Enhancing technical solutions to reduce fuel energy consumption of drilling equipment during well drilling with air cleaning

Rustam Djurayev*, *Bayrambay* Allanazarov, and *Dilshoda* Khatamova

Navoi State University of Mining and Technologies, Navoi, 210100, Uzbekistan

Abstract. Efficient fuel and energy resource utilization in drilling equipment can be attained through strategies such as decreasing the relative consumption in technological systems during well drilling, enhancing the integration of secondary energy resources in the equipment's power supply system, and refining the design of drilling equipment and technologies. This article showcases the outcomes of pilot studies conducted on a diesel power plant within a drilling rig and a device designed for recycling secondary energy resources from a compressor.

1 Introduction

When drilling wells with compressed air, the high-pressure air flow created in the compressor is transferred into the well through drill pipes, cools the drill bit in the well and moves to the wellhead through the annular space between the pipes and the walls of the well, cleaning the reservoir from dirt. At the wellhead, the air-mud mixture is sent to a mud trap [1-2].

When drilling wells with air purification, the mechanical drilling speed increases up to 4-5 times compared to drilling with washing solutions, the accident rate associated with the ingress of washing liquids is reduced, the collection of geological samples is simplified, water and other costs for preparing the washing mixture are reduced, as well as a number of other benefits [2].

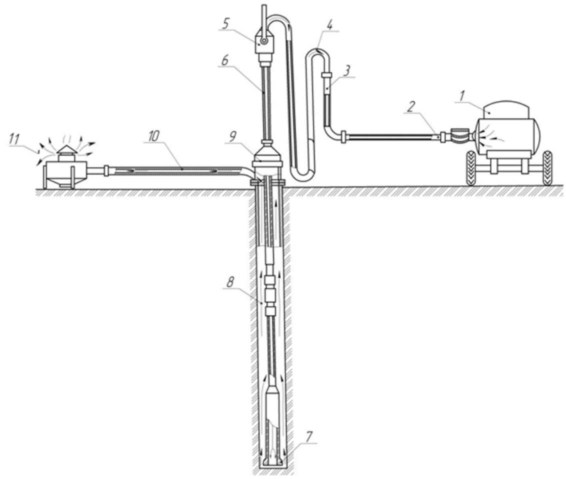
Drilling wells with compressed air reduces drilling costs by 2-3 times, depending on geological conditions [2].

However, drilling wells with cleaning with compressed air can only be carried out in dry rocks with a depth of 250-300 meters; in rocks with high humidity, negative consequences are observed in the form of compaction formation and swelling of the well walls [3].

The behavior of air flow during air cleaning drilling is shown in Figure 1.

Due to the high power of compressor devices used to produce compressed air, energy costs for drilling operations are high. The percentage of energy loss in the form of heat in a compressor engine reaches 50-55%. For example, the rated power of mobile compressor equipment with a ZIF-PV-8/0.7 diesel engine is 60 kW, and its energy losses in the form of heat are equivalent to 5-6 liters of fuel consumption per hour.

* Corresponding author: r.u.djuraev@yandex.ru



1 – compressor, 2 – manifold, 3 – settling tank, 4,10 – hose, 5 – swivel, 6 – drill pipe, 7 – drill bit, 8 – empty well cavity, 9 – sealant, 11 – sludge tool

Fig. 1. Air flow movement when drilling a well with air purification.

When drilling wells with a diameter of 76 mm using air, the compressor operates continuously, the ZIF-PV-8/0.7 compressor produces 8 m^3/minute of air, 3.5-4 m^3/minute of air is supplied to the well, and the rest. An air flow rate of 4-4.5 m^3/min is released into the atmosphere. The temperature of the compressed air in the compressor is on average 70-80 °C.

