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IMPROVED AXIAL FORCE TRANSFER BY ENHANCED LUBRICITY OF DRILLING FLUIDS

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ABSTRACT

The paper highlights a challenge faced by the drilling industry which is striving to go deep in order to extract beyond the unadventurous oil and gas resources. Besides other problems, one of the prominent and most frequently confronted problems in doing so is the buckling of the drillstring or coiled tubing due to increased length corresponding to the drilling depth. The factor mainly responsible for this buckling is understood to be the friction between the drillstring/coiled tubing (CT) and the wellbore that proliferate due to enormous surface area of contact. Drilling fluids serves the function of providing effective lubrication between the drillstring/coiled tubing but eventually fails to maintain its performance due to changing deep wellbore conditions. Besides overviewing the problem and its causes, the paper explains the development of an experimental setup that enabled to imitate the drilling process and study the effect of changing the drilling fluid on buckling behavior. The presented results, highlights the significance of changing the drilling fluid rheology, mainly the friction coefficient, to reduce the friction between the wellbore and the tubing, and thus improve axial force transfer which is mainly responsible for initiation of buckling and limited reach of drilling operation. The buckling patterns and force transfers were recorded corresponding to drilling fluids having different friction coefficients. Drilling fluids with lower friction coefficients significantly reduced the friction that appeared in the form of improved axial force transfers from top to bottom. The procedure for preparing different drilling fluids recipes and measurement of friction coefficient as per API standards is also discussed.

Keywords: Drilling, Coiled Tubing, Buckling, Friction

INTRODUCTION

Regardless of rigorous exploration efforts, most petroleum basins worldwide, are approaching or have already reached maturity. The oil industry is facing the challenges of reduced margins with respect to optimization of mature field and development of marginal discoveries. In this context conventional approaches are reaching their limits and a step change is required. In many ways, drilling with Coiled-Tubing Drilling (CTD) implies a radical departure from established practices and is therefore an ideal starting point for rethinking from scratch the process of building a well with due consideration of maintaining hydrocarbon supplies with minimum consequences (Kumar et al., 2011). Coiled tubing has abundant applications in well technology. Coiled tubing has been found useful for logging, well clean outs, well stimulation, gas lift and cementing. Encouraging attempts at drilling with coiled tubing have recently been carried out (Ramos AB et al., 1992).

Though having proven track record of economically viable drilling operations, the coiled tubing (CT) is mainly challenged by the buckling problem that occurs as a consequence of it being a long slender member unlike conventional drill-strings. When the axial compression force reaches a critical value, the coiled tubing will buckle. At first coiled tubing will buckle into a sinusoidal wave shape that will ultimately deform into a helix as the compression force increases further. Confined to the wellbore, the helically buckled coiled tubing will be forced against the wall of wellbore and additional wall contacting forces (WCFs) developed. The force needed to push coiled tubing into well increases dramatically once the coiled tubing is forced into a helix. The frictional drag developed as coiled tubing is forced against the hole or casing wall will ultimately overcome the pushing forces (Chai H., 1998). This phenomenon is called lock-up beyond which the drilling cannot be proceeded further and there is zero force transfer down-hole i.e. zero weight on bit (WOB). Thus the problem of high torque and drag and friction poses a major challenge to extended reach drilling operations (Abdo et. al., 2010 and Abdo & Danish, 2012) and clear understanding of the laterally constrained buckling phenomena and the co-relation amongst some crucial forces like top load, wall contact forces and weight on bit is essential.

Considering the importance of the subject matter, buckling behavior of pipes/tubes/shells and other structures has long been investigated by many researchers (Lubinski A., 1950, Wu J., 2004, Huang and Li, 2010, Chen Y. et al., 1990). Several models (He and Kyllingstad, 2003, Mitchell R. 1998, Lubinski A. 1962) have been proposed for prediction of forces causing helical shape (the so-called helical buckling) of pipes in vertical and curved wells. However, there is no agreement on which models should be used for better predictions.

