Technical and Economic Analysis of the Gas Reduction Schemes

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ABSTRACT

In the course of the work, an analysis of existing gas reduction schemes at the gas distribution stations was carried out. For development of an optimal reduction scheme, there was made a selection of equipment operating in the pressure range from 1.2 to 6.4 MPa with single-stage gas reduction. According to the results of the technical and economic calculation of each scheme, it was concluded that they should be used from the point of view of technological efficiency and economy. Gas reduction schemes are proposed for the study and use. They contain a regulator-monitor that performs the role of a redundant regulator and its use solves two problems at the same time—increasing the reliability of the gas reduction line and automating the throttling process.

INTRODUCTION

The relevance of the chosen subject is caused by the increasing pace of the natural gas use both in the field of household consumption (by expanding gas supply zone) and in the field of industrial consumption (introduction of the more complex technological processes), which significantly increases the requirements for failure-free and safe operation of the gas supply systems. Reliability issues and sustainability of the gas distribution systems directly influence the efficiency of transportation of the natural gas to the final consumer. Also, the fundamental factors should include the creation and maintenance of an optimal technological
state of the operational parameters of the gas distribution networks and gas-using equipment. The purpose of the study is assessment economic efficiency of the gas reduction schemes at the gas distribution stations on the basis of the amount of investment in the process of installation schemes, the cost of purchasing equipment and devices involved in the setup of the reduction lines.

Due to the geographical features of the territory of Russia, a single technological chain of the gas pipelines can run for many kilometers and pass through several climatic zones. The main costs are accounted for the transportation of the natural gas, so development of a new equipment, optimization of the schemes and methodical approach, as well as the issues of technical re-equipment still remain relevant. Technological reduction of the gas pressure at the gas distribution stations and the gas reduction points is implemented with the help of reducing valves and equipment, the main principle of which is the process of the gas throttling when an adjustable hydraulic resistance is generated on the way of moving the gas medium [1, 2].

SUBJECT AND RESEARCH METHODS

The regulator-monitor is configured for a specific range of input pressure values at which the automation operates [3]. In a steadily operating reduction line, regulator-monitor controls the level of inlet pressure and controls the main pressure regulator, while it is in a fully open state to skip the working medium. In a case of an emergency, regulator-monitor takes over the regulation function, or, otherwise, stops the gas flow through the reduction line. Regulator-monitor schemes use for a long time, but the absence of a shut-off valve was legislatively forbidden earlier.

Uninterrupted gas supply and, as a result, reducing the accident rate of the gas distribution systems, can mainly be achieved through various variations of the setup of the gas reduction points reduction unit, for clarity, the following variations can be demonstrated:

- Scheme 1—lock valves (LV), regulator-monitor, pressure regulator, LV, safety valves (SV).
- Scheme 2—LV, shut-off valves, regulator-monitor, pressure regulator, LV, SV.
- Scheme 3—LV, shut-off valves, regulator-monitor, pressure regulator, LV.
- Scheme 4—LV, regulator, controlled lock valves, LV, SV.

Consider in detail the basic setup schemes. Scheme 1 shows the simplest example of the regulator-monitor use. The main point of this scheme is a replacement the shut-off valve in the conventional setup of the reduction point with a regulator-monitor, which is enter into operation in a case of failure of the main pressure regulator. Operational principle is sequential installation of two
regulators on the reduction line. The main regulator operates in the normal mode, the regulator-monitor located in front of it and operates in the tracking and monitoring mode in the fully open position. Regulator-monitor has the same capacity and adjusted to a slightly higher output pressure than the main regulator. In the presented setup, it is necessary to choose a normally open type for the main regulator, and normally closed type for the regulator-monitor. When the main regulator fails, the pressure in the outlet collector rapidly grows, while the pressure of the regulator-monitor is set, it starts working, thus uninterrupted gas supply becomes possible. In this scheme, a two-stage consumer protection is implemented only against an emergency pressure increase. The disadvantage of this scheme is the lack of consumer protection from pressure drop in the networks, therefore it can be applied only if there is another step down behind the gas reduction points, equipped with a shut-off valves.

Scheme 2 can be used to provide three-stage consumer protection from both increasing and decreasing pressure. The main difference from Scheme 1 is the inclusion of a shut-off valve in its composition. Here there are measures of protection from both the pressure increase and its decrease, which is its main advantage. The main disadvantages of this scheme are the increased demands on the accuracy of monitoring the pressure regulator and the ability to switch the gas supply from the main line to the backup manually only.

