Development of an algorithm for determining the diameter and number of compressor stations of a gas pipeline in the C++ programming language

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Abstract. The paper considers the possibility of selecting the optimal diameter of a gas pipeline with a length of more than 1000 km and a capacity of 10 million m³ per year of natural gas using an algorithm developed in the C++ programming language in order to minimize time costs. The results of calculations for three options of pipeline diameters - 820, 1020, 1200 mm are considered to justify the proposed algorithm. The gas pipeline strength in the longitudinal direction was checked for the inadmissibility of plastic deformations and general stability using standard calculation methods laid down in the program. Temperature differences and parameters of the pumped product are taken into account.

1. Introduction
One of the main tasks of the gas pipeline design is to determine the technological parameters that ensure the greatest feasibility and economic efficiency [1]. These parameters include the diameter of the pipeline, operating pressure, the number of compressor stations (CS) and the distance between them. Calculation of the optimal diameter of a gas pipeline is a complex task requiring significant calculations and consideration of many particular factors [2]. Therefore, the search for methods for determining the necessary parameters with minimal time is an actual area of research.

This paper demonstrates the selection of the optimal diameter and the number of compressor stations, taking into account the verification of the underground pipeline for strength and stability, depending on various pressure safety factors using an algorithm developed in the C++ programming language. In addition, the program calculates the physical properties of the gas and the amount of metal that will be required for the pipeline construction.

2. Materials and methods
Input data for calculation:
- the gas pipeline: length, steel grade and category of the pipeline, welding characteristics, type of insulation coating and wrapper, operating temperature, type and characteristics of soil, gas pipeline operating area;
- gas: mass composition;
- required annual productivity;

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- type of gas-compressor unit (GCU);
- type of gas purification system;
- availability of cooling systems.

Figure 1 shows the graphical model of the algorithm for calculating the diameter and number of compressor stations of the main gas pipeline in the C++ programming language.

![Graphical model of the program algorithm](image)

**Figure 1.** The graphical model of the program algorithm.

The algorithm includes a hydraulic calculation of the gas pipeline. The hydraulic calculation requires main parameters of the gas mixture: density, molar mass, gas constant, gas compressibility coefficient,
viscosity. The known gas density can found Pseudo critical temperature (K) and pressure (MPa) for natural gases with a methane content of 85 % or more under standard conditions. Further, the suction and discharge pressure can be determined by the selected type of gas compressor unit and the required flow rate [3]. The three most suitable outer diameters are selected according to the data in table 1.

### Table 1. Approximate values of the gas pipeline diameter

| Passage diameter | Annual productivity Qg, mln. m³/year |
|------------------|--------------------------------------|
|                  | Discharge pressure = 5.5 MPa | Discharge pressure = 7.5 MPa |
|                  | Suction pressure = 3.8 MPa | Suction pressure = 5.1 MPa |
| 500              | 1.6-2.0                        | 2.2-2.7                        |
| 600              | 2.6-3.2                        | 3.4-4.1                        |
| 700              | 3.8-4.5                        | 4.9-6.0                        |
| 800              | 5.2-6.4                        | 6.9-8.4                        |
| 1000             | 9.2-11.2                       | 12.1-14.8                      |
| 1200             | 14.6-17.8                      | 19.3-23.5                      |
| 1400             | 21.5-26.4                      | 28.4-34.7                      |

The nominal wall thickness of the pipeline is determined using the standard method (equation 1)

\[
\delta = \frac{n \cdot P \cdot D_{outer}}{2(R_1 + n \cdot P)}
\]  

where \( n \) = load safety factor; \( P \) = pipeline pressure; \( D_{outer} \) = outer diameter of the pipeline; \( R_1 \) = calculated metallic resistance of the pipe.

When calculating the longitudinal axial stresses from the impact of temperature and internal pressure, it is necessary to take into account the modulus of elasticity of the material, the temperature difference and the Poisson’s ratio, it took equal to 0.3 [4, 5]. If the value of the longitudinal axial stresses is negative, a correction of the wall thickness is necessary. The wall thickness is adjusted, taking into account the coefficient \( \Psi_1 \). This coefficient represents the biaxial stress state of the gas pipeline metal (equation 2).

\[
\delta = \frac{n \cdot P \cdot D_{outer}}{2(\Psi_1 \cdot R_1 + n \cdot P)}
\]

According to the normative documentation, underground pipelines are checked for strength in the longitudinal direction, as well as for the absence of plastic deformations. The strength in the longitudinal direction is checked according to the following condition (equation 3):

\[
|\sigma_{axial} N| \leq \Psi_2 \cdot R_1
\]

where \( \sigma_{axial} N \) = longitudinal axial stresses; \( \Psi_2 \) = coefficient that takes into account the biaxial stress state of the pipe metal.

