Comparison of Ejection Plant Variants Under Conditions of Natural Gas Pumping Pressure Reduction

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Abstract. In the process of gas main transportation, repair work is periodically required with cutting off the extended section and emptying the internal cavity of the pipeline. According to the established practice, gas from the cut-off section is released into the atmosphere. Ejectors may be involved in gas scavenging, but due to pressure reduction in the cut-off area, it is necessary to ensure high efficiency of the gas ejection unit. It is proposed to compare different configurations of ejectors at reduction of pumping gas pressure (single-stage ejector, ejector with inner cone, two-stage ejector). The ejector parameters are defined using the ANSYS Fluent CFD package. For each version of ejection unit, a graph is drawn on the dependence of the intake gas flow rate on the intake gas pressure, the inner cone position in the nozzle and the active gas pressure in the first stage of the ejector.

1. Introduction

PJSC Gazprom has the world's largest gas transmission system (GTS). It includes the Unified Gas Supply System (UGSS) of Russia. And for large systems that have the interconnection of all elements, issues of reliability, energy saving and energy efficiency are of high practical importance due to the large scale of the system. A small, at first glance, cost reduction may well lead to a noticeable energy-saving effect.

The large costs of transporting gas over long distances require the maximum realization of the available energy saving potential [1].

The most efficient guidelines in terms of saving natural gas as a percentage of the total savings of the directions under the PJSC Gazprom Energy Saving Program in gas transport are:
- reduction of costs during repairs and scheduled operations at compressor stations (CS), linear part (LP), gas distribution stations (GDS) - 38.6%;
- gas compressor unit (GCU) repairs to improve their technical condition - 17.0%;
- modernization or replacement of CS, LP and GDS equipment - 16.4%;
- improving the quality of dispatch control to ensure rational modes of gas main transport using design and optimization systems - 13.6%;
- implementation of resource-saving measures during repairs and elimination of gas leaks at CS, LP and GDS - 11.7%.

Let's consider in detail the first direction due to the greatest potential for saving natural gas.

To prevent accidents and maintain high operability, repair work is periodically carried out on linear part of the gas pipeline.
According to the established practice of conducting fire and gas hazardous works on gas transmission systems, gas is released into the atmosphere from the repaired section of the pipeline with complete loss of emissions.

The average annual number of repairs is in the range from 12 to 15 every 1000 km of the gas pipeline route [2]. Units with linear valves and crossover between the gas pipeline lines (with a multistream gas pipeline) are located every 25-30 km of the gas pipeline route. The average amount of gas emitted in only one repair, depending on the size of the repaired section of the pipeline and the gas pressure in it, can reach 3 - 4 million m³ [3].

The need for repair and loss of gas to the atmosphere due to emissions will increase in the conditions of longer operation of the main gas pipelines. In addition to the loss of natural gas during emissions, the gas transportation enterprise pays for the emissions of pollutants of which methane belongs to hazard class IV.

2. Relevance of the problem

The relevance of reducing natural gas emissions to the atmosphere is closely related to the maintenance of energy efficiency in gas transport and the aging of operating gas pipelines.

Due to these reasons, from the position of resource energy saving, pumping, collection and subsequent utilization of natural gas during the repair of main gas pipelines will be correct.

The gas scavenge process have to meet certain requirements:

1) short duration - due to an increase in gas transportation costs in the process corridor when the repaired section is disconnected (for a pipeline with a diameter of 1420 mm, a length of 30 km with an initial pressure of 7.5MPa and a final pressure of 1.0 MPa, the pumping time should be not more than 100 hours);

2) high mobility of equipment - due to field operating conditions (transportation and deployment to the LP).

For these purposes, some schemes have been proposed for both single-strand and multi-strand gas pipelines (Figure 1). One of the main elements in these schemes is an ejector jet pump [4-6].

![Figure 1. Schematic diagrams of gas utilization during repair of single-line and multiline gas pipeline section.](image)

In the diagram for a single-line gas pipeline, the source of both driving and entrained flow gas is a disconnected section of the gas pipeline, and the gas pressure will fall on the suction line of both the ejector and the centrifugal compressor (CC). As a result, several CC compression steps will be required in the final pumping step. More common are cases of repair of a section of the main gas pipeline lying in the same technological corridor with one or more gas pipelines. In gas pumping schemes during repair in a process corridor with two or more gas pipelines and a source of driving gas is an adjacent gas pipeline, the pressure in which remains at the same level.

