Heating of natural gas before expander - generator unit

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Abstract. The article discusses the replacement of throttling at the stations of technological lowering of the pressure of main natural gas by an expander-generator technology that allows the production of a cheap one with high environmental indicators. The disadvantage of this method of generating electricity is a significant cooling of the gas at the outlet of the expander, which necessitates its heating. The efficiency of the expander-generator set is largely determined by the adopted gas heating scheme. Achieving such heating temperatures is possible only by using high-potential energy resources, which are present in the technological equipment of gas distribution stations in the form of gas heaters with an intermediate heat carrier, designed to heat gas before expansion. Calculations of the amount of fuel gas required for heating the main natural gas in front of the expander-generator unit at the gas distribution stations under consideration have been carried out. The results of the study of the influence of the temperature of gas heating in front of the expander on the consumption of fuel gas supplied for heating and the numbers of heaters are presented. An analytical dependence of the electric power of the heat pump installation on the difference between the total power consumption of the compressor and the power of the air turbine is obtained.

1. Introduction

In the period of globalization of the issue of energy conservation, research aimed at intensifying the efficiency of energy production, determined by the development and development of new technologies, which provide the possibility of more efficient, combined energy production, becomes relevant. The use of secondary energy resources in the form of energy, determined by the excess pressure of transported natural gas to generate electricity, has become one of the priority areas of energy conservation, since it allows more rational use of energy resources, reduce emissions of pollutants into the environment, and increase the efficiency of industrial production.

One of the energy saving measures is the use of the technological pressure drop of the transported natural gas. Installation of an expander - generator unit (EGU) instead of a throttling device makes it possible to generate cheap electricity with high (in comparison with generation at a thermal power plant) environmental indicators. The efficiency of the EGU is largely determined by the adopted gas heating scheme before the expander. The required amount of heating is determined by the ratio of the pressures at the inlet and outlet of the expander, and in a conventional EGU scheme, it may be necessary to heat the gas up to 150 °C [1].

Achieving such heating temperatures is possible only by using high-potential energy resources, which are present in the technological equipment of gas distribution stations (GDS) in the form of gas
heaters with an intermediate coolant, intended for heating the gas before expansion, which determines the volume and technical and economic indicators of the EGU.

To increase the efficiency of the expander-generator unit, it is necessary to increase the temperature of the gas before entering the unit. The efficiency of the EGU depends on the method of heating the gas before the expander [2]. The heating unit (prevention of hydrate formation) is designed to prevent freezing of the fittings and the formation of crystalline hydrates in gas pipelines and fittings.

Also, the choice of a gas heating source is one of the main conditions in the development of a technical and economic calculation to substantiate the economic feasibility of the selected type of unit. The indicators of the gas heating system also significantly affect the operating costs of the EGU and, as a consequence, the cost of the electricity produced by the EGU. Consequently, the selection and improvement of the method for heating gas in the EGU is one of the defining requirements for the design of the EGU [3].

2. Materials and methods
The analysis of the studied scientific works made it possible to identify the following main methods of heating natural gas before the expander:

- gas heating due to low-grade heat converted in a heat pump unit (HPU) [4,5];
- heating with electric heaters;
- heating of gas with the heat of autonomous boilers [6,7];
- gas heating due to the heat of selected steam from turbine plants at TPP [7, 8];
- heating of natural gas by the heat of exhaust gases from boiler units [7];
- heating of gas by the heat of compressed air at the outlet of the compressor [9].

At stations for reducing the pressure of transported natural gas, gas boilers are used to heat it, and if we compare them with the efficiency of using thermal secondary energy resources, then it will turn out to be less, since in this case high-potential heat of the fuel is spent to heat the gas. But in a number of cases, the use of autonomous boilers is inevitable, since the location of pressure reduction stations does not make it possible to use thermal secondary energy resources (SER) to heat natural gas before its expansion.

In remote areas where there is no possibility of using thermal energy resources, it is possible to install an EGU with a heat pump unit [10]. The exergy efficiency of an EGU unit with HPU, which converts low-grade heat for heating natural gas, is lower than the case of using waste heat, but significantly higher than for a scheme with an autonomous boiler, which is the rationale for using HPU for heating natural gas at a pressure reduction station. In this case, when a heat pump unit serves as a heat source, then it is necessary to take into account the temperature of a low-potential heat source, which is one of the directions of research [11].

