Tribology International 82 (2015) 493–503

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Effects of tribological properties of water-based drilling fluids on buckling and lock-up length of coiled tubing in drilling operations

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ARTICLE INFO

Article history:
Received 27 September 2013
Received in revised form
23 December 2013
Accepted 6 January 2014
Available online 12 February 2014

Keywords:
Water-based drilling fluids
Lubricants
Coiled tubing buckling and lock-up conditions
Lubricity index

ABSTRACT

This study evaluates the performance of three lubricants on reducing friction between wellbore and coiled tubing (CT) and hence improving axial force transfer, reducing buckling, and enhances the limited reach of CT. The lubricants were evaluated using water-based drilling fluids composed of lubricants of different concentrations. Experiments were conducted in a lubricity tester and by using an in-house experimental setup that imitates the wellbore being drilled in the presence of drilling fluids. Results showed that reducing *COF* does not change CT buckling shape or mode, but it alters the initiation and transition between buckling modes and increases lock-up length. Effects of increasing lubricants percentages on mud properties were also examined. They showed positive impact compared to tests conducted without lubricants.

1. Introduction and background

The growing concerns about maintaining the future adequacy of oil and gas resources driving the industry to explore new areas that are often challenging arises because of the changes in operational depth, the increased length of horizontal drilling to improve production, the nature of subsurface geo-hazards with deeper drilling, the complexity of drilling operations, and the shape of wellbore profiles or number of laterals from a mother-bore to maximize reservoir contact [1–4]. Some of these challenges include the formation damage, high torque and drag, lost circulation, thermal instability, pipe sticking, poor hole cleaning, and erosion. Due to these reasons it is essential for the oil and gas industry to develop more efficient, economical and environmentally friendly technologies for improved oil and gas recovery.

In conventional drilling, the drillstring which is flexible comes in contact with the borehole and the frictional resistance produced may require some more torque to rotate the drillstring. Also, there is a lot of frictional resistance that occurs when the drillstring is pulled or lowered in the borehole. This frictional resistance is known as drag. In situations like these, high torque and drag can lead to loss of power [5]. On the other hand, in coiled tubing drilling when the axial compression forces are applied on coiled tubing, the coiled tubing will buckle. The coiled tubing will first buckle into a sinusoidal wave shape. As the compression force increases further, it will ultimately deform into a helix [6]. 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 [7]. 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 friction poses a major challenge to extended reach drilling operations [8,9] 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.

The competence of the drilling process greatly depends on the performance of the drilling fluid and lubricants that is anticipated to perform definite tasks without which the drilling cannot progress. Incompetence in executing any of these tasks may lead to serious drilling problems like lost circulation, high torque and drag, differential and mechanical pipe sticking, formation damage and instability in rheological properties of the drilling fluid due to changing temperature, pressure (HTHP) and versatile types of formations [10–13]. These functions are purely dependent on the rheological properties of the drilling fluids mainly the viscosity,

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http://dx.doi.org/10.1016/j.triboint.2014.01.028
0301-679X

density, gel strength and lubricity. The drilling fluids act as an interfacial film between the borehole and drillstring [8,11]. The film between the drillstring and borehole reduces friction. However, the drilling fluid does not provide enough lubricity to decrease friction to an acceptable degree, so lubricants are utilized for increased and efficient drilling rates.

Lubricants are materials used to reduce the friction arising from moving parts. They can either be in the form of liquids or solids. The solid lubricants work like ball bearings and interfere with the surfaces but they do not bond to the surface. Because the solid lubricants do not bond to the contact surfaces, the performance of the lubricant is not dependent on the type of mud. Liquid lubricants are different in the mode of operation because they form a thick film that masks surface roughness and withstands high compressional forces. Their performance depends on their concentration in the drilling mud because they are in competition with other surface active materials.

The performance of oil-based mud as drilling fluids has been proved to improve mud lubricity and generally produces lower friction and torque values than the water-based drilling fluids, however, it is severely limited because of high cost and environmental concerns [14–16]. Some of the desirable properties of drilling fluid additives are non-toxicity, biodegradability and non-formation of an oily slick on water. For these reasons water-based mud is considered as the major drilling fluid but with the addition of additives in order to have the same effectiveness as oil-based mud.

