ASSESSMENT OF THE ENERGY EFFICIENCY OF EXPANDER-GENERATOR UNITS FOR THE UTILIZATION OF NATURAL GAS OVERPRESSURE ENERGY IN THE GAS TRANSMISSION SYSTEM FACILITIES OF UZBEKISTAN

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Abstract. A study was conducted on the performance characteristics of expander–generator units and the selection of the most energy-efficient method of gas preheating at the inlet. Various operating modes at gas distribution points were examined, and two main preheating methods were compared: traditional thermal boilers and heat recovery from gas turbine exhaust gases. The obtained results make it possible to rationally choose the preheating method that ensures optimal thermodynamic and economic performance.

Keywords: natural gas, electricity generation, gas turbine unit, expander generator unit, gas distribution point, throttle

Annotatsiya. Detander–generator qurilmalarining ishlash xususiyatlari va kirish qismini isitishning eng energiya tejamkor usulini tanlash bo‘yicha tadqiqot o‘tkazildi. Gaz taqsimlash punktlaridagi turli ish rejimlari ko‘rib chiqildi hamda ikkita asosiy isitish usuli — an’anaviy qozonlar orqali isitish va gaz turbinasining chiqindi gazlaridagi issiqlikni qayta foydalanish — taqqoslandi. Olingan natijalar optimal termodinamik va iqtisodiy ko‘rsatkichlarni ta’minlaydigan isitish usulini oqilona tanlash imkonini beradi.

Kalit so‘zlar: tabiiy gaz, elektr energiyasi ishlab chiqarish, gaz turbina qurilmasi, detander-generator qurilmasi, gaz taqsimlash punkti, drossellovchi moslama

Аннотация. Проведено исследование характеристик работы детандер-генераторных установок и выбор наиболее энергоэффективного способа подогрева газа на входе. Рассмотрены различные режимы работы установок на распределительных пунктах и сравнены два основных метода подогрева: с использованием традиционных котлов и за счёт утилизации теплоты

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выхлопных газов газотурбинных установок. Полученные результаты позволяют рационально выбрать метод подогрева для достижения оптимальных термодинамических и экономических показателей.

Ключевые слова: природный газ, выработка электроэнергии, газотурбинная установка, детандер-генераторная установка, газораспределительный пункт, дроссель

Introduction

There is growing interest in using expander–generator units (EGUs) for decentralized power generation, where the pressure drop of natural gas at GDS and GRP is converted into electricity. The efficiency of such systems largely depends on the selected gas-heating method [1]. This study examines autonomous EGUs operating at remote stations, comparing boiler-based heating with heat recovery from gas turbine exhaust.

Autonomous EGUs function independently of gas-consuming facilities, and their operation affects these systems only through changes in outlet gas temperature and auxiliary power demand. Their main purpose is to generate electricity either for internal needs or for delivery to the grid. When an EGU is engaged, gas consumption in downstream systems changes proportionally to the variation in the available heat of the gas, which is described by the corresponding dependence:

$$Q_{\text{ahg}} = Q_{\text{lhc}} + h_{\text{g}} - h_0, \qquad (1)$$

Where h_{g} and h_0 are the specific enthalpies of the gas fuel at the operating conditions and at the reference state (0 °C, 0.1 MPa), expressed in kJ/kg, and Q_{lhc} denotes the lower heating value of the fuel in J/kg. This effect is taken into account when assessing the influence of EGU operation on the overall fuel consumption of gas-using equipment.

OBJECT AND METHODOLOGY

One of the simplest methods of heating gas before the expander is the use of a specialized boiler (Fig. 1).