It is necessary to compare the pumping efficiency with different ejector configurations under conditions of gas pressure reduction in the cut-off area.
The calculation of the operation of complex-configuration ejectors was carried out in the numerical hydrodynamics package of the Fluent program complex ANSYS with a complete picture of the flow parameter distributions.

3. Setting of the task
The main ejector configurations under consideration are:
- single-stage ejector;
- single-stage ejector with inner cone [7-8];
- two-stage ejector.

Key parameters of ejector operation are flow rate of driving \( G(D) \) and entrained \( G(E) \) gas. To simplify the calculations, we will accept the following assumptions:
- constant pressure at ejector outlet;
- fluid - methane;
- identical nozzles (diameter 6.8 mm).

To perform calculations in the KOMPAC-3D the volume occupied by natural gas was built (Figure 2). Due to the axial symmetry of the entire volume, a sector of 180 ° was left.

![3D models](image)

Figure 2. 3D models.

The purpose of the calculation is to determine the operating parameters of the ejectors at different pressure of the pumped gas.

Specified boundary conditions:
- \( P_{inl} = P_{inl2} = 5.6 \) MPa - working gas pressure (working gas pressure at the 2nd stage);
- \( P_{out} = 4 \) MPa - gas pressure at the outlet of the device.

These conditions remain constant in all calculations.

Inner cone position change step - 4 mm. Inner cone positions - 3. The positions of the inner cone are shown below (Figure 3).

![Inner cone positions](image)

Figure 3. Inner cone positions in ejector.
Methane properties are taken from the Fluent Database library and the density was calculated using the ideal gas equation. Viscosity model is taken as k-epsilon according to recommendations for viscous fluid.

4. Computer Simulation Results
Parameters of ejectors operation at different pressures of entrained gas \( P(E) \) are determined in the course of computer simulation. Below are the results of the calculation (Tables 1 to 3).

**Table 1.** Ejectors operation parameters.

| Type of ejector    | \( P(E) \) (MPa) | \( G_{init} \) (kg/s) | \( G_{E} \) (kg/s) |
|-------------------|-----------------|------------------------|------------------|
| Single-stage      | 4.00            | 0.287                  | 0.999            |
|                   | 3.80            | 0.291                  | 0.777            |
|                   | 3.60            | 0.294                  | 0.566            |
|                   | 3.40            | 0.295                  | 0.503            |
|                   | 3.20            | 0.295                  | 0.380            |
|                   | 3.00            | 0.295                  | 0.028            |
|                   | 2.80            | 0.293                  | 0.000            |

**Table 2.** Ejectors operation parameters.

| Ejector type                  | Position inner cones | \( P(E) \) (MPa) | \( G_{init} \) (kg/s) | \( G_{E} \) (kg/s) |
|-------------------------------|----------------------|-----------------|------------------------|------------------|
| Single stage with inner cone  | 1                    | 4.00            | 0.170                  | 0.345            |
|                               |                      | 3.80            | 0.172                  | 0.173            |
|                               |                      | 3.60            | 0.172                  | 0.032            |
|                               | 2                    | 4.00            | 0.174                  | 0.333            |
|                               |                      | 3.80            | 0.176                  | 0.160            |
|                               |                      | 3.60            | 0.177                  | 0.035            |
|                               | 3                    | 4.00            | 0.174                  | 0.321            |
|                               |                      | 3.80            | 0.176                  | 0.152            |
|                               |                      | 3.60            | 0.177                  | 0.046            |

