Ballasting pipeline moving in horizontal well as method of control sticking phenomenon

V S Toropov and E S Toropov

Industrial University of Tyumen, 38 Volodarskogo Str., Tyumen, 625000, Russia

E-mail: vladimir.s.toropov@gmail.com

Abstract. The mechanism of the phenomenon of sticking a pipeline moving in a well while pulled by the facility horizontal directional drilling is investigated. A quantitative evaluation of the force arising from sticking is given. At the same time, the working hypothesis takes a view of the combined effect of adhesion and friction interactions as the reasons that cause this phenomenon. As a measure to control the occurrence of sticking and to reduce the resistance force to movement of the pipeline in the well, several methods of ballasting the working pipeline are proposed, depending on the profile of the well and the ratio of the length of the curved sections of the inlet and outlet and the straight horizontal sections of the profile. It is shown that for crossings, which profile contains an extended horizontal section, it is possible to partially fill the pipeline with water to achieve zero buoyancy, and for crossings with curvature along the entire profile, the ballasting efficiency will be minimal.

1. Introduction

The phenomenon of sticking the pipeline is possible at the stage of pulling on sections of the profile of a subsoil crossing with permeable soils. Its reason is the interaction of the pipeline with the filter cake, which is formed on the borehole walls [1].

To form a filter cake, it is necessary that the hydrostatic pressure of the solution in the considered section of the well is greater than the pressure in the rock, provided that it is permeable.

During the flow of a mixture of slurry and mud particles into the soil through the borehole wall, the borehole wall itself delays the penetration of solid particles through itself. Thus, particles suspended in the drilling mud accumulate, forming a filter cake.

An increase in the thickness of the filter cake leads to a decrease in the amount of liquid penetrating into the soil from the well, and accordingly slows down and then stops the process of formation of the filter cake.

2. Materials and methods

The factors determining the rate of formation and the size of the filter cake are:

- differential pressure quantity;
- proportion of solids in the drilling mud;
- filtering degree of the water solution base in the soil.

The dependence of the main parameters of the formation process of the filter cake on the factors determining this process is shown in Table 1.
Sticking caused by a high differential pressure value occurs, as a rule, in soils with a high degree of permeability, for examples sandstones [2]. This can happen because the pipeline is adjacent to the filter cake. The contact surface, in this case, is exposed to the difference between the internal pore pressure of the soil and the column pressure of the drilling fluid (Fig. 1).

**Table 1.** Dependence of the parameters of the formation process of the filter cake on the determining factors

| Factor | High | Low |
|--------|------|-----|
| The value of the differential pressure. | The speed of crust formation increases, its thickness increases. | The speed of crust formation decreases, its thickness decreases. |
| The proportion of solids in cuttings in the drilling mud. | The porosity and permeability of the crust as well as the rate of its formation and thickness increase. | The crust becomes thinner and more solid. |
| Degree of filtration of the water solution base in the soil. | The thickness of the crust increases; the crust is softer. | The thickness of the crust is small; the hardness is high. |

With the use of horizontal directional drilling technology, there are no serious limitations on the crossing depth, and therefore the pressure difference can be significant [3]. The force arising from this interaction hinders the movement of the pipeline in the well [4].

**Figure 1.** A design model for determining the sticking force of a pipeline moving in a well

At present, there is no single approach to the interpretation of the mechanism for the appearance of the sticking effect. There are researchers who suggest that the effect of sticking the pipeline is due to the filter cake, which becomes stronger during the growth of the pressure difference as the main cause of sticking.
If the soil, where the well is drilled, is composed of almost impenetrable clay soils, the sticking is
carried out not by the pressure difference but directly by the hydrostatic pressure of the drilling fluid
column, causing the pipeline to adhere to the filter cake.

There is also another opinion according to which when sticking, not only the process of adhesion to
the borehole wall takes place, but the frictional resistance arising between the pipeline and the clay
cake, which increases with the growing pressure drop of the drilling mud column and pore pressure of
the soil.

In order to take into account as many factors as possible, negatively affecting the process of pulling
the pipeline, let us consider the combined effect of adhesion and friction interactions on the working
hypothesis. Considering this, the sticking force will be equal to:

\[ F_s = D_1 + D_{st} \gamma_{dm} - P \frac{d}{2} \beta \cdot l \]  

(1)

where \( D_1 \) - penetration of the pilot well from the spudding site;
\( D_{st} \) - the depth of the spudding site in the starting pit from the day surface;
\( d \) – outer diameter of the pipeline;
\( \gamma_{dm} \) - specific gravity of drilling fluid, N/m³;
\( P \) – reservoir pressure, Pas;
\( \psi \) – the angle of the contact zone of the pipeline with the filter cake, radians (Figure 1);
\( l \) – length of the sticking segment.

And the force of the resistance to the movement of the pipeline from the effect of picking up the
filter cake is defined as follows:

\[ F = F_s + D_1 + D_{st} \gamma_{dm} - P \frac{d}{2} \beta \cdot l \cdot f \]  

(2)

where \( f \) – friction coefficient, taking into account adhesion and frictional resistance to pipeline
movement.

As can be seen from Figure 1, with increasing the filter cake thickness, the contact area of the
pipeline with the borehole wall also increases. The thicker the filter cake becomes, the more the area
of contact with the pipeline increases, and the more significant is the resultant force of differential
sticking.

![Image](image_url)

**Figure 2.** A value of adhesion of the filter cake to the steel wall of the pipeline depending on the
contact time at a pressure difference of 0.1 mPa.

