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R.U. Djuraev
Navoi State Mining Institute, shokirovrahimjon@gmail.com

J.B. Toshov
Tashkent State Technical University

D.N. Khatamova
Navoi State Mining Institute

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IMPROVING METHODS OF ENERGY- EFFICIENT OPERATION OF DRILLING EQUIPMENT USING VORTEX TUBES WHEN DRILLING WELLS WITH AIR PURGING.

R.U. Djuraev[2]*, J.B. Toshov[1], D.N. Khatamova[2]
[1]Tashkent state technical university, 100095, 2 str. University, Tashkent, Uzbekistan
[2]Navoi State Mining Institute, 210100, G`alaba shoh str. Navoi, Uzbekistan

Abstract: *The practice of drilling has proven that the use of compressed air as a cleaning agent provides a significant increase in ROP (mechanical drilling speed) and reduces the time spent on eliminating geological complications, which sharply increases the productivity and economy of drilling operations.*

However, air has a low heat capacity compared to liquid flushing solutions, this affects the operation of rock cutting tools through high contact temperatures with irreversible consequences such as deformation of matrices, destruction of diamonds, grinding, reduction of diamond hardness and tool burns. To prevent these problems, there is a need to develop technical means and technology to effectively ensure the temperature regime of the rock-cutting tool.

In addition to normalizing the temperature regime of the rock-cutting tool, there is the problem of increased energy consumption of drilling due to the use of compressor units, the drive power of which is much higher than that of pumps used in similar conditions.

This article discusses the possibility of normalizing and regulating the temperature regime of the rock-cutting tool due to forced cooling of the cleaning air at the bottom hole to negative temperatures. It also describes the possibility of increasing the efficiency of drilling wells with air blowing by using a heat recovery unit for compressor drive heat and excess air, and presents the results of experimental tests to determine the effect of the ejection of exhaust gases from an internal combustion engine on the efficiency of its operation.

Key words*: air purging, drilling, Rank effect, well, vortex tube, compressor, drill string, flushing fluid, bottom hole, temperature mode, heat recovery, heat exchanger, compressor, heat losses, internal combustion engine, injection nozzle, fuel consumption.*

Introduction

Air blast drilling is effective in the most unfavorable conditions for flushing: when drilling in areas with significant loss of circulation, when there are difficulties with water supply, in high mountain or difficult terrain, or in areas with harsh climates.

However, air has a low heat capacity compared to liquid flushing solutions, thus, a negative effect of the temperature factor arises, which affects the operation of rock cutting tools through high contact temperatures with irreversible consequences: deformation of matrices, destruction of diamonds, grinding, reduction of diamond hardness, tool burns, etc.

When drilling wells in rocks, rock destruction is accompanied by significant heat release, since about 1% of the mechanical energy supplied to the bottom is spent on rock destruction itself, all the rest of the energy is dissipated in the form of heat [1].

Heating of drill diamonds to 650 °C causes polishing of their cutting edges, and heating to 800 °C and above causes cracking and loss of diamond grains from the matrix of the rock-cutting tool, at diamonds heating temperature up to 600 °C their microhardness decreases by 30%, to 1000 °C - by 60% [2,3]. This leads to premature failure of diamond bits, i.e., to a decrease in productivity and an increase in the cost of drilling.

High temperatures of the drilling tool create emergency situations in the form of burning diamond bits, the time spent on elimination of which is 8 ÷ 10% [3,4]. It is obvious that the increase in efficiency is directly related to ensuring the optimal temperature regime when drilling wells.

Heating and cooling of a working rock cutting tool is determined by the power for rock destruction and friction at the bottomhole, by the thermophysical properties of the rock being traversed, the material from which the tool is made, the circulating flushing medium and its consumption per unit time. According to L.A. Schreiner, the physical efficiency of rock destruction during mechanical drilling does not exceed 0.01%, i.e. less than 0.01% of the total energy consumption is converted into surface energy, the rest is dissipated in the form of heat [2].

The heat generated at the contact of the carbide cutter, diamond, cutter tooth with the bottom rock is distributed into the heat of the tool and into the rock. The flushing medium washing the bottomhole zone under steady-state conditions receives the same amount of heat from the rock-cutting tool per unit time, which enters the tool body at the same time unit.

