Air heating in an air heat pump installation in the expander-generator set

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Abstract. The article touches upon the actual problem of the use of secondary energy resources in the transport and distribution of natural gas. Excess gas pressure as the main component of secondary energy resources for technological processes is practically not used at gas distribution stations, where throttling devices are used. The proposal to use excess gas pressure in turboexpanders both at gas distribution stations and at compressor stations of main gas pipelines without preheating has not yet found widespread use, and therefore the replacement of throttling devices with turboexpander units will be determined by energy and economic efficiency. Expander-generator technology is one of the effective technologies that allows to reduce the consumption of fuel and energy resources. In combination with heat pump units, expander-generator units make it possible to create highly efficient power generating complexes that are capable of generating electricity without burning fuel. The possibility of using heat pumps is considered, in which air is used as a working medium, the purpose of which is to increase the temperature potential of heat to ensure the possibility of heat exchange when transferring this heat to the heated medium. 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

The electric power industry of Uzbekistan is the basic branch of the national economy of the republic and, having significant production and scientific and technical potential, has a significant impact on the development of the entire national economic complex.

The unified electric power system of the republic fully meets the needs of economic objects and the population in electric energy. Uzbekistan is the largest energy power in the Central Asian region.

The technological requirements for the operation of gas pipelines force the gas to be heated upstream of the EGS expander to a temperature of 80-100 °C. Usually, this is done using the energy of the high temperature potential obtained from the combustion of fuel. However, there are technical solutions that make it possible to operate the EGS even without fuel combustion (figure 1).
2. Materials and methods

The efficiency of the EGS depends on the method of heating the gas before the expander [1-4]. In this connection, recently, a certain interest has begun to appear in air heat pump installations (AHPI) - heat pumps in which air is used as a working medium [5-7]. The purpose of AHPI is to increase the temperature potential of heat to ensure the possibility of heat exchange when transferring this heat to the heated medium. Figure 2 shows a schematic diagram of the AHPI.

The principle of operation of the installation is as follows. Atmospheric air, which is a working fluid in this installation, enters through line 1 into compressor 2, driven by an electric motor 3. In the compressor, the pressure and, accordingly, the air temperature increase. The pressure to which it is necessary to compress the air in the compressor must be such that the corresponding air temperature at the outlet of the compressor is higher than the temperature to which it is necessary to heat the coolant in the heat exchanger 4. In figure 1, for the sake of clarity, a counter-flow heat exchanger scheme is selected, therefore, the positions 5 and 6 in figure 2 - inlet and outlet of the heated medium, respectively. The air pressure leaving the heat exchanger remains higher than atmospheric pressure. In the air turbine 7, where the air enters after the heat exchanger, it expands, the energy of the air flow is converted into mechanical work, while the air is cooled. After the turbine, the air is directed to the atmosphere. The mechanical work obtained in the air turbine is used to drive the compressor, thereby reducing the required energy supplied to the installation from the outside.
The heat conversion coefficient is usually used as a criterion for determining the efficiency of heat pump installations $V$, which is the ratio of the heat $Q_1$ of high potential transferred to the consumer to the consumed electric power [8-10].

$$ V = \frac{Q_1}{N_e}, $$

where $Q_1$ - the heat transferred to the air to the gas in the heat exchanger, $N_e$ - electrical power consumed by the compressor.

The amount of heat is determined by the enthalpy difference:

$$ Q_1 = G_a (h_2 - h_3), $$

where $G_a$ is the air flow rate.

This criterion characterizes the efficiency of the installation and depends, among other things, on the temperatures of low heat and high heat potential. Due to the fact that the temperature $T_1$, which the air at the outlet from the compressor should have, is determined by the operating conditions and cannot be arbitrarily changed, it is of certain interest to study the effect of the air temperature at the inlet to the compressor on the conversion coefficient of the AHPI. Figure 3 shows the hs-diagram of the processes in the AHPI with an increase in the air temperature at the compressor inlet. In this paper, an increase in temperature is considered as a result of preliminary heating of air with low-grade heat from secondary energy resources (SER). The process 10-20-30-40 is considered as the initial one. Then the temperature $T_{atm}$, corresponding to point 10, rises to the temperature $T_{inlet}$, corresponding to point 11. In this case, constant operating conditions of the heat exchanger must be ensured.

To fulfill these conditions, as can be seen from the diagram shown in figure 3, the air in the compressor must be compressed to a lower pressure than the initial pressure $p_1$ (the process 11-21-31-41 must be organized in the AHPI).

![Figure 3. Processes in APHI in hs-diagram with increasing air temperature at the compressor inlet.](image)

Under the condition of a slight change in the air flow rate ($G_{A0} = G_{A1} = G_a$) - such an assumption is quite possible in the range of real temperatures and pressures of air in the high-voltage pump unit - the energy that must be supplied to the compressor decreases

$$ (h_3 - h_1) < (h_2 - h_0), $$

This also reduces the energy supplied to the compressor from the air turbine.
(h_{2_1} - h_{1_1}) < (h_{3_0} - h_{4_0}). \tag{4}

The increase in the heat conversion coefficient with an increase in the air temperature at the inlet to the compressor or decreases, depends on how intensively the total required power of the compressor and the power of the air turbine change. This is determined by the fact that the electrical power $N_E$ required to ensure the operation of the AHPI is the difference between the total required power $N_C$ of the compressor and the power of the $N_{AT}$ of the air turbine

$$N_E = N_C - N_{AT}. \tag{5}$$

Transforming formula (5), in accordance with the designations in figure 3, it can be reduced to the form

$$N_E = G_{a} \left[ (h_{2_1} - h_{1_1}) - (h_{3_1} - h_{4_1}) \right]. \tag{6}$$

3. Results and discussion

Calculations were carried out using formulas (1), (2) and (6) with the following initial data:

- $T_1=100^\circ C$; $T_2=25^\circ C$; $p_{\text{atm}}=0.15 \text{ MPa}$;
- $\eta_{\text{oil}}=0.82$; $\eta_{\text{oil}}=0.80$.

The air temperature $T_{\text{inlet}}$ at the compressor inlet varied from 5 to 25 $^\circ C$. The calculation results are presented graphically in figure 4.

![Figure 4](image-url)

**Figure 4.** Dependence of the conversion factor of an air heat pump on the air temperature at the compressor inlet.

4. Conclusion

The calculations showed that with an increase in the air temperature at the compressor inlet, the conversion coefficient increases.
Thus, under the accepted conditions, preheating the air in front of the compressor makes it possible to increase the efficiency of the AHPI operation.

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