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Gas-abrasive wear of shut-off valves and process piping of compressor and gas distribution stations

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Abstract. A high content of mechanical impurities in the gas flow causes intense gas-abrasive wear of the pipe surface, especially at the pipe bends and shut-off valves. To assess the effect of gas flow rate on the failure rate of piping elements, an installation, and a test procedure were designed. The test result was evaluated by the value of the intensity of linear wear of the material, related to the amount of abrasive that was projected on the sample for the entire time of testing. Based on the results obtained, materials were identified that have minimal wear when the gas flow is shut off and when the abrasive carrying gas flow rate changes from 24 m/s to 48 m/s. Steel 20 showed better wear resistance compared to steel 09G2S, but an increase in the flow rate leads to an increase in wear intensity.

Keywords: gas-abrasive wear, gas distribution station, shut-off valves, sealing materials of shutoff valves, gas medium flow rate

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Introduction

According to the requirements of state regulatory documents (GOST 54808-2011 "Pipeline valves. Leakage rates of valves" [1]) and regulatory documents of organizations (STO Gazprom 2-4.1-212-2008 "General technical requirements for pipeline valves supplied to the facilities of OAO Gazprom" [2]) for shutoff and control valves, the concentration of mechanical impurities in the natural gas flow transported in main and branch pipelines should not exceed 0.010 g/m^3. An analysis of the contaminants deposited on the filters and in the cavity of the shutoff valves shows that the content of solid particles in the main gas can significantly exceed the specified requirements. Such an increase in the proportion of mechanical impurities in the gas flow is observed during the commissioning of sections of main pipelines after their repair, as well as during the period of intensive gas extraction from underground storage facilities. The composition of impurities includes abrasive particles, corrosion products of pipe metal, welding slag, and other contaminants [3]. The size of individual crystalline particles is in a wide range from 10 to 500 microns, which is shown in Fig. 1, and the chemical composition determined by X-ray fluorescence analysis is presented in Table 1.

Fig. 1. Photograph of the appearance of various types of contaminants in the main gas

Table 1. Chemical composition of mechanical impurities

Element	Element content, %		
	1	2	3
Fe	53.89	68.87	56.71
S	6.40	6.97	1.94
Ba	4.05	7.11	4.30
Si	24.03	3.53	14.57
Na	1.45	2.00	1.85
Ca	2.52	2.09	10.38
Mn	1.14	1.03	1.53
Al	1.55	1.14	1.62
Cl	0.466	0.536	0.291
K	0.632	0.504	0.661
Mg	0.434	0.385	0.517
Ti	0.251	0.162	0.263

Getting into the flow of the transported gas, mechanical impurities cause gas-abrasive wear of the pipe walls on the pipeline bends and seals of shutoff and control valves when the flow is blocked. The most significant gas-abrasive wear is manifested during the operation of the piping of compressor (CS) and gas distribution (GDS) stations. The process pipelines of these gas pipeline infrastructure facilities have a large number of bends, and ball valves with polymer seals are mainly used to shut off the gas flow [4].

The purpose of this work was to study the effect of gas-abrasive wear on the development of failures of piping elements depending on the speed of the gas flow.

Testing method

The essence of the laboratory research on gas-abrasive wear was to test samples of steel and polymer materials subject to a stream of abrasive particles moving at a fixed speed in a gas medium at a given angle to the surface and to determine its wear indicators.

For testing, round quartz sand of 0.1-0.3 mm fineness was selected as an abrasive, the composition and properties are presented in Table 2.

Steel 20 and 09G2S were chosen to study the gas-abrasive resistance of the metal of CS and GDS process piping. Of the most widely used sealing materials for ball valves, we tested such materials as F4 fluoroplastic, F4K20 fluoroplastic, caprolon, paronite.

