Effect of fillers on the coefficient of friction of a polyurethane sealing element for a coiled tubing sealing device

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Abstract. The results of studies of wear resistance and friction coefficient of polyurethane grade PT-74 filled with solid lubricant powders are presented. The abrasion patterns of the obtained polyurethanes are presented. The type and quantity of the filler providing smaller wear of a sealing element are defined. The regression analysis revealed the physical and mechanical properties of the material that have the greatest effect on wear.

1. Introduction
Every year, the amount of the well workover, including usage of coiled tubing (CT) is growing. Due to environmental friendliness and cost-effectiveness coiled tubing is widely used, as well as the ability to work during a depression on a productive formation which excludes its pollution. The last one involves sealing at the space between the tubing and CT at the wellhead. It provides tightness with a sealing element (SE), made of an elastic material such as polyurethane – due to a higher (in reference to oil-gasoline-resistant rubber) endurance. Moreover, the wellhead sealer is an important component of a coiled tubing installation which guarantee safe and high-quality performance for work in the well.

In the process of trips, the SE exposed to intensive wear, which is associated with considerable friction forces at the contact of the SE-CT. For example, the lifetime of the sealing element in the wells of the Valanginian stage of the Yamburg field lasts for 1-2 trips.

Increased attrition (coefficient of attrition) not only accelerates the wear of the SE, but also reduces the range of loads applied on the CT during reciprocation, complicates the control of the load on the face and causes different sorts of problems [1]. The number of problems has been identified due to statistical researches of the operating experience of CI at the Yamburg field. The analysis and classification of complications created by the SE of the sealer gave us an opportunity to identify their main types and reasons.

1. The CT sticking in blowout preventer (BOP) due to hydrate formation. The reason is the wear of the SE and the formation of a gap that initiates the hydration mode of the well, rising of local thermobaric conditions which is a good opportunity for the hydrate formation. Existence in the stagnant zone of various inclusions which are good centers of crystallization.

2. The sticking of CT in the stripper due to the adhesion of the SE to the CT. The reason is increasing of trips speed (above 15 m/min), heating of the surface layer of the SE in the contact zone and, as a reason, temperature destruction of polyurethane. After a sharp stop, the destructured layer sticks to the CT.

3. Depressurization of the wellhead due to insufficient lubrication, high wear rate associated with high coefficients of friction in the SE-CT pair.
4. Hanging CT. The reason is insufficient lubrication, high wear rate associated with the high coefficient of friction in a pair of SE – CT.

In the down process to reduce the friction force the lubrication applied on the surface of CT and in the process of lifting - lubrication is carried out by the well environment [2]. Despite the presence of a lubricant, it cannot always provide sufficient efficiency under the existing conditions of operation of the seals. Actually, the lubricant is supplied to the pipe in a dusty atmosphere; the friction unit operates at high loads and lower temperatures, which makes some difficulties in lubrication of the friction unit. Pipe lifting during gas well development is accompanied by well development, therefore the lubricant is practically missing out.

The aim of the work is study the influence fillers on the friction coefficient of a polyurethane sealing element for a coiled tubing sealing device.

2. Materials and methods

A new method is proposed to reduce the wear of the seal of the sealer, due to the low efficiency of the measures implemented. This is a reduction in the friction coefficient for the SE material due to the introduction of a solid lubricant into this material. For the research, mixtures of fillers, such as graphite, molybdenum disulfide and PTFE (Polytetrafluoroethylene) or fluoroplastic, were prepared. The choice is made on the basis of the analysis of the efficiency of the used solid lubricant fillers, as well as on the basis of the price and availability of raw materials on the market. As a matrix used polyurethane PT-74 which is a domestic analogue of polyurethane brand Adipren L100. Adipren L 100 is a material used for seals in the oil and gas industry. It is widely used for the manufacture of SE sealants coiled tubing units.

The introduction of solid lubricants usually weakens the base material, as they have low adhesion and do not provide a strong chemical bond with the matrix polymer. Consequently, the weakening of the material may reduce the durability. Therefore, an important problem is the selection of the type of filler and its percentage.

The following physical and mechanical characteristics were determined for the manufactured samples: conditional strength, critical deformation, conditional modulus of elasticity, Young's modulus, residual deformation, and hardness. The tests were carried out in the laboratory at a temperature of 25°C using a set of test equipment, including the Instron 3365 test facility. Conditions for sample preparation and testing were in accordance with the corresponding GOST (State standards).

The experiment planning matrix was prepared for the experiments. Abrasion tests were carried out in the laboratory of the North Caucasus Federal University.

Typical laboratory installation MI-2 took for testing polymer samples for wear. It allows determining the force and coefficient of friction in sliding friction and the amount of the wear test samples.

![Figure 1. Design of the test device](image-url)
To reproduce the operating conditions of the sealing elements, the typical laboratory installation MI-2, figure 1, for testing polymer samples for wear was taken as the base, which allows determining the force and coefficient of friction during sliding friction and the amount of abrasion of the samples under study.

The principle of operation of the machine MI-2 for testing elastomers for abrasion is to determine the wear resistance of the material when samples slid on a rotating disk at a speed of 0.32 m/s in a controlled downforce. The installation design includes an electric motor (1), a presser disc with two samples (2), a control plate in the form of a wire disc (3), a lever with sensors of friction force (4), nozzles for blowing the contact zone (5). Temperature sensors and load device are not shown. In order to better approximate the operating conditions, the installation was improved. The metal mesh wire was used as an abrasive surface to account for the nature of the surface of the CT [3]. To determine the coefficient of friction and temperature in the contact zone in real time with the display on the computer in the form of graphs, special sensors were installed and the software was developed.

