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Cuttings transport in maxi HDD boreholes with front reaming and one way drilling mud return technologies

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A B S T R A C T

Cuttings transport becomes critical important when horizontal directional drilling (HDD) technology has been used more often in long distance and large diameter oil and gas pipeline construction in rocks. Front reaming (FR) and one way drilling mud return (OWDMR) were not new in oil and gas well drilling, but they were rarely used in HDD industry compared to the traditional back reaming (BR) and two way drilling mud return (TWDMR). FR and OWDMR technologies, when they were used in HDD, were designed mainly for highly non-leveled HDD projects to overcome some difficulties such as the recycling of drilling mud. Along with these technologies is that the cuttings need to travel longer distance to the ground surface. In addition, the effect of the drill rod rotation on the cuttings transport does not exist because hole bottom mud motor is usually used in FR. To find a solution for this problem, the cuttings transport mechanism was analyzed based on the drilling mud hydraulics, and then, an equation of cuttings transport distance was derived. It found that the average drilling mud velocity in the annulus and the consistency index of drilling mud are the two most important factors related to the cuttings transport distance. To help with the cuttings transport, a new MMH drilling mud system, which provides a high consistency index and a low flow index, was used in rock HDD projects, instead of the common Bentonite-water drilling mud system.

1. Introduction

Cuttings in large diameter and/or long distance horizontal directional drilling (HDD) projects need to be transported out of the borehole in time, especially when it was drilling in rock stratum because cuttings from rock stratum cannot be squeezed into the surrounding ground as it can be done in soils/sands. The cuttings transport is important because: (1) If the cuttings cannot be transported out of the borehole in time, it may block the way for drilling mud (fluid) to return to the ground surface. As a consequence, the drilling mud pressure in the borehole may dramatically increase, and hydraulic fracturing may occur due to the excessive mud pressure (Yan et al., 2016). (2) The accumulation of cuttings at the borehole will increase the rotation torque of drill bit or reamers (Lan et al., 2011), such that the drill bit or reamer may eventually stuck in the borehole.

There have been many research on the cuttings transport in oil and gas drilling industry, but all those research are concentrated on small diameter boreholes and therefore the flow mode of drilling mud in the annulus is turbulent flow with large pump rate (Becker et al., 1991; Nguyen and Rahman, 1998; Okrajni and Azar, 1999; Ozbayoglu et al., 2010). On contrary, the diameter of HDD borehole can reach up to 1.57 m (62 in.), and therefore the flow mode in the annulus is always laminar flow with relatively small pump rate (Shu et al., 2015) even in the pilot hole drilling stage. As a consequence, the cuttings transport mechanism in large diameter HDD boreholes is fundamentally different from that in oil and gas wells. Therefore, it is not applicable for us to simply use the experience in cuttings transport from oil & gas industry for HDD industry.

The cuttings transport mechanism of a typical large diameter HDD borehole has been studied by Shu et al. (2015). A new model for annular drilling mud was proposed assuming there are three types of cuttings in the borehole: fine cuttings that always suspend in the drilling mud; the medium-sized cuttings that settle down with a low velocity in the drill mud; and the over-sized cuttings that usually settle down very soon at the bottom of borehole (Shu et al., 2015).

In many HDD projects, the elevations of entry point and exit point are the same, or very close, thus, the drilling mud may return to either entry or exit point of the borehole. However, a more difficult situation to study is that of a non-level grade, with entry and exit points at different elevations, leading to a natural tendency for the mud to drain to

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the lower of these openings (Slavin et al., 2011). This situation was encountered very often when HDD was used in mountain regions. The elevation difference between entry and exit points can significantly affect the drilling mud return (Shu and Ma, 2016) and the cuttings transport, during reaming process.

At the same time, some very new technologies such as the “front reaming (FR)” technology, hole bottom mud motor technology, and the one way drilling mud return (OWDMR) technology were used for rock HDD projects. The FR and OWDMR technologies are very common things in oil and gas drilling industry, but they were rarely used in HDD industry compared to the backing reaming technology. Therefore, it is very needed to study the cuttings transport theory for such special HDD projects, so that proper advice may be given to help with HDD constructions.

2. Front reaming and one way drilling mud return

2.1. Front reaming

There are normally two scenarios of non-level drill holes: A. the exit point is higher than the entry point; B. the entry point is higher than the exit point. In scenario A, the drilling mud tends to flow back to the entry point (lower side), where the drill rig is located, and therefore the drilling mud can be reused.

