Increasing efficiency of boiler unit by installation of gas-piston micro central heat power plant

K V Osintsev, I S Prikhodko, V O Pashnin
South Ural State University, 76, Lenina Ave., Chelyabinsk, 454080, Russia
E-mail: pte2017pte@mail.ru

Abstract. The article is devoted to ways of increasing the efficiency of boiler houses producing heat in the form of hot water. The problems of the shortage and uninterrupted power supply are also touched upon. One of the methods for solving the problems is using gas piston engines and reconstructing the boiler house into a micro gas-piston power plant. Installations of this type can be used for production of various types, including at enterprises of the energy sector and the mineral-raw complex. Ways to improve the existing equipment are considered. The possibilities of using economic analysis for determining the installation location and the choice of the number and power of the gas piston unit are shown. The properties of the intermediate heat carriers of the gas piston engine are different depending on the required temperature of the heat carrier - hot water.

1. Introduction
Increasing the economy and energy saving of the boiler house requires the improvement of heat and power supply systems. The main objectives are to reduce losses to a minimum, ensure efficient fuel use and ensure the population of the country with reliable heat and electricity. At the same time, measures to improve economy and efficiency should be undertaken with small capital investments [1, 2].

One of the perspective directions is introduction of independent cogeneration systems, such as a mini central heat power plant. A wide use of a gas-piston engine was obtained by the joint generation of electric and thermal energy at a small distance from the consumer. At the same time, there is a cost saving due to a short distance from the gas-piston engine to the heat networks. It is advisable to install a mini central heat power plant if there are insufficient opportunities for existing sources of electricity and heat, with an increase in the efficiency of the boiler house, with a reduced quality of thermal energy from sources of generation that do not meet modern requirements. Also the dependence on the increase in tariffs for heat and electricity is reduced, since the cost price of the mini central heat power plant energy is much lower [3, 4]. The gas-piston engine operates on natural gas, which, when burned, releases carbon dioxide much less than that operating on fuel oil. Therefore, the gas-piston engine has much less impact on the environment. The construction of a mini central heat power plant is an affordable way of obtaining heat and electricity by the fact that natural gas is available practically throughout the whole territory of Russia. Combined energy production at the mini central heat power plant gives a number of advantages such as significant fuel savings, increased boiler room capacity and improved environmental conditions [5, 6]. The least polluting atmosphere is the greenhouse gases of a mini central heat power plant with a gas piston engine. From the ecological point of view, when
considering a gas-piston engine with a capacity of up to 1 MW, a choice was made in favor of a gas piston micro central heat power plant. Coke oven gas and biogas can be used instead of natural gas [1, 6, 7, 8, 10], and a gas turbine plant instead of a gas-piston [9, 11].

2. The principle of reconstruction of the boiler house into a micro gas-piston power station
Let us consider the operation principle of a micro gas piston power station.

![Diagram](image)

**Figure 1.** A scheme of connecting a mini central heat power plant to the boiler plant thermal diagram: GPE - gas piston engine; P1 - circulating pump; P2 - emergency cooling pump; V1 - three-way valve "small" circulation circuit; V2 - three-way valve of the emergency cooling system; R1 - emergency cooling radiator; R2 - heat exchanger of the emergency cooling system.

3. Methodology of research investigation
It is necessary to determine initial data before starting calculation of technical and economic indicators [7, 8]. Calculation data: cost of mini central heat power plant - 45 mln rub (variant B - 55 mln rub), cost of 1000 nm$^3$ of natural gas is 3726 rub (variant B - 4200 rub), cost of 1 liter of oil - 240 rub, periodicity of oil change is 1250 hours, the amount of oil to be changed is 232 liters and 8000 hours of gas-piston engine is work. The main characteristics of the mini central heat power plant are presented in Table 1.

