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Studying Issues of Compressed Gas Energy Recovery

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Abstract

Background/Objectives: One of promising researches to increase efficiency of oil and gas production is connected with compressed gas energy recovery. Potential gas energy may be converted to thermal energy or electric power using special gas turbines. **Methods:** The known methods for converting compressed gas energy into thermal or electric energy involve the use of impulse and reaction turbines. But high price for turbines hinders works on the use of compressed gas energy. Development of technologies for compressed gas energy recovery should be aimed at creating simpler and cheaper equipment. When developing new turbines for thermal generator, options using looped blades have been analyzed. **Findings:** At this stage of research and development work we have developed a new thermal generator, equipped with a gas turbine and a heat transfer fluid circulation loop. Looped blades were used in the turbine creation. A distinctive feature of the created turbine is that the working gas flow is directed along a plane that is perpendicular to the turbine rotation axis. In the known turbines, equipped with looped blades, the working gas flow is directed along the turbine rotation axis. Application of these results brings about the opportunity for creating simpler and less expensive power plants operating by means of compressed gas energy for a wider power range – from a few kilowatts to several hundred kilowatts. **Application/ Improvements:** The basic field of application for the created plant is associated with the production facilities of oil and gas industry. However, individual results can be used in other industries, for example, when creating machinery for sea and air transport, where weight reduction and improving the reliability of the equipment is particularly relevant.

Keywords: Energy Conversion, Gas, Generator, Looped Blade, Oil, Turbine

1. Introduction

Reduction of energy consumption in the production cycle remains one of the most urgent tasks for the majority of industrial enterprises in the Russian Federation, including for the enterprises engaged in production of hydrocarbons. According to numerous experts, in the oil and gas industry the opportunities are not fully opened for the practical use of the potential compressed gas energy, in the process of reducing gas pressure in technological systems, during gas conditioning or transportation. Potential gas energy can be converted into thermal energy or electrical energy using special gas turbines. However, a common problem can be singled out for all known technologies, without solving which it is impossible to talk about a wide practical use of these alternative energy sources. This problem is determined by high specific capital investments for the use of alternative energy sources. Development of technologies for compressed gas energy recovery, in our opinion, should be aimed at creating simpler and therefore cheaper and more reliable equipment.

When planning the research and development work a known fact can be noted that the desire to improve the process performance level only by providing the highest efficiency values is usually accompanied by a sharp increase in financial costs to achieve the objective. In such cases, the massive use of scientific achievements becomes virtually impossible because of the unacceptably high rise in prices for the finished product. So, one goal (reduction of capital costs per unit) and the other goal (improving plant efficiency) often contradict each other. In this case, it is rather important to seek a compromise solution. And in this regard it is appropriate to use lower-cost equipment, but at a certain level of efficiency reduction.

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To generate thermal energy by means of compressed gas energy in the production fluid gathering facilities at the hydrocarbon fields the provision is made to use a special thermal generator[1-3].

The options of using looped blades were analyzed while developing a turbine for the thermal generator[4–11]. Advanced computer technologies allow solving technical problems at a breakthrough level and obtaining new results that has been unattainable previously. Thus, for example, axial blade machines, shown in Figure 1, according to US Patent number 2273756 dated 1942, have been improved and are used in the products of modern Japanese company Loopwing Co. Ltd. with US Patent number 7018167 granted in 2006, this improved version is shown in Figure 2.

At the initial stage of studies the research was carried out with regard for the possibilities of impulse and reaction turbines. As is known, in the impulse turbine gas expansion is carried out only in the nozzles. The potential energy of compressed gas is completely converted into kinetic energy in the turbine nozzles. The conversion of kinetic energy into mechanical energy takes place on the turbine rotor blades. In reaction turbine flow expansion occurs both in the nozzles and channels of rotor blades. It is known that stages with varying degrees of reaction are widely used in modern turbines; these stages occupy an intermediate position between the cases of purely impulse and purely reaction stage[12-20].