In cases where a three-stage protection is not required, but it is necessary to provide pressure drop protection, Scheme 3 is used, which does not have a safety valve in its composition. This option is less demanding on the pressure regulators, in particular, on the regulation accuracy, since the setting range is not limited by the operation threshold of the safety valve. The scheme has the same advantages and disadvantages as Scheme 2. Currently updated documentation prescribes use of at least two reduction lines (at least one main and one backup) at the reduction points, and the submitted schemes represent variations of only one reduction line. Thus, if you follow the regulations of the standard literature, the scheme of the reduction point should have the form shown in Scheme 4. The scheme itself is one of the many variants of the functional scheme of the reduction point with the use of the regulator-monitor.

The schemes, using regulator-monitor, have different requirements for themselves, one of the main ones is the increased regulation accuracy. Consider this fact, in scheme 4 (without a safety valve) it is possible to implement the requirements of standard documents in terms of setting up the main regulator and the redundant line regulator to automatically switch the reduction point from the main line to the backup one. Thus, for Scheme 4, fourfold protection against pressure increase and decrease is carried out, while the pressure increase protection is carried out without stopping the supply of the gas to the consumer.

Scheme 5 (Figure 1) is one of the mostly promising setup variations of the reduction points with controlled shut-off valves, which are quick-acting valve. The main difference from the conventional scheme is that the shut-off valve is not
compulsory at all, since its function is performed by a quick-acting valve. In
addition, in a case of an emergency, the quick-acting valve also automatically
switches (without service personnel) from the main reduction line to the backup
one. Compared to the shut-off valve, it has a different principle of operation:
instead of mechanical (pneumatic) control, electric (more precisely, electronic)
control is used. In this variation, the presence of a telemetry system as part of the
equipment of the reduction point is imperative [4].

The basic principle of operation of this scheme is as follows: the telemetry
system controller (equipped with pressure sensors) controls the quick-acting
valves, automatical switch from the main to the backup reduction line is provided.
In the normal mode, the lock valves on the main and backup lines operate in the
open position, the quick-acting valves on the main reduction line is open, and on
the backup one is closed; pressure control is performed by the main line regulator.
In a case of pressure regulator failure, it either closes completely, and the pressure
drops at the outlet, or ceases to reduce, and an abrupt increase in pressure occurs
at the outlet.

The sensor records data on pressure changes, and subsequently transmits all
information to the telemetry system. Then it gives commands to close the valve of
the main line of reduction and open the valve of the backup line, thereby ensuring
uninterrupted gas supply to the consumer. Advantages of this scheme: there are

![Gas Reduction Scheme](image-url)

Figure 1. The gas reduction scheme 5: 1 – pressure regulator; 2 – redundant line regulator;
3 – regulator-monitor; 4 – shut-off valves; 5 – manometer;
6 – pressure meter; 7 – lock valves

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the main line of reduction and open the valve of the backup line, thereby ensuring
uninterrupted gas supply to the consumer. Advantages of this scheme: there are
no specific requirements for the type and characteristics of the regulators, the possibility of using reduction lines in parallel, the possibility of automatic transition from one line to another. The main disadvantage is the obligatory presence of a managing controller and dependence on an external power supply source. However, since there is a steady tendency to equip telemetry systems with almost all reduction points at facilities, that need uninterrupted gas supply, this disadvantage does not affect the reliability of the system, since it exists regardless of the product setup.

We will conduct comparative analysis of the five developed gas reduction schemes and one conventional schematic diagram consisting of a different combination of equipment.

The main comparative economic effect will be calculated on the basis of the formula below:

\[
E = M_1 - M_2 = \\
\sum_{p=1}^{P} C_{b1} \sum_{m=0}^{n} \alpha_{t-mt_0} + \sum_{p=1}^{P} C_{b2} \sum_{m=0}^{n} \alpha_{t-mt_0} + \ldots + O_{b1} \sum_{t=1}^{T} (1+E)^{-t} + O_{b2} \sum_{t=1}^{T} (1+E)^{-t} - \\
\sum_{p=1}^{P} C_{p1} \sum_{m=0}^{n} \alpha_{t-mt_0} + \sum_{p=1}^{P} C_{p2} \sum_{m=0}^{n} \alpha_{t-mt_0} + \ldots + O_{p1} \sum_{t=1}^{T} (1+E)^{-t} + O_{p2} \sum_{t=1}^{T} (1+E)^{-t} 
\]