Table 2. Characteristics of quartz sand

Composition	
Clay component content	less than 1 %
Iron oxide content (Fe_2O_3)	less than 1 %
Silicon oxide content (SiO_2)	95-99.8 %
Properties of quartz sand	
Class of use by radioactivity	1
Mohs hardness	7
Bulk density (specific gravity)	1480 kg/m^3

When choosing a test scheme, standardized test methods were considered in accordance with GOST 23.201-78 and GOST 23.208-79 [5,6]. The main requirement for the test setup was to ensure uniform distribution of the abrasive over the cross-section of the gas flow and maintain a given angle of attack over the entire cross-section of the sample. The use of a centrifugal accelerator according to [5] does not allow the formation of a uniform distribution of particles along the flow due to the deflecting action of the centrifugal force. Installation according to [6] does not provide the possibility of abrasive supply at different angles. Therefore, for the testing, we used a setup that simulates the movement of a gas-abrasive flow in a pipeline. The scheme and appearance of the testing installation for gas-abrasive wear are shown in Fig. 2.

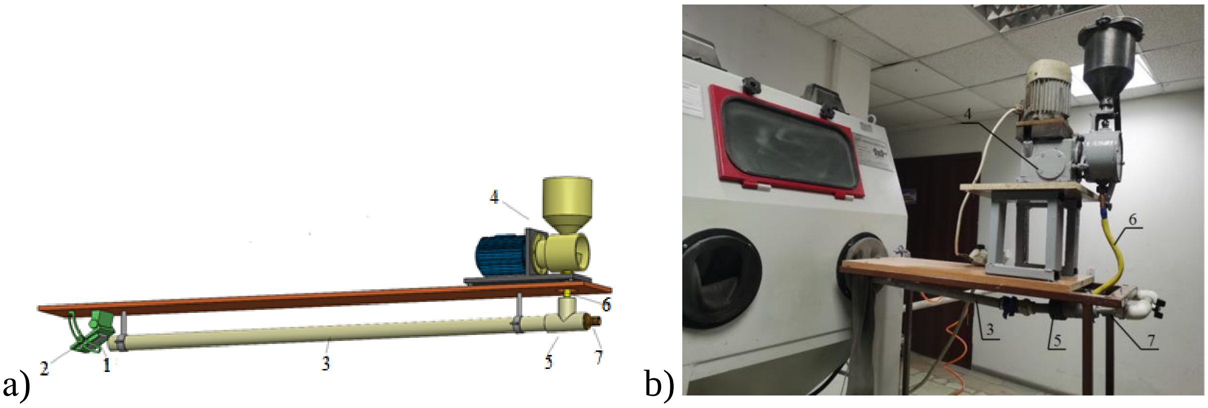


Fig. 2. Gas-abrasive wear test installation: a) design: 1 – sample, 2 – sample swivel holder, 3 – accelerating tube, 4 – feeder, 5 – mixing chamber, 6 – supply tube, 7 – air supply fitting, b) photograph of the external view

The principle of operation of the installation is as follows: the abrasive from feeder 4 is fed through supply tube 6 into mixing chamber 5, where it is picked up by air, which is supplied to the chamber through fitting 7. The resulting gaseous mixture enters sample 1 through pipe 3. The angle of inclination of sample 1 relative to the abrasive flow is fixed by sample holder 2 and changes from 15° to 90°.

The samples are flat rectangular plates of 110×30×4 mm in size.

The swivel holder allows deflecting and fixing the sample relative to the gas-abrasive flow. The front part of the setup with the holder, the sample, and the outlet end of the accelerating tube were placed in a sandblasting chamber (Fig. 2(b)), which was used to limit the projection and collect the waste abrasive.

The main adjustable test parameters are the gas-abrasive flow rate, the abrasive consumption per unit time, the time of a single test, and the angle of attack [7,8]. To assess the effect of the gas-abrasive flow rate on the wear process, studies were carried out at 24 m/s and 48 m/s [9,10]. The flow rate was controlled by the air pressure in the supply network and measured using a VMA-1 digital anemometer before the abrasive was supplied. The angles of attack of the gas-abrasive flow with respect to the surface of the sample were chosen based on the data described in [11-16] and amounted to 15°, 45°, and 90°. The amount of abrasive (q) for a single test was taken equal to 2 kg 700 g. The time of a single test cycle (t) was taken to be 1.0 hour for a rate of 24 m/s and 30 minutes for a rate of 48 m/s. Since the air flow rate changed during the experiment, in order to obtain comparable wear values, it was decided to use the same concentration of abrasive particles per unit volume of air equal to 90 g/m^3, which ensured contact of the samples with a fixed amount of abrasive per test cycle. Accordingly, the abrasive consumption was 0.75 g/s for a flow rate of 24 m/s and 1.45 g/s for a flow rate of 48 m/s.