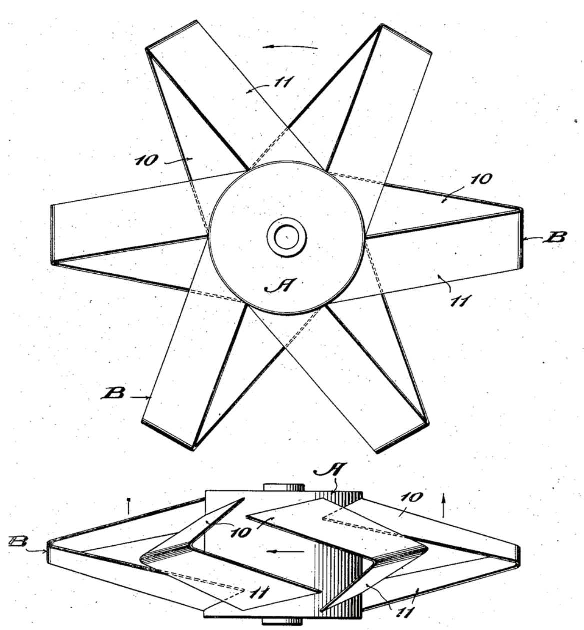

Figure 1. A scheme of the rotor with looped blades[6].

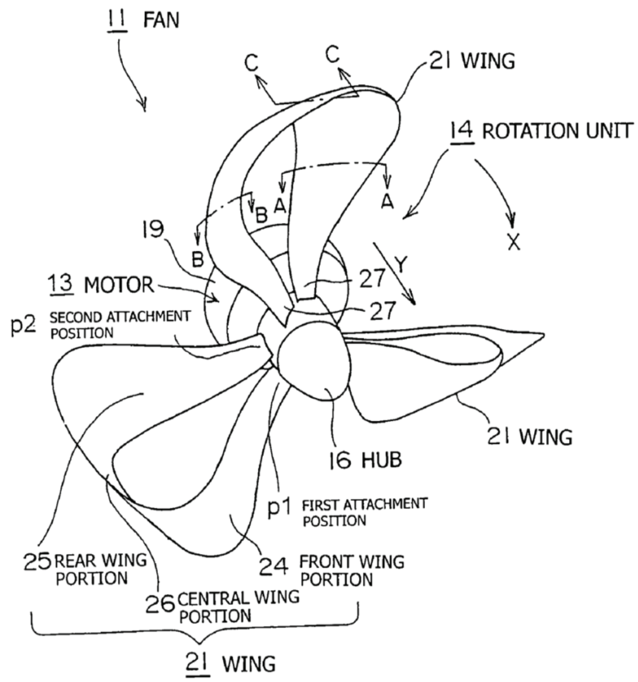

Figure 2. A scheme of the rotor with looped blades[7].

The options for turbines with an impulse (pulsed) mode of gas movement in nozzles turbine may be of practical and scientific interest.

In the stages with a partial gas supply, occurring ventilation losses are usually taken into consideration, since a directed flow comes into the working channels periodically. When a directed flow comes out of the channels, the gas available in the gap is sucked in by the impeller and it works as a fan. As is known, it is possible to reduce the ventilation losses by closing the rotor blades with protective cover along the arc between the segments of nozzle channels.

2. Concept Headings

The scientific problem of creating a new energy-efficient technology is interdisciplinary. As part of the research it is supposed to consider the options with a point and distributed supply of energy in the thermal generator elements using a serial and parallel connection of the individual elements. It is important to consider for the hydraulic part of the thermal generator both the hydraulic pressure losses due to friction along the length of the channels and the hydraulic pressure losses due to impact in the local hydraulic resistances. Hydraulic resistances may be constant or variable, considering the development of hydrodynamic processes in specific areas of the working chamber. The physical properties of the working fluid may change over time, with regard to steady or pulsed modes. The energy conversion chain, starting with compressed gas energy and ending with the thermal energy of heat transfer fluid flow, may include elements of the magnetic system[1–3].

As part of the research activities it is planned to develop and study the original versions of the gas turbine and a heater with a magnetic system, ensuring high adaptability in manufacture and operation of the equipment. The research activities are aimed at creating simple, cheap and reliable machinery, with opportunities for a quick solution to various technical tasks.

3. Results

In the laboratories of Gubkin Russian State Oil and Gas University carried out exploratory and applied research activities and experimental development within the framework of the creating advanced technologies and new equipment, including dynamic machines with looped blades[1–3,11]. Figure 3 shows a micro model of the turbine with looped blades; the photo was made during laboratory experiments with the conversion of gas kinetic energy into electrical energy. Compressed gas is fed into nozzle 1. A stream of gas is directed into the impeller 2 of the turbine. The turbine impeller 2 is mounted on the shaft of the electric generator. Electrical energy is transmitted from the electric generator to the lighting lamp 3. Orientation of nozzle 1 provides conditions for the gas motion along a plane that is perpendicular to the axis of rotation of the impeller 2.