**Table 3.** Ejectors operation parameters.

| Ejector type   | \( P_{init} \) (MPa) | \( P(E) \) (MPa) | \( G_{init} \) (kg/s) | \( G_{init2} \) (kg/s) | \( G_{E} \) (kg/s) |
|----------------|----------------------|-----------------|------------------------|------------------------|------------------|
| Two-stage      | 5.60                 | 4.00            | 0.245                  | 0.246                  | 0.383            |
|                |                      | 3.90            | 0.245                  | 0.247                  | 0.327            |
|                |                      | 3.80            | 0.245                  | 0.246                  | 0.187            |
|                |                      | 3.70            | 0.246                  | 0.247                  | 0.133            |
|                |                      | 3.60            | 0.245                  | 0.246                  | 0.074            |
|                | 5.20                 | 4.00            | 0.228                  | 0.246                  | 0.363            |
|                |                      | 3.90            | 0.224                  | 0.244                  | 0.345            |
|                |                      | 3.80            | 0.228                  | 0.247                  | 0.227            |
|                |                      | 3.70            | 0.227                  | 0.248                  | 0.119            |
|                |                      | 3.60            | 0.228                  | 0.247                  | 0.033            |
|                | 4.80                 | 4.00            | 0.204                  | 0.245                  | 0.340            |
|                |                      | 3.90            | 0.204                  | 0.248                  | 0.220            |
The pressure distribution in the single-stage ejector at the lowest intake gas pressure (2.8 MPa), at which the low-pressure gas continues to be pumped out, is given for the general evaluation of the ejectors in Figure 4.

![Image of pressure distribution](image_url)

**Figure 4.** Pressure distribution.

Built for three versions of ejection units in the flow chart of intake gas (Figures 5-7) depending on its pressure. Selection of intake gas flow rate for comparison of operation efficiency of ejectors is related to presence of large amount of high-pressure gas minimizing time of gas pumping out from cut-off section.

![Image of dependence](image_url)

**Figure 5.** Dependence of pumped gas flow rate on suction gas pressure and working gas pressure in stage 1 for two-stage ejector.
Figure 6. Dependence of pumped gas flow rate on intake gas pressure and inner cone position for single-stage ejector with inner cone.

Figure 7. Dependence of pumped gas flow rate on intake gas pressure for single-stage ejector.

Analysis of the obtained results shows that versions of ejection units are distributed according to the intake gas flow rate from the largest to the smallest as follows:

- two-stage ejector (flow rate 0.38 kg/s);
- single stage ejector with inner cone (flow rate 0.34 kg/s);
- single stage ejector (flow rate 0.10 kg/s).

The use of an inner cone in a single-stage ejector allows, in a certain range of pressures of the pumped gas, to significantly increase its flow rate. When extrapolating the flow chart (Figures 6, 7) at pressures below 3.6 MPa, a potential decrease in intake gas flow for a single stage ejector with an inner cone relative to the single stage ejector can be noted.

According to the accepted initial data and the conditions for the application of ejection installations, the optimal version of the ejector design is a two-stage ejector.

5. Conclusions

Ejection units used for resource saving purposes for process gas pumping shall provide, all other things being equal, the highest intake gas flow rate and the lowest preparation time of the pipeline section for repair works.

A comparison of three versions of ejection units (single-stage, single-stage with an inner cone, two-stage) in ANSYS Fluent with a reduction in the pressure of pumped natural gas showed that, all other things being equal, the largest pumped gas flow rate has a two-stage ejector. In general, it can be concluded that in order to carry out repairs on the linear part of the main gas pipeline, a two-stage structure will be the optimal ejection plant.

Further development of comparison of ejection plants for pumping of process gas is connected with joint operation of ejector, mobile compressor and main gas pipeline. Footnotes should be avoided whenever possible. If required they should be used only for brief notes that do not fit conveniently into the text.

6. References

[1] DOE Russia's Energy Strategy 2035
[2] Harris N A 2011 Resource-saving technologies of pump and compressor station equipment
[3] COMPANY STANDARD Gazprom 3.3-2-024-2011 A technique of rationing of a consumption of natural gas for own technological needs and technological losses of trunk transport of gas

[4] Patent RU 2167343 C1 Method of pumping gas from a disconnected section of a gas pipeline

[5] Patent RU 2108489 C1 Mobile unit for pumping gas from disconnected section of main gas pipeline (versions)

[6] Patent RU 2386862 C1 Processing of gas from repaired section of gas pipeline

[7] Buranshin A R, Godovskiy D A, Tokarev A P 2019 Regulation of the Operation of Ejector Systems under Unsteady Gas Pipage (Russky Island; Russian Federation: International Science and Technology Conference on Earth Science. Volume 459) chapter 1

[8] Buranshin A R, Godovsky D A and also Tokarev A P 2019 Ejector installations in resource-saving at trunk transport of gas Pipeline transport-2019 (Ufa: USPTU) pp 389-390