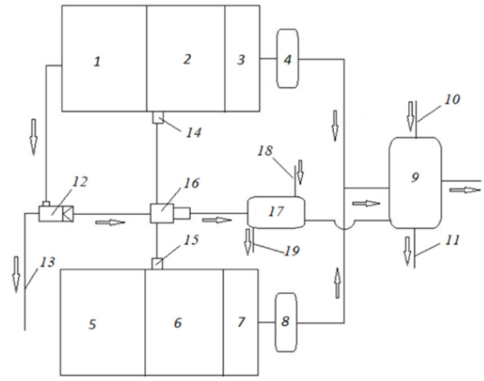
Compressor equipment used when drilling wells with compressed air has a separate internal combustion engine and operates independently of the diesel power plant of the drilling equipment. In most cases, power compressor equipment used in air drilling is equipped with a 46-kW engine. The heat generated from the internal combustion engine of a diesel power plant and compressor equipment can be utilized together [4].

2 Development of a device design for the beneficial use of internal combustion engine heat when drilling wells with air purification

In the cooling system of the compressor and engine of drilling equipment, the useful efficiency of drilling equipment can be increased due to the beneficial recovery of secondary energy resources in the form of heat lost with flue gases and compressed air [5].

Schematic view of a diesel power plant of a drilling rig and a device for useful heat recovery from an internal combustion engine of a compressor is given in Figure 2.

The device for recycling secondary energy resources of a diesel power plant of a drilling rig and a compressor operates as follows: after starting the drilling rig (5) and the compressor (1), after establishing the operating modes of their internal combustion engines. fans (4 and 8) of the compressor and diesel power plant transfer heat from radiators (3 and 7) to the heat exchanger (9) through pipes. The flue gas pipe (14 and 15) is connected to the thermoelectric generator unit (17) through the ejector nozzle (16), and the hot side of the shock pipe (12) is connected to the nozzle on the other side. Compressed air is supplied from the compressor (1) to the drum pipe (12).



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

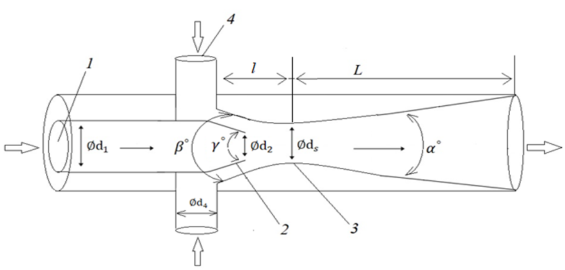
Fig. 2. Diesel power plant of a drilling rig and a device for recycling secondary energy resources of a compressor.

The hot air flow is directed into the ejector nozzle (16), in the ejection nozzle it, together with the flue gases, is transferred to the thermoelectric generating unit, which heats it and then transfers it to the heat exchanger.

Connecting a heat recovery device to the engine exhaust pipe creates resistance to the flow of exhaust gases, resulting in reduced engine power and increased fuel consumption. When hot air under high pressure is supplied to the ejector nozzle from the chimney, an ejection effect occurs in the nozzle and entrains the flue gases along with the nozzle at high speed, which leads to a decrease in the resistance to the flue gas flow.

The thermoelectric generator block is cooled with water. Water heated in a thermoelectric generator is used for technological needs. Cold water is supplied to the heat exchanger through a pipe (10), and heated water through a pipe (11) for technological and domestic needs.

The general view and characteristics of the ejection nozzle used in the diesel power plant of the drilling rig, and the device for recycling the secondary energy resource of the compressor is brought in Figure 3.



1- high pressure air supply tube, 2-nozzle, 3-mixing chamber, 4-low pressure air supply tube, $\varnothing d_1$- high pressure air supply tube diameter, $\varnothing d_2$- nozzle diameter, $\varnothing d_s$ – mixing chamber diameter, $\varnothing d_4$- diameter of the ejection gas pumping pipe, α° diffuser opening angle, β°- interference chamber narrowing angle, γ°- nozzle taper angle, L- mixing chamber length

Fig. 3. Ejection nozzle.

Today, there are several types of ejector nozzles, and they are mainly divided into gas-gas and gas-liquid. That is, in the gas-gas type, the ejected stream is high-pressure gas, and the ejected stream is low-pressure. gas pressure, and in the gas-liquid type, the ejected stream is liquid [6].