The inadmissibility of pipeline plastic deformations in the longitudinal and ring directions is checked on the basis of conditions that take into account the maximum total longitudinal stresses in the pipeline.
from standard impact (equation 4) and ring stresses in the walls from standards-compliant internal pressure (equation 5).

1 condition  \[ \sigma_{axial}^n \leq \psi_3 \frac{m}{0.9 k_T} R_2^n \]  

2 condition  \[ \sigma_\theta \leq \frac{m}{0.9 k_T} R_2^n \]  

where \( \sigma_{axial}^n \) = maximum total longitudinal stresses in a pipeline from standard loads and impacts; \( \psi_3 \) = coefficient taking into account the biaxial stress state of the pipeline metal; \( m \) = coefficient of pipeline operating conditions; \( \sigma_\theta \) = ring stresses in the walls of a pipeline from the standard internal pressure (equation 6).

\[ \sigma_\theta = \frac{n P D_{in}}{2 \sigma} \]  

where \( D_{in} \) = internal diameter of the gas pipeline.

Checking the overall stability of a pipeline in the longitudinal direction is performed in the plane of the least rigidity of the system, taking into account the internal pressure, temperature difference and a force at which there is a loss of longitudinal stability of the pipeline (equation 7).

\[ S \leq m \cdot N_{critical} \]  

The equivalent longitudinal axial compression force in the pipeline \( S \) arises from the action of two design loads and impact. The critical force is determined depending on the soil resistance by the longitudinal and transverse vertical displacements of a unit length of the pipeline and the axial moment of inertia of the pipeline cross-section. The weight of the backfill determines the resistance by transverse vertical movement of a unit length of a pipeline and the own weight of the pipeline referred to a unit of length. Also, when determining the critical force it is necessary to take into account the average specific pressure per unit contact surface of the pipeline with the soil, the load from a weight of insulation and the load from the weight of a product in the pipeline [5, 6]. Checking pipelines for stability takes a sufficient amount of time. As a result, the speed of design implementation is reduced, which directly reduces the economic efficiency of the project as a whole [7, 8].

3. Results and Discussion

As an experiment, the calculation of a 1010 km pipeline with a capacity of 10 million m³ per year of natural gas is considered using an algorithm developed in the C++ programming language. The pipeline starts near the Arkhangelsk city and crosses Arkhangelsk region. Table 2 presents the mass composition of the pumped product. GCU N-300-1.23 was selected as a working unit with a two-stage gas processing and an air-cooling system.

| Components | CH₄ | C₂H₆ | C₃H₆ | C₄H₁₀ | C₅H₁₂ | N | CO₂ |
|------------|-----|------|------|-------|-------|---|-----|
| The content of components, % | 97.3 | 1.7  | 0.4  | 0.2   | 0.2   | 0.1 | 0.1 |
- The pipeline belongs to Class 1 according to regulatory documents [5]. Gas pipeline material characteristics: tensile strength 550 MPa, yield strength 441 MPa [9]. The pipes are thermally hardened and made by submerged arc welding along a continuous technological seam [10]. Operating temperature is 6 °C.

- The insulation coating has the following characteristics: density 1200 kg/m³ with a thickness of 3 mm.

- Soil characteristics: internal friction angle is 24°, soil bearing capacity 390 kPa, soil specific gravity 18000 N/m³.

According to the calculation results of the program, the gas density was 0.7434 kg/m³, the molar mass was 16.62 g/mol, dynamic viscosity coefficient = 1.14·10⁻⁵ Pa·s, compressibility factor = 0.878. The calculation results for the pipeline with a diameter of 1020 mm are presented in Table 3.

| Pipe wall thickness, mm | Number of compressor stations | Distance between compressor stations, km | Volume of steel needed, m³ |
|------------------------|-------------------------------|----------------------------------------|--------------------------|
| 10                     | 10                            | 101                                    | 28857                    |

The average pressure in the pipeline was 4.602 MPa (pressure at the outlet of a compressor station is 5.36 MPa, pressure at the inlet of a compressor station is 3.75 MPa). The pipe friction number was 0.011. The magnitude of the longitudinal axial stresses was 54.882 MPa, and the maximum axial stresses from internal pressure were 256.202 MPa. The results were also obtained on the magnitude of the stresses from the temperature difference: 164.861 MPa - the value of the longitudinal axial stresses from the negative and positive temperature difference.