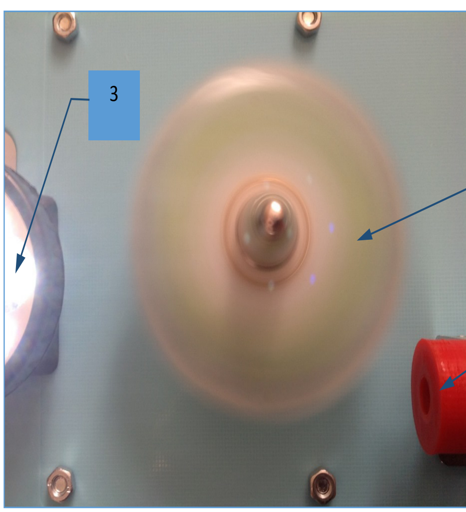

Figure 3. A micro model of the turbine with looped blades.

Figure 4 shows a scheme of the developed and patented device for heating heat transfer fluid – thermal generator[1,2].

The device for heating heat transfer fluid contains a source of mechanical energy in the form of gas turbine, comprising a turbine casing 1 and a turbine rotor 2. The turbine casing 1 is equipped with the gas inlet duct 3 and outlet duct 4. The turbine is connected with a pump via the transmission 5. The pump has an impeller 6, a housing 7 with the inlet 8 and outlet 9 fluid ducts. The impeller 6 may have different modifications, including those in the form of a blade impeller (as in the known blade pump) or in the form of a disk impeller (as in the known disc pumps). The fluid ducts 8 and 9 are connected to an external closed-loop pipeline 10, filled with liquid heat transfer fluid. The thermal energy consumer 11 is included in the closed-loop outer pipeline circuit 10. The pump impeller 6 comprises at least one disc 12 made of electrically conducting material. It is possible to use two or more disks 12 installed together with the impeller 6 onto the shaft 14. Permanent magnets 13 are located on the pump housing 7 circumferentially, the magnets polarity alternating in the circumferential direction ensuring the possibility to induce eddy currents in the disk 12 made of conductive material. The turbine rotor 2, pump impeller 6 and the disk 12 of conductive material are installed on the common shaft 14. For example, aluminum, titanium

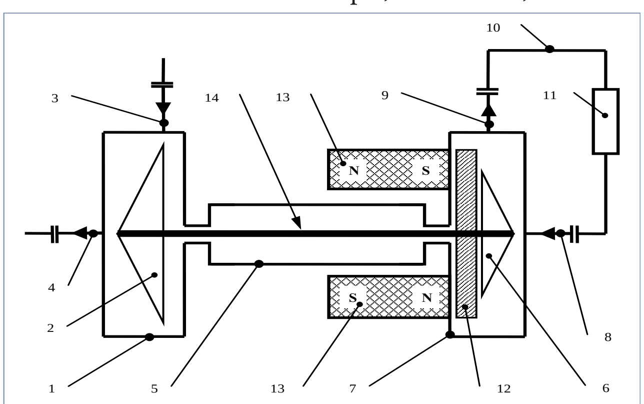

Figure 4. A scheme of the developed thermal generator (Option).

or copper alloys may be used as a conductive material. The disc 12 may be solid, in addition the disk 12 may be prefabricated, composed of several parts and these parts may differ in geometrical dimensions and the type of construction material used. The transmission 5 may include bearing supports to install the shaft 14 thereon and the sealing device to isolate the cavity with gas from the cavity with liquid heat transfer fluid (the sealing device is not shown in the figure).

Efficiency of the device for heating heat transfer fluid can be reduced when using the heat transfer fluid, the density of which may vary during operation, for example, when using gas-liquid mixtures as a heat transfer fluid. The known methods for step control do not allow maintaining a constant rotational speed of the turbine in this case. The conducted research also enables to solve the technical problem to improve the efficiency of the device for heating a heat transfer fluid using a heat transfer fluid, the density of which may vary during operation, for example, using gas-liquid mixtures as a heat transfer fluid. The magnetic system can be equipped with a device for infinitely variable control of the magnetic flux passing through the magnetic circuit. The magnetic circuit is usually designed for secure passing of magnetic flux through a special conductor with minimal losses; electrical engineering industry extensively uses the mutual dependence of the electrical and magnetic energy, their transfer from one state to another. The magnetic flux attenuation leads to the weakening of eddy currents, resulting in a torque reduction on the turbine shaft. The magnetic flux amplification leads to the increase in eddy currents, respectively, resulting in torque increase on the turbine shaft. Thereby infinitely variable control of the entire system is implemented. In this case the turbine can operate optimally, even though the density of heat transfer fluid flowing through the pump may vary from the liquid phase density to the gas phase density, when using gas-liquid mixture as a heat transfer fluid. At the same time constancy of the torque on the turbine shaft and constancy of the turbine shaft speed is ensured by means of the infinitely variable control: by adjusting the strength of the magnetic flux passing through the permanent magnets 13, through the disc 12.