An ejector nozzle is a device in which the kinetic energy of one medium moving at high speed is transferred to another medium, while the flow speed of the second medium increases [6-10].

In addition, ejector nozzles have different parameters depending on the application conditions, that is, the diameter and taper angle of the nozzle, the diameter of the mixing chamber, the expansion angle of the diffuser, the length of the mixing chamber, etc.

The basics of calculation and design of ejector nozzles are fully covered in a number of technical literature for experimental tests. In our case, since the ejecting medium is gas and the ejecting medium is also gas, the design dimensions of the ejector nozzles were taken according to the value given in Table 1, after analyzing the technical literature.

Table 1. Structural dimensions of the ejection nozzle.

$\varnothing\mathbf{d}_1$, mm	$\varnothing\mathbf{d}_2$ mm	$\varnothing\mathbf{d}_s$, mm	$\varnothing\mathbf{d}_4$, mm	**L, mm**	l, **mm**	α°, **deg**	β°, **deg**	γ°, **deg**
18	12	16	20	185	120	12°	33°	22°

In the diesel power plant of drilling equipment and the compressor secondary energy resource utilization device, the pressure of hot air supplied from the baffle pipe to the ejector nozzle is on average about 0,6-0,8 MPa, and the pressure of the engine exhaust gases is in the range of 0,12-0,14 MPa. When a high-pressure air stream is transferred from the chimney to the ejector, it mixes with the flue gases and increases their flow rate, thereby increasing the useful power of the engine by reducing the resistance force on the chimney piston engine.

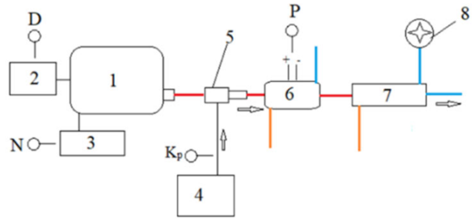
3 Pilot research of a diesel power plant of a drilling rig and a device for recycling secondary energy resources of a compressor

Experiments were conducted to determine the effect of flue gas emissions from a high-pressure air stream from a compressor on the fuel consumption of an internal combustion engine.

The purpose of the experiments was:

- determination of fuel consumption of an internal combustion engine without the use of an ejector nozzle;
- determination of fuel consumption of an internal combustion engine using an ejector nozzle;
- determine the influence of ejection flow pressure on the efficiency of using the ejection nozzle.

The experimental work was carried out in the following order: a 2-kW gasoline generator was supplied with loads of various powers through incandescent lamps and fuel consumption was measured at different air pressures supplied from the compressor, with and without engine ejection nozzle. Figure 4 below shows a schematic representation of the experimental equipment.



1-internal combustion engine, 2-fuel tank, 3-lamp unit, 4-compressor, 5-ejector nozzle, 6-thermoelectric generator unit, 7-heat exchanger, 8-fan, D-point for measuring fuel consumption, N-point for measuring engine load, K_P- compressor pressure measuring point

Fig. 4. Schematic view of a device for studying the effect of exhaust gas emissions from an internal combustion engine on fuel consumption.

At the first stage of experimental work, fuel consumption was recorded in the device without using an ejector nozzle; fuel consumption was 0,42 kg/h with single engine operation, fuel consumption was 0,6 kg/h with increasing load. up to 500 W, and the fuel consumption was 0 at a load of 1000 W 78 kg/h, when the load increased to 1500 W and 2000 W, the fuel consumption was 0,96 kg/h and 1,17 kg/h.

At the second stage of experimental work, it was carried out using an ejector nozzle in the chimney pipe of the device. In this case, at various engine loads, the ejection nozzle was supplied with ejection air pressure from the compressor from 0,4 MPa to 0,8 MPa, and the fuel consumption was recorded at each pressure at which the air pressure increased by 0,1 MPa.

The dependence of fuel consumption during engine operation on the air pressure supplied from the compressor to the ejector nozzle is graphically presented in Figure 5.

