

## **DEVELOPMENT AND RESEARCH OF JET PUMP-COMPRESSOR UNIT WITH PERIODICAL CONNECTION OF EJECTOR**

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*A new scientific approach to gas compression using jet pump-compressor units has been developed. The new patented technical solution offers an opportunity for the effective application of jet pump-compressor units for the compression of various gases up to pressures of 10...40 MPa. The purpose of the ongoing research work is to develop new scientific principles for gas compression using jet pump-compressor units. The new scientific approach is associated with the improvement of the pump-compressor unit, with the provision of conditions for the periodic connection of the ejector during the implementation of a cyclic low-frequency working process. The results of the research findings can be used to create energy-efficient technologies for the compression and pumping of various gases; it can be methane, associated petroleum gas, nitrogen, carbon dioxide, air, hydrogen or other gases. The creation of cheaper and more economical pump-compressor units will allow for the solution of urgent production problems in hydrocarbon production, including those in remote Arctic oil and gas fields.*

*Key words: oil and gas production, ejector, compressor, pump, separator, research*

### **INTRODUCTION**

At the late stage of oil and gas field development, the need for additional pumping and compressor equipment is increasing. This is due to the application of such technologies as the compressor-assisted gaslift, gas injection into the productive reservoir for enhanced oil recovery, air injection into the productive reservoir for the implementation of oxidizing processes as a part of work to increase the oil recovery factor and gas-liquid mixture pumping technology [18, 20]. However, well-known compressor machines do not yet fully solve such urgent problems. During hydrocarbon production, operating conditions of compressor machines are complicated by the presence of liquid fractions and solid particles in the flow of the pumped medium. The active use of compressor technologies is also hampered by rather high prices of equipment. In this regard, the development of efficient domestic pump-compressor units can be fully considered as an urgent task.

Today, foreign and domestic specialists with special interest began to discuss the possibilities of jet pump-compressor units for practical use in abnormal operating conditions of oil and gas field development [19].

Jet pump-compressor units have high reliability and a low price, as shown in papers [1-4]. In general, such unit includes the following main elements: a power liquid pump, ejector and separator. To regulate the operation mode, there are usually possibilities to change the power pump delivery. Besides, an adjustable ejector is used, which allows for changing the cross-sectional area in the flow channel at the nozzle, as is proven in papers [5-7] and described in patent [8]. In some cases described in patents [9-11] and in paper [12], the cyclic mode of

medium flow through the ejector nozzle is considered, but such options have not yet been brought to the wide practical application. High-frequency cyclic modes of the ejector operation were considered mainly in the field of aviation technologies, but low-frequency cyclic modes of the ejector operation are still poorly studied. The cyclic connection of the ejector at low frequencies, combined with the cyclic change of the power pump mode, is seen as very promising. This is in terms of both increasing the gas output pressure and improving the performance factor of the pump-compressor unit as a whole in relation to the solution of problems on the production of hydrocarbons [17].

The development of computer technologies opens up new opportunities for the automation of ejector systems in case of cyclic changes in values of operating parameters, as demonstrated in papers [13-15].

### **CONCEPT HEADINGS**

The purpose of the ongoing research work is to develop new scientific principles for gas compression using jet pump-compressor units. The new scientific approach is associated with the improvement of the pump-compressor unit, with the provision of conditions for periodic connection of the ejector during the implementation of the cyclic low-frequency working process.

### **RESULTS**

Conducted complex researches in the field of pumping and compressor technologies described in papers [1, 13-15] have allowed us to outline a new area of research related to the periodic connection of the ejector. The implementation of such a working process provides

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conditions for increasing the performance factor of the jet pump-compressor unit. New technical solutions have been developed and patented. These new technical solutions offer rather broad opportunities for the effective application of jet pump-compressor units for the compression of various gases and gas-liquid mixtures up to pressures at the level of 10...40 MPa.

Figure 1 shows one of the developed versions of the pump-compressor unit (the patent application of the Russian Federation No. 2019130889 of 01.10.2019).

