

Exergetic analysis of autonomous power complex for drilling rig

V A Lebedev, V S Karabuta

Saint Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia

E-mail: Luxyra@mail.ru

Abstract. The article considers the issue of increasing the energy efficiency of power equipment of the drilling rig. At present diverse types of power plants are used in power supply systems. When designing and choosing a power plant, one of the main criteria is its energy efficiency. The main indicator in this case is the effective efficiency factor calculated by the method of thermal balances. In the article, it is suggested to use the exergy method to determine energy efficiency, which allows to perform estimations of the thermodynamic perfection degree of the system by the example of a gas turbine plant: relative estimation (exergetic efficiency factor) and an absolute estimation. An exergetic analysis of the gas turbine plant operating in a simple scheme was carried out using the program WaterSteamPro. Exergy losses in equipment elements are calculated.

1. Introduction

Russia possesses unique reserves of hydrocarbon deposits, which are located next to the Arctic. This causes high costs for development of these deposits by oil companies, since there is no infrastructure beyond the Arctic Circle, while its construction is a very expensive item of expenditure. In these circumstances the main problem of oil deposits development is the low reliability of the power supply or its complete absence. In the development of oil fields the main stage is the process of wells drilling, which is very expensive. At the moment, the power supply of drilling rigs is provided in two ways. The first option is to deliver power from the centralized power supply system via transmission lines. The main disadvantage of this approach is initial excessive costs of the power line constructions. According to the rules of power supply security it is necessary to build a reserve power line. Frequent icing of lines may lead to interruption of the technological process of the drilling as well as to the equipment breakdown. The second option is to use diesel power plants with the heat supply from the boiler room. Disadvantages of such approach are as follows: the necessity of a tank farm to create reserve and store diesel fuel; the high cost of fuel in the current economic situation; high fuel consumption; high delivery costs. In the presented study, it is proposed to use an autonomous mobile energy complex as an alternative source of power supply for the drilling rig. When the power plants are to be installed, it is recommended to consider the possibility of using a cheap local energy source - associated petroleum gas (APG). Thus, at the initial stage of field development the power plant will operate on diesel fuel, while after the well construction it will operate on APG. The second feature of the power plant is the possibility of using secondary energy resources (such as exhaust gases) for technological needs, including the heating of the oil reservoir.



Several variants were considered as alternatives of power plant, which serves as a basis for energy complex construction: gas piston, gas-turbine, steam-turbine plants, as well as mini-nuclear power plants and microturbines.

Thus, one of the main principles for choosing the source of the power supply of the drilling rig is to minimize its construction and maintenance costs, as well as to ensure high reliability of energy supply and compliance with regulatory requirements for environmental safety.

The possibility of using APG as the main source of energy directly at the place of oil extraction attracted the attention of specialists for a long time [1]. A main difference of the APG from traditional fuels is the presence of a mixture of gaseous hydrocarbons in its composition, which significantly complicates its refining process. In absence of effective solutions for the rational utilization of associated gas, enterprises burn this resource on flare. Consequently, enterprises expose the environment to negative influences. Nevertheless, associated petroleum gas has an undoubted advantage - the cost of its production is lower than the cost of purchasing traditional fuels, so it is advisable to use it as an energy carrier (to reduce fuel costs in the structure of production costs). Therefore, the authors propose to use APG as the main energy resource for drilling. The main goal of the work is to create an experimental power plant that will operate in a dual fuel mode. Requirements to the quality of the gas used in power plant operation must comply with GOST (Russian National Standard) 29328-92. The technological cycle includes the process, during which the gas goes from wells through a gas pipeline with a small diameter and further enters the gas treatment and purification unit, where it has been cleaned of impurities and hydrogen sulfide (Fig. 1). A part of the gas flows to the compressor, where it becomes liquefied, and enters the accumulator tank for emergency reserve. After the purification unit, the second part of the gas goes immediately to the power plant for cogeneration operation.