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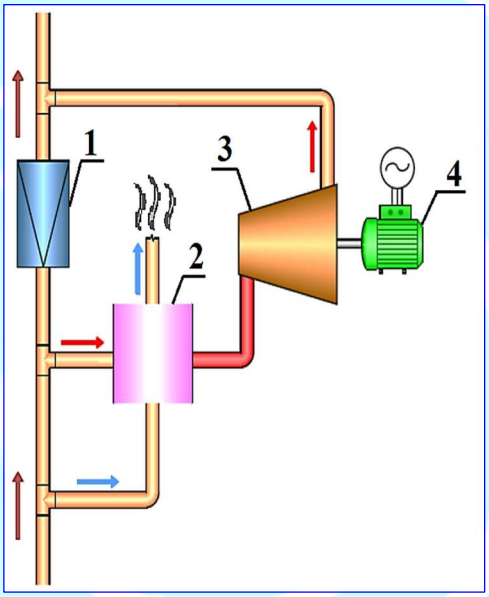


Figure 1. EGU with gas heating in the boiler: 1 - reducing device, 2 - boiler for gas heating, 3 - expander, 4 - generator of the expander

If the enthalpy of the gas at the outlet of the expander is h_2, kJ/kg, the same as at the inlet to the unit h_{ENT} kJ/kg, then the power of the expander is N_{EGU} kW, and the fuel consumption for heating the gas before the expander is VG_{fuel}^{bef} kg/s, as determined by expressions [2]:

$$N_{EGU} = G_{fuel} \cdot (h_1 - h_2) \text{ and } \quad VG_{fuel}^{bef} = \frac{G_{fuel} \cdot (h_1 - h_2)}{Q_{lhc} \cdot \eta_b} \quad (2)$$

and the specific fuel consumption for electricity generation by the unit, in kg/s·J, is calculated as:

$$G_{sfc} = \frac{1}{Q_{lhc} \cdot \eta_b}, \quad (3)$$

Where η_b – is the efficiency of the boiler, which preheats the gas before it enters the expander; G_{fuel} –fuel consumption in the pipeline, kg/s; h_1 and h_2 – the enthalpy of the gas before and after the expander is, respectively, kJ/kg.

If the $h_{in} \neq h_2$ change in the enthalpy of the gas upon entering the gas-consuming unit leads to a change in its consumption (in the case of using gas as fuel), then the formulas will take the following form:

c) total change in gas consumption VG_{fuel} kg/s:

$$VG_{fuel} = \frac{G_{fuel} \cdot \left[(h_1 - h_{ENT}) + (h_{ENT} - h_2) \cdot \eta_b\right]}{(Q_{lhc} + h_2 - h_{ENT}) \cdot \eta_b}; \quad (4)$$

Where h_{ENT} – enthalpy of gas at the entrance to the installation, kJ/kg;

g) power of the EGU, kW:

$$N_{EGU} = \left[G_{fuel} \cdot (h_1 - h_2)\right] \cdot \left[\frac{Q_{lhc} + h_{ENT} - h_0}{Q_{lhc} + h_2 - h_0}\right]; \quad (5)$$

d) specific fuel consumption for electricity generation (all changes in fuel consumption relate to electricity generation), kg/s·kW:

$$G_{sfc} = \frac{VG_{fuel}}{N_{EGU}} = \frac{h_1 - h_{ENT} + (h_{ENT} - h_2) \cdot \eta_b}{(Q_{lhc} + h_2 - h_0) \cdot \eta_b \cdot (h_1 - h_2)}. \quad (6)$$

THE RESULTS OF THE STUDY

Figure 2 shows the specific fuel consumption for power generation calculated using formula (6). The results demonstrate how fuel usage depends on

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the gas temperature upstream of the expander and on different inlet pressures, assuming constant p_2=1.5kg/cm^2 and η_b=0.9.