Since today at pressure reduction stations, in many respects, autonomous boilers are used, analysis and ways of reducing the amount of natural gas consumed for heating (fuel gas) is relevant and requires the introduction of new technological solutions. Therefore, to install the boiler, it is necessary to determine the optimal connection scheme, the design of the EGU and the operating parameters.

As measures to prevent hydrate formation, the following are used:

- general or partial heating of gas using gas heaters;
- local heating of pressure regulator casings.

If the hydrate plugs are still formed, then methanol is introduced into the gas pipeline communications, it destroys them and the gas pipeline works in normal mode. The gas heating unit must ensure that the gas temperature at the outlet of the GDS is not lower than minus 10 °C. As a rule, pipelines and fittings at the outlet of the heater should be protected by thermal insulation (the need for thermal insulation is determined by the design organization).
When heating gas at the GDS without EGU, a mixing technology is used, the schematic diagram of which is shown in figure 1. The gas entering the gas distribution station is divided into two flows with the help of control valves, one of which is sent to the gas heaters, where it is heated to a predetermined temperature. The remaining flow of cold gas is mixed in mixers, or directly in the gas pipeline with hot gas supplied after heating in the heaters. The gas mixture is directed to the reduction unit for pressure reduction.

![Figure 1](image1.png)

**Figure 1.** Scheme for switching on an autonomous boiler at the GDS: 1 - switching unit, 2 - gas heating unit, 3 - mixer, 4 - reducing unit.

Figure 2 shows the circuit for switching on an autonomous boiler in front of the EGU. The boiler is turned on in the same way as in the GDS without EGU. A significant difference is the fuel gas consumption, since the capacity must be high.

![Figure 2](image2.png)

**Figure 2.** Schematic diagram of turning on an autonomous boiler in front of the EGU: I-gas inlet to the pressure reduction station; II-gas outlet from the pressure reduction station; 1 - boiler for gaseous fuel; 2 - expander; 3 - generator; 4 - reducer.

The calculation of the amount of fuel gas is carried out according to the method given in [12]. The amount of gas supplied for heating:
\[ G_{in} = \frac{G \cdot (t_m \cdot C_m - t_{in} \cdot C_{in})}{(t_{hg} \cdot C_{hg} - t_{in} \cdot C_{in})}, \tag{1} \]

- where \( G \) - gas consumption at the inlet to the gas distribution station; \( nm^3/h \);  
- \( C_{hg}, C_{in} \) - heat capacity of hot, cold gas, \( \frac{kcal}{m^3 \cdot °C} \);  
- \( C_m \) - heat capacity of a mixture of hot and cold gas, \( \frac{kcal}{m^3 \cdot °C} \);  
- \( t_{hg} \) - hot gas temperature, °C;  
- \( t_{in} \) - gas temperature at the gas station inlet, °C;  
- \( t_m \) - temperature of the mixture of hot and cold gas, °C.

Based on the obtained flow rate of the heated gas, we select the type and number of gas heaters according to the formula:

\[ n = \frac{G_{hg}}{G_h \cdot K_1}, \tag{2} \]

- where \( n \) - number of heaters;  
- \( G_h \) - heater performance, \( nm^3/h \) (taken from table 1);  
- \( K_1 \) - the coefficient taking into account seasonal, daily changes in the productivity of the GDS is taken equal to 0.9.

The amount of fuel gas is determined by the following formula:

\[ G_{fg} = n \cdot G_{nom}, \tag{3} \]

- where \( G_{fg} \) - fuel gas consumption, \( \text{nm}^3/\text{h} \);  
- \( G_{nom} \) - nominal fuel gas consumption, \( \text{nm}^3/\text{h} \) (taken from table 1).

Since an expander rather than a reducer is used as a pressure reducing unit, the calculations took into account the fact that when the gas pressure decreases from 1.2 to 0.3 MPa, its temperature decreases by 50-60 °C (depending on the composition of the gas and expander efficiency). With an increase in the degree of pressure reduction to 6 (from 1.8 to 0.3 MPa), the temperature difference increases to 70–80 °C. Gas heaters used to determine the amount of gas consumed from the total amount of natural gas passing through the main pipeline are shown in table 1.

