

Computer Simulation of Stress-Strain State of Pipeline Section Affected by Abrasion Due to Mechanical Impurities

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Abstract. The paper presents the effect of abrasive wear of the pipeline section occurred due to mechanical impurities in the transported gas flow. The approaches to the detection of the maximum specific wear of the pipeline wall and the geometry of abrasion are the main problems of computer simulation described in this paper.

1. Introduction

Although the natural gas undergoes the required purification before its transportation, investigations of abrasive wear in main pipelines are rather relevant since purification systems fault sometimes or the natural gas composition contains a large number of particulates. In this connection, it becomes necessary to estimate the consequences of gas transportation and, possibly carry out a feasibility study of transportation with the original gas flow instead of its purification allowing for the abrasion effect produced by mechanical impurities.

Moreover, in the light of recent discoveries in the field of nanoparticles that have an effect on the intensity of turbulent fluctuations in moving media fluxes [1], the practical use of the interaction between solid particles and transported gas flow becomes possible in gas production. Thus, it seems to be indispensable to investigate all possible aspects of implementing research achievements in this field. One of these aspects is abrasive wear of the pipeline material induced by solid particles. Undoubtedly, abrasive wear is a negative phenomenon in the use of solid particles for the reduction of pressure losses in gas flow. A computer simulation of this process allows detecting all negative facts and making a proper decision concerning the use of this specific natural effect.

The experience in gas transportation with suspended solids shows that in absence of the pipeline bends, its surface wears in the bottom area. This is because solid particles are directed towards the bottom due to gravity and demonstrate the intensive interaction with the bottom surface of the pipeline [2].

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2. Results and discussion

Since relations that describe the abrasive wear in the main pipelines are absent, it is advisable to employ Putilov model designed for the related field, i.e. hydraulic pulverizing and ash/slag-discharge machinery at thermal power stations [3]. Since abrasive wear usually propagates uniformly along the pipeline, its model has two dimensions. The main parameters of abrasion in this work are accepted to be the maximum depth H_{max} and maximum width B_{max} as shown in figure 1.

The maximum width B_{max} of abrasion is obtained for geometrical reasons. In case the bulk concentration is known, the relation between transverse squares of the spot and the pipeline are known as well due to the uniform longitudinal distribution of impurities. At the same time, the maximum width of the spot equals to the chord of the circular segment formed by the spot of particulates (see figure 2).

Thus, the problem is reduced to finding the chord of the circular segment by the known square. The maximum width B_{max} is to be obtained as the third side of triangle formed by the given side and two radii:

$$B_{max} = R\sqrt{2 \cdot (1 - \cos \alpha)} \quad (1)$$

To obtain B_{max} , it is necessary to get the angle α that forms this segment. This angle can be obtained from the segment square, because it is known as well as the square S_p of the pipeline:

$$\gamma = \frac{S_1}{S_p}, \quad (2)$$

Therefore, we have

$$S_1 = \gamma \cdot S_p = \frac{R^2}{2} (\alpha - \sin \alpha) \quad (3)$$

From here

$$\alpha - 2\pi \cdot \gamma = \sin \alpha \quad (7)$$

Substituting the angle value for the cosine theorem, we get B_{max} value.

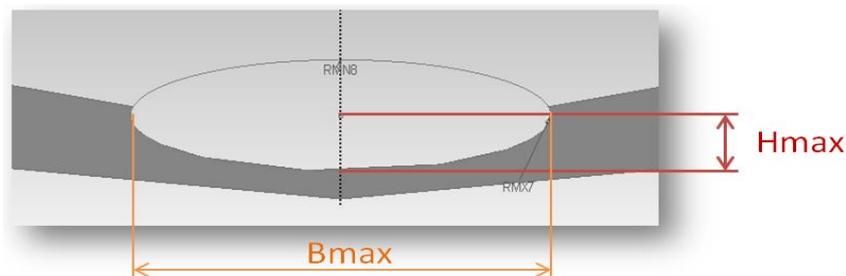


Figure 1. Simulation diagram of abrasive wear.

Having the maximum values of abrasion depth H_{max} and width B_{max} only, it is impossible to obtain the geometry of defects that satisfies the conditions of accurate simulation. These values allow obtaining only square, triangular or ellipsoid defects. Thus, the abrasive wear simulated in the form of annular groove, as