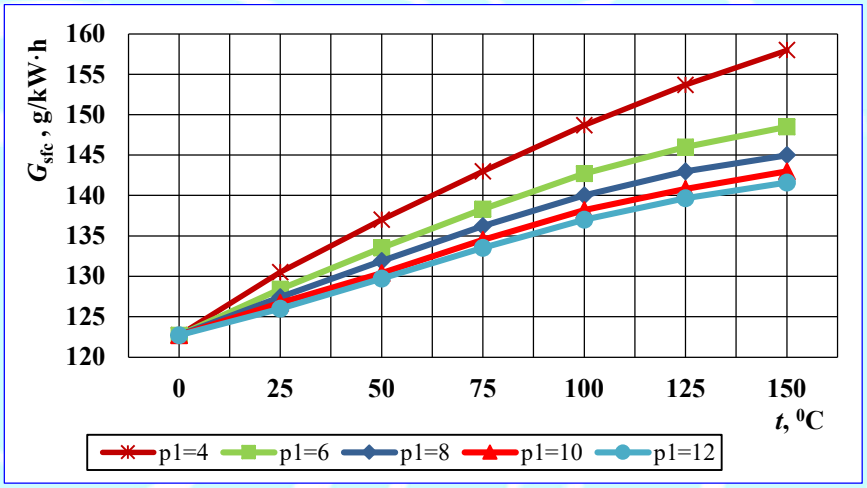


Figure 2. Specific fuel consumption for electricity generation

As the graph shows, gas temperature has little influence on specific fuel consumption, whereas boiler efficiency is the key factor. If variations in inlet gas enthalpy do not affect the consumer's gas flow rate, the analytical expressions simplify to:

a) Total change in gas consumption VG_{fuel}:

$$VG_{fuel} = \frac{G_{fuel}}{\eta_b} \cdot \frac{h_1 - h_{ENT}}{Q_{lhc} + h_{ENT} - h_0}; \quad (7)$$

b) Power output of the EGU (kW):

$$N_{EGU} = G_{fuel} \cdot (h_1 - h_2); \quad (8)$$

c) Specific fuel consumption (kg/s·J):

$$G_{sfc} = \frac{h_1 - h_{ENT}}{(Q_{lhc} + h_{ENT} - h_0) \cdot \eta_b \cdot (h_1 - h_2)} \approx \frac{h_1 - h_{ENT}}{Q_{lhc} \cdot \eta_b \cdot (h_1 - h_2)} \quad (9)$$

Waste heat from the GTU exhaust can preheat gas before the turboexpander (Fig.3). A common analysis assumes the gas enthalpy is equal upstream and downstream of the expander, making the heat input Q_{sup} equivalent to the expander-generator output N_{EGU} [3,4].

The total heat from the flue gases Q_{fg} must equal the sum of the generator power and the heat remaining in the gases after the exchanger. This energy balance is crucial for the system's operation [5,6].

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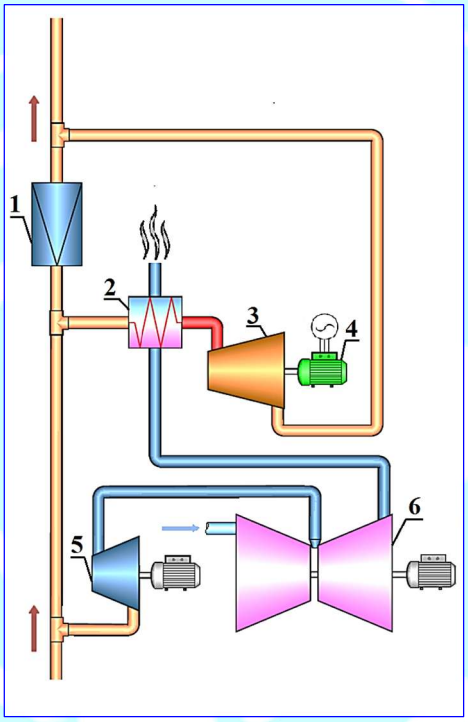


Figure 3. GTU exhaust-gas heating system: 1- reducing device; 2-heat exchanger; 3-turboexpander; 4 - generator of the expander; 5-compressor; 6-gas turbine unit

The power of the EGU and the heat of the exhaust gases are related by the formula:

$$Q_{fg} = N_{EGU} + Q_{eg}; \qquad (10)$$

where: N_{EGU} – power of the EGU, кВт; Q_{eg} - the heat of the exhaust gases, J.

