Reducing the energy costs of drilling rigs based on the beneficial utilization of secondary drive energy resources

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Abstract. Drilling wells is a process that requires a lot of energy. When conducting drilling operations, along with electrical energy, thermal energy is also consumed in large quantities. In modern conditions of drilling operations, energy supply issues are of particular importance, and their solution is associated, first of all, with the optimization of energy supply from the energy source to the drive of process equipment. Saving energy resources when drilling wells largely depends on the feasibility of proper organization and regulation of fuel and energy costs. This article presents the results of scientific and practical research on reducing fuel and energy costs of drilling operations based on the beneficial recovery of heat from the drive of a diesel power plant of drilling rigs through the implementation of modern scientific, technical and technological innovative solutions.

1 Introduction

When solving the main issues of energy supply for mining and geological work, it is necessary to comprehensively (integratedly) consider serious changes and, first of all, issues of electricity and heat supply.

The main objective of our research is to increase the efficiency of drilling equipment by increasing the efficiency of using secondary and renewable energy sources and reducing energy costs, as well as the development of a fuel and energy-saving energy technology complex. Today, with the increase in the volume of drilling operations, the need for energy resources for drilling and technological equipment has also increased. During the cold season, along with electricity, thermal energy is also consumed in large quantities.

An important factor affecting the efficiency of energy supply is the low efficiency of energy sources. The efficiency of diesel power plants depends on the type of operation and conditions and in real conditions does not exceed 30-40%. The efficiency of heating installations under geological exploration conditions does not exceed 50-70%. This shows that most of the fuel is wasted inefficiently during the energy production phase. For this reason, the problem of rational use of fuel and increasing the efficiency of energy sources remains relevant.

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2 Materials and methods

Despite the ease of use of electric heaters, this leads to excess energy costs for drilling operations due to the high cost of diesel fuel in diesel power plants that generate electricity; also, their efficiency in most cases does not exceed 30-35%, which makes the use of electric heaters used for heating during drilling operations [1-2].

When drilling in hard-to-reach areas, in most cases an autonomous power plant of the DES-100.1 brand with a capacity of 100 kW is used for power supply.

During the low-temperature period of the year (–5÷10 °C), on average, about 25-30% of the electricity generated by a diesel power plant is used for heating, and the remaining 70-75% is used to provide electricity for drives and other equipment [3-4].

Analysis of energy and resource costs for drilling shows that the cost of operating drilling equipment is significantly influenced by the consumption of fuel and energy resources. Over the past few years, there has been an increase in the cost of drilling as a result of sharp increases in prices for fuel and energy resources.

The cost of drilling can be significantly reduced by reducing energy costs for heat supply. In this case, it will be possible to usefully use the heat of internal combustion engines of drilling rigs and an autonomous power supply system.

Drilling operations are mainly mobile in nature. Due to the fact that drilling operations are carried out over large areas, the power supply system for drilling equipment differs in that it is sometimes connected to a centralized network, and sometimes to autonomous power systems in remote areas. In such cases, during the cold period, a number of difficulties arise related to the heat supply of drilling operations. At the same time, a certain part of the power of diesel power plants, which is mainly used to generate electricity, is spent on heating systems; during drilling operations at decentralized sites in remote areas, it is possible to reduce energy costs due to the useful utilization of heat from internal combustion engines of technological equipment [5-6].

The total heat flow generated during fuel combustion in an internal combustion engine depends on engine power, fuel consumption and heat generation ability [7]:

$$Q = \frac{Ne \cdot g \cdot Q_0}{360^0}, kVt \tag{1}$$

where Ne - is the rated power of the engine, kW; g – specific fuel consumption, g/kWh;

Q_0 – lower heating value of fuel, kJ/kg.

When fuel burns in an internal combustion engine, only 30-35% of the heat is converted into mechanical energy, and the rest is lost as heat in the cooling system, exhaust gases, friction of parts and incomplete combustion of fuel [7-8].

Indicators of the thermal balance of an internal combustion engine make it possible to determine the thermal load of the engine, that is, to calculate the cooling system and evaluate the possibility of useful utilization of exhaust gas heat. The heat balance of an internal combustion engine can be expressed by the following expression [8]:

$$Q = Ne + Q_{cs} + Q_{eg} + Q_{ot}, \tag{2}$$

where Ne - is heat converted into useful power, kW; Qcs – heat lost in the cooling system, kW; Qeg – heat lost with exhaust gases, kW; Qot – other heat losses, kW.