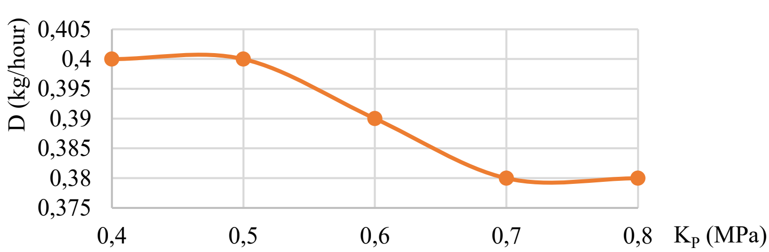


Fig. 5. Graph of the dependence of fuel consumption (D) on air pressure (KP) supplied to the ejector nozzle during engine operation.

As can be seen from the graph above, in the absence of engine load, fuel consumption is 0,4 kg/h at a compressed air pressure at the ejection nozzle of 0,4 and 0,5 MPa and 0,39 kg/h at an air pressure of 0,6 MPa. increased, fuel consumption decreased to 0,38 kg/h at an air pressure from the compressor to the ejector nozzle of 0,7 and 0,8 MPa.

The dependence of fuel consumption on the air pressure supplied from the compressor to the ejector nozzle at an engine load of 500 W is graphically presented in Figure 6.

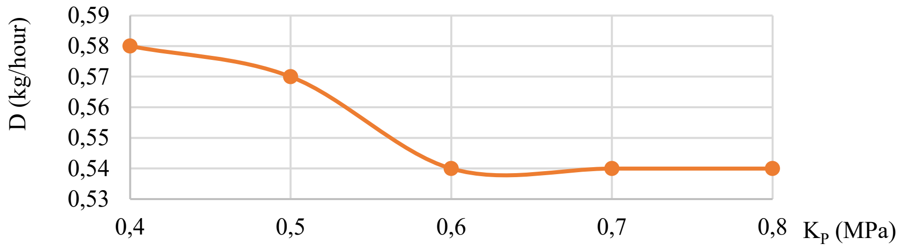


Fig. 6. Graph of fuel consumption (D) versus air pressure (KP) supplied to the ejector nozzle at engine load N=500 W.

With an engine load of 500 W, fuel consumption was 0,58 kg/h at a pressure from the compressor to the ejection nozzle of 0,4 MPa and 0,57 kg/h at an air pressure of 0,5 MPa. At pressures of air supplied from the compressor of 0,4-0,5 MPa, fuel consumption did not change significantly. When the pressure of the ejection air supplied to the ejector nozzle was more than 0,6 MPa, a significant reduction in fuel consumption was observed.

The dependence of fuel consumption on the air pressure supplied from the compressor to the ejector nozzle at an engine load of 1000 W and 1500 W is graphically presented in Figures 7 and 8.

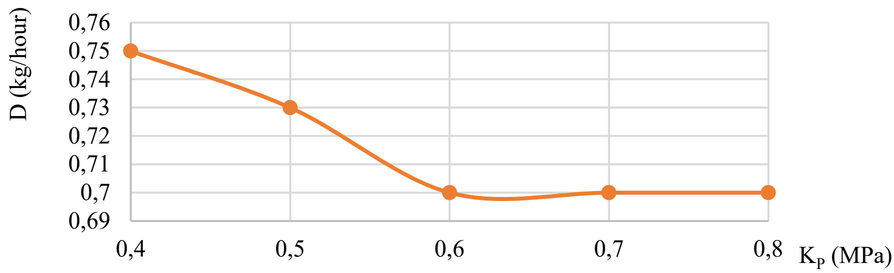


Fig. 7. Graph of fuel consumption (D) versus air pressure (KP) supplied to the ejector nozzle at engine load N=1000 W.