The paper presents brief insight of the buckling problem of coiled tubing, its causes and consequences on the drilling operation. The dependence of the buckling on friction between the well bore and coiled tubing is discussed. The paper also presents a solution to mitigate friction for minimizing the buckling, and this was done by developing an experimental setup to test drilling fluids with various friction factors enabling to reduce friction and studying the corresponding buckling phenomena. Axial force transfer were recorded by using the developed setup and it was found that fluids with lower friction coefficients gave better axial force transfers thus confirming it as a solution to reduce buckling in addition to providing a way to visualize what's happening down hole. The drilling fluids were prepared and tested by using standard API procedures to make sure that they sustain well in all of their rheological characteristics.

DEPENDENCE OF BUCKLING ON FRICTION:

The relationship between the friction between the tubing and wellbore has long been a subject of interest for many researchers. As described earlier that friction is mainly responsible for buckling of tubing which in turn generates additional wall contact forces (WCF) that could ultimately lead to a complete lock-up situation. It is thus crucial to have detailed insight upon the inter-dependence between friction, buckling and wall contact forces. Mathematically due to a lot of complex variables involved, none of the models precisely address the problem. In this paper a simple approach to test the dependence of buckling on friction is tested and improved drilling fluids are used as a solution to minimize friction and hence buckling. Mitchell (Mitchell, 1998) presented the following relation for wall contact force (N) between the CT and the wellbore. To Date this model is considered to be one of the most accurate models reported in literature.

$$N = EIr\,[4\theta'\theta''' + 3(\theta'')^2 - (\theta')^4] + F(\theta')^2 + w\sin\alpha\cos\theta \qquad (1)$$

However the complex nature of the problem makes it difficult to precisely predict the behavior under various external conditions like tripping in and out, rotation and/or reciprocating or both together. The friction factor μ_θ as reported by Samuel (Samuel, 2010) is a function of coefficient of friction (μ) between the materials, lubricity coefficient of mud (L), pipe sticking coefficient (S), pipe rotational speed (N), temperature (t), well path profile which includes the curvature and borehole torsion (τ) and other uncertainties.

$$\mu_\theta = f(\mu, L, S, N, t, \tau) \tag{2}$$

The involvement of so many complex variables have always been a challenge in accurately modeling the problem and hence experimental approaches and field case trials gained popularity as being precise is vital on field. This paper presents the development of an experimental setup to investigate this problem and study the buckling behavior under varying conditions.

DEVELOPMENT OF EXPERIMENTAL SETUP:

There are four stainless steel (class-C) pipes that and are placed vertically with another four steel pipes inside them as shown in figure 1. This allows easy adjustment of the length.

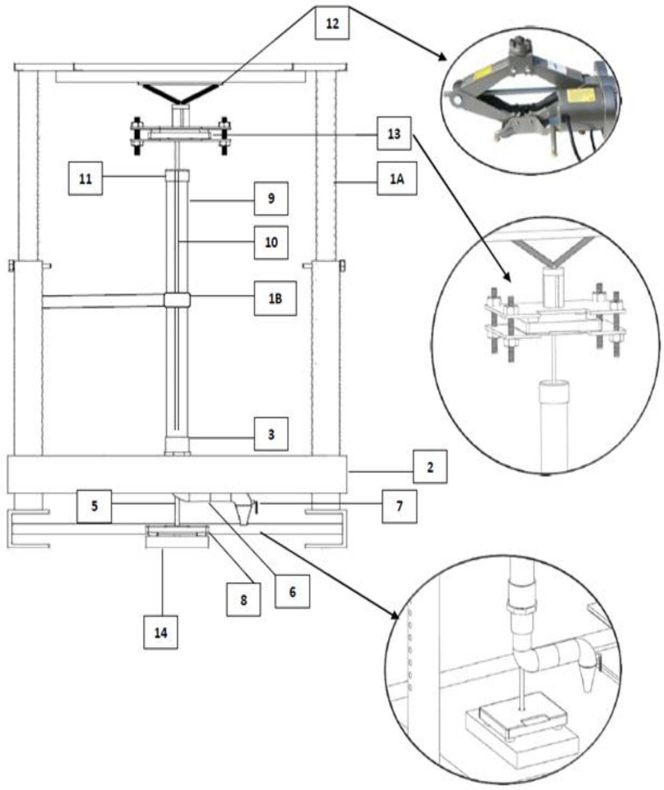

Figure 1: Configuration of the experimental setup

1A	Four base rods	5	The bottom rod	10	CT Specimen
1B	Clamp	6	90^0 elbow connector	11	HPVC cap
2	Main plate	7	Drain valve	12	Car Jack
3	HPVC Adapter	8	Bottom load cell	13	Upper load cell
4	Aluminum Circular	9	Pyrex glass tube	14	Vibration shaker