The location of the samples during testing at different angles to the gas-abrasive flow leads to a change in the contact area. Table 3 presents the values of the actual area of the samples in contact with the gas-abrasive flow when they were located at a fixed angle of attack with respect to the flow axis.

Table 3. Sample area for different angles of attack

Angle of attack	90°	45°	15°
Sample area, mm^2	314	440	1209

The value of wear of the samples before and after testing was determined by the gravimetric method on an electronic balance HTR-120 CE with an accuracy of 0.0001 g. The test result was evaluated:

- with respect to the specific mass loss:

$$M_n = \frac{m_1 - m_2}{F}; \quad (1)$$

- with respect to the intensity of linear wear of the material related to the amount of abrasive that got on the sample for the entire time of testing according to the following formula:

$$I_n = \frac{m_1 - m_2}{\rho \cdot F \cdot q}, \quad (2)$$

where ρ – material density, g/mm^3, (in the calculation, the following density values of materials were taken: 1.6-2.0 g/cm^3 for paronite (PON grade according to GOST 481-80), 2.18 g/cm^3 for fluoroplastic (F4 grade according to GOST 10007-80), 2.17 g/cm^3 for carbon-filled fluoroplastic (F4K20), 1.15–1.16 g/cm^3 for caprolon (PA-6), 7.8 g/cm^3 for steel); F – sample surface area, mm^2; q – amount of abrasive during testing, kg.

Discussion of test results

The results of testing steels for gas-abrasive wear at different flow rates are presented in Table 4 in terms of specific mass loss, and in Fig. 4 in terms of linear wear intensity.

Table 4. Specific mass loss of samples to abrasive mass at different gas-abrasive flow rates (g/kg)

Angle of attack, deg	Researched Materials					
	paronite	fluoroplast	carbon-filled fluoroplast	caprolon	Steel 09G2S	Steel 20
Gas-abrasive flow rate 24 m/s						
15	0.003	0.002	0.001	-0.004	0.008	0.007
45	0.045	0.008	0.017	-0.008	0.062	0.018

90	0.018	0.004	0.001	-0.015	0.052	0.008
Gas-abrasive flow rate 48 m/s						
15	0.088	0.006	0.006	-0.004	0.027	0.017
45	0.203	0.123	0.120	0.002	0.089	0.059
90	0.391	0.014	0.128	-0.016	0.079	0.027