Device for heating heat transfer fluid[1,2] operates as follows. It comprises a source of mechanical energy in the form of gas turbine, consisting of a turbine casing 1 and a turbine rotor 2. The turbine casing 1 is equipped with the inlet gas duct 3 and the out let gas duct 4. Compressed gas is fed to the inlet gas duct 3. In the turbine casing 1 the potential gas energy is converted to the kinetic energy, high-speed gas flow exerts power action on the turbine rotor 2, involving it into the rotational movement. Concurrently the kinetic gas energy is converted to the mechanical energy which is transmitted via the shaft 14 and transmission 5 to the pump impeller 6. The turbine rotor 2, pump impeller 6 and disk 12 made of conductive material are placed on the common shaft 14. The pump has an impeller 6, housing 7 with the inlet 8 and outlet 9 fluid ducts. The fluid ducts 8 and 9 are connected to an external closed-loop pipeline 10, filled with liquid heat transfer fluid. Water, oil or other service fluids applied in the heat supply systems and heat exchangers may be used as a liquid heat transfer fluid. The pump impeller 6 produces power action on the liquid heat transfer fluid and creates a flow of liquid heat transfer fluid. When rotating the disk 12 produces power action on the liquid heat transfer fluid by means of friction forces as in the known disc pumps. Part of the mechanical energy is thereby converted to the hydraulic energy providing circulation of the liquid heat transfer fluid. The flow is directed from the center of impeller 6 toward the outlet fluid duct 9, which is conditioned by the action of the centrifugal forces during rotation of fluid in inside pump casing 7. From the outlet fluid duct 9 the flow is discharged into the external closed-loop pipeline circuit 10, incorporating the thermal energy source 11. Then the flow is returned to the inlet fluid duct 8 and the cycle of liquid heat transfer fluid circulation is repeated. During such movement of liquid heat transfer fluid, as is known, hydraulic energy is converted to the thermal energy due to hydraulic losses of energy in the local hydraulic resistances and friction losses when liquid heat transfer fluid is moving the ducts of the external closed-loop pipeline circuit 10.

The pump impeller 6 comprises the disk 12 made of conductive material. Permanent magnets 13 are located in the pump casing 7 circumferentially, the magnets polarity alternating in the circumferential direction ensuring the possibility to induce eddy currents in the disk 12 made of conductive material. It is known that when a conductive body is moving through the magnetic field eddy currents are induced in the conductive body as such. Heating of the disk 12 made of conductive material is provided by the eddy currents. Magnetic system may also contain rotation bodies, cylindrical or spherical elements. Since the disk 12 is located inside the pump housing 7 filled with liquid heat transfer fluid, thermal energy is transmitted from the disk 12 to the liquid heat transfer fluid circulating along the external closed-loop pipeline circuit 10. In such a way, a part of the mechanical energy is converted to the thermal energy by means of eddy currents in the disk 12. This part of the operational process does not depend on the circulation mode of the liquid heat transfer fluid; accordingly, this part of the operational process is subject to the infinitely variable control, for example, by changing the number of constant magnets 13 or by varying the gap between the magnet13 and disk 12, as in the known magnetic systems for eddy current retarders within a known electrodynamic braking process. As is known, while solving the problem of the conductive body passage along the magnetic system, the main machine braking element is selected – a chain of permanent magnets with alternating polarity. When selecting the type of permanent magnets, the magnetic system adjustment is provided with regard to possible changes in the number of magnets in the system, and due to variations in the gaps when installing the magnets. It is also known that magnetic systems are used for converting the mechanical energy to the thermal energy, when a magnetic coupling is applied as a retarder. With the changes in pressure and gas flow in the turbine the rotation speed of the shaft 14 changes, as well as the torque on the shaft 14, in this case to maintain optimum operation mode of the gas turbine the operation mode of the pump and magnetic system should be also changed applying the control modes described above.

