Use of a turbine expander to generate electricity for own operation needs of a gas turbine unit at compressor stations of main gas pipelines

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Abstract. In order to save energy at compressor stations, it is proposed to use expander-generating units (EGU) to reduce gas pressure. An analytical justification for replacing a throttle by EGU is given. The results of economic calculation of electricity savings when using EGU are given. The scheme of gas turbine unit with EGU and gas heating before entering the combustion chamber is presented. When using this scheme, the cost savings for electricity purchase is 83%.

1. Introduction
The idea of utilizing the energy of natural gas overpressure in a turbine expander is highly relevant today from the point of view of energy saving in a gas transmission system. In order to regulate the gas pressure when it enters from the line into the combustion chamber of a GTU at compressor stations of main gas pipelines, a throttle or a turbine expander can be used. On the other hand, to improve energy efficiency of equipment at a compressor station, it becomes possible to use the energy of excess gas pressure to generate electricity using expander-generating unit (EGU). The existing problem of heating the gas before the combustion chamber is solved using the heated gas after the supercharger. For this purpose, gas is heated before EGU, or it isn’t heated [1-4] However, gas heating can also be carried out after EGU, which eliminates chemical incomplete combustion of fuel. As a result of gas heating, the temperature field is equalized.

The purpose of this work is to develop a set of measures aimed at reducing the cost of electricity during operation of gas turbines at compressor stations of main gas pipelines. For this purpose a gas heating circuit after EGU has been developed. This uses the exhaust gases at the outlet of the turbine.

2. Materials and methods
To describe a throttle work, the process of gas throttling is considered as an adiabatic process of gas expansion (h = const), which is characterized by the adiabatic expansion coefficient [1]:

$$\alpha_h = \left( \frac{\partial T}{\partial p} \right)_h = \frac{T \left( \frac{\partial \nu}{\partial T} \right) - \nu}{c_p}$$

(1)
When a turbine expander is included into the circuit, the process of reducing gas pressure in it can be considered as a reversible adiabatic expansion process (with return of external work). The coefficient of expansion of the reversible adiabatic process is [1]:

$$\alpha_s = \left( \frac{\partial T}{\partial p} \right)_s = \frac{T \left( \frac{\partial \nu}{\partial T} \right)_p}{c_p}$$  \hspace{1cm} (2)

It is of interest to compare these two methods of lowering the pressure, as well as the magnitude of the decreased temperature.

From the difference between the coefficients of adiabatic and isentropic expansion, we obtain the relation:

$$\alpha_s - \alpha_h = \frac{\nu}{c_p}$$  \hspace{1cm} (3)

Since the values $\nu$ and $c_p$ are always positive, then $\alpha_s > \alpha_h$. Consequently, a decrease in temperature during the process of reversible adiabatic expansion of gas during expander operation will be more than that for adiabatic process of throttling.

The change in temperature during adiabatic expansion can be determined from the integral throttle effect:

$$T_2 - T_1 = \int_{P_1}^{P_2} \alpha_h dp$$  \hspace{1cm} (4)

where $T_1, T_2$ is gas temperature before and after throttling, respectively; $P_1, P_2$ are gas pressure before and after throttling, respectively.

The temperature change at reversible adiabatic throttling is calculated using the expression:

$$T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{k-1}$$  \hspace{1cm} (5)

where $k$ is adiabatic exponent.

Using the formulae (4), (5), the gas temperature at the outlet of the turbine expander and throttle was calculated for a pressure change from 5.5 MPa and 7.5 MPa to 1.5 MPa for various gas temperatures. According to the obtained data, the graphs were constructed presented in Figure 1.

**Figure 1.**
Relationship between the gas temperature after expansion and the initial temperature at pressure decreases of 5.5 MPa/1.5 MPa and 7.5 MPa/1.5 MPa.
The plot analysis shows that the degree of gas temperature decrease during expansion in expander is higher than that during throttling. Therefore, when using the expander to reduce gas pressure, it is necessary to heat the fuel.

Analysis of the resulting plot (Fig. 1) shows that gas can be heated before or after the expander, as well as stepwise. With a decrease in pressure from 5.5 MPa to 1.5 MPa, it is necessary to preheat for 90-100 °C the gas before the expander, and after the expander it should be heated for 80-90 °C. With a decrease in pressure from 7.5 MPa to 1.5 MPa, it is necessary to heat the gas before the expander for 110-120 °C, and after expander it should be heated for 90-100 °C. Therefore, the most economically-feasible way is to carry out heating of gas before it enters the combustion chamber.

