PHYSICS AND CHEMISTRY OF SOLID STATE
V. 22, No. 3 (2021) pp. 551-560

Section: Technology

DOI: 10.15330/pcss.22.3.551-560

Vasyl Stefanyk Precarpathian National University

ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 22, № 3 (2021) С. 551-560

Технічні науки

UDK: 622.691.4 ISSN 1729-4428

Ya.V. Doroshenko, G.M. Kogut, I.V. Rybitskyi, O.S. Tarayevs'kyy, T.Yu. Pyrig

Numerical Investigation on Erosion Wear and Strength of Main Gas Pipelines Bends

Ivano-Frankivsk National Technical University of Oil and Gas, Ivano-Frankivsk, Ukraine, yaroslav.doroshenko@nung.edu.ua

The purpose of this work is to ensuring the strength of main gas pipelines bends by studying the peculiarities of single-phase and multiphase flows movement through the internal cavity, the processes of erosion wear and the wall stress state. The problem of synergistic influence of gas-dynamic processes (uneven pressure distribution in the internal cavity), temperature difference and erosion wear on the stress state of the bends of main gas pipelines was solved by numerical simulation. Based on the results of simulation the processes of bends erosion wear, an algorithm for three-dimensional simulation of bend walls erosion defects was developed. The complex three-dimensional geometric shape of the erosion defects of the bend wall varied according to the rate of erosion wear process. This algorithm made it possible to determine the regularities for the influence of the bend erosion defects magnitude on bends stress state. It was established that considering the maximum depth of bend erosion defects 9.6 mm, 10.5 mm and 11.9 mm, the equivalent stresses in the deepest places of the erosion defect were greater than on the concave side of the bend and in straight sections of the pipeline.

Keywords: multiphase flow, bend, gas pipeline, gas - dynamic process, erosion wear, stress state.

Received 18 July 2021; Accepted 30 August 2021.

Introduction

Modern gas transmission systems are complex branched networks of pipelines containing a large number of shaped elements. The most common shaped elements of gas pipelines are bends. The largest number of bends is contained in the string of compressor stations, underground gas storages, gas distribution stations, etc. Bends contain compensators for aboveground crossings of gas pipelines, and they are also in the places of turns of the pipeline route in the horizontal and vertical planes.

In gas pipelines' bends, the flow direction changes by an angle of 45º, 60º, 90º, which leads to an uneven distribution of pressure and flow velocity in their inner cavity. Also, in such shaped elements, dispersed phases in natural gas flow hit the wall, which leads to the processes of erosive wear and to the occurrence of erosion defects. Erosional defects of the bend wall affect their stress state and are dangerous, since they are in-line and visually invisible and unpredictable.

To ensure the reliability of gas pipeline bends, their wall thickness should be periodically measured, as accurately as possible to assess the degree of erosion-worn bends danger and predict their residual life. All this will improve the quality of diagnostics of the gas transmission system and affect the efficiency of its operation [1]. For this purpose, it is necessary to identify the locations of intense erosional wear of the bends, to investigate the stress state of such erosion worn pipe fittings, by taking into account the extremely complex three-dimensional geometric shape of erosional defects and gas-dynamic processes that occur in their internal cavity. The solution to this problem will make it possible to assess the strength and determine the residual life of erosion-worn gas pipeline bends, prevent emergencies and determine the frequency of routine maintenance to inspect gas pipeline bends in locations of their erosive wear.

The study of the single-phase, multiphase flows movement dynamics in the pipeline systems bends began in the early 1960s. Such studies were mainly carried out experimentally in laboratory conditions. The result was in the structure of the flow, which was determined by its visualizing in transparent bends [2-4]. However, the physical picture of the flow in pipeline bends is complex, three-dimensional, and depends on many factors and is extremely difficult, so in many aspects it is impossible to study it experimentally, or calculate theoretically. Moreover, experimental studies have many disadvantages. In the real conditions of pipelines operation, especially concerning main gas pipelines, such experiments are generally impossible to perform due to a number of different reasons. Therefore, there are many unresolved issues related to gas-dynamic processes, flow energy losses in gas pipeline bends. This is particularly true for multiphase flows, since in gas pipeline flows there are liquid and solid dispersed phases of various physical and mechanical properties. Liquid dispersed phases can be hydrocarbon condensate, water, and solid - particles of rocks removed from the well, scale, which has exfoliated from pipes, products of in-pipe corrosion [5-9]. All this leads to the fact that the prediction of erosive wear of pipe system bends is an extremely difficult and little studied problem today. In addition, a wide range of different parameters affects the location and rate of erosive wear of gas pipeline branches.

As well as corrosive wear [10-12], erosive wear is one of the factors affecting the stress-strain state of the bends, reducing their residual life [13]. Also, the stress-strain state of pipeline bends is influenced by a complex uneven distribution of pressure in their internal cavity, a change in pressure in the pipeline [14-17], bending of the pipe [18]. All these circumstances are superimposed on each other and on the complex geometric shape of the bends. For this reason, the bends contain zones with an increased level of stress-strain state, which significantly affects their strength. Therefore, to assess the strength of gas pipeline systems bends, synergy of gas-dynamic processes in their internal cavity, processes of erosive wear and stress-strain state in a three-dimensional setting is required, namely, it is necessary to perform multidisciplinary modeling. Analytical, numerical, experimental studies in literature relate to individual processes that occur in the bends - hydro-gas dynamic or erosive wear or stress-strain state. Currently, no attempts have been made to create a synergy of these processes, to combine them into a single integral physical picture. In many cases, there are no sufficiently expressive physical ideas about the laws of the processes that occur in the branches of gas pipeline systems, their influence on the wall and the basic equations that described these processes are often impossible to obtain.