| Table 1. Specifications of gas-piston engines |
|----------------------------------------------|
| **Index** | **Dimension** | **Value** | **Index** | **Dimension** | **Value** |
| Mechanical engine power | kW | 1055 | Heat of exhaust (120 ° C) | kW | 622 |
| Electric power | kW | 1025 | Thermal power | kW | 1325 |
| Exhaust temperature | °C | 496 | Heat radiation of the engine | kW | 50 |
| Ventilation air flow | m$^3$/h | 73850 | Heat radiation generator | kW | 30 |
| Diameter of the piston | mm | 160 | Fuel consumption, 100% | nm$^3$/h | 278.05 |
| Piston stroke | mm | 175 | Length | mm | 4669 |
| Number of cylinders | - | 16 | Width | mm | 1736 |
| Typical rated oil consumption | g / kWh | 0.2 | Height | mm | 2560 |
Heat jacket cooling engine kW 524 Heat of the secondary cooling circuit kW 179

4. Application of the economic analysis in the boiler house reconstruction and in the new equipment introduction

The actual value of the economic efficiency indicator of scientific and technical measures introduction is compared with the project value of the economic efficiency indicator of scientific and technical measures introduction. The method of chain substitutions calculates the cost factors influence size, production volume on the indicator of economic efficiency of the introduction of scientific and technical measures. To calculate and analyze the investment project actual effectiveness aimed at the new technologies introduction, types of resources, organizational and technical measures, the annual economic benefit is used from saving production and financial resources in the same products production [9, 10].

Let us calculate the cost of fuel:

\[ C_g = \frac{G_g \cdot P_g}{1000 \cdot N}, \]  

\( G_g \) – gas flow rate (nm\(^3\)/h); \( P_g \) – cost of 1000 nm\(^3\) of gas (rubles); \( N \) – power of the GPE (kW).

Oil costs for replacement are:

\[ C_o = \frac{V_o \cdot P_o}{t_{oc} \cdot N}, \]  

\( V_o \) – amount of oil (liter); \( P_o \) – cost of 1 liter of oil (rub.); \( t_{oc} \) – periodicity of oil change (hours).

Expenses for oil consumption are:

\[ C_{oc} = G_t \cdot P_t/1000, \]  

\( G_t \) – typical nominal oil consumption (g / kW).

Expenses for major repairs and spare parts are:

\[ C_k = \frac{P_k \cdot P_b}{t_k \cdot N}, \]  

\( P_k \) – cost of w/h for major repairs (euro); \( P_b \) – euro to ruble rate (rub.); \( t_k \) – resource before major repairs (hours).

Expenses for the after-sales service are:

\[ C_w = \frac{P_w \cdot P_b}{t_k \cdot N}, \]  

\( P_w \) – cost of maintenance work (euro).

Depreciation expenses:

\[ C_d = \frac{P_{gps}}{t_r \cdot N}, \]  

\( P_{gps} \) – cost of gas-piston power station (rubles); \( t_r \) – designated resource (hours).

Savings due to heat cogeneration by gas-piston engine are:

\[ C_c = \frac{G_k \cdot P_g}{1000 \cdot N}, \]  

\( G_k \) – the amount of gas that must be supplied to the boiler to produce 1325 kWh of thermal energy.

Calculation of the cost of electricity production is:

\[ C = C_g + C_t + C_{oc} + C_k + C_w + C_{d} + C_c. \]  

Economy production of 1 kWh of electricity is:

\[ C_b = P_e - C, \]  

\( P_e \) – the cost of electricity for 1 kWh (rub).

Annual production savings of 1 kWh of electricity:

\[ C_{aps} = C_b \cdot t_0 \cdot N, \]  

\( t_0 \) – times of operation of the GPU per year (hours).