The most unfavorable conditions for cooling the tool, especially diamond, when drilling with air blast. This is due to the following reasons:

- low mass flow due to very low air density;
- air has approximately 4 times less than water, specific heat (at constant pressure);
- complete absence of such a parameter as the specific heat of vaporization in air.

The cooling conditions of the bits when drilling with blowdown are significantly worse than when using gas-liquid systems. Therefore, the normalization of the temperature regime of the rock cutting tool during drilling with blowdown is possible, firstly, due to an increase in the mass flow rate at moderate speeds of air movement with the expansion of the passage channels and annular gaps and, secondly, due to the forced cooling of the blowdown air [5, 6].

The first direction will require an increase in the mass flow rate of the compressor with an increase in its power, which is ineffective. The second method is more acceptable, provided an effective cooler is developed.

In work [5], studies on the use of a vortex tube as an air cooler are presented. The results of the experimental studies made it possible to substantiate the possibility of obtaining negative temperatures of the purge air without the need to increase the compressor power. This suggests that the use of vortex tubes in drilling is quite energy efficient.

Methodology

The optimal solution for improving the temperature regime of the rock cutting tool is to ensure low temperatures at the bottomhole, i.e. without heating the air due to friction, due to the loss of the power of rotation of the string, this is possible due to the prospective use of a vortex tube as a refrigerator built into the drill string.

The use of a vortex tube, in which the Ranque effect occurs, as a refrigeration unit when drilling wells with air purge, is possibly more efficient, at the same time, and cost-effective unit for cooling the purge air [6].

The vortex effect, or the Ranque effect, consists in the fact that if a tangentially swirling gas flow is fed into a pipe, then temperature separation of the gas will occur in it under certain conditions. A colder flow is formed in the center than at the periphery, and gas will exit through the central opening of one of the ends of the pipe, the temperature of which will be much lower than at the inlet. Higher temperature peripheral gas layers will exit through the throttle hole at the other end of the pipe [6].

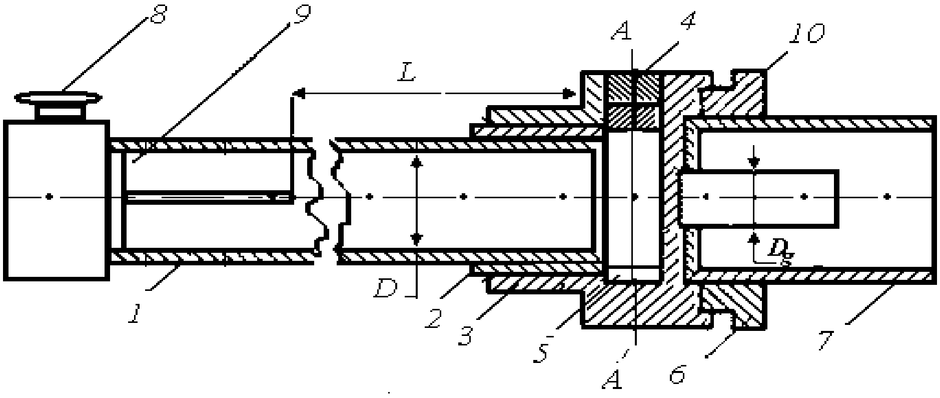

Fig. 1. Vortex tube design.

1 - tube, 2 - nut, 3 - body, 4 - volute, 5 - diaphragm, 6 - nut, 7 - tube, 8 - throttle, 9 - cross, 10 - gasket

In general, the design of the vortex tube (Fig. 1) [7, 8] consists of a body 3, in the annular cavity of which a tangential rectangular channel of width *b* and height *h* is propylene. On the outside of the rectangular channel, a fitting for compressed air supply is soldered to the body. A flanged tube 1 with a strictly cylindrical polished inner surface of diameter *D* is installed in the annular cavity of the body, and then a volute *4* so that its cut (the dimensions of which coincide with the rectangular channel of the body) coincides with the channel, forming a nozzle inlet. A diaphragm 5 with a hole *Dg* and a sealing gasket *10*, driven by a nut *6*, are inserted into the same cavity of the body. At the opposite end of the tube *1*, at a distance *L* from the volute, a four-blade crosspiece *9* and a throttle *8* are tightly installed.