Since it is impossible to obtain an analytical solution, numerical modeling can be used to establish quantitative relationships in modern software systems, which is an effective tool for solving such problems, both in a complex (multidisciplinary modeling) and partially. Visualized results of such modeling allow to see in detail a complex three-dimensional single-phase or multiphase flow inside various shaped elements of gas pipeline systems [19-22] and to study the distribution of pressure, flow velocity, kinetic energy of turbulence, to determine the trajectories of dispersed phases in the continuous phase, the location and rate of erosive wear of the wall, etc. The results of numerical modeling also help to create three-dimensional models of shaped elements of gas pipelines with erosional defects of complex structure, which will occur at certain intervals of pipeline operation. Also, the results of gas-dynamic modeling, three-dimensional models of shaped elements with complex erosion defects can be imported into strength modules and perform synergy of the studied processes (multidisciplinary modeling), which makes it possible to comprehensively study the stress-strain state of defective shaped elements of gas pipelines; and for main gas pipelines tees [23].

Nowadays, numerous studies of the dynamics of the movement of single-phase, multiphase flows in the shaped elements of pipeline systems, their erosive wear, stress state is small are presented in publications, and, mainly, they relate to water pipelines and pneumatic pipelines of small diameters. The geometric shape of defects in all analytical, numerical studies of the stress state of defective shaped elements [24-25] is extremely simplified (idealized to spherical or rectangular) and does not correspond to the real geometric shape of such defects.

Repair of erosion worn-out pipeline bends is difficult due to their complex geometric shape. Effective technologies for the repair of such bends are trenchless technologies, which consist in pulling a hose or flexible composite pipe with a piston. The regularities of the technological process of pulling the hose and pipes by the piston into the worn out steel pipelines were investigated in [26, 27].

I. Numerical model

To solve the problem of main gas pipelines strength research, the ANSYS Academic finite element analysis software was chosen. The procedure for numerical modeling of the problem under consideration consists of the following stages:

– modeling of the three-dimensional geometry of the bend walls and its internal cavity;

– CFD modeling of gas-dynamic processes in the internal cavity of the bens, applying the ANSYS Fluent module;

– import of three-dimensional geometry of the bend wall and the obtained results of CFD modeling from the ANSYS Fluent module into the ANSYS Static Structural mechanical module of the software package;

– modeling of the temperature difference in the bens wall in the Transient Thermal module;

– import of the obtained results of modeling the temperature difference in the bend wall from the Transient Thermal module to the ANSYS Static Structural mechanical module;

– simulation of the stress state of the bend in the mechanical modules ANSYS Static Structural.

The calculation scheme specified in the ANSYS Workbench calculation environment for numerical simulation of the problem under consideration is shown in Fig. 1.

CFD modeling of continuous phase flow by a gas pipeline bend was performed in ANSYS Fluent by numerical estimation of the Navier-Stokes and flow continuity equations, which were locked by a two-parameter turbulence model [28].

In order to fully investigate the processes of erosive wear of the main gas pipeline bends, it is necessary to determine the places of intense impact of dispersed particles into its walls, the speed, concentration, particle diameters, angles of attack in the place where the impact occurs. For such studies, the Lagrangian approach (DPM (Discrete Phase Model)) was chosen in ANSYS Fluent. This approach is based on the consideration of the motion of each dispersed phase individual particle under the action of forces from the flow of the continuous phase. The Lagrangian DPM model made it possible to determine and study the trajectories of a dispersed phase particles movement in a continuous phase flow by solving the differential equation of particles motion [29]. Finney's model [30] was chosen to simulate erosive wear of a gas pipeline bend, which is used for plastic materials such as pipeline steels. The stress state of gas pipelines in the ANSYS Static Structural module was modeled by the finite element method. The most basic ideas of the finite element method are discussed in [31].

II. Geometrical modelling

Three-dimensional geometric models of a gas pipeline bend with a bend angle of 90° (Fig. 2), which are widespread in the gas industry, were drawn. The outside diameter of the bend: $D_{o.bend}$ = 1420 mm; the nominal wall thickness: $\delta_{n.bend}$ = 24 mm. The elbow was modeled with

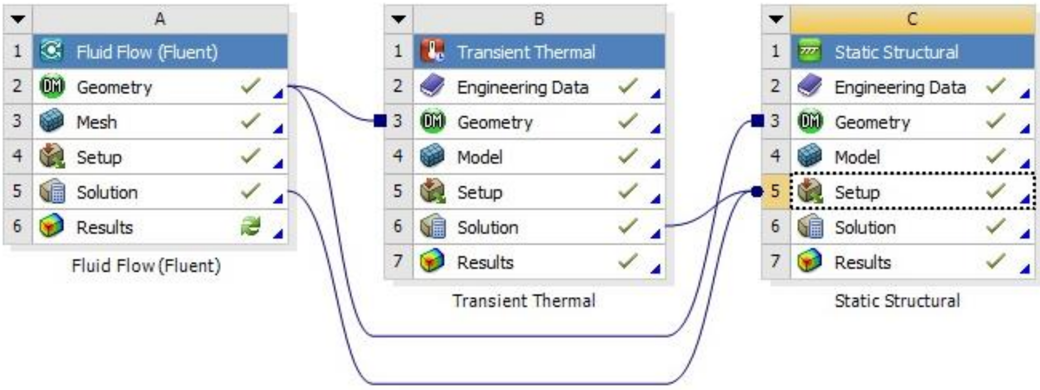


Fig. 1. Calculation chart provided by ANSYS Workbench.

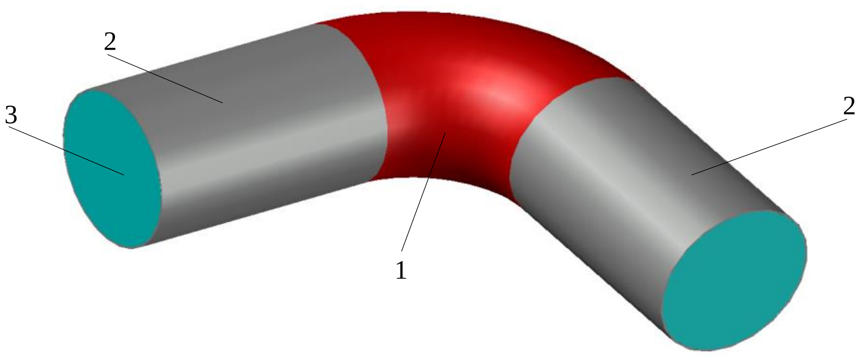


Fig. 2. Geometrical model of bend with adjusted pipe's sections: 1 – bend 90° 1420×24; 2 – pipe 1420×18.7; 3 – geometrical model of bend and adjusted pipe's inner cavity.

adjacent pipe sections of length 1 m, outside diameter: D_o = 1420 mm and nominal wall thickness: δ_n = 18.7 mm. To investigate the strength of the bend taking into account all the loads acting on it, it is necessary to solve the problem of the dynamics of the gas flow by the bend and the stresses in its wall in complex. Therefore, two separate volumetric geometric models were drawn. Geometric model of the inner cavity of the branch, along which the gas flow moves, and the geometric model of the branch wall.