The pump-compressor unit contains a working chamber 1, made in the form of a gas-liquid separator, a liquid pump 2 and an ejector. The inlet 4 of the gas-liquid separator to gas is connected through the pressure control gas valve 5 to the low-pressure gas pipeline 6. The outlet 7 of the gas-liquid separator to gas is connected through the pressure control gas valve 8 to the high-pressure gas pipeline 9. The outlet 14 of the gas-liquid separator 1 is connected through the first remote-controlled valve 15 to the inlet 12 of the liquid pump 2. It is connected to the inlet 16 of the mixing chamber 3 of the ejector, the outlet 17 of which is connected to the working liquid source 11 through the liquid mixture line 18 with the second remote-controlled valve 19 mounted on it. In its turn, the

working liquid source 11 is connected to the inlet 10 of the liquid pump 2, the outlet 12 of which is connected to the ejector nozzle 13. The liquid pump 2 is equipped with the electrical drive 20.

The operation of the pump-compressor unit can be automated and computerized using a control system based on remote-controlled valves 15 and 19.

As the working liquid source 11, a pipeline can be used through which the working liquid is constantly circulating. The upper part of the gas-liquid separator 1 is filled with gas, while the lower part of the gas-liquid separator 1 is filled with liquid. Figure 1 shows the boundary surface 21 between the gaseous and liquid phases.

The pump-compressor unit operates as follows.

The liquid pump 2 feeds the working liquid into the ejector nozzle 13. Due to the energy of the liquid jet at the inlet 16 of the ejector-mixing chamber 3 the pressure reduces, and the liquid comes from the outlet 14 of the working chamber 1 to the inlet 16 of the ejector-mixing chamber 3. The gas from the gas pipeline of low pressure 6 flows through the open suction gas valve 5 to the inlet 4 of the gas-liquid separator 1. At the outlet 17 of the ejector mixing chamber 3, the pressure increases in the liquid mixture flow due to conversion of the kinetic energy of the working liquid into the potential energy. This is accompanied by an increase in pressure when the liquid flow speed decreases. After that, the liquid flow at the outlet 17 of the ejector mixing chamber 3 passes through the liquid mixture line 18 via the open remote-controlled valve 19 and enters the working liquid source 11. The incoming gas from the low-pressure gas pipeline 6 accumulates in the upper part of the working chamber 1, which leads to the downward shift of the boundary surface 21. In this case, the liquid from the outlet 14 of the working chamber 1 is displaced to the outlet 16 of the ejector mixing chamber 3. As can be seen from the above, the reduction of power fluctuations of the liquid pump 2 as well as the extension of the working range of the gas pressure at the inlet 4 into the pump-compressor unit is provided.

If the gas-liquid mixture enters the inlet 4 of the gas-liquid separator 1, the separation process is performed, during which the liquid fraction goes down, and the gas remains at the top of the gas-liquid separator 1.

When the boundary surface 21 approaches the minimum permissible lower position of the liquid level in the working chamber 1, a control signal will be given to the remotely-operated valves 19 and 15 for closing and opening, respectively. The liquid will start to flow to the inlet 10 of the liquid pump 2 from the working liquid source 11 and will be pumped towards the outlet 14 of the working chamber 1 through the open remote-controlled valve 15. This will increase the pressure in the working chamber 1 and, respectively, will close the suction gas valve 5. During this time, the boundary surface 21 will start to shift from bottom to top. This will continue to compress the gas in the working chamber 1 with a corresponding increase in