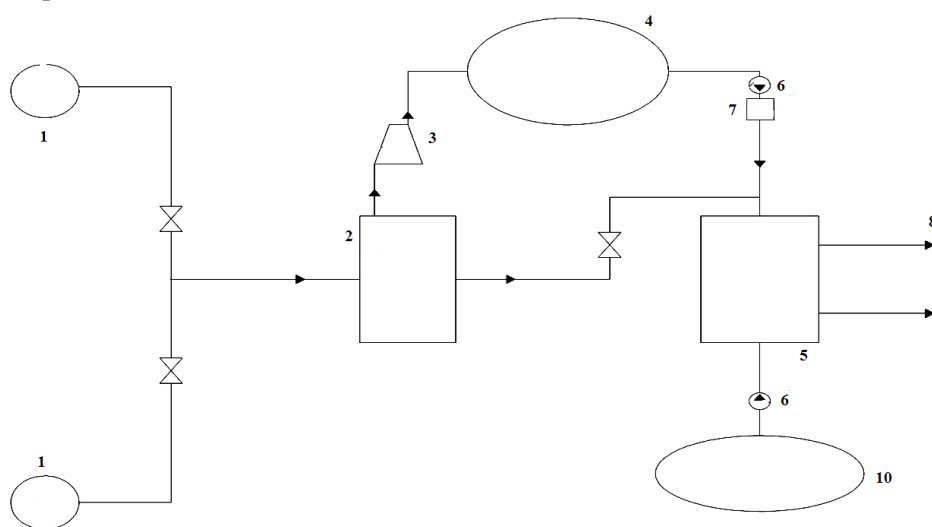


Figure 1. The technological scheme of the autonomous power supply system of the drilling rig
 1 – wells, 2 - purification unit of the gas, 3 – compressor, 4 - accumulator tank, 5 - autonomous power complex, 6 - fuel pumps, 7 - reduction installation, 8 - electric power, 9 - heat energy, 10 - diesel fuel tank.

The designed power plant should meet the following requirements: to be autonomous, to work on two types of fuel (main - APG, reserve - diesel fuel), to produce both electricity and heat, to have high energy efficiency in comparison with analogues.

The usage of local systems to produce electrical and thermal energy based on gas turbine power plants, which operate on natural gas or APG, is one of the viable solutions of this problem. Nowadays gas turbine plants have received recognition in the energy sector as fully developed and reliable

solution. Performance indicators of gas turbines as a part of power plants are at a fairly prominent level.

Gas turbine plants advantages include: low time costs for construction, high reliability of heat and power supply for consumers, minimal volumes of harmful emissions, decrease of thermal regulation inertia, reduction of thermal losses in heat networks and the possibility of using exhausts for technological needs.

One of the main criteria for choosing the type of power plant is its energy efficiency. Various methods are used to determine the effectiveness of the gas turbine plants.

2. Materials and methods

Currently, the most common method of analysis is the thermal balances method, which is based on the application of the first law of thermodynamics. According to this method, energy (thermal) balances are equated, based on which the thermodynamic parameters of thermal systems operation are determined. At the same time being a particular case of the law of conservation of mass and energy, the first law of thermodynamics can't give an answer about the degree of thermodynamic perfection as a separate element, as well as the entire combined heat-and-power system. The reason for this is the property of energy to remain constant in a closed system, i.e. it can't be created or disappear. Because of this the method of thermal balances can detect only energy losses across the boundaries of a closed system. According to this approach, there are already some inconveniences in determining energy efficiency criteria. For example, for a thermal engine, a measure of the thermodynamic losses is the thermal efficiency factor η_t , which can be determined from the correlation:

$$\eta_t = (Q_1 - Q_2) / Q_1 \quad (1)$$

Q_1 - heat, which is supplied to the working fluid from a hot source, Q_2 - heat, which is transferred from the working fluid to the cold source.

According to definition, the efficiency is always less than 1. However, for a refrigeration unit its refrigerating factor acts as a similar criterion, as well as transformation coefficient for the heat pump. Both coefficients are greater than 1 and can't be used as a criterion for the thermodynamic perfection of heat-and-power equipment. This approach leads to the large numbers of coefficients, which are different in physical meaning and have weak logical connection.