III. Simulation of gas-dynamic processes

CFD simulations of gas-dynamic processes in the internal cavity of gas pipeline bends were performed in the ANSYS Fluent module. For this purpose, a tetraider volumetric computational grid was generated in the Fluent-Meshing preprocessor. In order to describe the near-wall processes as qualitatively as possible, a near-wall layer of gratings was created. The turbulence model was the standard two-parameter Realizable. The near the wall flow was simulated by the near-wall Enhanced Wall treatment function. Natural gas was chosen as the media from the ANSYS Fluent material database. To set the characteristics of liquid and solid dispersed particles that are contained in the continuous phase, the Discret Phase model was selected by the Lagrangian model. Condensate and sand, which are most often found in natural gas transported through gas pipelines, were specified as dispersed phases.

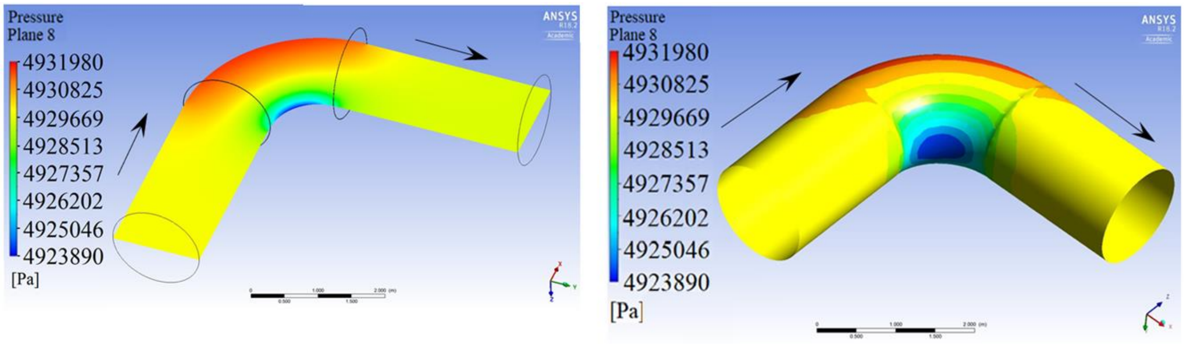
The characteristics of the dispersed phases and the boundary conditions that were set in the ANSYS Fluent preprocessor are given in Tab. 1.

In the postprocessor ANSYS Fluent, ANSYS CFD, the results of modeling the gas-dynamic processes in the bend were visualized. The results obtained made it possible to see the structure of the gas flow in the bend, the trajectories of condensate droplets and sand particles in the bend, to determine the places of intense erosion processes in the bend. Visualization was performed by plotting pressure fields in the plane of the horizontal longitudinal section of the bend (Fig. 3, a) and on the contours (Fig. 3, b), trajectories of condensate droplets and solid particles in the continuous phase flow, which were colored corresponding to their velocity (Fig. 4, b) and diameter (Fig. 4, c, d) in accordance with the scale of

Table 1

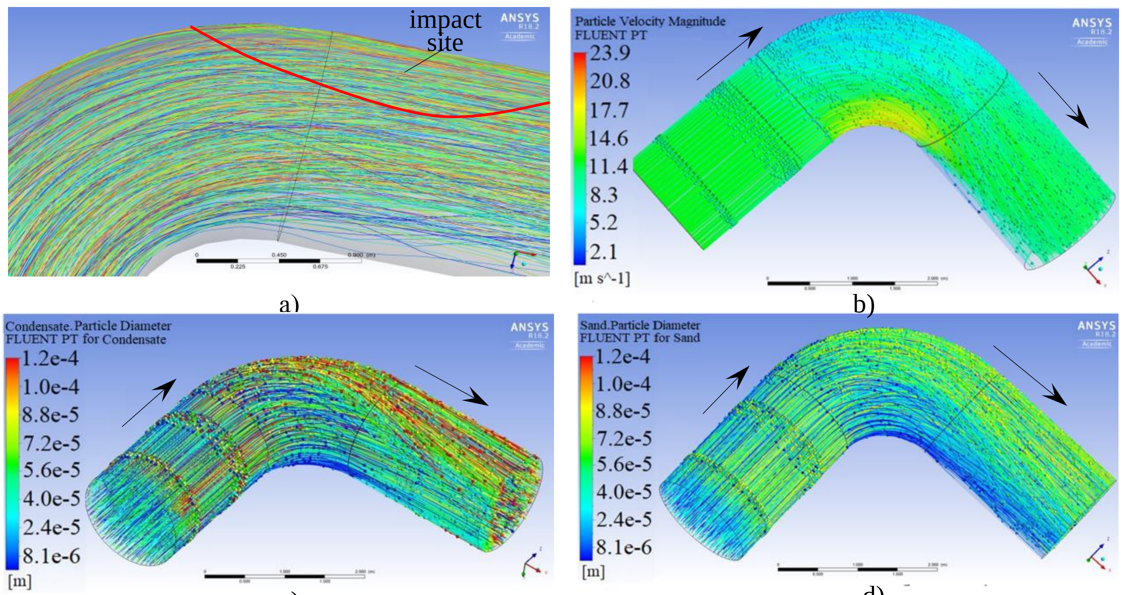
Parameters of multiphase flow CFD modelling in the research bend

Fluid	Natural gas	Condensate	Sand
Mass flow at the inlet, kg/s	697.9	0.25	0.0019
Outlet pressure, MPa	4.93	-	-
Density, kg/m^3	-	960	2800
Temperature, K	297	297	297
Turbulence intensity, %	5	-	-
Maximum particle diameter, mm	-	0.34	0.12
Minimum particle diameter, µm	-	3	0.1



a) b)

Fig. 3. Pressure distribution fields in the bend: a) – through the horizontal longitudinal section; b) – on the contours.



a) b) c) d)

Fig. 4. The results of modeling the motion of the dispersed phases in the gas flow bend: a) – trajectories of the dispersed phase; b) – trajectories of the dispersed phases are colored corresponding to their speed; c) – trajectories of the condensate droplets are colored corresponding to their diameter; d) – trajectories of solid particles are colored corresponding to the diameter of the particles.

values, the field of concentration of the dispersed phase (Fig. 5, a) and the field of the rate of erosive wear (Fig. 5, b, c) on the contours diversion.