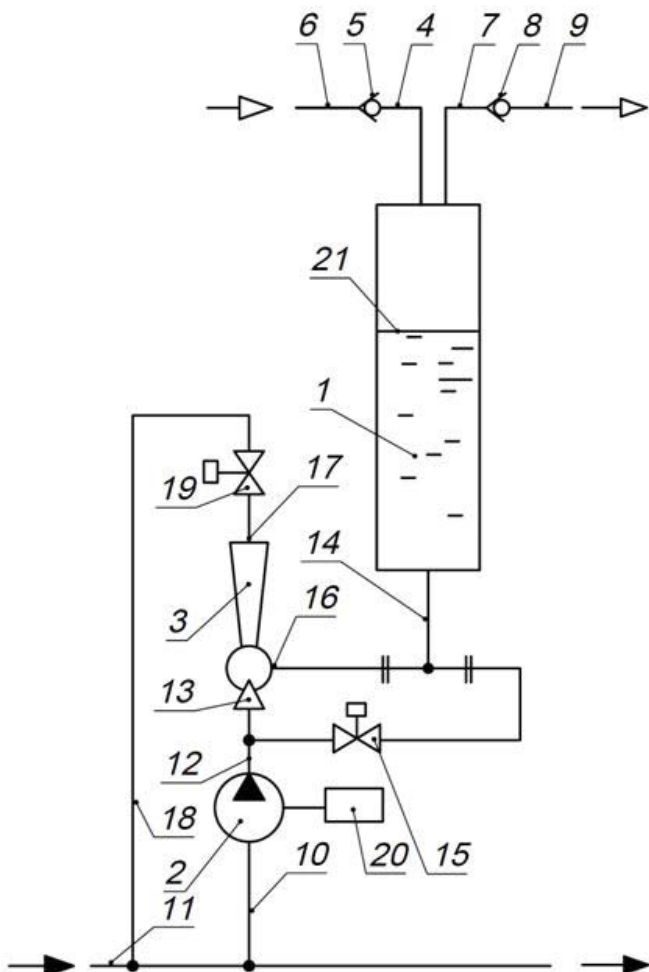


Figure 1: Schematic diagram of the pump-compressor unit

pressure. In case of the boundary surface 21 displacement upwards, there will be a moment when the pressure in the working chamber 1 becomes equal to the pressure in the high-pressure gas pipeline 9. This pressure equalization will open the gas pressure control valve 8. With the further upward displacement of the boundary surface 21, the compressed gas from the outlet 7 of the working chamber 1 will be forced out into the high-pressure gas pipeline 9 through the open pressure control gas valve 8 to the maximum permissible upper position of the liquid level in the working chamber 1. After completion of the gas displacement cycle, the remote-controlled valves 15 and 19 will receive a signal for their closing and opening, respectively. Then the operating cycle is repeated.

When using such a pump-compressor unit, the initial gas pressure may be less or more than the pressure in the working liquid source 11. This provides a wider operating range for the gas pressure at the inlet 4 of the pump-compressor unit. The advantage of the unit is the higher efficiency of the working process under gas compression because the power of the liquid pump 2 is used more efficiently when filling the working chamber 1 with gas.

Jet elements can also be used to control valves 15 and 19. When developing such switch-gears, the variants of jet elements in which the Coanda effect was used according to monograph [16], are considered separately. In figure 2, the variant of the developed jet element is shown as an example.

The jet elements are relatively poorly reflected in contemporary scientific literature. Now, the scientific and technical potential of fluidics created based on the Coanda effect remains practically undisclosed. It seems that available solutions in the fields of aviation and automation systems represent only an insignificant part of the huge potential that fluidics possesses. Our research work deals with the jet elements in combination with multi-flow ejectors of various designs when solving problems of the liquid and gas flow control. With the use of modern

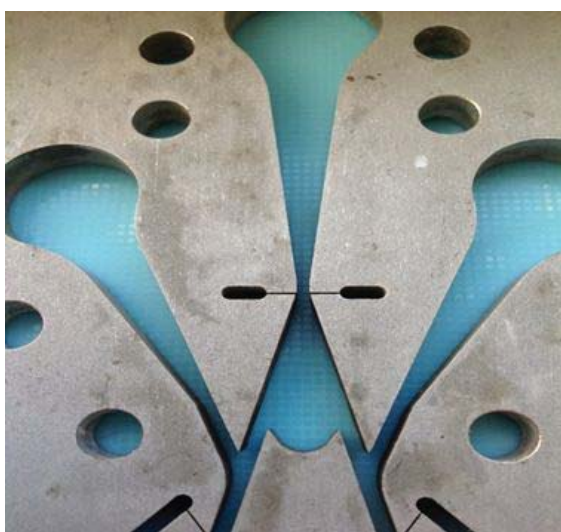


Figure 2: Variant of the jet element in which the working process is based on the Coanda effect

computer technology, it is possible to leave behind many expensive physical experiments, gradually moving from physical experiments to numerical ones.

### DISCUSSION

New scientific principles of gas compression with the use of ejectors and ejector systems operating in pulse mode at low frequencies have been developed within the framework of scientific research. New possibilities of the ejector system control with the use of high-speed systems for the liquid or gas flow control have been considered. New lines of research of jet pump-compressor units combining low-frequency and high-frequency pulse processes are outlined.