Table 1: Major components forming the experimental setup

The maximum length of the specimen (representing the CT) that can be tested is 2.5 meters. The weight of these sets is enough for stability of the structure. One of the four pipes is welded to a clamp (1B) which holds the Plexiglas tube (representing the wellbore). There are load cells placed at the top and bottom to measure the load applied from the top (top load) and the corresponding force transferred to the bottom (Bottom Load). A compressive force ranging from 0-1000N was applied from the top to buckling the tube and the corresponding bottom forces were recorded. A complete drainage system is provided that allows filling and draining the drilling fluid on purpose. The setup closely imitates the drilling process and the buckling phenomena in presence of a surrounding drilling fluid.

RESULTS AND DISCUSSION:

The developed experimental setup was used to test a rube demonstrating the buckling phenomena that is occurring down-hole in coiled tubing (CT) drilling operations. The setup is used to study various buckling patterns and the effect of increasing the top load on the axial force transfer was recorded. The top load was increased gradually from 0N to 1000N and the bottom loads were observed. Increasing the top load resulted in proportional reduction in axial force transfer as shown in table 2 and figure 11. The specifications of the test specimen used are as follows:

Material of tested tube: Steel tube A5388 (B)

Outer diameter: 6.35 mm

Inner diameter: 5.34 mm

Moment of inertia: 9.63 x 10^{-3} m^4

Length of the tube: 1.524 m

Without drilling Fluid:

The tube was subjected to a compressive from that gradually increased from 0-1000N without the presence of any drilling fluid.

Top Load (F_t) **N**	**Bottom Load (F_b)** **N**	**Difference (ΔF)** **N**
0	0	0
100	80	20
200	130	70
300	190	110
400	270	130
500	320	180
600	370	230
700	430	270
800	470	330
900	510	390
1000	560	440

Table 2: Reduction in axial force transfer (w/o drilling fluid)

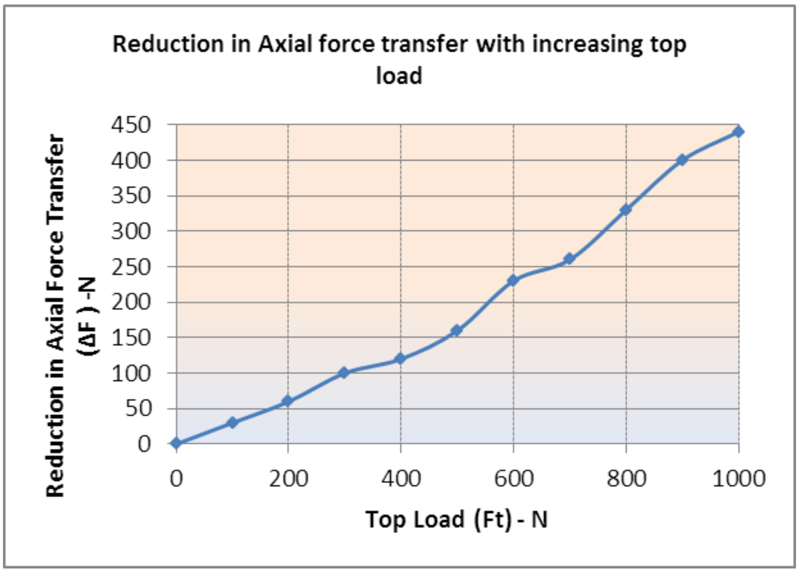

Figure 2: Reduction in Axial Force Transfer (w/o drilling fluid)

It is clearly discernible from the results presented in table 2/Figure 2 that there is huge reduction in axial force transfer with increasing top loads. This is caused by the buckling that developed huge wall contact forces at the interface.