The pressure in the inner cavity of the bend is not evenly distributed (Fig. 3). In the bend, the pressure increases in the direction from the concave to the convex side. At the concave side of the bend, the pressure drops to 4923890 Pa, and at the convex side it rises to 4931980 Pa. This uneven pressure distribution influences the stress state of the bend.

Studying the trajectories of condensate droplets and solid particles, it was found that in the bend convex side, most of the dispersed phases (up to 40 %) move in trajectories that approach the wall at the turning point, but the particles do not hit the wall. A smaller part of the dispersed phases at the point of the bend turn moves along trajectories whose radius is larger than the bend radius, as a result of which condensate drops and solid particles impact the bend wall and pipe welded to it on the right side (Fig. 4, a). The most intense impact of dispersed phases to the wall occurs at the end of the bend from its convex side and at the beginning of the pipe welded to the bend. With the distance from the bend turn, the angle of impact decreases. At the end of the bend, the angle of impact is about 40°, and along the pipe welded to the bend, the angle of impact decreases. The velocity of dispersed phases in the place of shock, where the bend ends, is about 8.5 m/s, and at the beginning of the pipe welded to the bend it reaches 13 m/s (Fig. 4, b).

Changing the direction of the gas flow in the bend leads to a restructuring of the velocity profile of the continuous and dispersed phases in longitudinal and cross sections (Fig. 4, b). Along the concave side, the dispersed phase accelerates to 25.8 m/s, and along the convex side, decelerates to 7 m/s. At the exit from the bend along its convex side, the dispersed phase accelerates to 13 m/s, and along the concave side slows down to 6 m/s.

The dispersed phase in the bend is redistributed unevenly along the diameter (Fig. 4, c, d). Most of the dispersed phases of large diameters, move from the convex side of the bend and some of them hit the wall of the bend and the wall of the pipe welded to the bend. Dispersed phases of smaller diameter move from the concave side of the bend.

IV. Erosive wear modelling

It can be seen from the concentration fields of the dispersed phase on the bend outlet that intense impact of liquid and solid particles to the wall occurs from its convex side (Fig. 5, a). The impact point extends along the bend and the adjacent pipe starting from the middle part of the bend and for a length of 1.5 m from the circular weld in the direction of the fluid movement by the pipe adjacent to the bend. The most intense impact of the dispersed phase to the wall occurs from the convex side of the bend at the location of gas flow outlet and at the beginning of the adjacent straight pipe section (maximum concentration of dispersed phases on the circuits 1.4 kg/s).

The erosive wear rate fields on the bend circuits made it possible to conclude that the most intense erosive wear occurs on its convex side between the angle of 60° and 90° at the point of gas flow outlet and at the beginning of the pipe welded to the bend for a length of 0.1 m in the direction of gas flow motion (Fig. 5, b, c).

The maximum erosive wear rate of the bend is $2.0 \cdot 10^{-8}$ kg/ $m^2 \cdot s$. At this speed, the wall of the bend becomes thinner at a rate of 0.08 mm/year. The rate of erosive wear decreases sharply at the beginning of the pipe welded to the bend (Fig. 5, b, c), although the intense impact of liquid and solid particles on the wall of the pipe

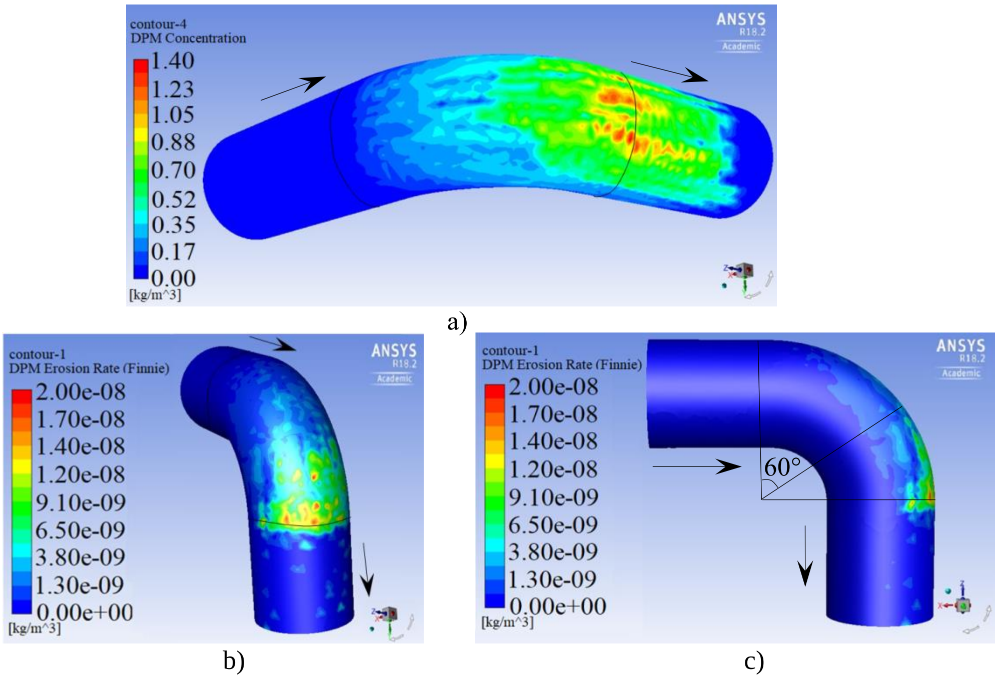


Fig. 5. The results of erosion wear modeling in the branch: a) – field concentration of dispersed phases on the circuits; b), c) – field of erosion wear rate on the contours.

welded to the bend occurs along the following 1.5 m from the circular weld (Fig. 5, a) in the direction of fluid movement. The reason for this is in a decrease in the angle of impact as the dispersed phase impact site moves away to the wall of the pipe welded to the bend from the circumferential weld.