The relationship between expander-generator power and exhaust heat is expressed through a formula dependent on heat exchanger efficiency. Estimation involves the enthalpy of flue gases at the GTU outlet, post-heat exchanger state, and cold air temperature:

$$Q_{eg} = Q_{fg} \cdot (1 - \eta_{HEU}); \ \eta_{HEU} = Q_{sup} / Q_{fg};$$

where: η_{HEU} – efficiency of the heat exchanger-heat exchanger in which the gas is heated; Q_{sup} – the heat supplied to the gas in front of the expander, J.

The value η_{HEU} can be estimated using the formula:

$$\eta_{HEU} = \frac{h_{fg} - h_{eg}}{h_{fg} - h_{ca}} \cong \frac{t_{fg} - t_{eg}}{t_{fg} - t_{ca}}, \qquad (11)$$

where: h_{fg},h_{eg},h_{ca} –the enthalpy of flue gases at the outlet of the gas turbine unit, exhaust gases after the heat exchanger and at cold air temperature, respectively, kJ/kg;

t_{fg},t_{eg},t_{ca} – the temperature of flue gases at the outlet of the gas turbine unit, exhaust gases after the heat exchanger and at a temperature of cold air, respectively, ^{0}C.

The power of the GTU will be, kW:

$$N_{GTU} = N_{EGU} \cdot \frac{t_{fg} - t_{ca}}{t_{fg} - t_{eg}} \cdot \frac{\eta_{GTU}}{1 - \eta_{GTU}}; \qquad (12)$$

where η_{GTU} – efficiency of a gas turbine installation.

If accepted $\eta_{EGU} \approx 0{,}3; t_{fg} \approx 500^0\text{C}; t_{ca} \approx 20^0\text{C}; t_{eg} \approx 100^0\text{C}$, the required power of the GTU will be more than 50% of the power of the expander-generator unit.

The specific indicator of such an installation in the form of specific fuel consumption for power generation G_{sfc} of the installation is equal to:

$$G_{sfc} = \frac{G_{GTU}}{N_{GTU} + N_{EGU}} = \frac{t_{fg} - t_{ca}}{Q_{lhc} \cdot \left[\left(t_{fg} - t_{ca} \right) \cdot \eta_{GTU} + \left(t_{fg} - t_{eg} \right) \cdot \left(1 - \eta_{GTU} \right) \right]}. \qquad (13)$$

ISSN 3030-3907

If the enthalpy of gas at the outlet of the expander differs from the enthalpy at the entrance to the gas-consuming installation, two scenarios are considered: one with a change in gas flow rate to the installation after switching on the EGU, and the other without such a change [7,8].

The capacity of the GTU will be:

$$N_{\text{GTU}} = \frac{G_{\text{fuel}} \cdot (Q_{\text{lhc}} + h_{\text{ENT}} - h_0) \cdot (h_1 - h_{\text{ENT}}) \cdot (t_{\text{fg}} - t_{\text{ca}}) \cdot \eta_{\text{GTU}}}{(Q_{\text{lhc}} + h_2 - h_0) \cdot (t_{\text{fg}} - t_{\text{eg}}) \cdot (1 - \eta_{\text{GTU}})}, \quad (14)$$

and the fuel consumption on the GTU will be equal to:

$$G_{\text{GTU}} = \frac{N_{\text{GTU}}}{(Q_{\text{lhc}} + h_{\text{ENT}} - h_0) \cdot \eta_{\text{GTU}}} = \frac{G_{\text{fuel}} \cdot (h_1 - h_{\text{ENT}}) \cdot (t_{\text{fg}} - t_{\text{ca}})}{Q_{\text{lhc}} + h_2 - h_0 \cdot (t_{\text{fg}} - t_{\text{eg}}) \cdot (1 - \eta_{\text{GTU}})} \quad (15)$$

