Algorithms of energy recovery at the automatic gas station

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Abstract. The paper is devoted to efficiency improvement of the gas-distributing system of main gas pipe-lines due to parallel generation of electric energy at gas distribution stations. When the natural gas is supplied from the main pipelines to municipal systems and large industrial enterprises its pressure at gas distribution stations and gas distribution units is reduced. This aspect allows converting potential energy of pressure drops in a gas pipeline into electric energy thus improving the efficiency of gas transportation.

1. Introduction

Russia has large energy reserves, but at the same time, according to the International Energy Agency, it takes the 28th place in terms of energy consumption. According to the study in the field of energy consumption of the ACEEE Council, Russia holds the 12th place on rational energy consumption among the biggest economies [1].

When gas is supplied from the main pipeline to municipal systems and the systems of large industrial enterprises its pressure is reduced. Such cases result in potential energy of gas pressure, which shall be utilized. At the same time, gas pressure is reduced in special pressure-reducing valves with parallel energy consumption to overcome hydraulic resistance and is followed by potential pressure drop energy.

Gas pressure can be reduced in many ways and with different energy inputs (Table 1) [2].

| Method of air expansion | Energy consumption in comparison with ideal adiabatic expansion |
|-------------------------|---------------------------------------------------------------|
| Adiabatic method        | 1                                                             |
| In a pressure-reducing valve at adiabatic efficiency=0.8 | 1.4                                                           |
| In vortex cylindrical pipe without heat transfer by hot component | 13.4                                                          |
| By pressure reduction   | 28.9                                                          |

Table 1 shows that pressure-reducing valves are the most suitable for gas pressure decline. Such valves represent devices transforming energy of gas expansion into mechanical work [3].
Relevance of the study. The relevance of this study is caused by tasks of improving the efficiency of applied technologies declared by the Russian President as “The Energy Strategy…” [4].

Compressor stations are the most energy-consuming objects within the entire gas transmission infrastructure. This is caused by the fact that the potential energy transferred to gas through reduction makes about 7-8% of the whole volume [5]. The calculations show that in case of pressure drop at compressor stations the recovery per every 1000 m³ of gas, on average allows generating 47 kW/h of electric energy [6].

About 10% of transmitted energy is lost by friction in gas pipelines. The remaining 90% of potential energy of compressed gas is dispersed as heat at gas reducing stations.

The working hypothesis is based on the fact that the use of pressure-reducing generating units will allow increasing energy efficiency of gas reduction system due to more efficient transformation of pressure drop energy.

2. Results

It was decided to develop a phenomenological model for adequate technique to assess values influencing energy recovery at gas pressure reduction [7].

Recovery efficiency was chosen as the optimization criterion:

\[
\eta = f(\Delta P, T, Q)
\]

where \(\Delta P\) – difference of gas pressure at input and output to a pressure-reducing valve, MPa; \(T\) – gas temperature at input to a pressure-reducing valve, °C; \(Q\) – gas consumption in a distribution network in thousand m³/h.

The range of control factors was chosen within the following threshold values:

\(\Delta P = 0.9-1.8\) MPa; \(T = 30-90\) °C; \(Q = 20-33\) thousand m³/h.

The following were identified as uncontrollable factors:

\(\rho\) – gas density, kg/m³; \(T_{\text{air}}\) – air temperature, °C.

The choice of rational design data is defined by the requirement of the above range of experimental parameters, in particular, difference of gas pressure at input and output to a pressure-reducing valve, gas temperature at input to a pressure-reducing valve, gas consumption in a distribution network and metrological aspects of optimization parameter, etc.

The main operating procedure used to register initial parameters for analysis are as follows:

- pressure measurement;
- temperature measurement;
- measurement of gas consumption in a network.

It is natural that the volume of experimental work will increase taking into account a variety of factors. Nevertheless, thus obtained results will represent a specific case since the given methods of study do not allow evaluating the role of their joint influence. This complicates the search of the optimum combination of existing factors.

Such tasks may be solved via mathematical methods of experiment design.

The study methodology implies fixation of generated energy on a unit representing a centripetal turbo-expander, an asynchronous electric generator, a reducing valve, a pipeline and pipeline fittings.

The design of the turbo-expander is as follows:

* sealed case;
* rotor;
• variable valve;
  • inlet guide vane (with rotary mechanisms) [3].

The most reliable results can be achieved in case of complete factorial experiment at three levels $3^n$. In this case the exponential dependence of the response function on each factor is expected.

The randomization by the Monte Carlo method is made to introduce a uniform element of randomness of the influence of uncontrollable factors on the response function.

After randomization the plan of the experiment looks as follows (Table 2).

| Experiment No. | X1($\Delta P$), MPa | X2(T), $C^0$ | X3(Q), th. m$^3$/h |
|---------------|----------------------|--------------|-------------------|
| 1             | 0.9                  | 30           | 20                |
| 2             | 1.8                  | 30           | 20                |
| 3             | 0.9                  | 90           | 20                |
| 4             | 1.8                  | 90           | 20                |
| 5             | 1.8                  | 60           | 20                |
| 6             | 1.35                 | 90           | 20                |
| 7             | 0.9                  | 60           | 20                |
| 8             | 1.35                 | 30           | 20                |
| 9             | 1.35                 | 60           | 20                |
| 10            | 0.9                  | 90           | 33                |
| 11            | 0.9                  | 30           | 33                |
| 12            | 1.8                  | 90           | 33                |
| 13            | 1.8                  | 30           | 33                |
| 14            | 0.9                  | 60           | 33                |
| 15            | 1.8                  | 60           | 33                |
| 16            | 1.35                 | 90           | 33                |
| 17            | 1.35                 | 30           | 33                |
| 18            | 1.35                 | 60           | 33                |
| 19            | 0.9                  | 90           | 26.5              |
| 20            | 0.9                  | 30           | 26.5              |
| 21            | 1.8                  | 90           | 26.5              |
| 22            | 1.8                  | 30           | 26.5              |
| 23            | 0.9                  | 60           | 26.5              |
| 24            | 1.8                  | 60           | 26.5              |
| 25            | 1.35                 | 30           | 26.5              |
| 26            | 1.35                 | 90           | 26.5              |
| 27            | 1.35                 | 60           | 26.5              |

Retrospective analysis. The retrospective analysis showed a continuous interest to the problem of energy recovery in case of gas pressure reduction during its transportation from the main to service pipelines.

In the future to continue the study the authors suggest conducting the laboratory physical experiment.

3. Conclusion
The research is quite relevant to improve the efficiency of gas transportation, especially in Russia. The operating experience and calculations of foreign and domestic expander-generating units confirm parallel energy generation in the amount of 30…50 kW/th m3. The use of units generating energy due to pressure reduction allows introducing secondary energy resources into economic turnover.

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