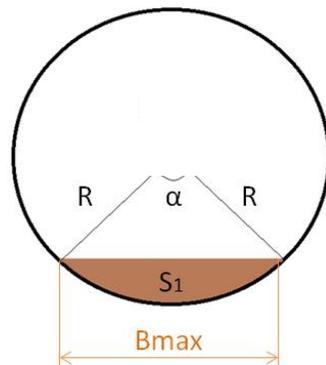


Figure 2. Geometrical substantiation of maximum abrasion width estimate

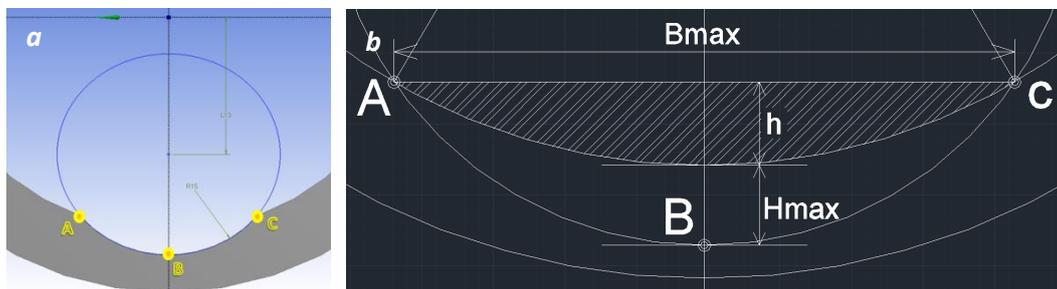


Figure 3. Simulation model of abrasive wear in the form of annular groove: *a* – model; *b* – schematic drawing

shown in figure 3 seems to be the most suitable for the pipe body. The values H_{max} and B_{max} should be transferred to X_c and Y_c coordinates of the circle centre with radius R for the correct simulation of the geometric model. Since the coordinates centre can be easily placed into the centre of the simulation model, then $X = 0$ and Y is the distance from X axis to the centre of the annual groove.

Having got points A, B, C , the distance between the centres of the pipeline and the circle that forms the spot of particulates can be obtained to properly model the geometry. Let us use the coordinate translation formulas for three points of the circle into the centre coordinates and radius value. Thus, having obtained the geometry of the pipeline (length, wall thickness, inner diameter) and the annular groove (coordinates of the circle midpoint and radius), it is possible to simulate the abrasion as a geometric object cut out of another one, and further analyze the stress-strain state of the defective pipeline.

A typical design was used to represent initial data of the stress-strain state of the pipeline based on OOO ‘Gazprom transgaz Tomsk’ technical requirements for the reconstruction of Parabel’ - Kuzbass main pipeline (see table 1).

Table 1. General parameters of the pipeline

Internal diameter, (mm)	Wall thickness, (mm)	Length, (m)	Pipeline depth, (m)	Natural gas density, (kg/m ³)	Operating pressure, (MPa)
1000	15 mm	11 m	1.5 m	0.770	5.4
Soil properties					
Specific weight, (N/m ³)	Angle of internal friction				
19000	20°				

Material properties				
Type	Density, (kg/mi)	Yield stress, (MPa)	Vickers number	
17G2SF steel	7850	372	171	
Particulate properties				
Origin	Density, (kg/mi)	Average size, (mm)	Bulk concentration	Particle velocity, (m/s)
Oxides, corrosion	4500	600	$1 \cdot 10^{-4}$	1

Having got the geometrical parameters of the pipeline section, it is necessary to determine loads induced by both the soil from above and below and transported product, insulating coating, metal and also pressure that has the effect on the inner surface of the pipeline wall [4].

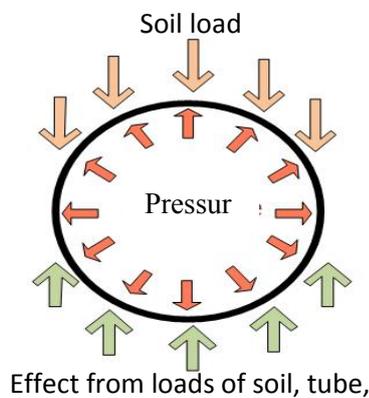


Figure 4. Pipeline wall exposed to loads

These calculations are characterized by the use of relations that generate results in Newtons. This is because the computer simulation of the stress-strain state of the pipeline is carried out in ANSYS software package in which loads are suitable to express in unit of force. The theoretical force acts on the half-area of the pipeline. As shown in figure 4, the force acting from soil above comes to 443130 N, while force produced from soil below, transported product, insulating coating, and pipeline material achieves 445611 N.

The geometry of the pipeline and abrasive wear is then simulated with ANSYS Workbench [5-8]. The suggested design techniques facilitate the simulation of this type of defects in CAE programs due to visualization of the interaction between two bodies having the simple geometry (figures 5).