The total fuel consumption, $\text{V}G_{\text{fuel}}$ including changes in consumption for gas-consuming equipment, will be equal to:

$$\text{V}G_{\text{fuel}} = \frac{G_{\text{fuel}} \cdot (h_1 - h_{\text{ENT}}) \cdot (t_{\text{fg}} - t_{\text{ca}})}{(Q_{\text{lhc}} + h_2 - h_0) \cdot (t_{\text{fg}} - t_{\text{eg}}) \cdot (1 - \eta_{\text{GTU}})} + \frac{G_{\text{fuel}} \cdot (h_{\text{ENT}} - h_2)}{Q_{\text{lhc}} + h_2 - h_0}. \quad (16)$$

After performing some simple transformations, the total capacity of the gas turbine unit and the expander generator set can be determined:

$$N_{\text{UNIT}} = \frac{G_{\text{fuel}} \cdot (Q_{\text{lhc}} + h_{\text{ENT}} - h_0) \cdot (h_1 - h_{\text{ENT}}) \cdot (t_{\text{fg}} - t_{\text{ca}}) \cdot \eta_{\text{GTU}}}{(t_{\text{fg}} - t_{\text{eg}}) \cdot (1 - \eta_{\text{GTU}})} + \frac{G_{\text{fuel}} \cdot (Q_{\text{lhc}} + h_{\text{ENT}} - h_0) \cdot (h_1 - h_2)}{(Q_{\text{lhc}} + h_2 - h_0)}. \quad (17)$$

The increase in fuel consumption ΔG_{UNIT} will depend on various factors, including the gas consumption of the boiler room:

$$\Delta G_{\text{UNIT}} = \frac{G_{\text{fuel}} \cdot (Q_{\text{lhc}} + h_{\text{ENT}} - h_0) \cdot (h_1 - h_{\text{ENT}}) \cdot (t_{\text{fg}} - t_{\text{ca}}) \cdot \eta_{\text{GTU}}}{Q_{\text{lhc}} + h_2 - h_0} + \frac{G_{\text{fuel}} \cdot (h_{\text{ENT}} - h_2)}{Q_{\text{lhc}} + h_2 - h_0} \quad (18)$$

where G_{B} – boiler room gas consumption.

The calculation was performed for the following conditions: gas pressure before the EGU 0.5 MPa, gas pressure after the EGU 0.15 MPa, gas temperature before the EGU 278 K, boiler capacity 116 MW, own needs of the boiler plant 1048 КВт, t_{fg} = 673 K, t_{eg} = 373 K, t_{ca} = 293 K, $\eta_{\text{EGU}} = 0{,}9$, $\eta_{\text{GTU}} = 0{,}9$.

The calculation results are shown in Table 1.

Table 1

The results of calculating the power of a gas turbine installation, increasing fuel consumption and boiler gas consumption at initial and final gas temperatures

t_1, ^{0}C	T_1, K	T_2, K	N_{UNIT}, kW	G_{fuel}, kg/s	ΔG, kg/s
5	278,15	218,03	321,789	2,564	0,0065
10	283,15	221,95	340,913	2,565	0,0070
20	293,15	229,78	379,589	2,566	0,0081
30	303,15	237,62	418,851	2,567	0,0092

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40	313,15	245,46	458,634	2,568	0,0104
50	323,15	253,30	499,084	2,569	0,1150
60	333,15	261,14	540,211	2,570	0,0127
70	343,15	268,98	582,061	2,571	0,0138
80	353,15	276,81	624,695	2,573	0,0150
90	363,15	284,65	668,030	2,574	0,0162
100	373,15	292,49	712,118	2,575	0,0175
110	383,15	300,33	757,003	2,576	0,0187
120	393,15	308,17	802,695	2,578	0,0200
130	403,15	316,01	849,193	2,579	0,0213
140	413,15	323,85	896,516	2,580	0,0226
150	423,15	331,68	944,654	2,581	0,0239