An optical microscope Levenhuk D70L was used to study the surface of worn samples and determine the type and mechanism of wear, and the VL-224 analytical balance with an accuracy of 0.0001g was used to measure material wear.

3. Results and discussion
The results of studies of the friction coefficient of samples on a metal mesh wire are shown in the graph, figure 2. From figure 2 it follows that filling polyurethane with components of all types of solid lubricant reduces the friction coefficient compared to the unfilled matrix, and the samples filled with fluoroplastic have the lowest values.

![Figure 2. The dependence of the friction coefficient on the filler content](image)

The results of the study of abrasion of the samples on the metal wire mesh are shown in figure 3. As can be seen from figure 3, an increase in the percentage of solid lubricants in polyurethane leads to an increase in the abrasion of the samples.
This tendency is preserved for filling with fluoroplastic, however, the abrasion rate is less than that of unfilled polyurethane PT-74. An increase in abrasion is associated with a decrease in the strength properties of samples filled with solid lubricants.

The study of the surface of the samples allows us to associate the nature of wear with the wear rate. Figure 4 shows the wear surfaces obtained after the abrasion of the samples at the test installation MI-2. Pure polyurethane PT-74 and polyurethane filled with graphite and molybdenum disulfide have a frictional wear mechanism. Proof of this is the presence of transverse ridges (waves) [4]. At the same time, the less intense fatigue wear mechanism is implemented when filling with (PTFE) fluoroplastic, figure 4(d). Proof of this is the presence of a relatively smooth surface.

Thus, when polyurethane is filled with solid lubricants, the friction coefficient decreases, but at the same time, the strength properties are reduced. The test results shown in Table establish the connection between the polyurethane filling and the change in the friction coefficient $f$ on the mesh wire and the specific power wear $Y$ measured in $m^3 \cdot TJ^{-1}$ (where TJ is terajoule) with the physical and mechanical
properties of the composites such as conditional strength $T$ (MPa), critical deformation at break $K_d$ (%), conditional modulus of elasticity $E$ (MPa), Young's shear modulus $G$ (MPa), residual deformation under compression $\varepsilon$ (%).

Table 1. Physical and mechanical properties and wear of the samples

| Filling Material | %  | Physical and mechanical properties GOST 270-75 | $f$ | $Y$, m$^3$/TJ |
|------------------|----|-----------------------------------------------|-----|--------------|
|                  | $T$, MPa | $K_d$, % | $E$, MPa | $G$, MPa | $\varepsilon$, % |
| 1                | 21.96 | 821     | 4.9     | 16.7     | 18           | 1.04 | 6.98 |
| 2                | 13.3  | 492     | 5.7     | 20.4     | 10           | 0.74 | 6.76 |
| 3                | 11.7  | 732     | 6.6     | 26.6     | 10           | 0.61 | 8.07 |
| 4                | 22.14 | 1116    | 4.2     | 12.3     | 20           | 0.82 | 5    |
| 5                | 20.2  | 1163    | 4.5     | 18.1     | 20           | 0.89 | 19.43 |
| 6                | 12.1  | 1039    | 4.3     | 14.1     | 50           | 0.88 | 50.9 |
| 7                | 16.71 | 622     | 5.2     | 22.7     | 14           | 0.72 | 0.81 |
| 8                | 15.1  | 588     | 5.6     | 26.6     | 20           | 0.65 | 1.39 |
| 9                | 12    | 552     | 6.1     | 29.7     | 16           | 0.65 | 1.4  |

To identify the degree of influence of individual physic-mechanical properties on abrasion, a regression analysis was performed. The analysis is made on the basis of data about the relationship of physical and mechanical properties of filled polyurethanes with the value of wear, table.

The influence factors are the physic-mechanical properties of polyurethane, which are regulated by the introduction of fillers. The response is the specific power wear of polyurethane, which is determined using the abrasion machine $M_I$-2.

As a result of the regression analysis, using the Statistica program, a regression equation (1) for specific power wear is obtained:

$$Y = -27,29 + 0,0316 \cdot K_d + 89,52 \cdot f - 3,5 \cdot T$$

(1)

As follows from the equation, the coefficient of friction $f$ and the conventional strength of polyurethane have a determining and competing effect on the abrasion of composites. Reducing the strength properties reduces and even eliminates all the advantages obtained from reducing the coefficient of friction.

4. Conclusions

As a result of research, experimental dependences of the influence of such solid lubricants as graphite, molybdenum disulfide and fluoroplastic on the physic-mechanical properties of polyurethane-based composites, the coefficient of friction and wear were obtained.

(1) It has been established that the fluoroplastic filling has the greatest effect on the reduction of the friction coefficient. Moreover, the increase in the content of the filler over 10-12% does not influence the magnitude of the friction coefficient and wear.

(2) It is proved that the main effect on reducing wear has a decrease in the friction coefficient $f$ and the conditional strength of polyurethane.

(3) Shows the limits of filling, allowing increasing the service life of seals for sealers. When exceeding 10% of the filling, the strength decreases and, as a result, the wear increases.

References

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