The vortex tube is small in size and has no moving parts, which allows it to be used as a bottomhole cold generator when drilling wells.

The best cooling of the cleaning air at the bottom hole can be achieved by installing a vortex tube in the composition of the drill string above the rock cutting tool. But, in this case, it becomes necessary to develop a reliable design of the downhole drill, which ensures uninterrupted operation.

Results and Discussion

Generalization of the research results and experience of using vortex tubes made it possible to develop a design of a vortex tube for installing it in the bottomhole zone of the drill string to cool the purge air directly at the bottom of the well. In order to normalize and regulate the temperature regimes of the rock-cutting tool during drilling with cleaning the bottom hole with air, the following design of the drill string, which includes a vortex tube, has been proposed (Fig. 2).

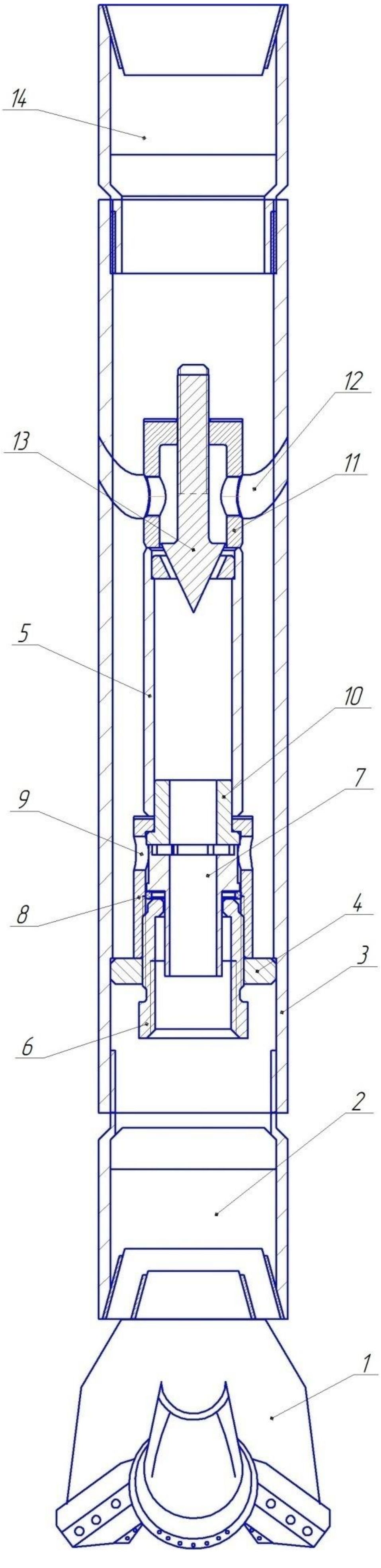

Fig. 2. A drill, including a vortex tube for drilling with air cleaning.

1 – roller cone bits; 2 – adapter; 3 – outer tube; 4 – jumper (washer); 5 – vortex tube; 6 – nut; 7 – cold fraction generator at cold outlet; 8 - building; 9 - inlet; 10 – washer; 11 – throttle body at hot outlet; 12 – tangential opening for hot air outlet; 13 – hot outlet choke; 14 – top adapter.

The vortex tube drill works as follows. When drilling a well, compressed air through the outer pipe 3 through the inlet holes *9* is supplied to the generator of the cold fraction *7* of the vortex tube *5* and is twisted in it. The flow of compressed air passing through the vortex tube is divided into two flows, the flow of cold and hot air. The flow of cold air flows out of the nut hole *6* and through the adapter *2* and the drill bit *1* enters the bottom of the well to carry the products of destruction into the annular space with simultaneous cooling of the drill bit. The generator of the cold fraction in this device is removable, which can be replaced with another type of generator, which allows changing the cooling mode if necessary when changing the drilling modes.

Hot air from the vortex tube 5 through the tangential opening for the outlet of the hot air flow *12* flows into the annular space. Since the hole *12* is made tangentially ejector, it creates a vortex motion in the annular gap, which allows a cold flow with destruction products to be ejected, which improves bottomhole cleaning and favorably affects the cooling of the bit, since the energy consumption for repeated over-grinding of rock particles is reduced.