The specific fuel consumption G_{sfc} for electricity generation is determined using formula:

$$G_{\text{sfc}} = \frac{h_{\text{ENT}} - h_2}{\left(Q_{\text{lhc}} + h_{\text{ENT}} - h_0\right)\cdot\left(h_1 - h_2\right)}. \qquad (19)$$

Fig. 7 shows the variation of specific fuel consumption with gas temperature upstream of the expander and inlet pressure. The curve confirms that gas temperature has only a slight impact, consistent with earlier trends (Fig. 2).

If the change in gas enthalpy at the expander exit does not affect the mass flow rate of the downstream gas-consuming unit, the governing equations reduce to:

a) Fuel consumption:

$$\Delta G_{\text{fuel}} = G_{\text{GTU}} = \frac{G_{\text{fuel}}\cdot\left(h_1 - h_{\text{ENT}}\right)\cdot\left(t_{\text{fg}} - t_{\text{ca}}\right)}{\left(Q_{\text{lhc}} + h_{\text{ENT}} - h_0\right)\left(t_{\text{fg}} - t_{\text{eg}}\right)\cdot\left(1 - \eta_{\text{GTU}}\right)}; \qquad (20)$$

b) Electrical output:

$$N_{\text{UNIT}} = \frac{G_{\text{fuel}}\cdot\left(h_1 - h_{\text{ENT}}\right)\cdot\left(t_{\text{fg}} - t_{\text{ca}}\right)\cdot\eta_{\text{GTU}}}{\left(t_{\text{fg}} - t_{\text{eg}}\right)\cdot\left(1 - \eta_{\text{GTU}}\right)} + G_{\text{fuel}}\cdot\left(h_1 - h_2\right); \qquad (21)$$

c) Specific fuel consumption:

$$G_{\text{sfc}} = \frac{\left(t_{\text{fg}} - t_{\text{ca}}\right)\cdot\left(h_1 - h_{\text{ENT}}\right)}{\left(Q_{\text{lhc}} + h_{\text{ENT}} - h_0\right)\cdot\left[\left(t_{\text{fg}} - t_{\text{ca}}\right)\cdot\eta_{\text{GTU}}\cdot\left(h_1 - h_{\text{ENT}}\right) + \left(h_1 - h_2\right)\cdot\left(t_{\text{fg}} - t_{\text{eg}}\right)\cdot\left(1 - \eta_{\text{GTU}}\right)\right]}. \qquad (22)$$

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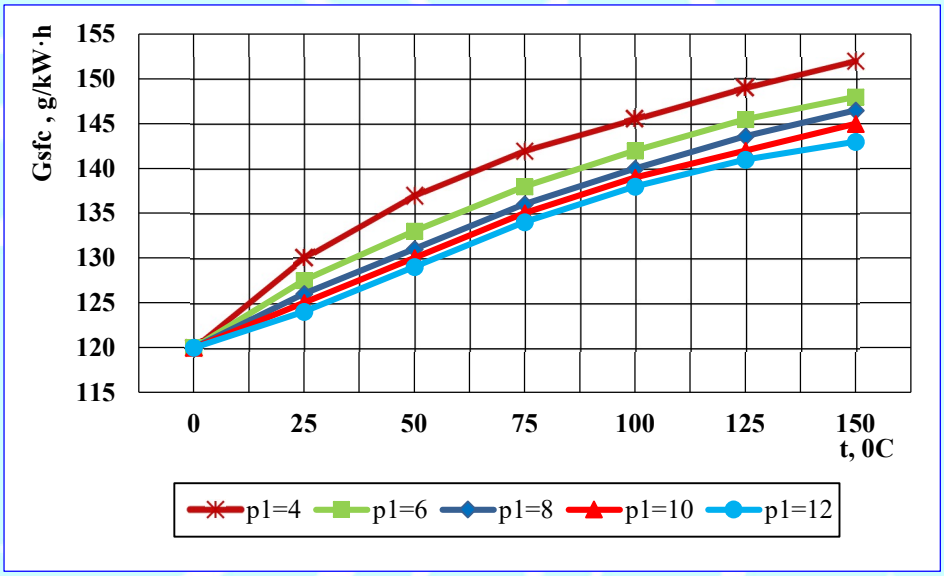