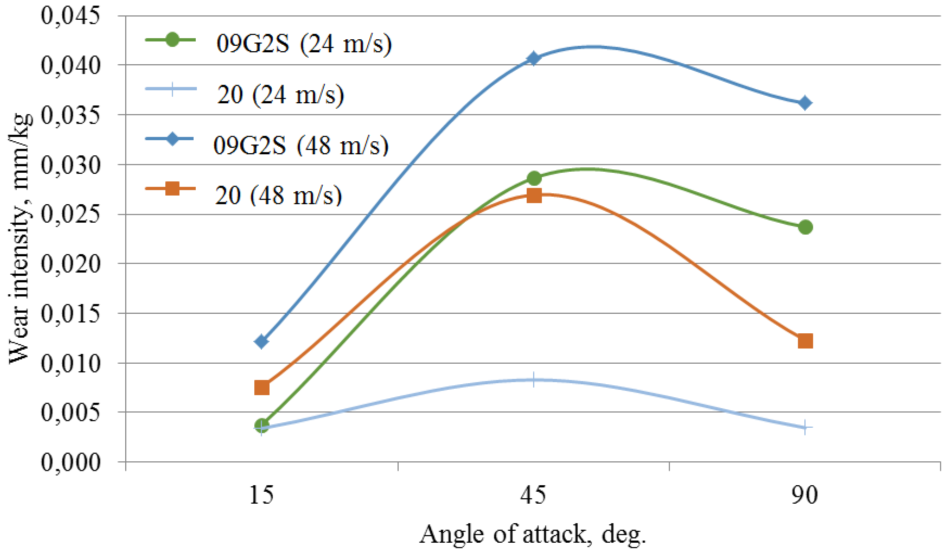
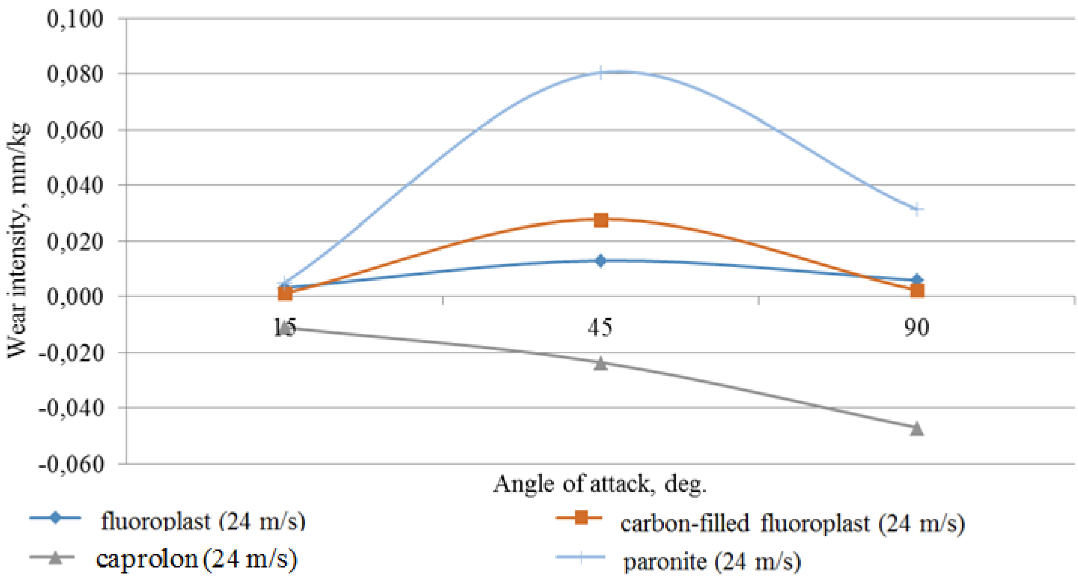


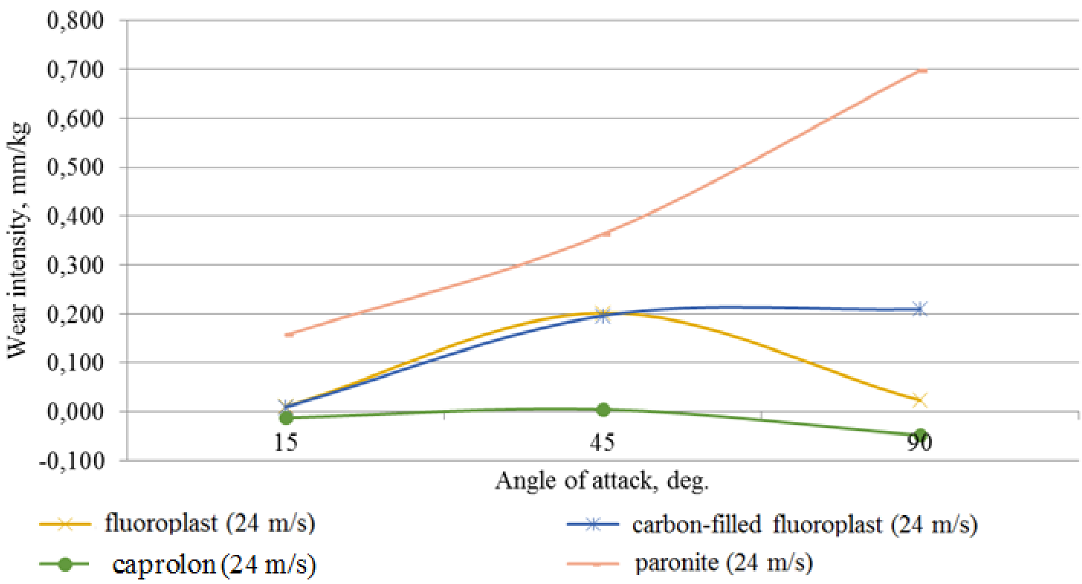
Fig. 4. Dependences of the change in the wear intensity of pipe steels at a gas-abrasive flow rate of 24 m/s and 48 m/s