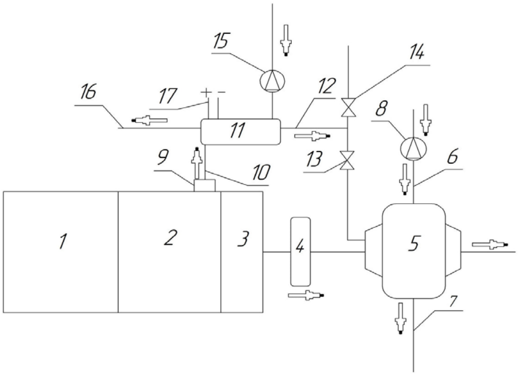
The amount of heat flow is determined by the main indicators of the internal combustion engine:

$$\mathrm{Q_{hf}} = \mathrm{M_{co}} \cdot \mathrm{C_{co}} \cdot \Delta \mathrm{t_{co}} + \frac{\pi \cdot \mathrm{D_c^2} \cdot \mathrm{P_c} \cdot \mathrm{T_{og}} \cdot \mathrm{n} \cdot \mathrm{K}}{480 \cdot \mathrm{P_{sg}} \cdot \mathrm{T_c}} \rho_2 \cdot \mathrm{C_{cg}} \cdot \Delta \mathrm{T}, \mathrm{kVt}\,. \tag{3}$$

where Mco - is the coolant flow rate in the cooling system, kg/s; Cco – heat capacity of cooling water, kJ/kg deg; Δtco – difference in temperature of cooling water at the inlet and outlet of the radiator, °C; ΔT – difference in gas temperatures in the heat exchanger, °C; ρ_2 – exhaust gas density, kg/m^3; Dc – cylinder diameter, n – number of revolutions, r/pm; K – number of cylinders, Tc – gas temperature in the cylinder before release, °K; Psg – gas pressure in the cylinder at the end of the output stroke, Pa; Tog – gas temperature at the end of the output stroke, °K; Pc – pressure in the cylinder before the outlet, Pa; Scg – heat capacity of exhaust gas, kJ/kg deg.

The above expression allows you to determine the heat flow based on the parameters of the internal combustion engine, and makes it possible to calculate the main characteristics of heat recovery systems.

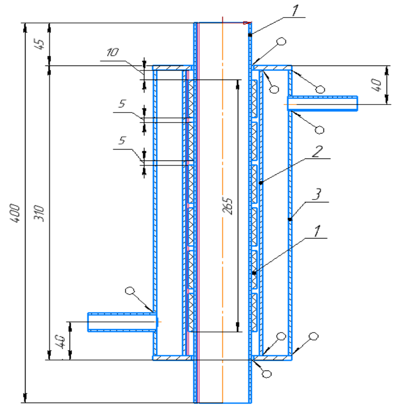
When drilling a well with flushing fluid for the useful utilization of heat released from the internal combustion engine of drilling equipment, a device has been developed, a schematic view of which is shown in Fig. 1.



1 – drilling rig; 2 – internal combustion engine; 3 – engine cooling radiator; 4 – fan; 5 – heat exchanger; 6 – cold water supply pipe; 7 – heated water pipe; 8 – pump; 9 – muffler; 10 and 12 – exhaust gas transmission pipe; 11 – block of thermoelectric generators; 13 and 14 – valves; 15 – pump; 16 – water supply pipe connected to the sump; 17 – wires of the thermoelectric generator block.

Fig. 1. Device for useful recovery of internal combustion engine heat of a drilling rig.

The effective use of thermoelectric generators in the proposed device for the useful recovery of internal combustion engine heat of a drilling rig presents some technical difficulties, i.e. heating one side due to the secondary energy of the internal combustion engine and cooling the other side without the use of additional energy requires the development of new technical solutions. For this reason, the design of the thermoelectric generator block was developed, shown in Fig. 2.



1-pipe, 2-thermoelectric generator sealing plate, 3-shell, 4-thermoelectric generator, 5-and 6-cooling water inlet and outlet pipes

Fig. 2. Construction block thermoelectric generators.