Figure 7. Variation of specific fuel consumption with gas preheating temperature

DISCUSSION

The efficiency comparison of gas-preheating methods assumes a constant mass flow rate upstream of the EGU. The analysis calculates power output, fuel consumption, and specific fuel consumption for each method, assuming the expander outlet temperature does not affect downstream flow.

Comparing relative fuel consumption $\Delta G_{fuel} / G_{fuel}$ shows that raising the preheat temperature impacts fuel use more significantly for GTU-based heating than for boiler heating, due to the GTU's higher power output.

Notably, the absolute fuel consumption for heating remains the same whether using GTU exhaust or a boiler.

CONCLUSION

Analysis shows the highest relative power output is achieved using GTU exhaust gases, due to their greater thermal potential and resulting higher fluid enthalpy before expansion.

Specific fuel consumption depends on the heating method, pressure, and temperature. At lower preheat temperatures, boiler heating is more economical due to lower thermal requirements and simpler setup. At higher temperatures, using GTU exhaust becomes preferable, as waste-heat recovery reduces overall fuel demand and improves efficiency.

Thus, the optimal gas-heating method depends on the required preheat temperature and available thermal resources, balancing fuel use and power output.

REFERENCES

1. A.A. Mukolyants, M.D. Buranov, I.V. Sotnikova and H.F. Makhmudov.: Operation analysis of expander-generator unit at a gas distribution station. Journal

ISSN 3030-3907

of Physics: Conference Series 1515, 022053 (2020), doi:10.1088/1742-6596/1515/2/022053

2. Yaxuan X., Shuo A., Peng X., Yulong D., Li Chuan, Zh.Qunli, Ch.Hongbing.: A novel expander-depending natural gas pressure regulation configuration: performance analysis. Applied Energy 220, 21-35 (2018)

3. Zhi-Dong Li, Qing-Lin Cheng, You-Wang Chen, Jiang-Dong Wei, Li-Li Lv, Hao Wu, Yang Liu,: Electric power generation technology of natural gas pressure reduction: Insights from black box-gray box hierarchical exergy anal-ysis and evaluation method. Petroleum Science 19, 329-338 (2022)

4. Andreev A.R.: Changes in Boiler Performance with the Use of EGU and Gas Heating by Exhaust Gases of the Gas Turbine Unit. Industrial Energy. No 1. 42–44 (2005).

5. Mukolyants A.A., Buranov M.D., Sotnikova I.V., Taubaldiev A.A.: Improving the efficiency of air transport heat pump unit in the expander-generator unit. Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft. No 8(1), 49-522021. DOI: 10.24412/2701-8369-2021-8-1-49-51.

6. Dzhuraeva E.V.: *Study of the Schemes for the Use of Expansion Turbine-Generator Units in Energy and Gas Supply Systems.* Ph.D. thesis in Technical Sciences. Moscow, 2005.

7. I.V. Sotnikova, A.A., Mukolyants, Z., Nizomov.: On the Influence of the Expansion Turbine-Generator Unit on the Efficiency of Boiler Operation When Heating Gas with Flue Gases from a Gas Turbine Unit. Journal "Problems of Energy and Resource Conservation", Tashkent, Special issue. No 85, 168-175 (2024)

8. Arsen Mukolyants, Irina Sotnikova, Dilbar Ergasheva.: Investigation of a fuel-free power generating plant and evaluation of the effectiveness of its use.E3S Web of Conferences 474, 01011. (2024)https://doi.org/10.1051/e3sconf/202447401011.

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