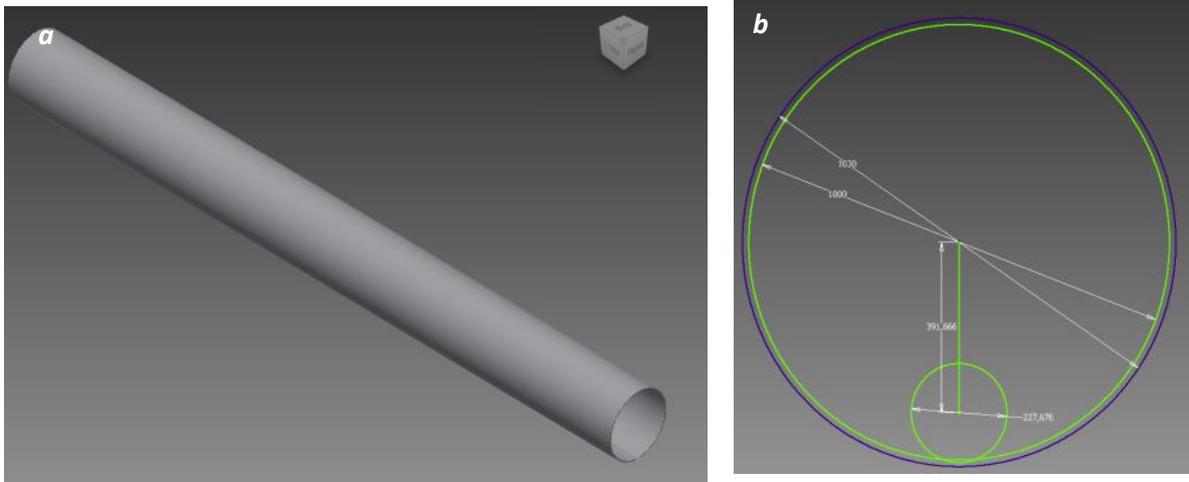


Figure 5. Pipeline model (a) and geometry (b)

To estimate the suggested model, the stress-strain state analysis is carried out for the pipeline with abrasion that increases during its operation (figure 6).

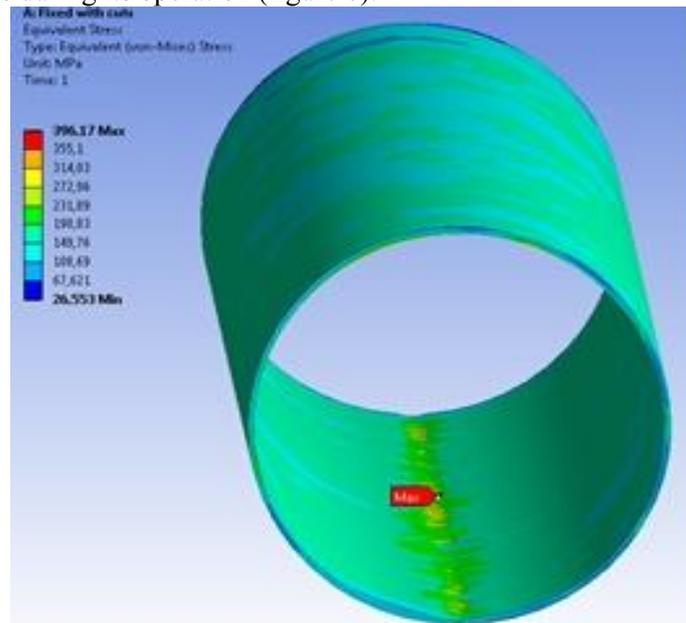


Figure 6. Pipeline equivalent stresses at abrasive wear after 18.1 years. Yield stress is exceeded

The model of abrasive wear of the pipeline, defect geometry, load effects, and the initial data for value calculation allow creating table 2 to represent the results by the tabulated function of maximum stresses in the pipeline wall depending on its lifetime. Also, these results are represented by influence curves in figures 7-9.

Table 2. Pipeline lifetime

Years	0	7.5	15	16	17	18.1
H_{max} (mm)	0	2.22621 5	4.45243	4.749259	5.046087	5.37259 9
σ_{max} (MPa)	230.1	239.63	282.54	332.4	355.72	396.17