3 Results and discussion

In order to determine the performance and efficiency, as well as the amount of generated electricity and heat flow in the developed device for the useful utilization of heat from the internal combustion engine of a drilling rig, experimental work was carried out in two stages. At the first stage of experimental work, the power of heat released from the radiator of the engine cooling system was determined.

As a result of the analysis of the results of experimental work, the dependence of the heat flow (Q) leaving the heat exchanger at various engine loads (N) on the secondary coolant flow rate (G) was established; this dependence is shown in graph form in Fig. 3.

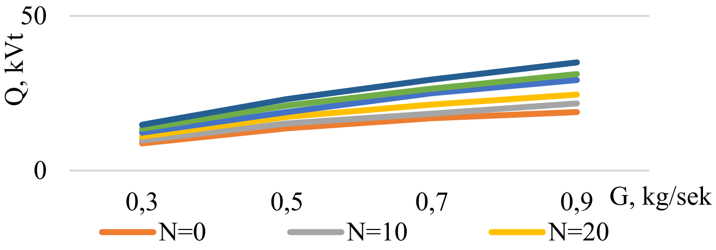


Fig. 3. Graph of the dependence of the heat flow power (Q) on the heat exchanger on the secondary coolant air flow rate (G) at various loads (N).

Thus, it has been established that the temperature and power of the heat flow generated in the heat exchanger of the device for useful heat recovery of the internal combustion engine of drilling equipment depends on the flow of the secondary coolant and the load on the engine.

The purpose of the second stage of experimental work was to determine the performance of thermoelectric generators when installed on the exhaust pipe of an engine, as well as to determine the possibility of generating electricity, heat flow and hot water, which can be used for domestic and technological needs of drilling operations.

As a result of experimental work, the dependence of the power of the electric current (P) generated in thermoelectric generators on the load on the engine (N) was established; this dependence is shown in Fig. 4 in graph form.

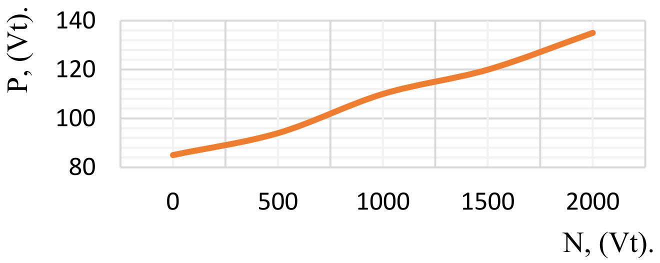


Fig. 4. Dependence of the electric current power (P) of the thermoelectric generator on the engine load (N).

In order to determine the effectiveness of the proposed heat recovery device, the engine fuel consumption was investigated. In Fig. 5 shows the graphical dependence of engine fuel consumption (D) on engine load (N).

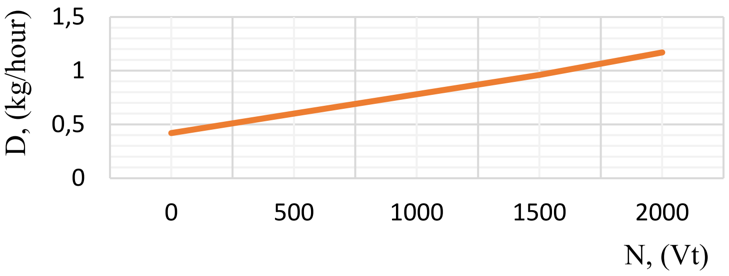


Fig. 5. Dependence of engine fuel consumption (D) on engine load (N).

From the graph of engine fuel consumption (D) versus engine load (N), it can be seen that fuel consumption increases uniformly with increasing load. Fuel consumption has a linear characteristic and is displayed on the diagram.

$$D = D_s + b \cdot N, \text{ kg/hour,} \tag{4}$$

In order to determine the efficiency of the developed heat recovery device for the internal combustion engine of drilling equipment, a comparison was made of the efficiency of the installation with and without the use of a heat recovery device.

