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Upgraded Algorithm for Calculating the Turbo-Expander of Gas Distribution Stations

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Abstract. The article deals with the urgency of adapting computational turbo-expander unit parameters techniques to the conditions of their application at gas distribution stations. Existing computational methods based on the use of air as the working medium yield incorrect data to determine the actual design parameters for operating conditions where the working medium is natural gas. A modernized algorithm of thermogasdynamic calculation of turbo-expanders in order to form the correct initial data for design calculations has been proposed. The objective of calculating turbo-expanders is to identify thermogasdynamic parameters and dimensions of the flow channel, rotational speed, and shaft power. Procedure of thermogasdynamic calculations is shown on the example of a turbo-expander running on natural gas. The result will simplify the process of selecting or designing turbo-expander units for gas distribution stations.

1 Introduction

Currently, obtaining electrical energy using resource-saving, environmentally friendly technologies becomes relevant. One of these areas is using the potential energy of high-pressure natural gas from main gas pipelines with the use of turbo-expander units (TEU). It is known that at gas distribution stations (GDS) and gas control units (GCU) natural gas is reduced. In this case, the potential energy of the compressed gas is lost permanently which can be used to generate electricity and cooling.

For several decades, many European countries (Italy, Germany, etc.) have successfully been using this technology, installing TEU at GDS and GCU pipelines to reduce the gas pressure to the desired pressure for the consumer, both serving as GDS and GCU and simultaneously generating electricity. Wherein the gas is not burned but is used only as a working medium, moving further to the consumer. Thereafter, fuel combustion products do not pollute the environment.

2 Research

The process of gas expansion in the TEU is accompanied by an increase in its temperature. Therefore, in order to prevent hydrate formation, as well as to meet the SNIP temperature standards, at the TEU input gas heating is provided.

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When designing the TEU at the GDS located in the energy-deficient regions, it is advisable to build a gas turbine power plant (GTP) next to the GDS. Combining a turbo-expander with a heat exchanger of the power plant gas turbine engine which is intended for heating the natural gas at the inlet of the TEU will allow the production of electricity by this complex with a performance coefficient from 65 to 75 % [1, 7, 8]. Therefore, studies aimed at improving the TEU design techniques at GDS are connected with Energy Saving Strategy of Russia and are relevant.

The objective of calculating turbo-expanders is to identify thermogasdynamic parameters and dimensions of the flow channel, rotational speed, shaft power. Procedure of thermogasdynamic calculations is shown on the example of a turbo-expander running on natural gas.

Turbo-expanders of gas distribution stations (GDS) are used to generate electricity by natural gas differential pressure on the turbine stage. Approximate composition and characteristics of the components of natural gas transported through the main gas pipeline and entering the GDS are presented in Table 1.

Table 1. Composition and characteristics of the natural gas components.

Characteristics	**Components**						
	CH4	C2H6	C3H8	C4H10	CO2	H2S	N2
Molar concentration %, ri	98.0	0.4	0.2	-	0.1	-	1.3
Molecular weight of the components, μi, kg/kmol	16.04	30.07	44.09	-	44.02	-	28.00
Molecular weight of the mixture	$\mu_m = \frac{1}{100} \cdot \sum r_i \cdot \mu_i = 16{,}34$ kg/kmol						
Gas constant	$R = \frac{\bar{R}}{\mu_m} = 0.509,$ where $\bar{R} = 8.314$ kJ/kg·K						
Density of gas under normal conditions (st)	$\rho_s = \frac{P_s}{R \cdot T_s} = \frac{101{,}33}{0{,}509 \cdot 273} = 0.7292$ kg/m3						

Table 2 shows sample GDS initial data.

Table 2. Main GDS initial data.

Title	**Value**		**Note**
Gas pressure at the inlet	PI = 45 kg/cm	4410 kPa	Density of gas under normal conditions ρst = 0,73kg/m3
Gas pressure at the outlet	PO = 11.9 kg/cm2	1166.2 kPa	
Gas flow rate through the GDS	V=340 thousand n·m3/h	M=69.01 kg/s	
Gas temperature at the inlet	tI=35°C	TI=308 K	
Index of adiabatic gas expansion	Kg =1.2		

Using the initial data in Tables 1 and 2, we made an upgraded algorithm for thermogasdynamic calculation of a turbo-expander in order to form correct input data for design calculations:

1. Gas temperature at the GDS outlet [2, 9, 10], K:

$$T_{OUT} = T_{IN} / \left(\frac{P_{IN}}{P_{OUT}} \right)^{\frac{K_{\Gamma}-1}{K\Gamma}} \tag{1}$$

2. Average heat capacity of natural gas [3], kJ/kg·K:

$$C_{Pg_1} = \left(0{,}66 + 0{,}34 \cdot \frac{r_{CH_4}}{100} \right) \cdot \left[\left(0{,}00344 - 0{,}00009 \cdot P_{IN}\right) \cdot \left(\frac{t_{IN} + t_{OUT}}{2}\right) + 0{,}011 \cdot P_{IN} + 2{,}06 \right] \tag{2}$$

3. Available capacity of the GDS, kW:

$$N_{GDS} = M \cdot C_{P\text{г}1} \cdot \left(T_{IN} - T_{OUT}\right) \tag{3}$$

As an example, table provides data on the TEU.