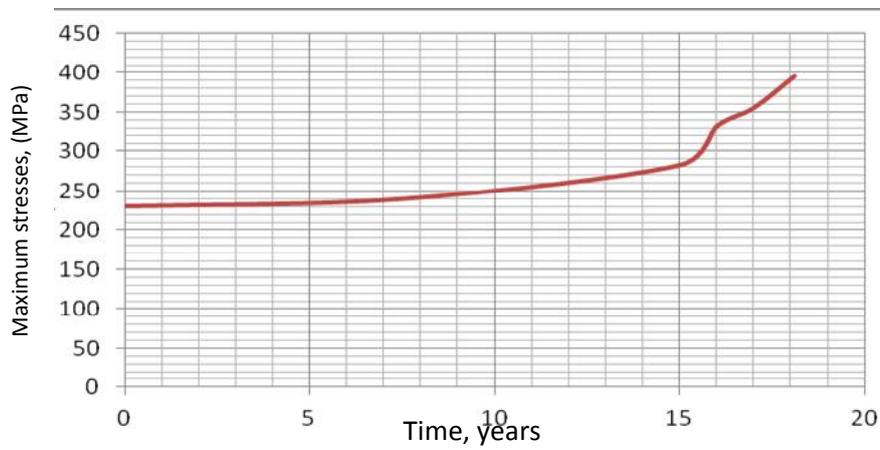


Figure 7. Dependence between maximum stresses and pipeline lifetime

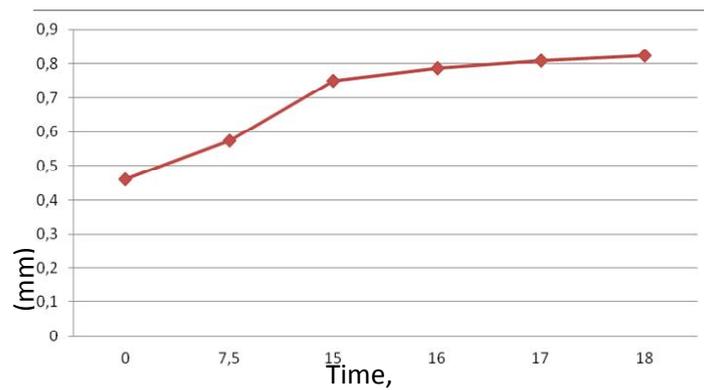


Figure 8. Dependence between displacement (generalized spatial movements) and pipeline lifetime

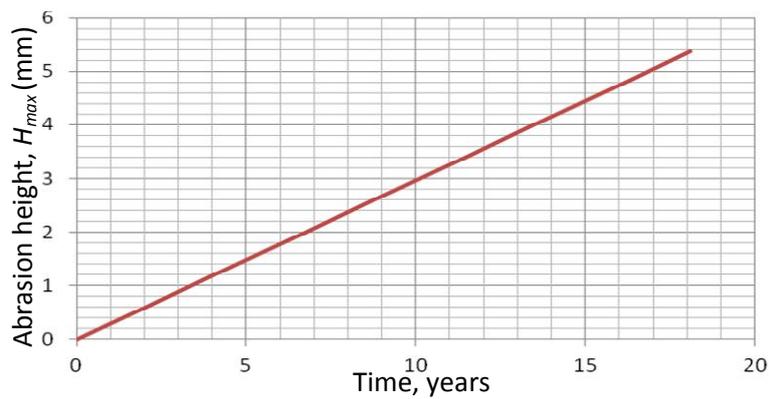


Figure 9. Dependence between abrasion height and pipeline lifetime

These curves show that the stress-strain state of the pipeline is not linear time dependence and changes stepwise. The growth of stresses at the beginning of the pipeline operation is almost insufficient. On the contrary, at the end of its operation stresses increase.

The adequacy of the suggested model is assessed by the comparison of results of numerical calculations and those prescribed by the construction regulations of Russia. For this, let us detect the maximum allowable depth of abrasion of the underground pipeline section. The pipeline section is made of the type 17G2SF steel tubes having 1030 mm diameter and 15 mm thick. The ultimate tensile stress is 372,6 MPa; the pressure of transported product is 5,4 MPa (figure 4).

Circular stresses can be obtained from

$$\sigma_c = \frac{m}{k_l \cdot k_s} \cdot R_1^n = \frac{0.9}{1.47 \cdot 1} \cdot 372 = 227.8 \text{ MPa}, \quad (10)$$

where m is the coefficient of operating conditions equaled to 0.9; k_l is the safety factor of material equaled to 1; k_s is the safety factor of the pipeline purpose equaled to 1,47; R_1^n is the standard tensile strength of material.

The maximum allowable depth of abrasion is

$$(c) = \delta - \frac{p \cdot D_y}{2 \cdot ((\sigma_c) + p)} = 15 - \frac{5.4 \cdot 1030}{2 \cdot (227.8 + 5.4)} = 3.08 \text{ m}, \quad (11)$$

that is 20,53 % of the pipeline wall thickness. Thus, the error of the suggested model and estimation methodology is not over 10%.

Conclusion

With a view to improve the pipeline serviceability, estimate its mechanical conditions and predict the durability, technical diagnostics should be provided in time as well as the stress-strain state analysis by the finite element method.

The stress-strain state of the pipeline was not linear time dependence and changed stepwise. The growth of stresses at the beginning of the pipeline operation was almost insufficient. On the contrary, at the end of its operation stresses increased.

The allowable circular stresses agreed with the construction regulations equaled to 250 MPa, and stresses will exceed the allowable stresses after 10 years of operation. Computations carried out with ANSYS software package showed that stresses will exceed the allowable stresses after 17 years of operation. Therefore, the construction regulations should be taken into consideration in interpreting results obtained from the application software product based on ASME standards.

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