When using a device for useful heat recovery from the internal combustion engine of the drilling equipment being developed, the efficiency coefficient was determined:

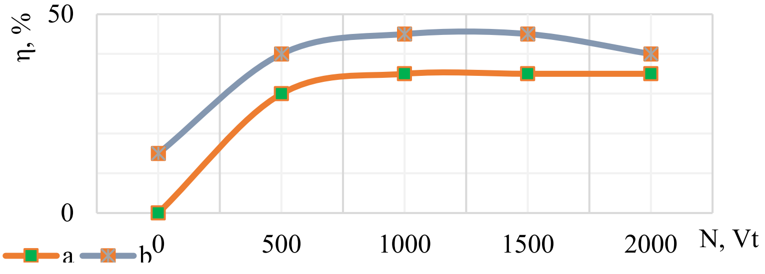
$$\eta = \frac{N+\mathrm{P}+Q_{ut}}{Q} \tag{5}$$

The heat flow of engine exhaust gases in the heat exchanger is determined as follows.

$$Q_{ut} = G_g \cdot C_g\left(T_{g2} - T_{g3}\right), \text{kWt;} \tag{6}$$

here C_g - heat capacity of flue gases, kJ/kg·°C ; T_{g2} and T_{g3}– exhaust gas temperature at the inlet and outlet of the heat exchanger, °C

In Fig. 6 shows the dependence of the efficiency (η) of a diesel power plant of drilling equipment on the load (N) applied to the engine.



a-when heat is not removed, b- when heat is removed

Fig. 6. Graph of the dependence of the efficiency coefficient (η) of a diesel power plant of drilling equipment on the load (N) attached to the engine.

Analysis of the results of experimental work shows that the efficiency of the internal combustion engine of a diesel power plant of drilling equipment is actually 30-35%. It has been established that this figure can be increased to 45% when using the proposed heat recovery device.

Due to the high power of compressors used to generate compressed air, energy costs for drilling operations are high. The share of energy loss in the form of heat in the compressor engine reaches 50-55%.

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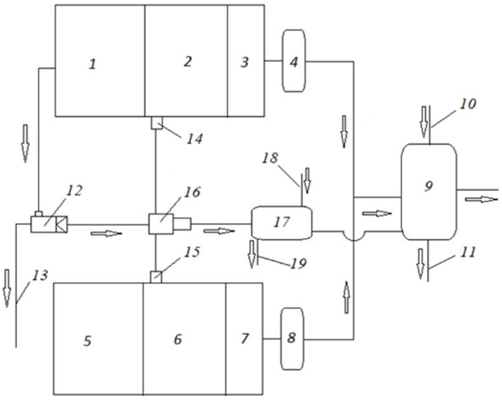
Based on the useful recovery of secondary energy resources lost in the form of heat in the cooling system of the engine of drilling equipment, with exhaust gases and compressed air from the compressor, it is possible to increase the useful efficiency of the drilling rig [9-10].

In Fig. 7 schematically shows a diesel power plant of a drilling rig and a device for useful heat recovery from an internal combustion engine of a compressor.



1 - compressor, 2 and 6 - internal combustion engine of a compressor-diesel unit, 3 and 7 - radiator, 4 and 8 - fans, 5 - diesel power plant of drilling equipment, 6 - internal combustion engine, 9 - heat exchanger, 10 - cold water pipe, 11 - hot water pipe, 12 - smoke pipe, 13 - vertical compressed air transmission hose, 14 and 15 - chimney pipe, 16 - ejector nozzle, 17 - thermoelectric generator unit, 18 - cold water transmission pipe, 19 - hot water pipe

Fig. 7. Device for useful recovery of internal combustion engine heat of a drilling rig.

In order to determine the effect of ejection created by the air flow coming from a high-pressure compressor on the fuel consumption of an internal combustion engine, experimental studies were carried out.

The experimental work was carried out in the following order: various loads were supplied to a 2 kW gasoline generator using incandescent lamps and the engine fuel consumption was measured at various air pressures supplied from the compressor, with and without the use of an ejector nozzle.

The dependence of fuel consumption during engine operation on the air pressure supplied from the compressor to the ejector nozzle is graphically presented in Fig. 8

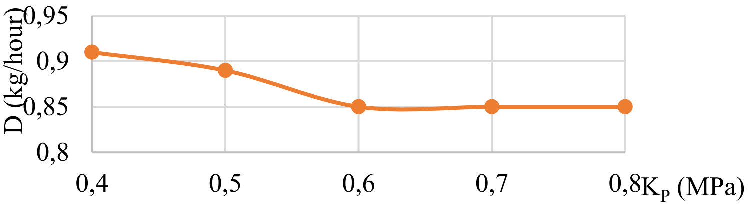


Fig. 8. Graph of the dependence of fuel consumption (D) on air pressure (KP) supplied to the ejector nozzle at engine load.