Table 3. Initial data on the turbo-expander.

Title	Value		Note
Gas pressure at the inlet	P1 =40 kg/cm2	3920 kPa	Density of gas under normal conditions ρst=0,73 kg/m3
Gas pressure at the outlet	P2=9 kg/cm2	882 kPa	
Gas flow rate	130 thousand n·m3/h	26,386 kg/s	
Gas temperature at the inlet	t1=90 °C	T1=363 K	
Gas temperature at the outlet	t2 = 10 °C	T2 = 283 K	

4. Average heat capacity of natural gas [3, 11, 12], kJ/kg·K:

$$C_{Pg_2} = \left(0{,}66 + 0{,}34 \cdot \frac{r_{CH_4}}{100} \right) \cdot \left[\left(0{,}00344 - 0{,}00009 \cdot P_1\right) \cdot \left(\frac{t_1 + t_2}{2}\right) + 0{,}011 \cdot P_1 + 2{,}06 \right] \tag{4}$$

5. Available capacity of the GDS, kW:

$$N_{TD} = M \cdot C_{P\text{г}} \cdot \left(T_1 - T_2\right) \tag{5}$$

6. Joule-Thomson coefficient, which is a function of pressure, temperature and gas composition, kJ/kg•MPa [4, 13, 14]:

$$(C_P D_i)_m = 10 \cdot \left(1{,}98 - \frac{r_{CH_4}}{100} \right) \cdot \left[\left(0{,}0000012 \cdot t_1^2 - 0{,}000135 \cdot t_1 + 0{,}00298\right) \cdot P_A - 0{,}00463 \cdot t_1 + 1{,}119 \right] \tag{6}$$

7. Enthalpy change considering the Joule-Thomson coefficient, kJ / kg:

$$\Delta h_s = C_{P\text{г}} \cdot \left(T_1 - T_2\right) - \left(C_p D_i\right)_m \cdot \left(P_1 - P_2\right) \tag{7}$$

8. Actual capacity of the TEU, kW:

$$N_{TD\,A} = M \cdot \Delta h_s \tag{8}$$

To realize the available capacity of the GDS it is expedient to install two turbo-expanders with a capacity of 4000 kW each.

Let us specify the natural gas parameters by the technique formulas developed by "Gazprom VNIIGAZ", Moscow:

9. Density of gas under standard conditions, kg/m3:

$$\rho_{ST} = \frac{P_{ST}}{R \cdot T_{ST}} \tag{9}$$

where: standard pressure P_{ST} = 101.33 kPa and temperature T_{ST} = 293 K

10. Critical gas pressure, MPa:

$$P_{CR} = 0{,}1773(26{,}831-\rho_{ST}) \tag{10}$$

11. Critical gas temperature, K:

$$T_{CR} = 156{,}24(0{,}564+\rho_{ST}) \tag{11}$$

12. Reduced value of gas pressure:

$$P_R = (P_1 + P_2)/2P_{CR} \tag{12}$$

13. Reduced value of gas temperature:

$$T_R = (T_1 + T_2)/2T_{CR} \tag{13}$$

14. Let us find τ [5, 15, 16]:

$$\tau = 1-1{,}68T_R+0{,}78T^2_R+0{,}0107T^3_R \tag{14}$$

15. Let us define the gas compressibility factor, in a case if a TEU worked as centrifugal gas blower (that is, compressed gas) [6, 17, 18 etc]:

$$Z = 1 - 0{,}0241\frac{P_R}{\tau} \tag{15}$$

16. Available potential work of a turbo-expander, kJ/kg:

$$\omega = Z \cdot R \cdot \left(\frac{T_1 + T_2}{2}\right) \cdot \ln\frac{P_1}{P_2} \tag{16}$$

17. Available potential capacity of a TEU, kW:

$$N_{GDS} = M \cdot \omega \tag{17}$$

18. Polytropic performance efficiency of a turbo-expander [19, 20]:

$$\eta_P = \frac{\Delta h}{\omega} \tag{18}$$

Sample calculation results are summarized in Table 4.

3 Conclusion

Application of a TEU at the GDS produces electricity due to the pressure difference at the input and output of the unit.

Table 4. Calculation results.

№	Parameter symbol	Unit of measurement	Value
1	TOUT	K	246.76
2	Cpg1	kJ/kg·K	2.12
3	NGDS	kW	8877.7
4	Cpg2	kJ /kg·K	2.235
5	NTD	kW	4717.6
6	CpDi	kJ/ kg•MPa	7.036
7	Δhs	kJ /kg	154.12
8	NTDA	kW	4067
9	ρST	kg/m3	0.679
10	PCR	MPa	4.636
11	TCR	K	194.5
12	PR	-	0.518
13	TR	-	1.661
14	τ	-	0.412
15	z	-	0.97
16	ω	kJ /kg	237.78
17	NGDS	kW	6274
18	ηp	-	0.66

This method is adapted for natural gas, since existing techniques are based on calculations for air. The adaptation is made taking into account the heat drop in the TEU; gas density; the degree of expansion as inverse of the compression rate.

Modernization of the existing methods allows generating the correct input data for design calculations of TEU. Calculated by the developed technique thermogasdynamic and design installation parameters for a specific GDS will allow to find the optimal number of existing imported TEU or produce them in Russia, providing jobs and increasing import substitution of the units.

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