In the course of scientific research, the compressor technology and machinery based on the ejector system have been developed and patented. The results of these works have been supported by patents for inventions and utility models of the Russian Federation No. 2674042, No. 2680021, No. 2680028, No. 2702952, No. 2707989, and No. 192513. New scientific principles of gas compression to pressures of 10...40 MPa based on the application of ejector systems operating in pulse mode at low frequencies have been developed within the framework of scientific research. New designs of compressors and control systems are developed and patented. New lines of research of ejector systems have been outlined and recommended, which combined low frequency and high-frequency pulse processes with bringing the gas output pressure up to 40 MPa. The research results can be considered as the basis for a promising technology that allows for the single-stage isothermal gas compression without restrictions on the compression ratio, including a 400-fold increase in gas pressure in one stage. The technologies of multistage compression with the adiabatic working process applied today are considerably inferior in parameters of one stage. There are restrictions on the compression ratio, which usually does not exceed the value of 5 for one stage. Figure 3 shows the dependence of the relative power consumption on the compression ratio (or the rate of compression) for comparison. The power parameters for the adiabatic gas compression  $N_n/N_t$

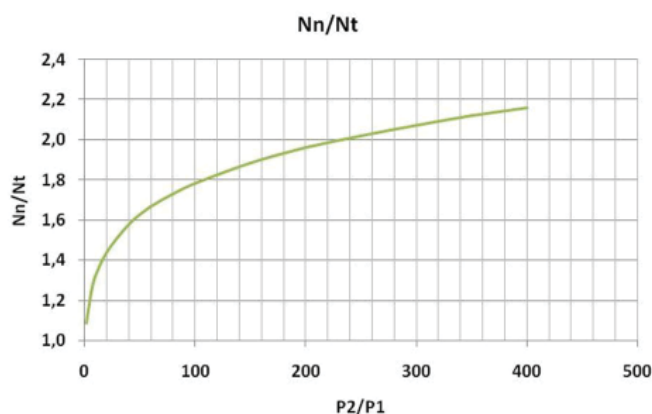


Figure 3: Dependence of the relative supplied power on the compression ratio in gas compression

and isothermal gas compression  $N_t$  are compared. The compression ratio reflects the ratio of gas pressure  $P_2$  at the compressor outlet to gas pressure  $P_1$  at the compressor inlet. Calculations show that the isothermal process of gas compression at high pressures can reduce the power consumption in one stage of the compressor almost twice.

Figures 4-6 represent a promising option of the compressor unit for the single-stage isothermal compression of gases practically without restrictions on gas pressure at the inlet and outlet. The compressor unit contains the working chamber 1, ejector 2, suction gas valve 3, and pressure control gas valve 4. The power pump and the hydraulic distribution equipment system are not shown in this diagram. The blue arrows show the flow direction of the liquid. The white arrows show the flow direction of the gas. The gas is compressed and pumped in the following sequence. At the stage when the working chamber 1 is filled with the gas, the suction gas valve 3 is open, as shown in figure 4. The ejector 2 ensures the gas pressure increase in the chamber 1. This pressure increase is provided by the working liquid energy supplied to the nozzle of the ejector 2. In doing so, the liquid is forced out from the working chamber 1 through the lower connection pipe, as shown in Figure 4.

After working chamber is filled with gas, the flow direction of the liquid is changed, as shown in Figure 5. The working liquid is pumped into the working chamber through the lower connection pipe. This reduces the gas volume and increases the gas pressure. Part of the working liquid continues to flow into the nozzle of the ejector 2, and then into the upper part of the working chamber 1. This direction of liquid flows allows for creating conditions for the heat exchange and isothermal gas compression in the working chamber 1. At the stage when the gas is compressed in the working chamber 1, the suction gas valve 3 is in the off condition, as shown in Figure 5. In this case, the pressure control gas valve 4 is also in the off condition because the gas pressure

in the working chamber 1 is still lower than the valve 4 outlet gas pressure.

The continuing injection of the liquid into the working chamber 1 will cause an increase in pressure inside the working chamber 1, which will cause the pressure control gas valve 4 to open, as shown in Figure 6. The compressed gas will be forced out from the working chamber 1 through the open pressure control gas valve 4. The process of gas displacement from the working chamber 1 continues until the entire working chamber 1 is filled with liquid. The operating cycle is then repeated (with the description using Figures 4-6). The automatic control system for the compressor unit can be assembled using commercially available equipment.