The calculation results for the pipeline with a diameter of 820 mm are presented in Table 4.

| Pipe wall thickness, mm | Number of compressor stations | Distance between compressor stations, km | Volume of steel needed, m³ |
|------------------------|-------------------------------|----------------------------------------|--------------------------|
| 7                      | 31                            | 32.581                                 | 18048                    |

The pressure values at the inlet and outlet of a pipeline remained unchanged. The value of axial stresses remained at the same level hydraulic friction coefficient was 0.011.

The calculation results for the pipeline with a diameter of 1220 mm are presented in Table 5.

| Pipe wall thickness, mm | Number of compressor stations | Distance between compressor stations, km | Volume of steel needed, m³ |
|------------------------|-------------------------------|----------------------------------------|--------------------------|
| 10                     | 4                             | 252.5                                  | 38374                    |

The average pressure in the gas pipeline was 4.602 MPa, as in the case with diameters of 820 and 1020 mm. The value of the longitudinal axial stress increased to 61.464 MPa. Maximum axial stresses from internal pressure were 276.145 MPa, and the values of the longitudinal axial stresses from negative and positive temperature difference were 140.969 MPa.
4. Conclusions

According to the results of the research, we can say that the presented algorithm, developed in the C++ programming language, greatly facilitates the calculation of the selection of the optimal diameter in the design of gas pipelines. This fact, in its turn, allows making the design process less time-consuming. The user can choose the optimal diameter of the gas pipeline based on the required factor of safety for pressure (it is selected according to regulatory documents), the number of compressor stations and the distance between these stations.

For the considered pipeline with a length of 1010 km with a throughput capacity of 10 million m³ of natural gas being designed in the city of Arkhangelsk, it is possible to take a diameter of 1020 mm and a wall thickness of 9 mm at the lowest cost. In this case, ten compressor stations will be required, and the volume of the pipe metal will be 28800 m³.

References

[1] Alinia Kashani A H, Molaei R 2014 Techno-economical and environmental optimization of natural gas network operation Chemical Engineering Research and Design 92 (11) 2106-2122
[2] Sanaye S, Mahmoudimehr J 2013 Optimal design of a natural gas transmission network layout Chemical Engineering Research and Design 91(12) 2465-2476
[3] Wei L, Dong H, Zhao J, Zhou G 2016 Optimization model establishment and optimization software development of gas field gathering and transmission pipeline network system Journal of Intelligent and Fuzzy Systems 31(4) 2375-2382
[4] El-Shiekh T M 2013 The optimal design of natural gas transmission pipelines Energy Sources, Part B: Economics, Planning and Policy 8(1) 7-13
[5] SP 36.13330.2012 Trunk pipelines (Updated version of SNiP 2.05.06-85) Russia 93
[6] Kucheryavyi V I, Mil’kov S N 2017 Evaluation of strength reliability of an oil-and-gas pipeline wall Journal of Machinery Manufacture and Reliability 46(3) 309-312
[7] Chvileva T A, Golovina E I 2017 Publication of reporting of metallurgical companies in context of the concept of corporate sustainable development Journal of Industrial Pollution Control 33 (1) 926-930
[8] Cherepovitsyn A E, Kraslavski A 2016 Study of the innovative potential of an oil and gas company at different stages of field exploitation [Исследование инновационного потенциала нефтегазовой компании на разных стадиях эксплуатации месторождений] J. of Min. Inst. 222 892-902
[9] Bolobov V I, Chupin S A, Bochkov V S, Mishin I I 2019 Service life extension for rock cutters by increasing wear resistance of holders by thermomechanical treatment Gornyi Zhurnal (5) 67-71
[10] Slater S, Andrews R, Boothby P, Barnett J, Armstrong K 2014 Under pressure welding and preheat temperature decay times on carbon dioxide pipelines Proceedings of the Biennial International Pipeline Conference, IPC 3 1-10