Such a design of the drill bit for drilling with air blowing makes it possible to increase the durability of the drill bit and to normalize the temperature conditions of the rock cutting tool.

The use of cooled purge air significantly reduces the temperature in the well, which creates favorable temperature conditions for the operation of the rock cutting tool, preventing the negative effect of high temperatures at the bottom hole.

In addition to normalizing the temperature regime of the rock cutting tool, there is the problem of increased energy consumption of drilling due to the use of compressor units, the drive power of which is much higher than that of pumps used in similar conditions.

For drilling exploratory wells with bottomhole cleaning with air, mobile piston compressors driven by an internal combustion engine (ICE) are used.

When fuel is burned in an internal combustion engine, only part of the heat is converted to useful work. This part is determined by the effective efficiency of the motor, the value of which depends on a number of factors and in real conditions does not exceed 30–35% [5]. All other heat is removed to the atmosphere with the exhaust gases and from the engine cooling system. Currently, this heat is not used and is lost, polluting the environment [14, 15].

For example, the total heat flow losses (50 ÷ 55%) for the ZIF-PV-8 / 0.7 compressor unit with a D-243 diesel engine with a rated power of 60 kW are approximately equivalent to a combustion heat of 5-6 kg of diesel fuel per hour.

When drilling wells with air blowing, the compressor units constantly operate in the nominal mode, for example, the ZIF-PV-8 / 0.7 compressor produces 8 m^3 / min of compressed air, and for drilling wells with a diameter of 76 mm, only 3.5 ÷ 4 m3 is used / min, which is fed into the well, the other part is discharged into the atmosphere.

Currently, a free exhaust engine can only be found as an exception. It is a very uneconomical and irrational machine, since it emits a significant amount of energy into the atmosphere, which can be used quite fully using a number of systems.

The recovered heat from the internal combustion engine of the compressor and the hot outlet of the vortex tube can be used for heating industrial and domestic facilities, for hot water supply, as well as for technological needs of production.

The use of exhaust gas energy in any system is always associated with an increase in pressure at the engine exhaust, the amount of back pressure at the exhaust is limited by the fact that with increased back pressure, the working process in the engine cylinder deteriorates, the air flow through the engine decreases and the effective power drops [7].

In order to increase the efficiency of a compressor driven by an internal combustion engine and reduce the cost of heat supply when drilling wells with air blowing, we proposed a device for utilizing the heat of the internal combustion engine of the compressor and heated air coming out of the hot outlet of the vortex tube (Fig. 3).