The process of bends erosive wear occurs at a certain rate and the depth and shape of erosion defects are changing all the time. There is a constant increase in the size of erosion defects. In order to take into account the influence of the complex three-dimensional shape of the inner surface of the bend wall in place of erosion wear and an increase in the magnitude of erosion defects on the stress state of the bend, it is necessary to develop geometric models of bends with erosional defects of the wall at certain intervals. The wall of the pipe bend in the place of erosive wear must be "moved" in accordance with the rate of erosive wear. For this purpose, the field of erosive wear rate on the bend contours (Fig. 5, b) was used for calculating the value of bend erosive wear rate at many of its points by which the rate of wall thinning at these points was calculated. Based on the rate of the bend wall thinning, the value of the bend wall thinning were determined at many points of the bend after 30, 42, 46 and 52 years of gas pipeline operation, and geometric models of bends with a complex three-dimensional geometric shape of erosional wall defects were built (Fig. 6), which will be at certain intervals time. The maximum depth of erosional defects in the bend wall after 30 years of operation was 6.9 mm, 42 years - 9.6 mm, 46 years - 10.5 mm and 52 years - 11.9 mm.

V. Modelling of temperature difference

Temperature influences cause longitudinal forces in the pipe walls, shaped elements of gas pipelines, which lead to the occurrence of longitudinal temperature stresses. The magnitude of the temperature stresses depends on the value of the temperature difference. The temperature difference is the difference between the maximum or minimum possible temperature of the pipeline walls during operation and the lowest or highest temperature of the pipe walls, at which the design diagram of the pipeline is fixed. For underground pipelines, the temperature difference is assumed to be ± 40°C.

The temperature difference in the bend wall was simulated in the Transient Thermal module for thermal processes calculations. To accomplish this, the characteristics of the pipe steel were set, the temperature of the branch wall at the initial moment of time (+20 °C) and the temperature of the branch wall at the final moment of time (-20 °C).

VI. Results and Discussions

The stress state of the gas pipeline bends was simulated in the mechanical modules ANSYS Static Structural. For this purpose, the 3D geometry of the bend wall with and without erosion defects was imported into this module. In the material database, pipe steel of strength class K60 was specified (ultimate strength MPa: σ_{str} = 589 MPa, yield strength: σ_{ys} = 441 MPa).

To take into account the influence of uneven pressure distribution in the bend internal cavity (Fig. 3) on its stress state, the results of gas-dynamic modeling from the ANSYS Fluent module were imported into the ANSYS Static Structural mechanical module. The pressure distribution on the bend inner wall was imported (Fig. 7). To account for the effect of the temperature difference on the stress state of the bend, the temperature difference simulation results from the Transient Thermal module were imported into the ANSYS Static Structural mechanical module.

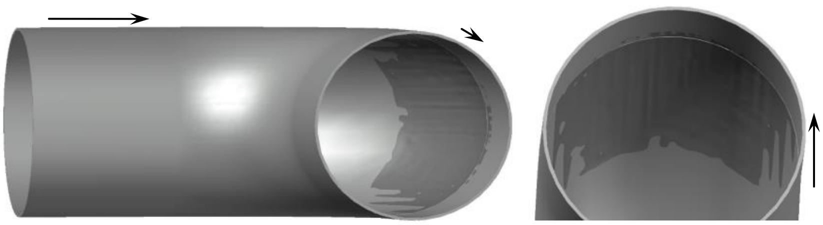


Fig. 6. Geometric model of bend with erosion defects.

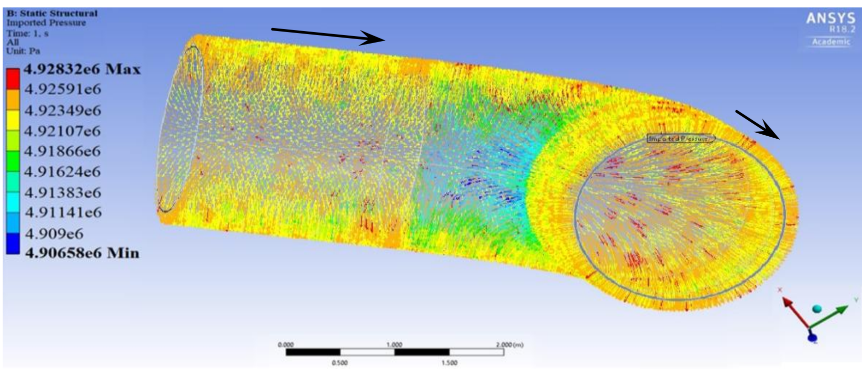


Fig. 7. The results of the calculation of the pressure distribution on the inner wall of the bend imported from ANSYS Fluent в ANSYS Static Structural.