As can be seen from the data obtained for the steel pipes, the highest wear intensity is observed at an attack angle of 45°. An increase in flow rate from 24 m/s to 48 m/s has a more significant effect on steel 20: its increase in wear intensity at angles of attack of 45° and 90° was more than 3 times compared to a 1.5 times increase in 09G2S. However, at the same time, Steel 20 showed better wear resistance compared to Steel 09G2S both at a gas flow rate of 24 m/s and 48 m/s. Which agrees well with the data from [17, 18].

Graphs of changes in the wear intensity of sealing materials are shown in Fig. 5.



a)



b)

Fig. 5. Dependences of changes in the wear intensity of sealing materials at a gas-abrasive flow rate of a) 24 m/s, b) 48 m/s

Analysis of the obtained data shows that the maximum wear intensity is observed in paronite. Carbon-filled fluoroplastic has lower wear resistance compared to F4K fluoroplastic. Caprolon shows a tendency to abrasive charging and shows weight gain at all angles of attack.

Increasing the gas flow rate to 48 m/s leads to an increase in the wear intensity for all studied sealing materials. Paronite demonstrated the greatest increase in wear intensity with an increase in the gas-abrasive flow rate by 22-30 times. At the same time, at a gas flow rate of 24 m/s, the maximum wear is achieved at an angle of attack of 45°; with an increase in the gas flow rate to 48 m/s, the maximum wear shifts to 90°. Carbon-filled fluoroplastic demonstrated a significant increase and a similar trend in the change of wear intensity. Only for caprolon, the values of mass had practically no change.

Method for calculating the service life of piping bends and ball valve seals in contact with a gas-abrasive flow. The wear of piping bends in contact with a high-velocity gas flow-carrying abrasive should be evaluated to prevent wall thinning above the regulated level. The value of the ultimate wear of the pipeline wall is determined by the formula:

$$\Delta\delta^i = \delta^i - {\delta_{all}}^i, \quad (3)$$

where $\Delta\delta^i$ – maximum wear of the wall of the i^{th} piping bend, mm; δ_{all}^i – minimum allowable thickness of the wall of the i^{th} piping bend, mm; δ^i – nominal thickness of the wall of the i^{th} piping bend, mm.

Using the experimental values of the pipe metal wear intensity at the most aggressive angle of attack of the gas-abrasive flow, the maximum allowable operation time determined by the number of months of the operation can be calculated using the following relationship:

$$\mathrm{T}_B{}^i = \frac{\Delta\delta^i}{t \cdot q \cdot I_{g/a} \cdot Q_A} = \frac{\Delta\delta^i}{720 \cdot q \cdot I_{g/a} \cdot Q_A}, \quad (4)$$

where T_B^i – maximum allowable service life of a piping bend, mth; $I_{g/a}$ – maximum intensity of gas-abrasive wear of the piping bend depending on the material, mm/kg; Q_A – actual pipeline performance, m^3/h; q – abrasive content in the gas flow, kg/m^3, t – duration of a single period taken equal to 1 month (720 hours).

The impact of the gas-abrasive flow on the performance of ball valves is assessed by the amount of leakage in the shut-off body. The destruction of the ball valve seals subject to the gas flow carrying the abrasive leads to a loss of tightness and a gradual transition from class A according to GOST 54808-2011 "Pipeline valves. Leakage rates of valves" to tightness class D regarded as the limit for gas systems in accordance with STO Gazprom 2-4.1-406-2009 "Methodology for assessing the life of shut-off and control valves of main gas pipelines". The maximum allowable gap areas for shut-off valves of different nominal diameters, corresponding to the specified tightness classes, are presented in Table 5.