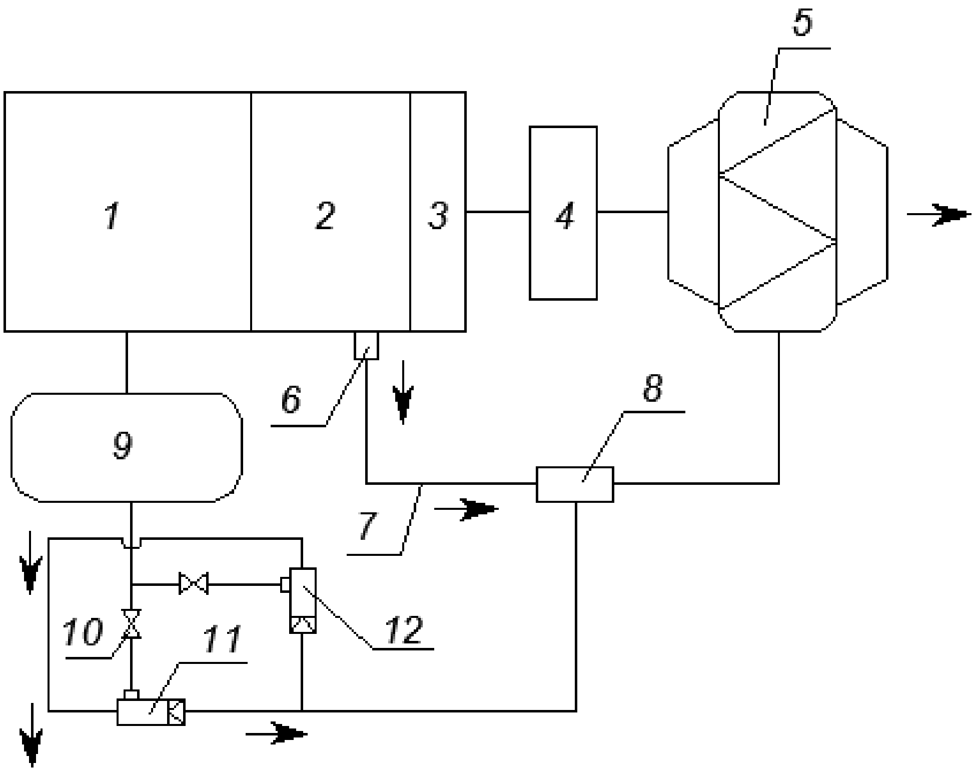

Fig. 3. A device for utilizing the heat of an internal combustion engine.

1-Compressor, 2-ICE, 3-radiator, 4-fan, 5-heat exchanger, 6-exhaust pipe, 7-pipe, 8-injection nozzle, 9-receiver, 10-valve, 11-vortex pipe, 12-warm stream, 13-cold stream.

The device operates in the following way after the compressor engine is started, compressed air from the receiver *9* of the compressor 1 is supplied to the vortex tubes 11 and 12, where the temperature is divided into cold and hot streams. After separation in vortex tubes, a cold air stream is fed into the well. The hot air flow through the injection nozzle 8, mixing with the hot flow coming with the exhaust gases from the exhaust pipe 6 of the internal combustion engine 2, is supplied to the heat exchanger 5. The fan 4, taking heat from the radiator 3, directs it to the heat exchanger. The heat exchanger 5 creates resistance to the movement of the exhaust gases, which reduces the net power of the engine and increases its fuel consumption. To reduce the harmful effect of the resistances of the heat exchanger, the high pressure hot stream from the vortex tube 11 is fed to the injection nozzle 8 installed in the exhaust pipe. In the nozzle, a rarefaction of gases occurs, in which a jet of hot air flow, leaving the vortex tube at high speed from the nozzle, carries along the exhaust gases. This reduces the resistance to the movement of exhaust gases created by the heat exchanger, which helps to reduce the fuel consumption of the engine. When the drilling process is stopped for short periods of time, the bottom hole is not cleaned, while the compressor runs idle, which leads to additional fuel consumption, this negatively affects the drilling efficiency. Vortex tubes 11 and 12 work independently of each other, since they are connected in parallel, and to the receiver through valves, to alternately block the flow of air from one vortex tube when the other is working. The second vortex tube 12 is designed to supply hot air to the heat exchanger to reduce losses during idle operation of the compressor.

In order to determine the influence of the ejection of exhaust gases from an internal combustion engine on the efficiency of its operation, we carried out experimental studies of the fuel consumption during the ejection of exhaust gases by an air flow from a vortex tube. The main tasks of the experimental research were the following: - determination of the internal combustion engine fuel consumption when using a heat exchanger without ejection; - determination of the

internal combustion engine fuel consumption when using a heat exchanger and an ejection nozzle;
- establishing the dependence of fuel economy on engine load.

The main objectives of the experimental research were:

- determination of internal combustion engine fuel consumption when using a heat exchanger;
- determination of the internal combustion engine fuel consumption when using a heat exchanger and an injection nozzle.