(1)

where \( M_1 \) and \( M_2 \) are the integral costs of the basic and proposed options; \( C_{b1}, C_{p1} \) are the capital investments in the element according to the basic and proposed options, \( m \) is the number of the next capital investment; \( n \) is the number of the regular capital investments (the number of replacements of a piece of equipment during the service life of the system); \( t \) is the year of the next capital investment; \( t_0 \) is the element service life, years; \( \alpha \) - capital investment efficiency ratio, 1/year; \( Ob_1, Op_1 \) are the operational costs for the maintenance, energy resources according to the basic and proposed options, respectively, \( P \) per year; \( t \) is the year of operation; \( T \) is valve service life, years; \( E \) is discount rate, 1/year, is taken to be equal to the average credit rate of a bank in a market economy.

The service life of the elements in the compared variations is taken according to the data received from the equipment supplier.

RESULTS AND CONCLUSIONS

Calculations were carried out for all considered reduction schemes, the results are summarized in Table I. As follows from the economic effect indicators presented in Table I, proposed gas pressure reduction schemes have advantages over the conventional scheme. The most effective are the schemes 1÷3, but it
should be noted that these schemes have a narrow applicability to the gas
distribution stations, since they have only one line of reduction.

Schemes 4 and 5 have a lower economic effect, but, compared to the others,
provide a much greater level of reliability and failure-free reduction lines. From
the point of view of the safety of the maximum economic output of the system, it
is advisable to use scheme 1, to ensure maximum safety of operation of the gas
reduction unit, scheme 4 is proposed for usage.

During calculation process the investment in the installation of the reduction
line, the main costs accounted for the regulator-monitor. The increased cost of
this equipment is caused by its wide functionality, and the lack of analogues in
the domestic market. Calculations showed the effectiveness of the use of this
regulator by reducing investment in automation, as well as measures to improve
the safety of the gas reduction system.

Based on calculation results, it is possible to draw conclusion about the
economic and practical effectiveness of the proposed options for the reduction
lines compared to the conventional reduction scheme in operation.

<table>
<thead>
<tr>
<th>Comparison with a conventional scheme</th>
<th>Economic effect</th>
<th>Δ% in a relative term</th>
</tr>
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<tbody>
<tr>
<td>Scheme 1</td>
<td>325800</td>
<td>18</td>
</tr>
<tr>
<td>Scheme 2</td>
<td>300600</td>
<td>17</td>
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<td>Scheme 3</td>
<td>285900</td>
<td>16</td>
</tr>
<tr>
<td>Scheme 4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Scheme 5</td>
<td>120560</td>
<td>12</td>
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</tbody>
</table>

The first three schemes are single-stage lines of reduction, with no backup
line of reduction. It significantly reduces the cost of installation and operation of
the system, but the main level of system security is achieved mainly through the
use of the regulator-monitor. During operation, the monitor periodically traces the
pressure level after the main regulator, and, if necessary, automatically adjusts or
stops the gas supply. The fourth scheme is the most costly gas reduction line. It
directed through a backup line, without a loss of efficiency and
performance of the reduction line, for a long time. The safety of the proposed
scheme is caused by existence of several regulator-monitors, which allows several
lines to have the same automation level, and, in fact, makes them independent of
each other.

The fifth scheme is a compromise between capital costs and the operational
safety of the gas reduction line at the gas distribution stations. Profitability and
efficiency of the scheme is achieved due to the difference of the equipment used
in the main and backup lines, without losing the level of system efficiency. In the main line of reduction, the input pressure adjustment in the automatic mode is performed by the regulator-monitor. The pressure regulator, previously set to the calculated inlet pressure values, is installed in the backup reduction line. The backup line of reduction is designed for 100% efficiency from the value of the main line, but the process of manual regulation of the main reducing device reduces the safety of this line in comparison with the main one.

According to obtained comparisons of the economic effects, it can be concluded that, from the investment point of view, scheme 1 is the most profitable, however, scheme 5, which has a difference of 6%, shows the best result in assessing uninterrupted gas supply. Scheme number 5 suits the required automation level of the process of reduction. The main perspective task is development of more compact equipment, and the domestic analogue of the regulator-monitor. Domestic development will reduce the cost of transporting and manufacturing the product, as well as reduce the time and resources required to supply the product to the place of installation of the gas reduction scheme. Such developments, in the future, can significantly improve technical and economic indicators and, consequently, the effectiveness of the proposed schemes.

REFERENCES