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A critical review of the coiled tubing friction-reducing technologies in extended-reach wells. Part 2: Vibratory tools and tractors

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ABSTRACT

Well intervention in long lateral-reach wells, i.e., wells with laterals 10,000-ft or longer, is predicted to become more common within the current low price oil environment. During drilling, the drill pipe can be rotated, significantly reducing its friction in the long lateral-reach wells comparing to coiled tubing (CT) that can only slide linearly. The CT industry's trend to transfer more weights-on-bit (WOBs) to the bottom hole assembly (BHA) has been to increase the CT size to 2- or 2 $^{3}/_{8}$-, 2 $^{5}/_{8}$-, or even 2 $^{7}/_{8}$-in. However, without specialized friction-reduction technologies, these typically larger CT sizes still don't have enough rigidity to reach the bottom of the long lateral wells. As currently there is no economically practical technology to rotate the CT, entirely or partially, and the larger CT sizes bring significant operational challenges, the only available CT friction-reduction technologies are chemical (i.e., lubricants) and mechanical or hydraulic (i.e., vibratory tools and tractors) that are traditionally used to extend the CT reach. However, the field performance of these CT friction-reducing technologies is usually less optimistic than that observed in laboratory. In addition, the field experience with the vibratory and tractor tools, in particular, is usually unpredictable and unreliable, depending on unknown or unexpected downhole conditions.

In the first part of this critical review study, the most important aspects related to the CT lubricants, including their laboratory and field performance and the current understanding of their predictability and reliability within the CT industry, were discussed. In this second part, the same aspects for CT vibratory tools and tractors are discussed for the first time, focusing on the challenges and limitations encountered in the field. It is shown that field performance studies regarding vibratory tools and tractors are mostly anecdotal or proprietary. Given their importance for well intervention operations in extended-reach wells, it is hoped that this critical review will trigger further research and development of CT vibratory tools and tractors and best field practices to improve their predictability and reliability in the field.

1. Introduction

While the horizontal wells have become longer and longer for increasing the reservoir contact in many parts of the world, the coiled tubing (CT) capabilities to entirely intervene in these wells are limited by the ability of the CT friction-reducing technologies to reduce the CT mechanical friction and transfer enough weight-on-bit (WOB) downhole. Among the most used and performant such CT technologies are lubricants and vibratory tools (Bhalla, 1995; Sola and Lund, 2000; Robertson et al., 2004; Newman, 2007; Barakat et al. 2007; Newman et al., 2009, 2014; Castañeda et al., 2011; Alali and Barton, 2011; Schneider et al., 2011, 2012; Azike-Akubue et al., 2012; Hilling et al., 2012; Wicks et al., 2012, 2014; Dhufairi et al., 2013; Guo et al., 2013; Macdonald et al., 2013; Livescu and Watkins, 2014; Parra et al., 2014; Ahn, 2015; Benson et al., 2016; Kolle et al., 2016; McIntosh et al., 2016; Duthie et al., 2017; Livescu et el. 2017; Griffin and Nichols, 2012; Liston et al., 2014) and tractors (Hallundbæk et al. 1994; Nasr-El-Din et al., 2004; Hashem et al., 2005, 2008; Bawaked et al., 2008; Arukhe et al., 2012, 2013a,b; Newman et al., 2014; Al-Buali et al., 2015; Lee et al., 2016; Livescu and Misselbrook, 2016; Manil et al., 2017; Rajamani and Schwanitz, 2017). The simplest solution is the use of lubricants. Some lubricants have been shown to have the best, most predictable and reliable friction-reducing properties. However, arguably large lubricant volumes are required for effectively reducing the CT friction in long laterals, making some

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operators circumspect due to cost concerns. Alternatively, the operational costs of vibratory tools and tractors may be lower, but their field performance is usually not very well documented, raising questions about their predictability and reliability in the field. In addition, the vibratory tools are slow beyond the CT lock-up and the CT tractors perform unpredictably depending on the presence of sand, proppant or debris in the well (Hallundbæk, 1994; Sola and Lund, 2000; Hashem et al., 2005; Bawaked et al., 2008; Newman et al., 2009; Alali and Barton, 2011; Castañeda et al., 2011; Schneider et al., 2011, 2012; Wicks et al., 2012; Arukhe et al., 2012; Azike-Akubue et al., 2012; Hilling et al., 2012; Arukhe et al. 2013a, b; Guo et al., 2013; Parra et al., 2014; Pawlik et al., 2014; Wicks et al., 2014; Ahn, 2015; Al-Buali et al., 2015; Castro et al., 2015; Kolle et al., 2016; Livescu et al., 2017).

As shown in the first part of this review study (Livescu and Craig, 2017), the field performance of lubricants is still highly misunderstood, despite several recent studies on modelling and laboratory and field testing (Livescu and Wang, 2014; Livescu et al., 2014a,b; Livescu and Craig, 2015; Livescu et al., 2015; Elrashidi et al., 2016; Livescu and Delorey, 2016). There are still anecdotal case histories presented within the industry without strong scientific fundamentals (Yeung et al., 2017; Sherman et al., 2017). In general, the use of lubricants for CT operations is still based on their cost and marketing information rather than on their field-validated performance (Livescu and Craig, 2015). Note that in addition to lubricants, vibratory tools and tractors, several papers have reported optimized taper designs for extending the lateral reach (Newman et al., 2014; Lee et al., 2016; Galvan et al., 2017). While these have some advantages in extending the CT reach, they have significant technological and operational limitations that are discussed below.