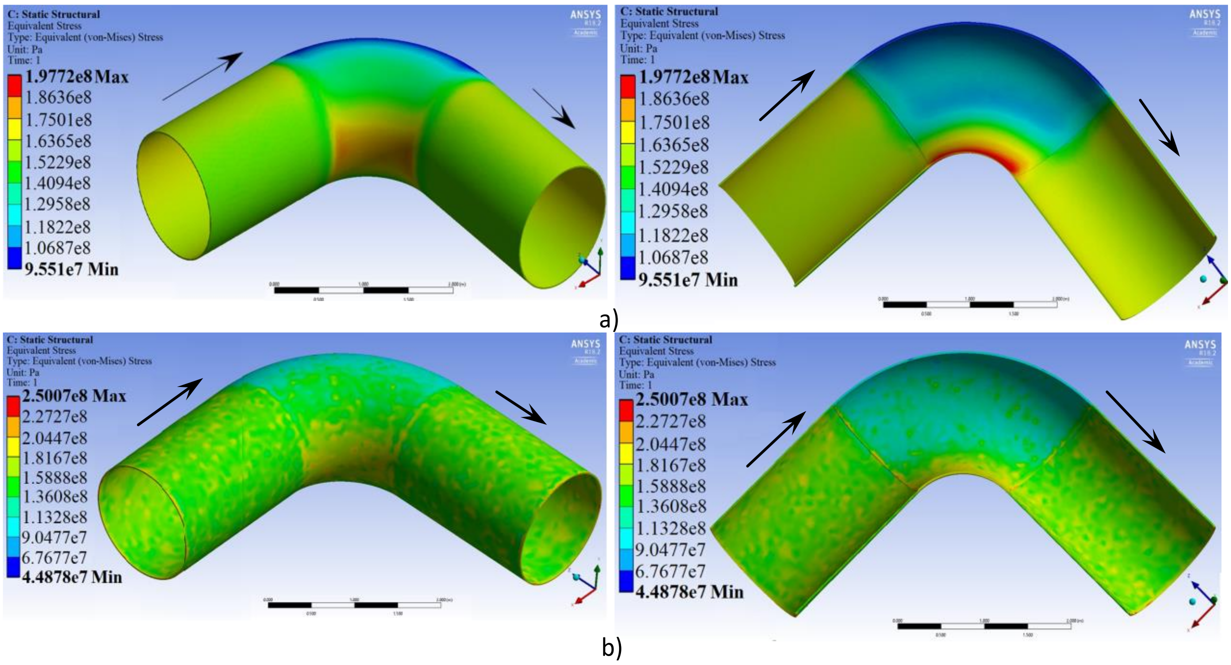


Fig. 8. Distribution of equivalent Mises stresses in the bend wall: a) – from the impact of internal pressure; b) – from the impact of internal pressure and temperature difference.

The results of numerical simulation of the stress state of the bend without erosion defects were visualized by plotting the distribution of equivalent stresses according to Mises principle in the bend walls from only the internal pressure impact (Fig. 8, a) and from the impact of internal pressure and temperature difference (Fig. 8, b). Equivalent stresses are unevenly distributed in the bend wall. Their maximum values are observed from the bend concave side (the highest value is 197.7 MPa in case of only internal pressure impact and 250 MPa under the impact of internal pressure and temperature difference), the minimum values are observed with the convex side (the lowest value is 95.5 MPa under only the internal pressure impact and 44.9 MPa under the impact of internal pressure and temperature difference). The minimum bends safety margin is observed from the concave side. In this case, the equivalent stresses in the wall of the bend from its concave side are greater than in the straight sections of the pipeline. The highest value of the equivalent Mises stresses from the bend concave side is 197.7 MPa in case of only internal pressure and 250 MPa in the case of internal pressure and temperature difference.

Modeling of the stress state of a bend with erosional defects of the wall was carried out in the same way as modeling the stress state of a bend without defects. For such modeling, firstly geometric models of bends with a complex three-dimensional geometric shape of erosional wall defects (Fig. 6) were imported into the ANSYS Fluent fluid dynamics module for modeling gas dynamic processes and into the Transient Thermal processes calculation module to simulate the temperature difference in the bend walls. Then the results of such simulations and geometric models of erosion-worn bends were imported into the mechanical module ANSYS Static Structural to simulate the stress state.

The results of modeling the stress state of bends with erosional wall defects were visualized by plotting colored fields of equivalent Mises stresses in the bend wall from the impact of only internal pressure (Fig. 9, a, b, d, f, g) and from the action of internal pressure and temperature difference (Fig. 9, c, e, h, i) for different sizes of erosion defects.

If the maximum depth of the erosion defect of the bend wall was 6.9 mm, then the maximum equivalent stresses were concentrated from the concave side of the bend and in deep places of the erosion defect (Fig. 9, a, b, c). If the maximum depth of erosional defects of the bend wall is 9.6 mm, 10.5 mm and 11.9 mm, then the maximum equivalent stresses were concentrated in the deepest places of the erosion defect (Fig. 9, d, e, f, g, h, i). The values of the maximum equivalent stresses in the bend with erosional defects of the wall obtained from the impact of only internal pressure and from the impact of internal pressure and temperature difference are given in Tab. 2.

Conclusion

Changes in the direction of flow in main gas pipelines bends leads to the occurrence of a transverse pressure gradient, dispersed phase impacting the wall, which leads to erosive wear. In bends with a bend angle of 90°, about 40 % of the particles of the dispersed phase are impacting the wall, while the concentration of particles of larger diameter at the impact site is much higher than less. The most intense impact of particles occurs at the end of the bend from its convex side and at the beginning of the pipe welded to the bend. Therefore, the maximum erosive wear