The risk of the sticking effect is significantly increased in case of a long stay of the pipeline
without movement inside the borehole drilled in the sandy ground, as the process of covering the
pipeline with a filter cake gradually increases with an increase in the contact surface area [5].

Because of the increase in the area, the value of frictional forces grows, the frictional interaction
effect appears, since the drilling fluid begins to be displaced from the contact zone, and an area is
formed in which there is already a sliding friction of the pipeline material over the soil. As a result, the
efforts necessary for ultimate strength of the pipeline increase significantly.
To reduce the friction force of the pipeline against the soil surface of the well, the pipeline to be pulled is ballasted with water [6]. The method of ballasting depends on the well profile and the ratio of the curved sections of the inlet and outlet and the straight horizontal sections [7].

For crossings, which profile contains an extended horizontal section, it is possible to fill partially the pipeline with water until it reaches zero buoyancy. This makes it possible to minimize the frictional forces on the soil when pulling the pipeline.

For a well without a horizontal section, i.e. with curvature along the entire profile, water will collect in the lower part of the pipeline [7]. This makes it possible to minimize the frictional forces on the soil when pulling the pipeline.

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For a well without a horizontal section, i.e. with curvature along the entire profile, water will collect in the lower part of the crossover [8]. In this case, the lower part of the pipe will have the excess negative buoyancy, and the peripheral sections will have the maximum positive buoyancy, i.e. the efficiency of ballasting will be minimal.

It should be noted that positive buoyancy has other negative factors. When pulling the pipeline with insufficient ballasting under the influence of tension forces, it is possible to lift the pipeline to the borehole high. This is especially evident in the curved sections of the inlet and outlet of the pipeline from the well [9]. In this case, the pipeline destroys the soil of the upper part of the borehole high, which can lead to the high collapse and sticking of the pipeline.

From this it follows that the "excessive" ballasting of the pipeline is less harmful from the point of view of protection against sticking than the preservation of "excessive" buoyancy. This is especially true for profiles that do not have a horizontal section, i.e. the variant of the pipeline movement with the pressure against the lower forming wall of the well is more preferable [10].

The floating force acting on the pipeline depends on its diameter and wall thickness. With increasing the diameter, there is an intensive growth of the floating force.

The condition for floating force on the pipeline is an equality:

\[ q = \pi \cdot d \cdot \gamma \cdot \delta - \frac{\pi \cdot d^2}{4} \gamma_{dm} \]  \hspace{1cm} (3)

where \( q \) – load from the weight per unit length of the pipeline, taking into account the floating force occurred in the drilling mud, N/m;
\( \gamma \) – specific gravity of the material of the pipeline being pulled into the well, N/m³;
\( \delta \) – wall thickness of the pulled pipeline, m.

Figure 3 shows the alignment chart of the dependence of the load on the weight per unit length of the pipeline, taking into account the floating force occurred in the drilling mud, and on the wall thickness for different pipeline diameters.

From the condition that the upper well height does not collapse (the pipeline lies at the bottom of the well), the previous equation can be represented in the form of an inequality:

\[ q = \pi \cdot d \cdot \gamma \cdot \delta - \frac{\pi \cdot d^2}{4} \gamma_{dm} \geq 0, \]  \hspace{1cm} (4)

or if one expresses the value of the wall thickness:

\[ \delta \geq \frac{d}{4} \cdot \gamma_{dm} \]  \hspace{1cm} (5)

where \( \delta \) is the thickness of the pipeline wall at which the pipeline's zero buoyancy is ensured. The inequality sign shows that for large values of \( \delta \), the pipeline will lie on the lower generating line of the well and will not touch the upper high.
Figure 3. The dependence of the load on the weight per unit length of the pipeline, taking into account the floating force occurred in the drilling mud, on the wall thickness of the pipeline.

In expression (5), the value of \( q \) will be numerically equal to the weight of water that must be poured into the pipeline to create zero buoyancy. When pulling, water is periodically poured into the cavity of the pipe, thereby unloading the pipeline to be pulled (4).

Figure 4. A flow chart of ballasting of the pipeline by completely filling it with water: \( L_1, L_2 \) - curved sections of the inlet and outlet; \( L \) - straight section of the profile.

When the pipeline is completely filled with water, too much effort may be exerted to hold down the pipeline to the lower generating line of the well [11, 12]. They can be adjusted by using an internal pipe or by partial filling with water (Fig. 5, 6).
Figure 5. A flow chart of ballasting of the pipeline with the help of a water filled pipe placed in the inner cavity: 1 – a pipe of a smaller diameter in the internal cavity of the working pipeline.

In the last two cases, the loading flow charts will differ.

Figure 6. A flow chart of ballasting the pipeline by partially filling it with water: \( q \) - the resulting force of the pipeline effect on the upper generating line of the borehole wall in different sections.

The pulling process should go without stopping and interruptions (excluding those justified by the horizontal directional drilling technology itself) in order to prevent sticking of the pipe in the well [13].

3. Conclusion
In order to avoid sticking the drill string and the pipeline to be pulled to the borehole walls, in cases when the pulling process is stopped because of technical reasons and breaks during which the pipeline remains stationary in the borehole, it is necessary to rotate the drill pipes and flush the well with drilling mud after certain periods [14].

In addition, several different flow charts for ballasting the pipeline with water are proposed, which use will not only reduce the load on the well wall from the pipeline side, thereby reducing the resistance to pipeline movement in the well, but will reduce significantly the danger of the pipeline sticking to the well walls [15]. These schemes of full and partial ballasting in the process of pulling are relevant for crossings, which profile contains an extended horizontal section.
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