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Experimental and numerical simulation of cuttings transportation in coiled tubing drilling

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ABSTRACT

Coiled tubing technology (CTT) showed its capabilities in oil and gas (O&G) drilling in many cases. Some of the advantages of CT drilling are rapid mobilization/demobilization and rig up/down times, faster tripping in and out of the hole, small hole size capability, faster drilling operation, and less environmental footprint. Because the CT does not rotate, a down-hole motor/turbine, which needs high flow rate, is required to rotate the drill-bit. The cuttings transport in the small size annulus space is the core part of this research study. This was done through both laboratory experiments using a flow loop and numerical modeling.

The results of flow loop experiments determined the minimum transportation velocity (MTV) to effectively bring all the cuttings to the surface. Directional boreholes were tested and the effect of cuttings size as well as mud properties was investigated. Testing actual cuttings in CT drilling presented different results than those observed in the literature for conventional O&G drilling. The different outcomes, for instance on the effect of rheology on cuttings transportation, necessitates conducting this research to develop a model for cuttings transportation in CT drilling.

Computational fluid dynamics numerical simulation with Eulerian Granular approach was applied in this study to investigate the effect of different parameters in cuttings transportation. The simulation results were validated against the experimental results of the flow loop. Various flow patterns were simulated by changing different parameters.

1. Introduction

Coiled tubing is a continuous length of tube that is spooled or coiled around a reel. The tubing generally has an outside diameter (OD) of 0.75–4.5 in (19–114.3 mm) but can sometimes attain a 6.625 in (168 mm) OD for offshore flow line applications. The first development of spool-able steel tubulars is attributed to the early 1940's World War II, Project 99 - pipeline under the ocean (PLUTO) for oil transportation of allied armies (PLUTO, 2014). However the use of a continuous length of tubing in O&G wellbore services is first documented in a US Patent #1965563 entitled "Well Boring Machine" that was awarded on 1934 (Bannister, 1934). Since then the use of the CT system has rapidly grown and nowadays it serves as one of the tools for drilling in O&G industries.

There are still some obstacles to overcome before CT drilling (CTD) is more widely adopted. For instance, it was expected to drill 18000-20000 wells to 5000 ft in the US, however only 25 was selected to be drilled by CTD (Spears, 2003). Some investigators have a pessimistic perspective to CTD like Byrom (1999), however, some demonstrated successful CTD cases, for example, by Leising and Rike (1994), Perry (2009), and Littleton et al. (2010). In another instance, the US Department of Energy (US DOE) developed a CTD technology for shallow O&G wells with depths less than 5000 ft (1524 m) with improved reservoir imaging ability and reduced environmental footprint (Lang, 2006).

Slurry transport is the transportation of solid particles in a liquid medium. In this mode of transportation the liquid phase is the continuous phase that carries the solid particles within a confined space such as a pipe or in the annulus between a drill string/CT and a borehole wall. Slurry transportation has been the subject of study in the food, pharmaceuticals, chemical, construction, power generation and O&G industries (Doron et al., 1987; Eesa and Barigou, 2009; Kelessidis et al., 2007). From a drilling engineering

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perspective slurry transport is known as cuttings transport where the drilling mud (liquid phase) carries the cuttings (solid phase) along an annulus space in a well in an overall upward direction.

One of the advantages of CTD is small hole size capability and the holes drilled with CTD technology are relatively smaller than conventional oil and gas wells. Small size boreholes can also be called slim-hole or micro borehole (MBH); and their sizes vary depending on required applications. Example of MBH diameters that have been reported in the past are 4.5 in (114 mm) (Lang, 2006), 4.75 in (121 mm) (Perry, 2009), 5.75 in (146 mm) (Albright et al., 2005) and 6 in (152 mm) (Enilari et al., 2006). Albright et al. (2005) suggested that holes with internal diameter of 2–3/8 in (60 mm) should be considered as MBHs. In this study MBHs are defined as those wells with internal sizes less than 3in (76 mm).

Many investigations have been performed to study slurry annular cuttings transportation. Such studies are based on field or laboratory test data, numerical simulations or other methods. Although field testing is the most valuable method to study cuttings transportation, it is both costly and time consuming and therefore field tests have often been restricted to a small number of studies. For example, Matousek (1996) performed tests with a 10 km long pipeline.

A flow loop simulation is an alternative experimental laboratory method but its results need to be scaled up to the applicable field size. For instance, Doron et al. (1987) performed an experimental study of slurry transport in a horizontal pipe and used laboratory test results to calibrate the computer simulated models.

In numerical simulation, the domain of interest is divided into smaller portions or grids and the equations are solved for each grid. Two main governing continuity and momentum equations are combined with the constitutive equations. Based on the assumptions, all equations are solved together to find the results.