**Table 1.** Main parameters and characteristics of gas heaters with intermediate coolant.

| Indicator name | Value by type or use | GPM-PTPG-30M-02 | GPM-PTPG-30M-02-01 | GPM-PTPG-100 | GPM-PTPG-100-01 |
|----------------|----------------------|------------------|--------------------|---------------|------------------|
| 1. Nominal heating capacity, MW (Gcal/h) | 1.08 (0.93) | 2.7 (2.32) | |
| 2. Coefficient of efficiency, %, not less | 82 | | | |
3. Range of capacities for heated gas, \( nm^3/h \) 15000 -30000 30000 -100000
4. The temperature of the heated gas at the inlet to the heater, \( ^\circ C \), not lower - 20 - 10
5. The maximum permissible temperature of the heated gas at the outlet of the heater, \( ^\circ C \) + 70
6. Temperature difference at the inlet and outlet of the heater in the nominal mode, \( ^\circ C \), no more 70 60
7. Pressure in the tube bundle, MPa (kgf/cm\(^2\)) - working, no more 10.0 (100) 7.5 (75)
8. Nominal fuel gas consumption at \( Q = 8000 \) kcal/h), \( nm^3/h \), no more 110 320

As the initial data for calculating the amount of fuel gas for heating before the EGU at the GDS, actual values were taken to carry out the calculation and subsequent analysis of the economic effect of installing an autonomous boiler as a natural gas heater (table 2).

**Table 2.** Initial data for calculating the amount of fuel gas.

| Indicator name                        | Industrial pipeline 1 | Industrial pipeline 2 | Industrial pipeline 3 |
|--------------------------------------|-----------------------|-----------------------|-----------------------|
| Gas consumption \( G \), \( m^3/h \)  | 1100                  | 2700                  | 11000                 |
| Inlet pressure \( P_{in} \), kgf/cm\(^2\) | 15.5                  | 15.5                  | 15.5                  |
| Outlet pressure \( P_{out} \), kgf/cm\(^2\) | 9                     | 7                     | 8.7                   |
| Inlet temperature \( t_{in} \), \( ^\circ C \) | 24                    | 24                    | 24                    |
| Outlet temperature \( t_{out} \), \( ^\circ C \) | 20                    | 18                    | 18                    |

3. Results and discussion
As a result of calculations, data were obtained that reflect information on the amount of fuel gas required for heating natural gas before the EGU and other necessary indicators (table 3).

**Table 3.** Results obtained in the course of calculations.

| Indicator name                                      | Calculation result |
|-----------------------------------------------------|--------------------|
| **Gas temperature before the EGU (mixture temperature), \( ^\circ C \)** | 50 48 58 |
| **The amount of gas directed for heating, \( nm^3/h \)** | 96936 218388 1263861 |
| **Heater outlet temperature, \( ^\circ C \)** | 66 66 66 |
| **Number of heaters, pcs.** | 1 2 12 |
| **Fuel gas consumption, \( nm^3/h \)** | 320 640 3840 |
From the above data and the calculation results, it follows that with an increase in natural gas consumption and the ratio of inlet and outlet pressures, the need to increase the temperature before the EGU increases. This is primarily due to the pressure drop and the required temperature of natural gas at the outlet of the EGU. The amount of heated gas passed through the heat exchangers of the autonomous boiler also increases with an increase in the consumption of transported natural gas. In connection with an increase in the temperature before the EGU and the consumption of transported natural gas, the number of heaters also increases, which leads to an increase in the consumption of fuel gas.

4. Conclusion

Based on the above analysis of the use of an autonomous boiler for heating gas, it can be noted that at high consumption of transported natural gas (more than 10000 m³/h), as well as at large pressure ratios (the ratio $P_{in}/P_{out}$ more than 3 times) is not economically feasible. In the general case, the use of an autonomous boiler for heating natural gas is inferior to the use of thermal SER, since when using the boiler, natural gas is burned, which leads to a decrease in the efficiency of the EGU itself. But in a number of cases, the use of autonomous boilers is inevitable, since the location of pressure reduction stations does not make it possible to use thermal SER for heating natural gas.

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