Exergy is the maximum work that can be accomplished with the reversible transition of a thermodynamic system from a state with predetermined parameters to a state of environmental balance [2]. In addition the exergy is a measure which takes into account the quality of energy.

The exergetic method allows one to bear in mind the different value of energy sources or energy processes depending on environmental parameters, to make the balance operations of different types of energy that involves the revenues and expenditures in terms of their physical nature, to be compared quantitatively and qualitatively, to determine irreversible losses in work processes, to take regime and constructive measures for reduction of irreversible losses or their prevention.

The evaluation of the efficiency of energy processes is carried out on the basis of exergetic balances, which reflects the equality of the exergy exhaled to the system and the exergy which is taken away from it. For the system, the exergy balance can be written as:

$$\sum_n e_{e_t} = \sum e_{ex} + \sum e_{loss} \quad (2)$$

$\sum_n e_{e_t}$ – sum of exergy at the entrance, including exergy of substance, energy of flows, of heat, of fuel, etc.; $\sum e_{ex}$ – sum of exergy at the exit and $\sum e_{loss}$ – sum of exergy of losses.

The most important indicator of the system energy efficiency is the exergy efficiency factor, which is the ratio of the effective exergy to the spent one:

$$\sum e_{e_{nt}} = \frac{\sum e_{eff}}{\sum e_{spent}} = \frac{\sum e_{spent} - \sum e_{loss}}{\sum e_{spent}} \quad (3)$$

At present, the exergy method is used to determine the efficiency of heat-and-power equipment [3,4]. As an object of exergic analysis let us consider the gas turbine plant represented by the thermal circuit in Fig 1.

The traditional method of heat balance for a simple gas turbine plant scheme indicates, that the only losses are losses of heat with exhausts.

In this case the efficiency of using the fuel heat for gas turbine plant has the form:

$$\eta_Q = \frac{W_i}{Q_1} = \frac{Q_1 - Q_2}{Q_1} \quad (4)$$

The exergy efficiency factor of gas turbine plant has a more complex expression than the efficiency of heat utilization:

$$\eta_{exergy} = \frac{e_f - (\nabla e_{losscc} + \nabla e_{lossc} + \nabla e_{lossturb} + \nabla e_{losslg} + \nabla e_{lossw})}{e_f}, \quad (5)$$

$e_f \approx Q_1$ – exergy of fuel; ∇e_{losscc} – exergy losses in the combustion chamber;

∇e_{lossc} – the loss of exergy in compressor;

$\nabla e_{lossturb}$ – the loss of exergy in a turbine;

∇e_{losslg} – the loss of exergy during cooling of the leaving gases;

∇e_{lossw} – the losses of work on a friction in the bearings and during converting of energy in the electric generator are the losses of exergy.

The exergy method allows estimating of the losses of gas turbine units in more detail [6].

For conducting exergy analysis the WaterSteamPro(the computer program) was used [5].

As an example, let us consider that there is the gas turbine unit - GT 009M, power is 9,7 mW, included in the gas turbine energy complex for drilling rig, presented in picture 1. The diagram of a simple gas turbine is shown in Fig. 2, and the main characteristics of the installation GT 009M used in the calculations are given in table. 1 [8].