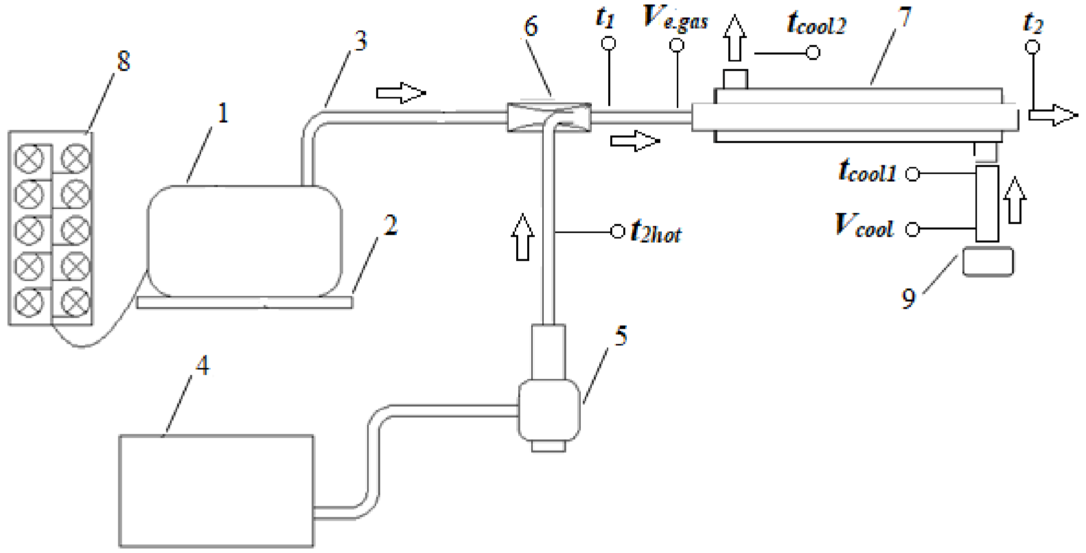

Fig. 4. Diagram of an experimental setup for studying the influence of the ejection of exhaust gases from an internal combustion engine on the efficiency of its operation

1 - engine (internal combustion engine), 2 - scales, 3 - exhaust pipe, 4 - compressor, 5 - vortex pipe, 6-ejection nozzle, 7-heat exchanger, 8-block with lamps.

t_1 is the temperature of the exhaust gas at the inlet to the heat exchanger, (°C), t_2 is the temperature of the exhaust gas at the outlet of the heat exchanger, (°C), t_{cool1} is the temperature of the cooling air supplied to the heat exchanger, (°C), t_{cool2} is the temperature of the cooling air leaving the heat exchanger, (°C), $V_{e.gas}$ in is the flow rate of the exhaust gas supplied to the heat exchanger, (m/s), V_{cool} is the flow rate of the cooling air supplied to the heat exchanger, (m/s), t_{2hot} in is the air temperature at the hot end of the vortex tube, (°C).

The studies were carried out using a gasoline unit with a 2 kW generator. Incandescent lamps were used as the generator load. The load was increased by 300 W, from 0 to 1800 W. The vortex tube was installed in an ejection nozzle located in the exhaust manifold of the gasoline unit, in front of the heat exchanger. Compressed air was supplied to the vortex tube from the compressor.

Experimental studies were carried out in two stages. The first stage of the test was carried out with a heat exchanger connected to the silencer of the gasoline unit, without using an ejection nozzle. The gasoline unit was loaded discretely after 300 W, and the load was varied from 0 to 1800 W. At each load level, fuel consumption, temperature and flow rate of the exhaust gas entering the heat exchanger and the temperature of the exhaust gas leaving the other end of the heat exchanger were measured over a constant period of time. To cool the heat exchanger, air was supplied at a speed of 2.5 m/s and a temperature of 20 °C; the temperature of the cooling air at the outlet of the heat exchanger was also measured.

The second stage was carried out with the connection of an ejection nozzle and a vortex tube in front of the heat exchanger, and the entire set of measurements was carried out anew in the same order. The results of experimental studies are shown in table 1.

Table 1.

№		Engine load. Watt					
		300	600	900	1200	1500	1800
	Experiment without the use of an ejection nozzle.						
1	**t_1.** Exhaust gas temperature at the inlet to the heat exchanger, (°C).	132	145	160	178	196	211
2	**t_2.** Exhaust gas temperature at the outlet of the heat exchanger, (°C).	74	90	105	125	143	159
3	**t_{cool1},** Temperature of the cooling air supplied to the heat exchanger, (°C).	20	20	20	20	20	20
4	**t_{cool2},** Temperature of the cooling air leaving the heat exchanger, (°C).	75	90	100	112	125	135
5	**$V_{e.gas}$,** Exhaust gas flow rate supplied to the heat exchanger, (m/s).	6	8	9,2	11	12,5	13,7
6	**V_{cool},** Cooling air flow velocity supplied to the heat exchanger, (m/s).	2,5	2,5	2,5	2,5	2,5	2,5
7	**G_1,** Fuel consumption, kg/h.	0,42	0,54	0,6	0,72	0,84	0,96
Experiment with the use of an ejection nozzle.							
1	**t_1.** Exhaust gas temperature at the inlet to the heat exchanger, (°C).	123	135	146	166	180	201
2	**t_{2hot},** Air temperature at the hot end of the vortex tube, (°C).	83	83	83	83	83	83
3	**t_2.** Exhaust gas temperature at the outlet of the heat exchanger, (°C).	67	80	92	110	128	147
4	**t_{cool1},** Temperature of the cooling air supplied to the heat exchanger, (°C).	20	20	20	20	20	20
5	**t_{cool2},** Temperature of the cooling air leaving the heat exchanger, (°C).	62	78	86	103	122	138

