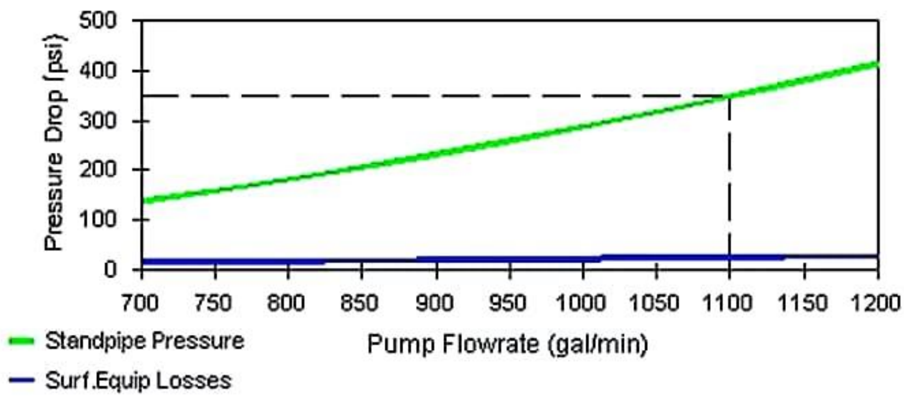

Fig. 5. The sensitiveness of pressure drop to the pump flow rate in standpipe and surface equipment in 23 ½.

Table 2. Volumetric hydraulic results in 23 ½ hole.

	Volume (bbl)	**Time (mins)**	**strokes**
Full circulation	630.80	24.09	51.28
Inside drill string	16.91	0.65	138
Annulus [bit to sea floor]	613.89	23.44	4991
Bit to shoe	317.58	12.13	2582
Shoe to seafloor	296.32	11.31	2409

Table 3. Pressure drops in different sections in each hole.

Hole/pressure drop	Surface equipment (psi)	Drill string (psi)	annulus (psi)	Bit (psi)	Internal TJ (psi)	External TJ (psi)	Imbalance (psi)	Total pressure drop(psi)
23 ½	23	84	3	280	0	0	-43	347
16	37	362	27	490	9	0	0	926
12 ¼	103	2142	78	337	59	2	0	2721
8 ½	62	1381	545	231	37	65	0	2321

Table 4. Critical transport rate at different holes

Properties/Holes	Rate of penetration (ft/hr)	Pump rate (gal/min)	Critical transport rate (gal/min)
23 ½	27	1100	508
16	22	1100	508
12 ¼	24	750	331
8 ½	18	550	276

Conclusions

In this manuscript, torque, drag and hydraulic data of drilled well in the south of Iran were surveyed to investigate torque and drag as well as hydraulics of drilling. Both hydraulic data and torque and drag data was used to determine the risks to study whether pipe sticking is probable or not. Comparison of stresses and von Mises graph in all of the holes showed the consistency of proposed well trajectory besides of selection of pump flow rate. The final result of the survey was the existence of risks to the pipe sticking to be at its minimum value, and well stability was considered to be reliable.

Nomenclature

V_{sl}	Minimum velocity for cuttings transport (ft/s)
V_{sl}	Cuttings slip velocity (ft/s)
V_{cut}	Cuttings velocity (ft/s)
V_{slip}	Cuttings slip velocity (ft/s)
ROP	Rate of penetration (ft/hr)
D_{pipe}	Pipe diameter (in)
D_{hole}	Hole diameter (in)
θ	Well inclination (degree)
$D_{50\ cut}$	Diameter at which 50% of the sample's mass is comprised of particles with a diameter less than this value.
d_s	Cutting average diameter
f	Friction factor
ρ_s	Cuttings density (ppg)
ρ_f	Drilling fluid density (ppg)
ρ_m	Mud density (ppg)
μ_a	Apparent viscosity(cp)
C_{mw}	Larsen's correction factor for mud weight
C_{ang}	Larsen's correction factor for hole inclination
C_{size}	Larsen's correction factor for average cuttings size
PDC	Polycrystalline diamond compact
MW	Mud weight (lbm/gal)

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