Independent of what CT friction-reducing technology is used, a default coefficient of friction between the CT and well should be assumed. As discussed in detail in the first part of this critical review, the unified coefficient of friction theory (i.e., one coefficient of friction for the entire CT) was introduced by Craig (2003). He concluded that a constant default coefficient of friction of 0.24 was representative for most of the wells analysed, independent of the well deviation complexity, production rates, and CT sliding direction (i.e., running in hole, RIH, or pulling out of hole, POOH). Although this generic coefficient of friction of 0.24 is successfully used in the field for 2-in. CT operations in 5 ½-in. laterals as long as 5000 to 6000 ft, the friction force corresponding to this value is too large to reach longer laterals, assuming the CT ability to transfer at least 500 lbf WOB (Livescu and Craig, 2017). Thus, CT friction-reducing technologies are needed to intervene in longer laterals.

Although not in the scope of this critical review, it is worth mentioning that studies on friction, buckling and helical lock-up between two tubulars in wellbores such as drill pipe or CT and completion, have been published extensively in the last three decades (see, for instance, Dawson and Paslay, 1984; Mitchell, 1986; Miska and Cunha, 1995; Qiu et al., 1997; Zheng and Adnan, 1997; Qiu, 1999; Qiu and Miska, 1999; Aasen and Aadnøy, 2002; Zdvizhkov et al., 2007; Mitchell, 2007, 2008a, b, 2009; Gao and Miska, 2010; McCormick et al., 2011; Mitchell et al., 2015). For more details about the theory of CT friction, buckling and helical lock-up, the reader is directed to those studies.

Independently of reducing the coefficient of friction and thus the friction force, another mechanism to extend the CT reach is to increase the downhole axial pulling load. This has been achieved in the field by using either vibratory tools or tractors. Despite a broad use of these CT vibratory and tractor tools and their potential benefits for well interventions, reliable and consistent field validation studies of their friction-reducing capabilities are rare. For instance, as of November 2017, a search in the Society of Petroleum Engineers (SPE) electronic library of technical papers resulted in 2072 papers with the keywords "coiled tubing extended-reach". For comparison, a search for "coiled tubing vibratory tool" yielded 6252 results, while a search for "coiled tubing tractor" resulted in 707 results. However, field performance studies are mostly anecdotal or proprietary. The most relevant studies regarding the modelling, laboratory and field performance of CT vibratory tools and tractors are discussed below. In addition, there was no available literature review of the knowledge gained to date. Thus, a critical review paper of the existing studies addressing the CT vibratory tools and tractors and scientific demonstrations of their field performance will indicate the challenges and limitations encountered in the field. This will hopefully trigger further research and development and best field practices for well intervention operations in extended-reach wells.

The paper proceeds as follows. First, the previous studies on CT vibratory tools are reviewed, including their field performance, laboratory testing, and modelling. Second, the CT tractors are reviewed, including their field performance and laboratory data, as no modelling study is available. Third, best field practices for all these friction-reducing technologies are discussed. Finally, the principal findings of this critical review and further recommended work are summarized.

2. Vibratory tools

2.1. Previous studies with vibratory tools

Significant advancements in using vibratory tools for CT applications have been reported in the last two decades (Sola and Lund, 2000; Robertson et al., 2004; Newman, 2007; Barakat et al. 2007; Newman et al., 2009, 2014; Castañeda et al., 2011; Alali and Barton, 2011; Schneider et al., 2011, 2012; Azike-Akubue et al., 2012; Hilling et al., 2012; Wicks et al., 2012, 2014; Guo et al., 2013; Macdonald et al., 2013; Livescu and Watkins, 2014; Parra et al., 2014; Ahn, 2015; Kolle et al., 2016; Benson et al., 2016; Livescu et el. 2017). For instance, the development of unconventional shale reservoirs in North America has increased the demand for long horizontal wells. With increased lateral well length, milling with CT becomes less efficient, as not enough force is transmitted to the bottom hole assembly (BHA). The axial force produced by a vibratory tool may help increase the axial BHA load in order to efficiently remove all composite plugs. (Castañeda et al., 2011; Schneider et al., 2011). It is worth mentioning that downhole pressure pulses developed by CT fluid hammer vibratory tools have recently emerged as a potential technology for interrogating and mapping the fractures from shale plays (Carey et al., 2015; Moos and Livescu, 2016). If these technologies will prove useful, they could be used for both increasing the CT reach and helping acquire hydraulic fracture geometry data.

A fluid hammer tool (or, in a limiting sense, a water hammer tool) is a vibratory tool that uses the pressure surge appearing when an incompressible fluid, such as water, or compressible fluid, such as gas or steam, flowing through the CT and the tool is forced to suddenly change its momentum. This momentum change leads to an axial BHA force and radial vibrations that travel along the CT length. Within the well intervention community, there are only a few papers discussing different aspects on how the fluid hammer is specifically modelled for CT operations and how several fluid hammer tools are used for extending the CT reach by generating an axial force and reducing the CT mechanical friction (Newman et al., 2009; Livescu and Watkins, 2014; Kolle et al., 2016; Livescu et al., 2017).

To incorporate the fluid hammer effect in the most common tensile force analysis (TFA) models for CT operations, a constant axial BHA load and a potential coefficient of friction reduction are usually assumed without effectively calculating them by taking into account the effects of such operational parameters as the pumping rate, downhole pressure and temperature, vibration frequency, well profile, CT parameters, etc. (Livescu and Watkins, 2014; Livescu et al., 2017). Thus, when a fluid hammer tool is planned to be used, the assumed axial BHA force and coefficient of friction are usually implemented in the pre-job planning phase based on previous experience from similar operations. This simplistic approach is vulnerable to inconsistent results when comparing the pre-planned and post-job CT axial and frictional forces (Castañeda et al., 2011; Schneider et al., 2011, 2012). While the change of momentum due to the fluid hammer does translate into an axial force equal