The friction between the tubing and wellbore has long been a subject of interest for many researchers. Friction affects the 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 interdependence between friction, buckling and wall contact forces. Mathematically due to a lot of complex variables involved, none of the models precisely address the problem. Samuel [5] and Mitchell [17] investigated the wall contact force between the CT and the wellbore. They reported that the friction factor is mainly responsible for the buckling of the CT and the lock-up depth. They determine that the friction function is a function of coefficient of friction between the materials, lubricity coefficient of mud, pipe sticking coefficient, pipe rotational speed, temperature, well path profile and other uncertainties.

Due to the complexity of the drilling operations mathematical or numerical techniques are not yet well established to address the broad range of situations and factors influencing the process. The experimental approach is expected to be the most promising to get the best insight interactions between friction, CT buckling and CT lock-up length. Thus, this paper presents the detailed design and construction of an experimental setup of a constrained tube in presence of a surrounding drilling fluid. The goal is to investigate the effects of tailoring the properties of drilling fluids, mainly altering the friction coefficient, with the addition of different types of lubricants on the buckling behavior and lock-up length of the CT.

2. Experimental details

2.1. Material

2.1.1. Water based drilling fluids

In the light of aforesaid functional requirements of drilling fluids, it is thus a topic of greatest interest to develop tailored made drilling fluids that could be able to perform the job and maintain their functionality over a wide range of variables like temperature, pressure, types of formations and drilling environments. The viscosity, yield point, gel strength, density, shear thinning, spurt lost, fluid lost, and Lubricity index are the key factors that determine the functional specifications of the drilling fluids with the obvious inference of the fact that they should remain constant over a wide range of operating conditions [8,11,18].

In this study, water-based lignosulfonate mud is chosen as our base drilling fluid. It is one of the most common and the cheapest water-based drilling fluids. In addition, lignosulfonate water based mud lubricity is inadequate which makes it not strong enough to tolerate high torque. Moreover, it contains ferrochrome lignosulfonate for viscosity and gel strength control. The water-based lignosulfonate mud is resistant to most types of drilling contamination because of the thinning efficiency of the lignosulfonate in the presence of large amounts of salt and extreme hardness. Therefore, the water based lignosulfonate is considered as our base mud and different lubricants are added to determine the highest lubricant performances.

2.1.2. Drilling fluids lubricants

Normally, oil-based drilling fluids produce lower friction and lower torque values than the water-based drilling fluids while drilling the well. However, the use of oil-based drilling fluids is very limited due to high costs and environmental concerns. Under these circumstances the water-based drilling fluids with the addition of lubricants are considered the best alternative. The addition of lubricants helps to improve the lubricity of the drilling fluid which in turn leads to lower friction. In order to find the best performance on reducing the coefficient of friction studies were made with water-based drilling fluids and different lubricants, using different experimental approaches. Published lubricity test results showed that most of the lubricants significantly reduce the coefficient of friction of the drilling fluids. Some lubricants are less effective in polymer-based drilling fluids than clay-based drilling fluids.

The selection of the proper lubricants used in the drilling fluid is an essential decision that ultimately decides the success of the drilling operation. In this study, three different types of commercial chemical lubricants; highly purified polyamide; triglyceride and vegetable oil based; fatty acid and glyceride based are selected and used in water-based lignosulfonate. Their effects on reducing *COF* and in turn their influences on CT buckling behavior and lock-up length are investigated.

2.2. Samples preparations

The formulations were prepared using water-based drilling fluids composed of water-based lignosulfonate mud and three types of lubricants with concentrations 1%, 2% and 3% by volume. The performance of the formulations is evaluated first in a standard lubricity tester made by OFITE to test the ability of the lubricant in the drilling mud to reduce friction and second the formulations are tested on the experimental setup to investigate the effects of the three lubricants on the lock-up conditions and buckling behavior of the CT. The compositions of the water-based lignosulfonate mud are presented in Table 1 and the names of the lubricants used in the water-based lignosulfonate mud are presented in Table 2.

To confirm the field drilling conditions the compositions in Table 1 are mixed to prepare the water-based lignosulfonate mud samples and then aged for 18 h in hot rolling conditions at the most frequent field mud temperature of 70 °C. The lubricants in Table 2 are then added in different concentrations to form the samples that are used for testing.