6	$\mathbf{V}_{e.gas}$**,** Exhaust gas flow rate supplied to the heat exchanger, (m/s).	7,3	9,5	10,7	13	14	15
7	$\mathbf{V}_{\mathbf{cool}}$**,** Cooling air flow velocity supplied to the heat exchanger, (m/s).	2,5	2,5	2,5	2,5	2,5	2,5
8	$\mathbf{G}_{\mathbf{1}}$**,** Fuel consumption, kg/h.	0,36	0,48	0,54	0,66	0,72	0,9

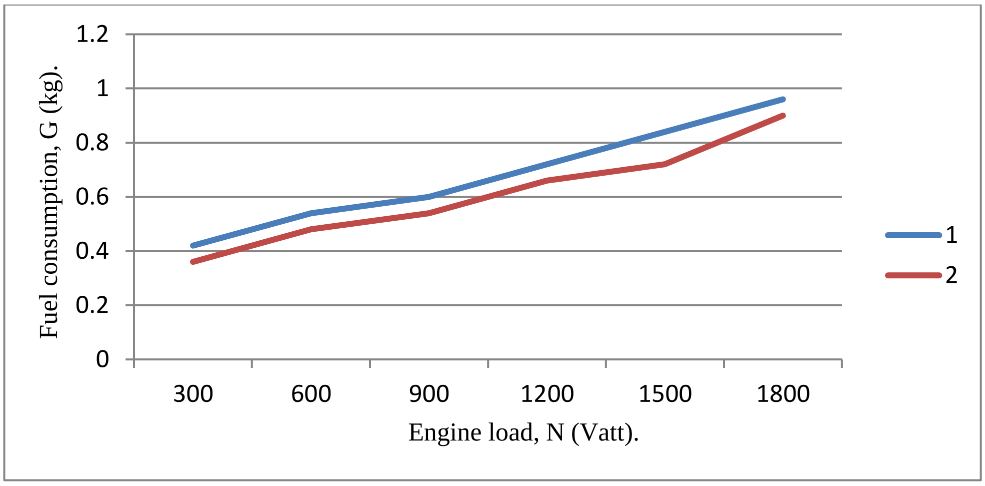

Fig. 5. The graph of the dependence of the fuel consumption (G) of the internal combustion engine on the load (N). 1- without using an injection nozzle, 2- using an injection nozzle.

During tests using an ejection nozzle, a decrease in fuel consumption was observed. The amount of fuel economy increases with increasing engine load. The results of experimental studies show that the use of an ejection nozzle can reduce the fuel consumption of an internal combustion engine by an average of 10%.

Conclusions

The presented research results allow us to draw the following conclusions:

- the temperature regime of the rock cutting tool has a significant impact on the drilling efficiency, which is especially important when drilling wells with blowdown;

- ensuring the temperature regime is most acceptable due to air cooling using a vortex tube; in order to obtain the required air temperature at the bottomhole, a new technical solution has been proposed that makes it possible to place a cooler in the form of a vortex tube in the bottomhole zone of the drill string;

- the proposed design allows you to provide a given temperature of the rock cutting tool and change the cooling mode when changing the drilling mode;

- when utilizing the heat of the internal combustion engine of the compressor, the savings are obvious, because the heat from the internal combustion engine and the vortex tube is directly used to supply heat to the facility, while fuel purchases for these needs are reduced. The economic effect increases from the use of such a technology when it is implemented in conditions of a constant increase in fuel prices, taking into account the costs of transporting it to the place of operation of the power plant.

- the use of recovered heat will reduce heat losses to the environment and increase the efficiency of the energy source.

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