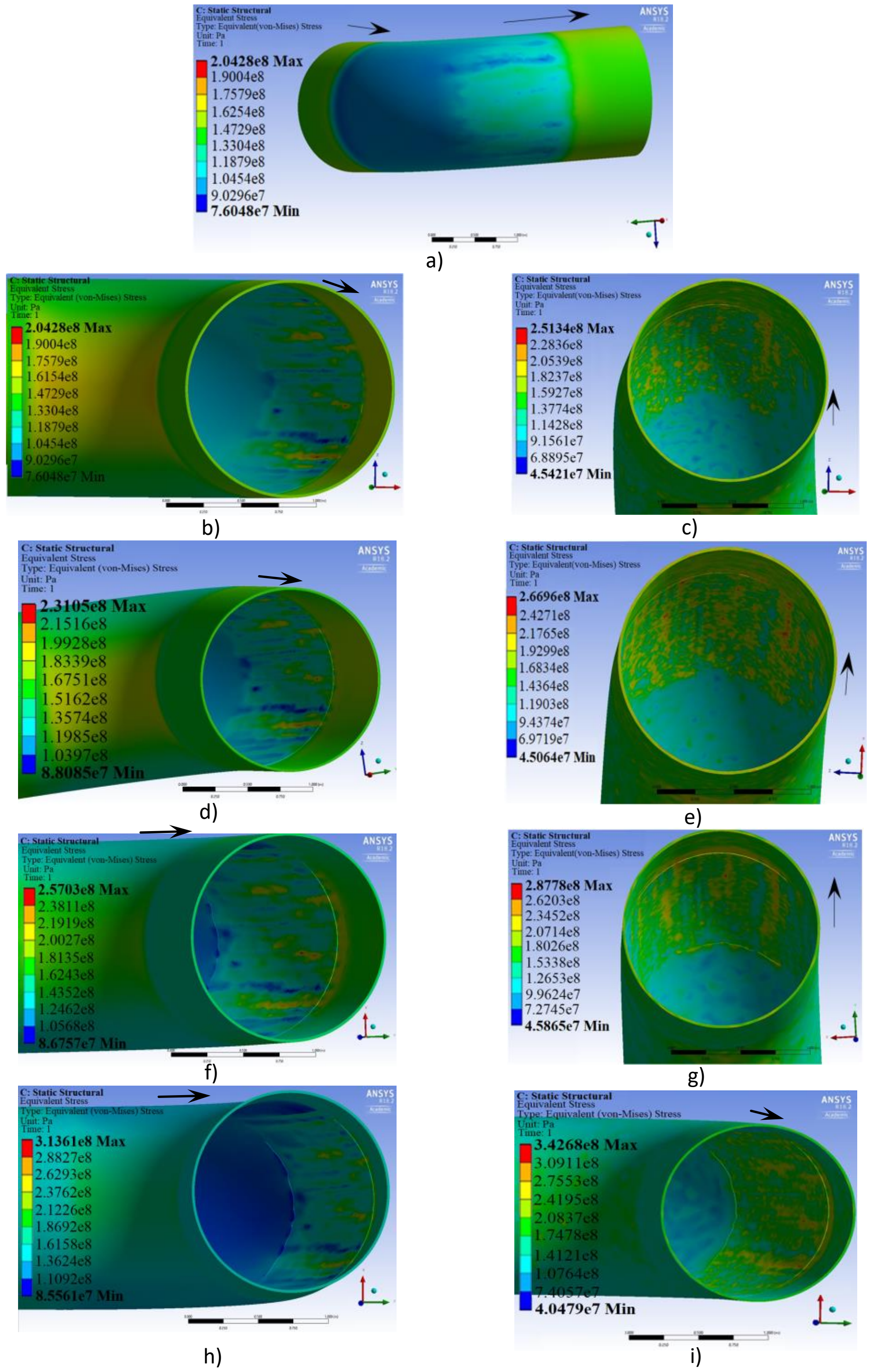


Fig. 9. Distribution of equivalent Mises stresses in the bend with erosive wear of the wall: a), b), c) – maximum depth of the erosion defect of the wall 6.9 mm; d), e) – maximum depth of the erosion defect of the wall is 9.6 mm; f), g) – maximum depth of the erosion defect of the wall is 10.5 mm; h), i) – maximum depth of the erosion defect of the wall is 11.9 mm.

of the bends occurs from their convex side at the place of the gas flow outlet between the angle of 60° and 90° of the bend and at the beginning of the pipe welded to it in the direction of flow.

The problem of the synergistic effect of gas-dynamic processes (uneven pressure distribution in the internal cavity), temperature difference and erosion wear on the stress state of main gas pipelines bends was solves by means of numerical modelling. The obtained results of modeling the processes of bends erosional wear made it possible to develop an algorithm for modeling three-dimensional erosional defects of their walls. The complex three-dimensional geometric shape of bend erosional defects varied in accordance with the rate of their erosional wear. This algorithm made it possible to determine the regularities of the influence of bend erosional defects magnitude on their stress state. It was found that with a maximum depth of erosion defects in the

Table 2

Maximum equivalent stresses in the bend with erosive wall defects

№	Maximum depth of pipe wall erosion defect, mm	Maximum equivalent stresses, MPa	
		Internal pressure impact	Internal pressure and temperature difference impact
1	6.9	204.3	240.9
2	9.6	231.1	267.0
3	10.5	257.0	287.8
4	11.9	313.6	342.7

bend wall of 9.6 mm, 10.5 mm and 11.9 mm, the equivalent stresses in the deep places of the erosion defect are greater than on the concave side of the bend and in straight sections of the gas pipeline and can lead to a loss of strength.

The results obtained make it possible to determine early the location of erosion defects in the wall of gas pipelines bends, to assess their performance and to rank such bends with defects according to the degree of danger, to determine which of them are in critical condition and require immediate repair.

Doroshenko Ya.V. – Doctor of Technical Sciences, Professor of the Department of Gas and Oil Pipelines and Storages;
Kogut H.M. – Doctor of Philosophy, Associate Professor of the Department of Energy Management and Technical Diagnostics;
Rybitskyi I.V. – Doctor of Technical Sciences, Associate Professor of the Department of Energy Management and Technical Diagnostics;
Tarayevs'kyy O.S. – Doctor of Technical Sciences, Professor of the Department of Gas and Oil Pipelines and Storages;
Pyrig T.Yu. – Candidate of Technical Sciences, Associate Professor of the Department of Gas and Oil Pipelines and Storages.