In scenario B, the drilling mud tends to flow to the exit point. If the elevation difference is very big, there may be even no drilling mud return to the entry point (Shu and Ma, 2016). The problem is that the recycling of drilling mud becomes difficult. Drilling mud returned to the exit point may be recycled at the exit point side, but it is extremely difficult to transport them back to the drill rig at the entry point for reuse. On the other side, if drilling mud was not recycled and reused, it is impossible in practice to provide a continuously supply of drilling mud of around 1–3 m^3/min for a typical maxi HDD project. Even if the recycled drilling mud may be pumped into the borehole directly through the drill rod from the exit point (Shu et al., 2011), it still means extra pumps and solid control facilities are required at the exit point side, and an extra transport of drill rods from the entry point to the exit point is required. Besides, without the support of drilling mud pressure at the empty borehole section, the borehole wall may become unstable (Wang and Sterling, 2007; Shu and Ma, 2015).

In reality, due to the limitation of drilling techniques and/or the site topography, scenario B sometimes is inevitable in mountain areas. For example, due to the limitation of mud pump capacity, it is difficult and sometimes even impossible, for the mud pump to send the drilling mud to a high elevation if it was drilling “up”. Besides, if it was drilling “up” using front reaming, the drill rig has to overcome the weight of drill rods. And due to the limitation of the push force capacity of drill rig, the drill rig may unable to apply enough pressure on the drill bit to break rocks.

In scenario B, it may be a good choice to use front reaming plus one way drilling mud return, instead of the traditional back reaming and two way drilling mud return.

Front reaming was briefly mentioned in Dr. Ma’s (Ma, 2008) book, but it was not often used in practice, so it is a new technology for many people in HDD industry. Fig. 1 shows the differences between back reaming and front reaming. Compared to the traditional back reaming, the reamer in front reaming moves from the entry point to the exit point, but the drilling mud can still return to both the entry and exit points at the same time.

2.2. One way drilling mud return

In addition to the front reaming, if the exit point was not drilled through, or it was sealed after drilled through, all the drilling mud may only return to the entry point which is the so called “one way drilling mud return”, see Fig. 2.

In the one way drilling mud return, the end portion of the drill path, which is usually around ten meters depends on the geological condition, may be closed in either way as below:

(1) The end portion of the drill path may not be drilled though so the exit point was closed “naturally”;
(2) The end portion of the pilot hole may be first drilled through and then was sealed with cement “manually”, see Fig. 3 for a manually closed exit point.

After the pilot hole was completed, the drill rods and the drill bit were pulled back to the entry point side. Then, each cycle of FR process starts from the entry point, and stops at the same location as the pilot hole stops. See Fig. 4 for the FR process with OWDMR. After all the FR cycles were completed and the borehole diameter has reached the designed size, the end portion may be drilled through.

2.3. Features of FR and OWDMR

In BR process, drill rods were pulled back to the entry point one by one, and at the same time, some other drill rods need to be connected to the reamer at the exit point. Therefore, drill rods need to be transported from the entry point to the exit point after every reaming cycle. Fortunately, with the FR technology, such a drill rod transportation is not needed anymore. With the FR and the OWDMR technologies, drilling mud only return to the entry point, so the aforementioned disadvantages of drilling mud recycle and reuse in Scenario B may be overcame.

In the traditional BR technology, cuttings can be transported to either entry or exit point, to whichever it is closer, so the maximum travel distance of cuttings is about half of the borehole length. In comparison, the cuttings in the FR and OWDMR can only be transported to the entry point, so the maximum travel distance of cuttings is almost the full borehole length.

2.4. Hole bottom mud motor

When it was drilling with FR technology in rock stratum, hole bottom mud motor is usually used in order to provide sufficient reaming torque to the drill bit or reamers. This is another major difference between FR and BR technologies. A mud motor attached to a HDD reamer is shown in Fig. 5. The hole bottom mud motor can provide rotation torque to run the reamer, so drill rods in the borehole actually do not rotate at all when a mud motor is used.

The drill rod rotation is a big issue when the cuttings transport was studied because it changes the velocity of cuttings. It is usually considered that drill rod rotation is good to the cuttings transport. The faster the drill rod rotates, the better the cuttings transport efficiency. However, in this study, the drill rod does not rotate when hole bottom mud motor is used in FR, so cuttings transport in FR might be more difficult than in BR. Therefore, there is a question that how the cuttings can be transported in a borehole such as in Fig. 4 when the FR was used, especially at the end part of the borehole since it is so far away from the entry point. To answer this question, a theoretical analysis of cuttings transport was conducted, and based on which some good advices were given to engineering practice.

3. Drilling mud hydraulics

It has been demonstrated in many research (Shu et al., 2015; Shu and Ma, 2016) that the flow in the annulus of HDD borehole is laminar flow because drilling mud velocity is low, no matter whether it is in the pilot hole drilling stage or in the reaming stage. Therefore, in this research, the details of how to distinguish laminar flow and turbulent flow in annulus were not repeated. Although for non-leveled maxi HDD borehole, there are certain elevation difference (usually less than