Analysis of the results of experimental work shows that the use of an ejection nozzle in a device for the useful utilization of secondary energy resources in a diesel power plant of a drilling rig and compressor can reduce fuel consumption by up to 12%.

The efficiency of using an ejection nozzle depends on the pressure of the supplied ejecting air flow from the compressor; with an ejection flow pressure of up to 0.5 MPa, fuel consumption decreased on average by 6-7%; with ejection flow pressure values of 0.6 MPa or more, fuel consumption decreased by 10-12%.

Also at low engine loads, i.e. at loads of 25-50%, the use of an ejection nozzle reduces fuel consumption by 7-8%, and at engine loads of 50% and above, fuel consumption is reduced to 10-12%.

Figure 9 below shows a graph of changes in fuel consumption with and without an ejector nozzle at various loads applied to the engine, on which indicators were taken with an ejector nozzle, the ejected air pressure is more than 0,6 MPa.

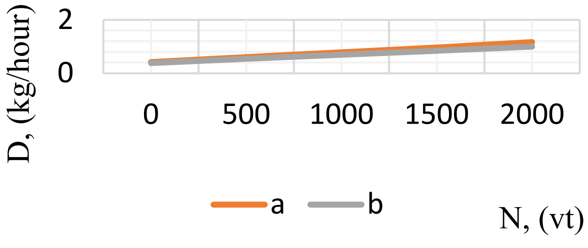


Fig. 9. Change in fuel consumption (D) at different engine loads (N) with the use of an ejector nozzle (a) and without its use (b).

When using an ejector nozzle in the heat removal device of an internal combustion engine, fuel consumption decreased by 5-6% compared to the absence of an ejection nozzle at idle speed; with an engine load of 500 W, fuel consumption decreased by 7% compared to without using an ejector nozzle, with increasing load up to 1000 W, fuel consumption was 10%, with an increase to 1500 W - 12%. A 10% reduction in fuel consumption was observed at a maximum engine load of 2000 W.

Based on the analysis of the experimental test results, the following conclusions can be drawn:

- the use of an ejection nozzle in a device for the useful utilization of secondary energy resources of a diesel power plant of drilling equipment and a compressor allows reducing fuel consumption by 10-12% by reducing the resistance to the flow of exhaust gases created by the heat exchanger;
- the efficiency of the ejection nozzle depends on the pressure of the ejecting air flow transmitted to it and is achieved at pressures above 0.6 MPa, that is, increasing the pressure of the ejecting flow increases the speed of the ejected flow from the nozzle, and as a result, the resistance in the engine exhaust pipe decreases.

It has been established that when using an ejection nozzle in a device for the useful utilization of secondary energy resources in a diesel power plant, drilling equipment and a compressor, the highest rates of fuel consumption reduction are achieved at engine loads of 50-75%.

4 Conclusion

Based on the research results, the following conclusions of theoretical and practical significance were made:

- based on the beneficial utilization of secondary energy resources in the form of heat from internal combustion engines used in drilling operations, it is possible to obtain thermal energy that can be used for technological needs, and a reduction in energy consumption during drilling operations is achieved;

- the introduction into the drilling process of the design of a heat recovery device for internal combustion engines of diesel power plants of drilling rigs makes it possible to obtain a heat flow in the amount of 108 MJ/h, used for technological and domestic needs;
- the dependence of the power of the heat flow obtained from the heat exchanger on the flow of secondary heat-carrying air at various engine loads has been established. By increasing the secondary heat-carrying air, it is possible to increase the power of the utilized heat flow;
- the highest efficiency values of the device for the useful utilization of secondary energy resources of drilling equipment are achieved at an engine load of 50-75%;
- the efficiency of the internal combustion engine of a diesel power plant of drilling equipment in reality is 30-35%. It has been established that this indicator can be increased by using the proposed heat recovery device for internal combustion engines, while the efficiency of the engine increases due to the recovery of secondary energy resources in the form of heat released into the atmosphere;
- the developed unit of thermoelectric generators, which allows obtaining electricity from the heat of exhaust gases of an internal combustion engine, allows obtaining electricity in the amount of 0.9 kW/h.

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