[1] M.O. Karpash, A.P. Oliynyk, G.M. Kogut, A.M. Klyun, Science and Innovation 15(6), 73 (2019); https://doi.org/10.15407/scin15.06.079.
[2] N. Aung, T. Yuwono, ASEAN Journal on Science and Technology for Development 30(1&2), 1 (2013); https://doi.org/10.29037/ajstd.344.
[3] M. Toda, N. Kamori, S. Saito, S. Maeda, J. Chem. Eng. Jpn. 5, 4 (1972).
[4] R. Wood, T. Jones, N. Miles, J. Ganeshalingam, Wear 250, 770 (2001); https://doi.org/10.1016/S0043-1648(01)00715-3.
[5] J. Smart, Pipeline and Gas Journal 10, 82 (2007).
[6] Ya. V. Doroshenko, O. M. Karpash, B. N. Hozhaiev, Rozvidka ta rozrobka naftovykh i hazovykh rodovyshch 4(73), 35 (2019); https://doi.org/10.31471/1993-9973-2019-4(73)-35-45.
[7] V.B. Volovetskyi, A.V. Uhrynovskyi, Ya.V. Doroshenko, O.M. Shchyrba, Yu.S. Stakhmych, Journal of Achievements in Materials and Manufacturing Engineering 101(1), 27 (2020); https://doi.org/10.5604/01.3001.0014.4088.
[8] V.B. Volovetskyi, Ya.V. Doroshenko, G.M. Kogut, I.V. Rybitskyi, J.I. Doroshenko, O.M. Shchyrba, Archives of Materials Science and Engineering 108(1), 24 (2021); https://doi.org/10.5604/01.3001.0015.0250.
[9] V.B. Volovetskyi, Ya.V. Doroshenko, O.S. Tarayevs'kyy, O.M. Shchyrba, J.I. Doroshenko, Yu.S. Stakhmych, Journal of Achievements in Materials and Manufacturing Engineering 105(2), 61 (2021); https://doi.org/10.5604/01.3001.0015.0518.
[10] O. Tarayevs'kyy, Metallurgical and Mining Industry 3, 61 (2013).
[11] O. Tarayevs'kyy, Metallurgical and Mining Industry 3, 68 (2013).
[12] O. Taraevskyy, Metallurgical and Mining Industry 7(2), 62 (2015).
[13] L.S. Shlapak, M.P. Linchevskyi, V.O. Sarkisov, Naftohazova haluz Ukrainy 3, 44 (2014).
[14] M.D. Serediuk, Journal of Achievements in Materials and Manufacturing Engineering 106(2), 77 (2021).
[15] M.D. Serediuk, S.Ya. Hryhorskyi, Neftianoe khoziaistvo 2, 100 (2015).
[16] M. Serediuk, S. Grygorsky, European Journal of Enterprise Technologies 5/2(83), 30 (2016); https://doi.org/10.15587/1729-4061.2016.77190.
[17] I.V. Rybitskyi, V.I. Trofimchuk, G.M. Kogut, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu 3, 47 (2020); https://doi.org/10.33271/nvngu/2020-3/047.
[18] Y. Melnychenko, L. Poberezhny, V. Hrudz, V. Zapukhliak, I. Chudyk, T. Dodyk, Lecture Notes in Civil Engineering 102, 241 (2021); https://doi.org/10.1007/978-3-030-58073-5_19.
[19] P. Dutta, S. Saha, N. Nandi, International Journal of Applied Engineering Research 10(11), 128 (2015).

[20] Ya. Doroshenko, I. Rybitskyi, Eastern-European Journal of Enterprise Technologies 1/8(103), 28 (2020); https://doi.org/10.15587/1729-4061.2020.192828.
[21] M. Abdulwahhab, N. Kumar, F. Dakhil, International Journal of Engineering Science and Technology 4(7), 33 (2012).
[22] J. Zhang, J. Kang, J. Fan, J. Gao, Journal of Natural Gas Science and Engineering 32, 334 (2016); https://doi.org/10.1016/j.jngse.2016.04.056.
[23] Ya. Doroshenko, V. Zapukhliak, Ya. Grudz, L. Poberezhny, A. Hrytsanchuk, P. Popovych, O. Shevchuk, Archives of Materials Science and Engineering 101(2), 63 (2020); https://doi.org/10.5604/01.3001.0014.1192.
[24] S. Marie, S. Chapuliot, Y. Kayser, M. Lacire, B. Drubay, B. Barthelet, P. Delliou, V. Rougier, C. Naudin, P. Gilles, M. Triay, International Journal of Pressure Vessels and Piping 84(10-11), 659 (2007); https://doi.org/10.1016/j.ijpvp.2007.05.006.
[25] O.O. Larin, K.E. Potopalska, Праці Одеського політехнічного університету 3(53), 12 (2017); https://doi.org/10.15276/opu.3.53.2017.02.
[26] Ya.V. Doroshenko, Naftohazova enerhetyka 1(33), 36 (2020); https://doi.org/10.31471/1993-9868-2020-1(33)-36-46.
[27] Ya. Doroshenko, V. Zapukhliak, K. Poliarush, R. Stasiuk, S. Bagriy, Eastern-European Journal of Enterprise Technologies 2/1(98), 28 (2019); https://doi.org/10.15587/1729-4061.2019.164351.
[28] K. Squires, J. Eaton, Phys. Fluid 2(7), 1191 (1990); https://doi.org/10.1063/1.857620.
[29] J.O. Hinze, Turbulence (McGraw-Hill, New York, 1975).
[30] I. Finnie, Y. Kabil, Wear 8, 60 (1965); https://doi.org/10.1016/0043-1648(65)90251-6.
[31] R.H. Gallagher, Finite element analysis: Fundamentals (Prentice-Hall, New York, 1975.

Я.В. Дорошенко, Г.М. Когут, І.В. Рибіцький, О.С. Тараєвський, Т.Ю. Пиріг

Чисельне дослідження ерозійного зношування та міцності відводів магістральних газопроводів

Івано-Франківський національний технічний університет нафти і газу, Івано-Франківськ, Україна,
yaroslav.doroshenko@nung.edu.ua

Виконано CFD моделювання руху одно, багатофазного газового потоку відводом магістрального газопроводу, ерозійного зношування його стінки. Досліджено газодинамічні процеси, структуру однофазних потоків у внутрішній порожнині відводу. Лагранжевим підходом (модель Discrete Phase Model) виконано тривимірне моделювання руху багатофазних потоків у відводі. Визначено траєкторії руху рідких і твердих частинок відводом, розподіл швидкості та розмірів дисперсних фаз у його внутрішній порожнині, виявлено місця інтенсивного ударяння частинок до стінки, місця інтенсивного ерозійного зношування відводу. За результатами моделювання побудовано геометричні моделі відводів з складною тривимірною формою ерозійних дефектів стінки. В модулі Static Structural виконано комплексне моделювання напруженого стану відводів магістральних газопроводів з урахуванням газодинамічних процесів, які відбуваються у їхній внутрішній порожнині (нерівномірного розподілу тиску у внутрішній порожнині), ерозійного зношування стінки та температурного перепаду. Визначено зони потенційного ризику втрати міцності відводів із ерозійними дефектами. Визначено закономірності впливу величини ерозійних дефектів на напружений стан відводів.

Ключові слова: багатофазний потік, відвід, газопровід, газодинамічний процес, ерозійне зношування, напружений стан, температурний перепад, форма ерозійного дефекту.