High-temperature heating of fuel gas results in evaporation of condensate and of C₃ – C₅ hydrocarbon fractions, which are contained in it and to a large extent eliminates the chemical incomplete combustion of fuel [5-12]. Another positive feature of preheating the fuel gas in front of combustion chamber is equalization of temperature field at the exit from it and at the entry of power turbine [12-17].

In addition, we determined the specific technical work of gas expansion in turbine expander, and its dependence on gas temperature and degree of pressure decrease. In our calculations, we used the expression (6):

\[ l_{1-2} = \frac{p_1 v_1}{k-1} \left[ 1 - \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \right] \]  

Figure 2. Relationship between specific technical work during gas expansion in expander, gas temperature and the degree of pressure reduction.

The calculation results were used to plot the dependence shown in Figure 2. The plot analysis shows that when compression ratio increases, the specific gas work increases. When the gas temperature rises, the specific work also increases. Thus, to improve the energy efficiency of GTU operation at compressor stations of main gas pipelines, we can propose a scheme that includes a turbine expander with gas heating after it.
3. Results and discussions
In this paper, we consider the use of the expander-generating unit based on compressor station, in order to reduce the pressure of the transported gas and generate electrical energy for the needs of compressor station (Figure 3).

![Figure 3. Scheme of gas turbine unit GTK-16 with air heating before compressor, gas supply through expander-generator and air heating after it: 1 - axial compressor; 2 - combustion chamber; 3 - high pressure turbine; 4 - low pressure turbine; 5 - power shaft; 6 - clutch; 7 - supercharger; 8 - starting turbine expander; 9 - heat exchanger for gas heating; 10 - expander; 11 - generator.](image)

Gas supply to the combustion chamber is carried out after heating it in the heat exchanger 9, since when using the turbine expander 10 the gas temperature significantly decreases as a result of adiabatic expansion of gas flow, with work release. The excess energy of natural gas pressure is used to generate electricity by generator 11.

The use of a turbine expander in the system under consideration is driven by the use of overpressure energy to generate electricity. There is a need to evaluate additional energy savings due to the use of a turbine expander to reduce pressure.

An estimate of savings of consumption due to the electricity generated by a 100 kW turbine expander for pressure step of 5.5/1.5 MPa was made for the GTK-16 and is presented in Table 1.

**Table 1.** Calculation of electricity savings during operation of the GTK-16 owing to the use of a turbine expander.

| Characteristics                                | Meas. unit | Value  |
|-----------------------------------------------|------------|--------|
| Power of the turbine expander                 | kW         | 100    |
| Electricity consumption of GTK-16             | kW·h       | 120    |
| Year duration                                 | h          | 8760   |
| Relative time of GTK-16 operation             | -          | 0.384  |
| Annual output of electricity by turbine expander | ths. kW·h | 336.384|
| Annual expenses for electricity               | ths. kW·h | 403.661|
| Annual savings of expenses for electricity    | ths. kW·h | 67.277 |
The result is shown in Figure 4. It should be noted that this electricity consumption is given for one working unit of the compressor shop (without taking into account the auxiliary equipment, i.e. ventilation, heating, lighting, etc.).

![Figure 4. Share of the annual electricity generation by the expander-generator in the electricity consumption for GTK-16 operation (without taking into account the auxiliary equipment, i.e. ventilation, heating, lighting, etc.).](image)

Consequently, the generated energy can be used by replacing the purchased one, which is spent on operation of the gas turbine unit and its auxiliary equipment. Evaluation of the use of electricity produced by the turbine expander showed that 83% of the purchased energy spent for operation of the GTU and its auxiliary equipment can be replaced by the generated one. The discounted payback period is 8.53 years, which corresponds to the average payback period of projects in the power industry.

4. Conclusions
Using the proposed scheme it becomes possible to achieve the following results:

1) Approach the GTU operation conditions close to nominal ones, which results in improved reliability and durability of the unit.

2) Usage of expander-generator will reduce expenses for electricity by covering up to 83% of expenses which are spent for operation of the GTU. This will have a positive impact of the CS operation efficiency.

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