According to preliminary estimates, significant reductions in investment and operating costs are expected. If multistage pumps are used for the ejector 2 operation, then in the Russian market compressor equipment costs can be reduced by 10 times in general (compared to mul-

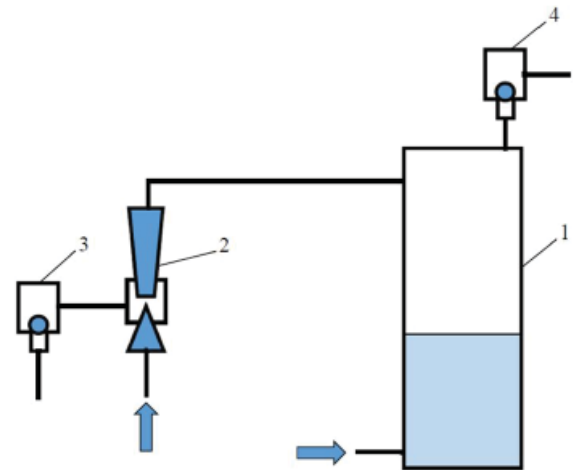


Figure 5: Schematic diagram of the compressor unit for the single-stage isothermal compression of gases (at the stage when the gas is being compressed in the working chamber)

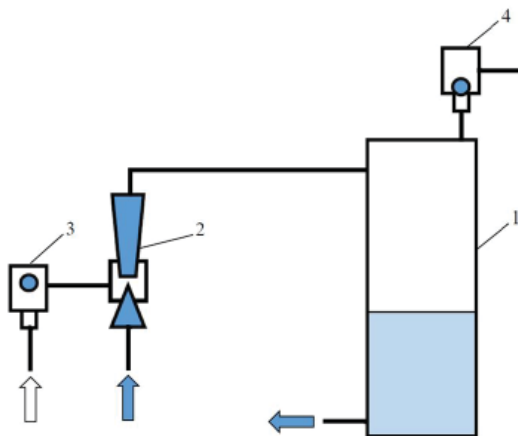


Figure 4: Schematic diagram of the compressor unit for the single-stage isothermal compression of gases (at the stage when the working chamber is being filled with gas)

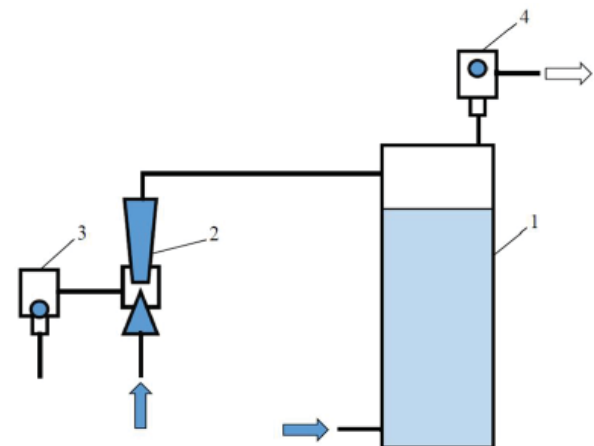


Figure 6: Schematic diagram of the compressor unit for the single-stage isothermal compression of gases (at the stage when the compressed gas is being forced out from the working chamber)

tistage piston compressors). Taking into account the cost of gas pre-cleaning systems, these costs can also be reduced by 20 times.

Based on such technology, there is an opportunity to develop other branches of science and technology, including gas turbine units for various purposes, because it is known that today scientific and technical reserves for further improvement of gas turbine units are already fully exhausted. Many specialists are now shifting to finding fundamentally new technical solutions, including technologies related to the isothermal compression, isothermal expansion of gases or impulse combustion of fuel-air mixtures at a constant volume.

Some results of the work performed can also be used in other industries, among other things in the creation of jet control systems for air-based or sea-based drones, including the solution of problems in the development of offshore oil and gas fields.

### CONCLUSIONS

A new scientific approach has been developed for the improvement of jet pump-compressor units. The problem of providing conditions for periodic connection of the ejector within the framework of the cyclic low-frequency working process realization has been considered. This technical solution offers an opportunity for effective application of jet pump-compressor units for the compression of various gases up to pressures of 10...40 MPa. In this version, cheaper jet compressors can replace expensive multistage positive displacement compressors. Variants of automated systems for control of the pump-compressor unit have been developed and patented using new scientific principles for gas compression. In this regard, some results of the work performed can be used in other industries, among other things in the creation of jet control systems for air-based or sea-based drones, including the solution of problems in the development of offshore oil and gas fields.

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