In the proposed technical solution[1,2] two methods for converting mechanical energy into thermal energy are used, they are a hydraulic method and an eddy current-based method (electrodynamic method). Using two processes that are different in nature it is possible to optimize the design of the device for heating a heat transfer fluid, enhance the ability to regulate this device, and increase, respectively, the operation efficiency changing the pressure and gas flow in the turbine.

The developed technical solution enables to improve the efficiency of the device for heating a heat transfer fluid with density which can be changed during operation, for example, when using gas-liquid mixtures as a heat transfer fluid. The gas-liquid mixture can be a mixture of water and steam, when using the claimed device in the water treatment systems or desalination plants. As another example, the gas-liquid mixture may be a mixture of liquid and gaseous hydrocarbons when conditioning and refining oil and gas.

Wider controlling opportunities contribute to the expanding the scope of effective application of the device for heating a heat transfer fluid. The application of technical solution developed gives the opportunities to reduce the weight and dimensions of the device for heating a heat transfer fluid, including decrease in the turbine and pump weight. The technical result is achieved by creating an improved design of the device for heating the heat transfer fluid, which enhances operation efficiency.

4. Discussion

The exploratory and applied research activities and experimental development for creation of advanced technologies and new equipment, including dynamic machines with looped blades[1-3,11]. New results have been obtained in testing turbine models with looped blades. One of the distinctive features of the developed turbine lies in the fact that working gas flow is directed along a plane that is perpendicular to the turbine rotation axis. In the known turbines, equipped with looped blades, the working gas flow is directed along the turbine rotation axis. Experiments with the models of looped blades allowed making interim conclusions about the possibilities of creating new vane machines with an axial or radial flow direction, with respect to the turbines, pumps, fans, and propellers. At the initial stage of research the most interesting quality of looped blades has been identified, it is high adaptability of such blades during their manufacture and operation, while maintaining the minimum turbine manufacturing costs. Looped blades can also be used in the development of technology and equipment for oil and gas production, where, as is known, the potential energy of compressed gas, supplied from a reservoir into the oil, gas and water gathering and processing system, is used as an alternative energy source[12-20]. Potential gas energy can be converted into another type of energy, including the thermal one, with the help of special gas turbines.

The thermal generator design described in the article is patented[1]. As opposed to the known technical solutions in this case two methods for converting mechanical energy into thermal energy are used: a hydraulic method and an eddy current-based method (electrodynamic method). The device for heating a heat transfer fluid comprises a source of mechanical energy in the form of the gas turbine, consisting of the turbine casing and rotor. Turbine casing is equipped with inlet and outlet gas ducts. The gas turbine is connected with the pump via transmission. The pump has an impeller and housing with inlet and outlet fluid ducts. The fluid ducts are connected to the external closed-loop pipeline, filled with liquid heat transfer fluid. The thermal energy consumer is included in the external closed-loop outer pipeline circuit. The pump impeller comprises a disc made of conducting material. The turbine rotor, pump impeller and the disk of conductive material are installed on the common shaft. The magnetic system consisting of permanent magnets is located on the pump housing, the magnets polarity alternating in the circumferential direction ensuring the possibility to induce eddy currents in the disk made of conductive material.

5. Conclusion

The research and development results confirmed the viability of the created new equipment for compressed gas energy recovery. Potential gas energy can be converted into the thermal or electrical energy using special gas turbines.

Looped blades were used in developing the new turbine. One of the distinctive features of the developed turbine lies in the fact that working gas flow is directed along a plane that is perpendicular to the turbine rotation axis.

The basic field of application for the created plant is associated with the production facilities of oil and gas industry. However, individual results can be used in other industries, for example, when creating machinery for sea and air transport, where weight reduction and improving the reliability of the equipment is particularly relevant.

At this stage of research and development activities a new thermal generator has been developed, which is equipped with a gas turbine and a heat transfer fluid circulation loop. In the developed technical solution two methods for converting mechanical energy into thermal energy are used: a hydraulic method and an eddy current-based method (electrodynamic method). Using two processes that are different in nature it is possible to optimize the design of the device for heating a heat transfer fluid, enhance the ability to control this device, and increase, respectively, the operation efficiency changing the pressure and gas flow in the turbine and changing the heat transfer fluid density with the increased temperature.

The obtained results bring about the opportunities for creating simpler and less expensive power plants operating by means of compressed gas energy for a wider power range – from a few kilowatts to several hundred kilowatts.

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