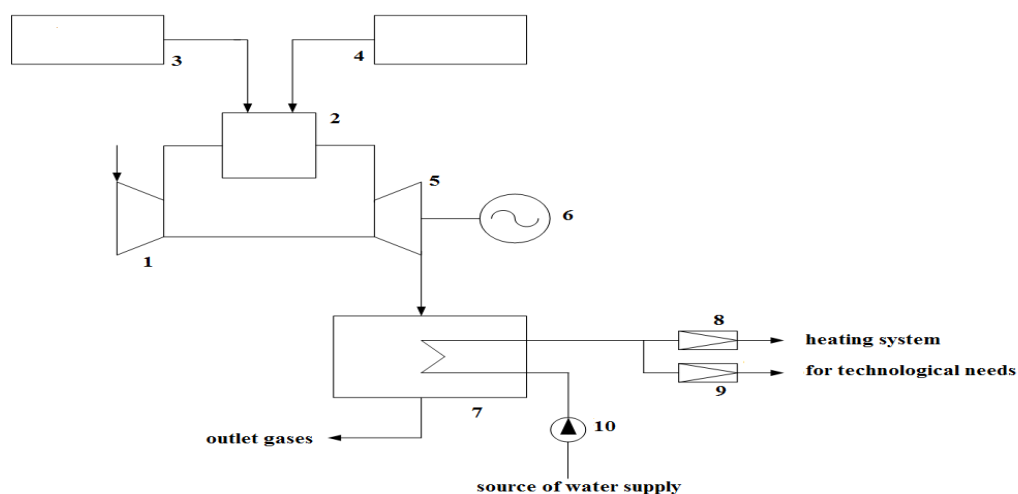


Figure 2. The principle heat scheme of the energy complex.

1- compressor; 2- the combustion chamber; 3-the system of preparation of associated oil gas; 4- the supply system of diesel fuel; 5- gas turbine; 6- electric generator; 7- heat-recovery boiler; 8 – reducing cooling installation; 9 - reducing cooling installation; 10 - pump

Table 1. The main characteristics GTU

Name value, dimension	Value
pressure of air on enter in compressor, mP	0.1
pressure of air on exit in compressor, mP	1.5
temperature of the air on enter in compressor, °C	15
temperature enter in turbine, °C	950
internal relative efficiency of the turbine	0.86
internal relative efficiency of the compressor	0.85
efficiency of the combustion chamber	0.98
mechanical efficiency	0.98
efficiency of the electric generator	0.965
heat of combustion of fuel, kJ/kg	49350
temperature of the environment, °C	20
pressure of the environment, mP	0.1

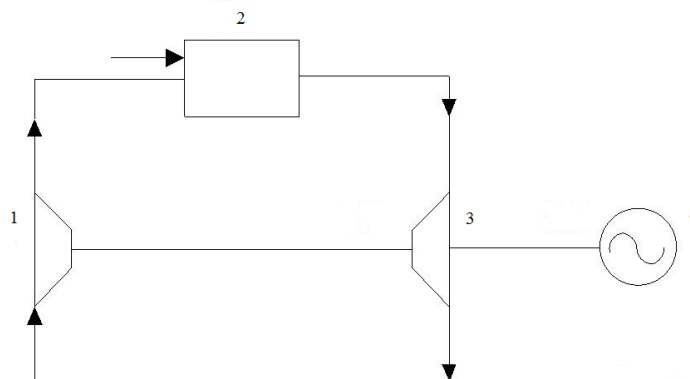


Figure 3. The design scheme of the common GTU. 1 – compressor; 2 – combustion chamber ; 3 – gas turbine; 4 – electric generator

Results of calculating exergy parameters of the gas turbine unit is given in accordance with [7] and presented in table 2.

Table 2. Exergy balance GTU

Components of balance	Value of the component of balance	
	kJ/kg	%
The cost of exergy	633.275	100
The losses of exergy		
In combustion chamber	209.26	33.04
The loss in compressor	27.03	4.27
In turbine	43.3	6.84
Cooling of flue gases	157.43	24.86
Mechanical losses	18.3	2.89
Total	455.32	71.89
Useful work	177.97	28.1
Exergy efficiency	28.1	28.1

3. Results and Discussion

From the table, one can notice, that the greatest losses of exergy happen in the combustion chamber (33.04 %) and during cooling the flue gases (24.86%). Consequently, to increase exergy efficiency, it is required to reduce temperature of the flue gases and improve conditions of combustion of the flue gases. By the results of exergy analysis of the GTU, it is possible to make a conclusion on particular recommendations for the installation modification: to upgrade the construction of the combustion chamber; to add heat recovery boilers to the power plant structure that allows one to reduce temperature of the flue gases and to get sufficient amount of heat energy.

4. Conclusion

Thus, the exergy method of the energy efficiency estimation of GTU is more effective than the traditional method of the heat balance, as it allows one to assess the losses of GTU in greater detail. The exergy analysis helps to detect the weakest elements of the steam power plant in terms of the energy efficiency and to determine measures and design solutions to improve their thermodynamic perfection.

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