With drilling Fluid:

1. Preparations of drilling fluid samples

Three drilling fluids with different friction coefficients are reported here. The three samples reported here are named as S1, S2 and S3 and the composition of the samples are recorded in table 1.

2. Measurement of friction coefficients:
The drilling fluid samples (S1-S3) were processed by using dynamic filtration equipment to prepare a thin mud cake. The mud cakes were then tested by using the mud cake adhesion factor meter to record the friction coefficients. The friction coefficients recorded are shown in table 3 below:

Sample	Composition	Friction coefficient
S1	500 ml water + 30 gm Bentonite	0.1405
S2	500 ml water + 15 gm Bentonite and 15 gm Barite	0.2308
S3	500 ml water + 30 gm Barite	0.3057

Table 3: Friction coefficient for sample S1-S3

3. Investigation of Axial Force Transfer:

Sample 1 (S1)			Sample 2 (S2)			Sample 3 (S3)		
F_t	F_b	ΔF_1	F_t	F_b	ΔF_2	F_t	F_b	ΔF_3
0	0	0	0	0	0	0	0	0
100	85	15	100	80	20	100	75	25
200	145	55	200	125	75	200	115	85
300	200	100	300	180	120	300	170	130
400	255	145	400	220	180	400	190	210
500	310	190	500	280	220	500	235	265

Table 4: Reduction in Axial force transfer (ΔF) for samples S1-S3

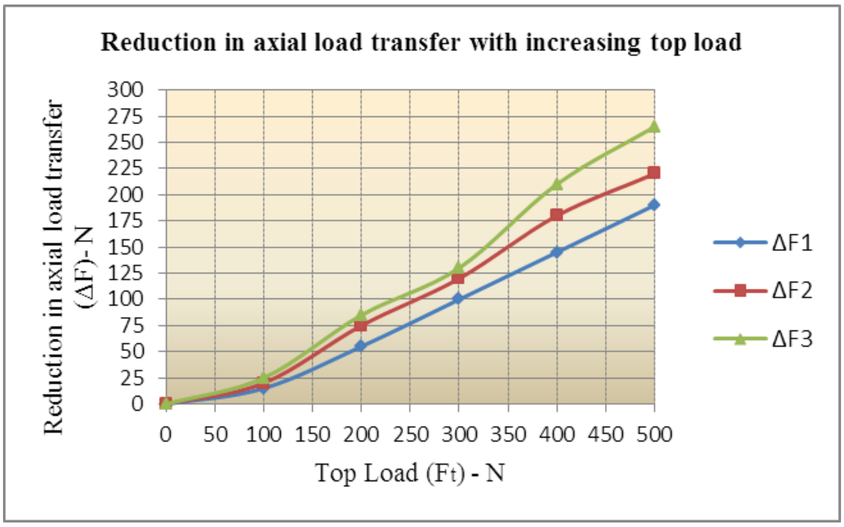

Figure 3: Reduction in Axial force transfer (ΔF) for samples S1-S3

The results in table 4/figure 3 show clearly that sample S1 with lowest friction factor has minimum reduction in axial force transfer i.e. improved force transfer. The worst force transfer was observed with sample S3 which possess the highest friction factor. Thus it is concluded that by altering the friction factor the friction between the CT and wellbore can be reduced considerably while improving the axial force transfer.

The results when compared with the testes carried out without drilling fluids showed that there is a remarkable impact of drilling fluid lubricity on the buckling behavior of tubing.

CONCLUSION:

The paper presented a brief overview of the problem of buckling of coiled tubing which is a modern technology for cost effective drilling. Due to complexity in mathematical modeling experimental methods and field case trails though expensive but is gaining more popularity due to enormous commercial benefits anticipated. The paper discussed the development of an experimental setup to imitate buckling phenomena and study the correlation between crucial parameters like friction, wall contact forces, axial force transfer and their effect on buckling behavior. Buckling experiments were carried out with and without drilling fluids and showed remarkable improvement in axial force transfer with fluids having lower friction coefficients. It is thus obvious that improving drilling fluids in their lubricity characteristics could be used as a solution to reduce buckling and improving force transfer in order to satisfy the quest for deep drilling.

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