Calculation of the payback period is:

\[ t_{pp} = \frac{P_{GPI}}{C_{aps}}, \]  

In the course of calculating the economic feasibility of the boiler house reconstruction in a micro gas-piston power plant, two variants were compared. For the first of them, the cost of the micro gas-piston power station itself and the cost of natural gas are taken according to current estimates and tariffs. According to the second variant, data are given with a forecast of 1 year ahead.
Table 2. Results of economic analysis

| Parameter                                      | Dimension     | Variant A  | Variant B  |
|------------------------------------------------|---------------|------------|------------|
| cost of fuel                                  | rub/kWh       | 1.010      | 1.139      |
| oil costs for replacement                     | rub/kWh       | 0.043      | 0.043      |
| expenses for oil consumption                  | rub/kWh       | 0.048      | 0.048      |
| expenses for major repairs and spare parts    | rub/kWh       | 0.370      | 0.370      |
| expenses for the after-sales service          | rub/kWh       | 0.055      | 0.055      |
| depreciation expenses                         | rub/kWh       | 0.170      | 0.211      |
| savings due to heat cogeneration by GPE       | rub/kWh       | 0.509      | 0.574      |
| cost of electricity production                | rub/kWh       | 1.187      | 1.151      |
| economy production 1 kWh of electricity       | rub/kWh       | 1.733      | 1.410      |
| annual production savings of 1 kWh of electricity | ml rub/year  | 14.211     | 11.562     |
| payback period                                | year          | 3.17       | 4.75       |

5. Conclusion
The gas-piston engine is an effective way to increase the efficiency and power of the boiler house. Also the boiler house efficiency is increased by the lower costs for own needs. The reliability of heat and power supply is increasing. The amount of emissions to the environment is reducing.

References
[1] Sobolewski A, Ściezako M, Robak Z, Rudkowski M and Borowiec Z 2013 Coke oven gas as a fuel for gas engine Combustion Engines 153(3) 23-25
[2] Ziębik A, Liszka M, Hoinka K and Stanek W 2012 Poradnik inwestora i projektanta Układów wysokosprawnej dużej kogeneracji Politechnika Śląska 1 12-14
[3] Kasprzyk S, Rusinowski H and Plis M 2016 Ocena Energetyczna Wykorzystania Energii Gazu Koksoniczego W Układzie Kogeneracyjnym Z Silnikiem Tłokowym Konferencja Rynek Ciepła, Rynek Gazu Ciepła, Rynek Gazu 3 44-46
[4] Favorovskii O, Aminov R, Shkret A and Garievskii M 2009 Comparative effectiveness of using gas-turbine and gas-piston units for additional redundancy of an NPP’s own needs Thermal Engineering 56(4) 305-11
[5] Lo A and Liu S 2018 Towards sustainable consumption: A socio-economic analysis of household waste recycling outcomes in Hong Kong J. of Env. Manag. 214 416-25
[6] Darabadi Z, Khoshbakhti S, Mirmasoumi S and Bahlooli K 2018 Extensive thermodynamic and economic of the cogeneration of heat and power system fueled by the blend of natural gas and biogas Energy Conversion and Management 164 329-43
[7] Kang J, Kang D, Kim T and Hur K 2014 Comparative economic analysis of gas turbine-based power generation and combined heat and power systems using biogas fuel Energy 67 309-18
[8] Kang J, Kang D, Kim T and Hur K 2014 Economic evaluation of biogas and natural gas co-firing in gas turbine combined heat and power systems Ap. Therm. Eng. 70(1) 723-31
[9] Chatzipaschali A and Stamatis A 2015 Exergetic and economic analysis of a cheese whey wastewater anaerobic treatment plant with a cogeneration system Desalination and Water Treatment 56(5) 1223-30
[10] Brizi F, Silveira J, Desideri U, Reis J, Tuna C and Lamas W 2014 Energetic and economic analysis of a Brazilian compact cogeneration system: Comparison between natural gas and biogas Renewable and Sustainable Energy Reviews 38 193-211
Osintsev K, Zhirgalova T and Khasanova A 2017 Operation principles of gas turbine generator International Conference on Industrial Engineering, Applications and
Manufacturing, ICIEAM 2017 1-4