Table 5. The area of the shut-off valve gap at the maximum allowable leakage

Nominal diameter	Cross-sectional area of the gap at maximum allowable leakage at nominal pressure (ΔF), mm^2
DN 65	0.0233
DN 80	0.0287
DN 100	0.0359
DN 125	0.0449
DN 150	0.0538
DN 200	0.0718
DN 250	0.0897
DN 300	0.1077
DN 350	0.1256
DN 400	0.1435
DN 500	0.1794
DN 600	0.2153
DN 700	0.2512

The increase in the area of the gap in the shut-off body of ball valves mainly occurs in the process of shutting off the flow and is determined by the friction of the surface of the shut-off element against the seal and the action of the gas flow carrying the abrasive. The maximum allowable number of cycles of repositioning the ball valve shutter when the gas-abrasive flow is shut off can be determined by the following formula:

$$n_{max}{}^{i} = \frac{\Delta F \cdot b \cdot \rho_{seal}}{i_{g/a} \cdot q \cdot Q_A \cdot t}, \qquad (5)$$

where $n_{max}{}^{i}$ – maximum allowable number of cycles of repositioning the ball valve shutter operating in contact with the abrasive-carrying gas flow, cycles; $i_{g/a}$ – mass gas-abrasive wear intensity of ball valve seals, g/kg (Table 6); b – shut-off valve sealing width, mm (in the absence of data on the design of ball valves, the sealing width is assumed to be 3–5 mm); ρ_{seal} – seal material density respectively, g/mm^3; t – duration of a single cycle of repositioning the shutoff valve shutter, h (Table 7).

Table 6. Mass intensity of gas-abrasive wear of sealing materials of valves

Material	Mass intensity of gas-abrasive wear ($i_{g/a}$), g/kg	
	at flow rate of 24 m/s	at flow rate of 48 m/s
paronite	0.0709	0.4389
fluoroplast	0.0125	0.1936
carbon-filled fluoroplast	0.02	0.1432
caprolon	0	0.0024

Table 7. The duration of a single cycle of shifting the shutter of valves with a manual gearbox or manual override is within STO Gazprom 2-4.1-212-2008 "General technical requirements for pipeline valves supplied to the facilities of OAO Gazprom".

Size	The duration of a single cycle of shifting, h	
	seconds	hours
DN 50–150	60	0.016667
DN 200–400	180	0.05
DN 500–700	600	0.166667
DN 1000	900	0.25

An assessment of the influence of the gas flow rate on the remaining service life of shut-off valves for the pipeline section of a gas distribution station using the example of a flanged ball valve (Dn200, Ru 40, 11nzh67p) showed that with an increase in the gas flow rate containing a regulated mass concentration of mechanical impurities in the gas equal to 0.001 g/m^3, from 24 m/s to 31 m/s, the number of valve repositioning cycles was reduced from 1035 cycles to 809. A 20% reduction in the service life of shut-off valves shows the need to take into account the effect of gas flow rate when assessing the intensity of gas-abrasive wear of piping.

Conclusions

Based on the research, the following conclusions can be drawn:

1. The presence of mechanical impurities in the natural gas flow leads to gas-abrasive wear, which is most significantly manifested in the piping bends of the CS and GDS and seals of valves due to the contact with the gas flow at variable angles from 15° to 90°.
2. The most intensive wear of the pipeline bends made of steels 20 and 09G2S is observed at an angle of attack of 45°. Steel 20 showed better wear resistance compared to steel 09G2S, but an increase in the gas flow rate from 24 m/s to 48 m/s contributes to a more significant increase in its wear intensity.
3. The minimum wear of the shut-off valve seals when the abrasive carrying gas flow is shut off is observed in caprolon. Carbon-filled fluoroplast has lower resistance to gas-abrasive wear compared to F4K fluoroplast.
4. Increasing the gas flow rate from 24 m/s to 48 m/s leads to an increase in the wear intensity for all studied sealing materials. At the same time, for carbon-filled fluoroplast and paronite, the wear maximum shifts from 45° to 90°.
5. The application of the proposed calculation technique makes it possible to take into account the influence of such characteristics as the gas flow rate and the abrasive content on the service life of piping bends and ball valve seals in contact with the gas-abrasive flow.

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