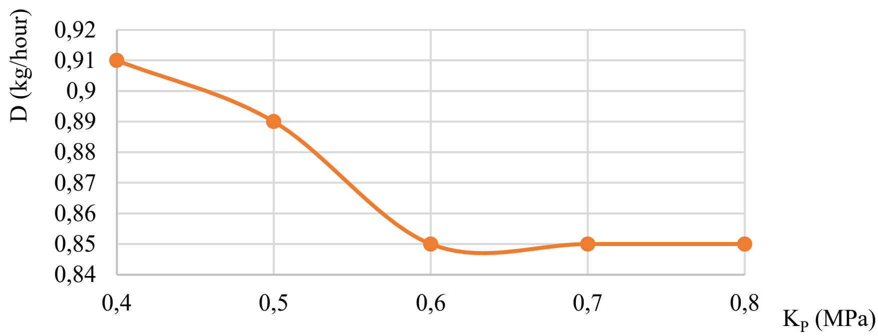


Fig. 8. Graph of the dependence of fuel consumption (D) on air pressure (KP) supplied to the ejector nozzle at engine load N = 1500 W.

At an engine load of 1000 W, fuel consumption was 0,75 and 0,73 kg/h at air pressures at the ejector nozzle of 0,4 MPa and 0,5 MPa, and fuel consumption as a result of an increase in air pressure of 0,6 MPa and above was 0 decreased to 0,7 kg/h.

The same change in fuel consumption was observed at an engine load of 1500 W.

When the engine reached a maximum power of 2000 W, a decrease in fuel consumption was observed as a result of an increase in the air pressure transmitted from the compressor from 0,4 MPa to 0,6 MPa, which is 0,6 air pressure; At pressures of 0,7 and 0,8 MPa, fuel consumption remained unchanged. Figure 9 shows a graph of the dependence of fuel consumption (D) on air pressure (AP) supplied to the ejection nozzle at engine load N = 2000 W.

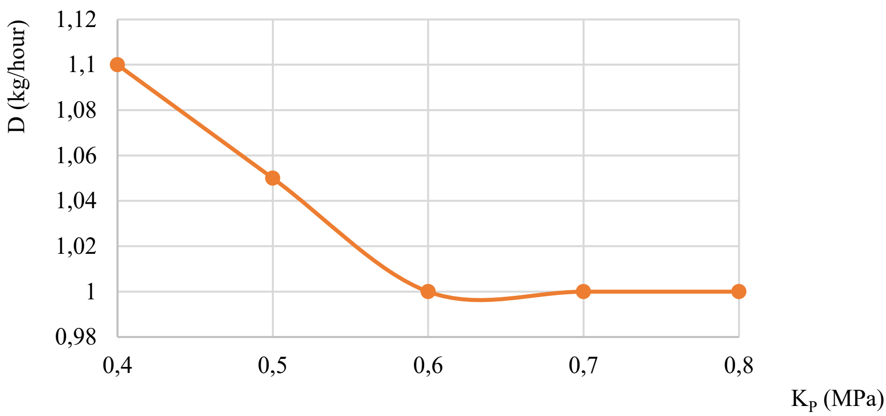


Fig. 9. Graph of fuel consumption (D) versus air pressure (KP) supplied to the ejector nozzle at engine load N = 2000 W.

The diagram presented in Figure 10 shows the dependence of fuel consumption on the air pressure supplied from the compressor to the ejector nozzle at various loads applied to the engine.

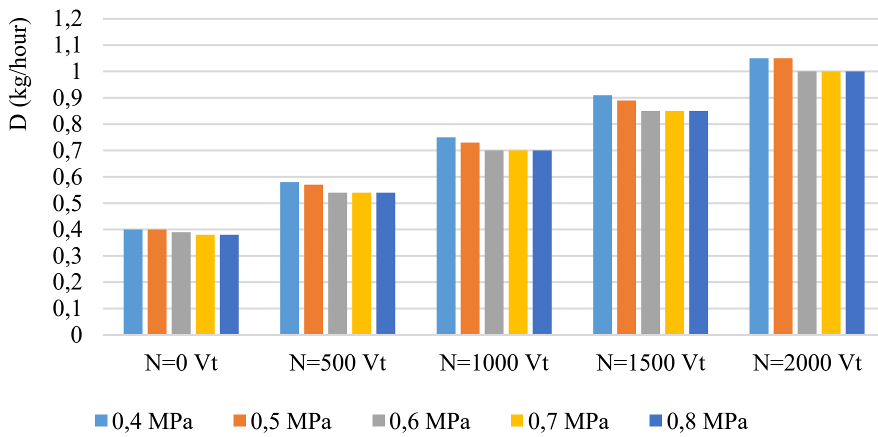


Fig. 10. Dependence of fuel consumption (D) on air pressure (KP) supplied to the ejector nozzle at various loads applied to the engine.