In addition to field and experimental tests and numerical simulations, several correlations have been proposed by researchers in which the parameters governing the process of cuttings transportation are grouped together (Sorgun, 2010). Dimensional analysis is used to check the validity of an equation in terms of the units based on the Buckingham-π Theorem (Buckingham, 1914). Artificial neural network is another technique in which the input data is connected to the output data through functions and weights. The objective of this method is to find these weights and functions in a way that yields the output results as close as possible to the actual results. Ozbayoglu et al. (2002) used least square regression and neural network method to determine the cuttings bed thickness in horizontal and deviated wells. They encapsulated the parameters into dimensionless groups.

Much research has been performed in studying cuttings transport in vertical O&G wells. This is probably because the collinear fluid velocity and the gravity force that act in opposite directions are easier to model and analyze. However, in directional wells the gravitational force acts downward whereas the fluid velocity vector is aligned with the angle of the borehole wall. If the vertical component of the fluid flow cannot hold the cuttings in the flow stream the cuttings will fall out of suspension and collect on the low side of the borehole which may cause hole cleaning problems. Improper hole cleaning problems may follow and cause: reduced ROP; higher equivalent circulating densities (ECDs); increased fluid loss, formation fracture and loss of circulation; over-pull on connections; increased drag and torque; hole pack-off; and stuck pipe (Li et al., 2007; API RP 13D, 2010).

Cuttings bed formation in directional and horizontal wells is difficult to rectify because the fluid velocity near the bore-hole wall is very low and eccentric pipe rotation or special drilling tools are needed to deter the accumulation of cuttings or break up the consolidated cuttings pile (Ramadan et al., 2003, 2005). It is important to remember that when drilling with CT there is no tube rotation except at the bottom-hole assembly and bit via a downhole motor and poor hole cleaning is more likely to occur.

1.1. Patterns of cuttings transportation

Different flow profiles or patterns for cuttings movement are formed in the annulus of a well and they depend upon several controlling factors. The following profiles are depicted schematically in Fig. 1 where a yellow background indicates the drill string and the white background shows the annulus between the string and walls of the bore-hole; the latter being represented by two black lines. They have been reported by different investigator (Ford

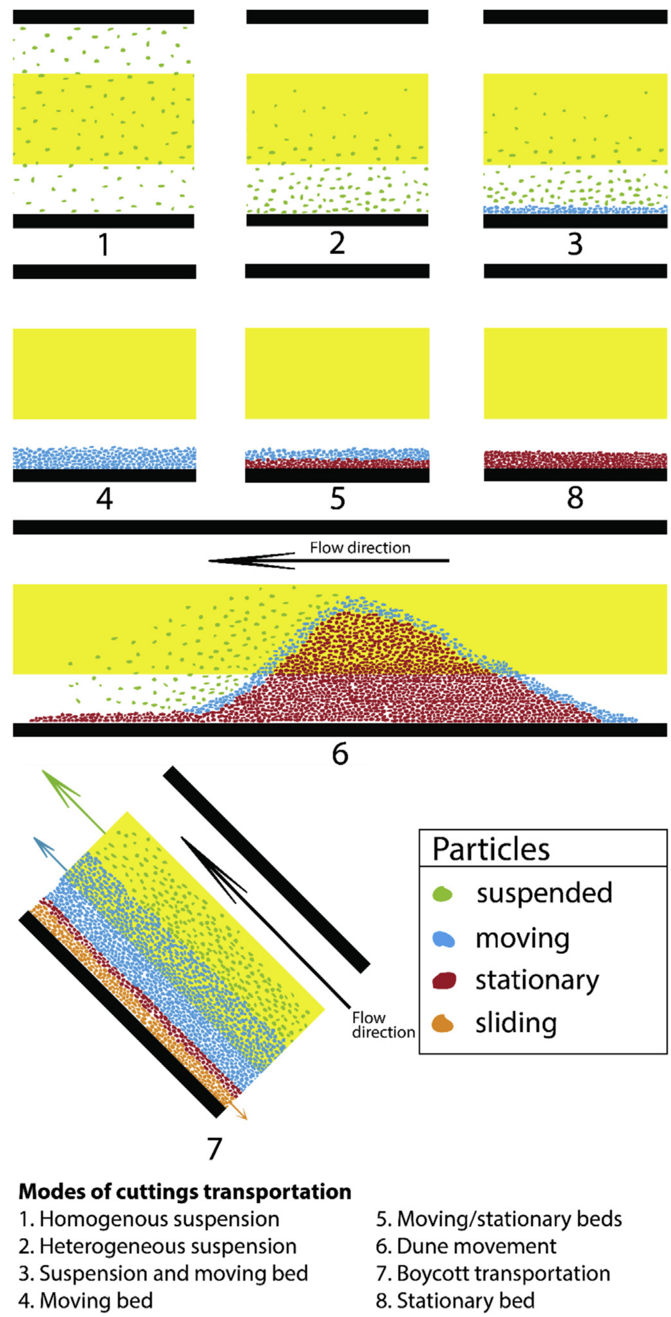

Fig. 1. Cuttings transportation profiles in the annulus space.