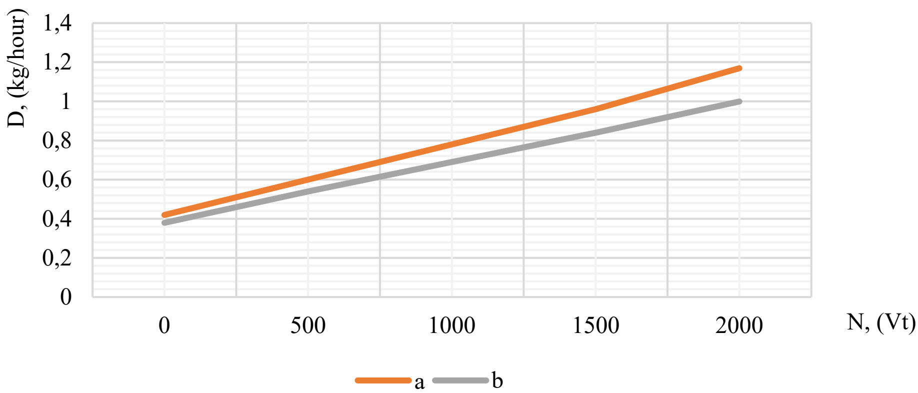
Analysis of the results of experimental work shows that the use of an ejector nozzle in a diesel power unit of drilling equipment and a device for recycling the secondary energy resource of a compressor can reduce fuel consumption by up to 12%.

The efficiency of using an ejector nozzle depends on the pressure of the air supplied to it from the compressor, that is, the pressure of the ejecting flow; fuel consumption is reduced by an average of 6-7% at pressure values of the ejecting flow up to 0,5 MPa, and fuel consumption is 10-12 at values 0.6 MPa or more. A decrease of up to % was observed.

Also, at low engine loads, i.e. at loads of 25–50%, the use of an ejector nozzle reduced fuel consumption by 7–8%, and at engine loads of 50% and above, fuel consumption decreased by 10–12%.

When using an ejection nozzle in a diesel power unit of drilling equipment and a device for recycling the secondary energy resource of a compressor, it was found that the efficiency of the ejection nozzle is high when the ejection air pressure is 0,6 MPa and higher.

Figure 11 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.



a - without an ejector nozzle, б - with an ejector nozzle.

Fig. 11. Change in fuel consumption (D) at different loads (N) applied to the engine.

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.

4 Conclusion

Upon analyzing the experimental test results, the following conclusions have been drawn.

The substantial power of compressor devices utilized for generating compressed air results in elevated energy expenses for drilling operations, with up to 50-55% of energy loss occurring as heat in the compressor engine.

During air-assisted well drilling, the compressor operates continuously, directing only a portion of the produced air into the well while releasing the remainder into the atmosphere, with the compressed air temperature averaging 70-80 °C.

Development has been completed on the design of a diesel power plant for drilling equipment and a device for recycling secondary energy resources from a compressor.

A nozzle design has been devised to reduce fuel consumption in the internal combustion engine of drilling equipment, leading to an 8-10% reduction in fuel usage.

The efficacy of the ejector nozzle is contingent upon the air pressure supplied to it from the compressor, with fuel consumption decreasing by an average of 6-7% at exhaust pressures up to 0.5 MPa and by 10-12% at higher pressures.

Implementing the ejector nozzle at lower engine loads (25-50%) resulted in a 7-8% reduction in fuel consumption, while at loads exceeding 50%, fuel consumption decreased by 10-12%.

Utilizing an ejector nozzle in a heat dissipation device for an internal combustion engine demonstrated the most significant reductions in fuel consumption at engine loads of 50-75%.

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