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TURBOSPHERE – MULTISTAGE MICRO TURBINE FOR SECONDARY ENERGY SOURCES RECOVERY

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ABSTRACT

The TurboSphere is a new type of micro turbine that recovers secondary energy sources. This innovative turbine performs the following tasks:

1) **Power generation from waste heat using the Organic Rankine Cycle (ORC);**
2) **Electricity production from low-potential fuel, such as trash and wood;**
3) **Recovery of natural gas overpressure at gas stations;**
4) **Conversion of steam overpressure energy into electricity during steam throttling, minimizing energy loss.**

The TurboSphere simultaneously combines several units, such as a turbine, a heat exchanger, and a power generator. It has only one blade wheel, and its multistage gas-flow expansion is performed by heating gas between the stages. The turbine's original design and concept allow for earlier implementation of complicated power cycles. Allowing the use of any type of steam or gas as a working fluid, this process creates a wide spectrum of input and output characteristics, including flow rate, pressure, and temperature.

Currently, the innovative project is at the prototype-creation stage. It was decided to concentrate on the application of TurboSphere as a turboexpander at natural gas letdown stations. Future works will describe other applications.

NOMENCLATURE

dT increment of temperature [˚K]
i enthalpy [kJ/kg]
p, p_1, p_2 pressure [MPa, bar]
s entropy [kJ/kg˚K]
v volume [m^3/kg]

INTRODUCTION

As fuel prices have risen, so has the need for energy efficiency and savings. The rational use of various types of energy can solve these problems. Optimal usage of primary fuel will create the opportunity to decrease negative environmental impact.

The best way to save energy is by using it multiple times. This means that energy with the highest temperature capabilities should be used first, which means that the optimal use of energy is in the following order:

1. for effective power (electrical or mechanical energy production);
2. for industrial process (drying, steaming, heating, etc.); and
3. for conditions creation (heating, ventilation, air conditioning).

One of the main directions in making primary-energy usage more efficient is co-generation. This means that if there is a constant consumer of thermal energy, it is advisable to create electricity generation based on this. The biggest and most constant consumers of thermal energy are industrial manufacturers (makers of construction materials, metallurgy, chemicals, etc.) [1].

While power plants can maximize energy production and reduce emissions through more efficient technologies, the situation is more complicated in heavy industry. Most manufacturers have focused their investments on creating industrial technology, while the optimization of energy supply has become underfunded. That means that independent research on the rational reutilization of waste energy has become even more important.

Every industrial process creates at least some waste heat or secondary energy sources. A rational solution is to recycle this industrial waste energy in the actual manufacturing process - regenerative usage. Likewise, this waste energy can be used as a secondary energy source, which consists of three main groups: gas overpressure, waste heat and combustible waste.

SECONDARY ENERGY SOURCES RECOVERY

Types of secondary energy sources

The main sources of waste heat are technological devices, which are typically energetically inefficient.

One potential secondary energy source is the overpressure that results from lowering natural-gas pressure to meet consumer specifications. In order to be transported through pipelines, natural gas has to have a very high pressure. At this level of pressure, however, it cannot be used by consumers, which means that it has to be forcibly lowered. This creates energy losses. Natural gas pressure is reduced in two steps. First, it is lowered at a gas-regulating station, where the pressure goes from a range of 3,5 – 7,5 MPa to a range of 0,3 – 1,2 MPa. Then, at gas control points, it is reduced to a range of 0,005 – 0,6 MPa. Water steam is treated similarly. Many industrial boilers produce steam with a pressure range of about 1,3 MPa. To make it usable, it needs to be at 0,3 – 0,6 MPa. The pressure has to be reduced through a throttling process.

Finally, combustible waste can be used directly as a fuel in other industries. Examples of combustible waste include metallurgy gases, liquid and solid fuel wastes from chemical, oil and gas industries, wood waste, etc.

Secondary energy sources recovery

Secondary energy sources can be recovered by using machines that convert energy streams into a more valuable energy form. Most frequently, the most useful forms are electrical and mechanical energy, due to their widespread use and the need for high exergy value. Low-grade thermal energy does not satisfy modern requirements. Frequently, the secondary energy sources produced by manufacturers significantly exceed their needs for low-temperature heat.

For this purpose, different types of machines can be applied: turbines, piston engines, screw engines, etc [2]. Each year, turbines are getting more popular in small-energy production. This is due to certain advantages, such as the direct transfer of torque to the electric generator, the small number of moving parts, etc.

Such technologies became popular with the practice of converting waste heat into electrical or mechanical energy through the use of substances that boil at low temperatures. These include carbohydrates (e.g. pentane or butane) and chlorofluorocarbons, among others. Traditionally, energy is converted through machines that follow the Organic Rankine Cycle (ORC) [3]. There are other cycles as well, such as the Kalina Cycle, which uses ammonium hydrate as a working fluid. The electric or mechanical energy generated via these processes then can be used directly to fulfill manufacturing needs.

Usage of the low power units

Turbines with a large capacity (several megawatts) are nowadays applied in industrial systems with large and continuous streams of secondary energy sources. In order to increase the number of possible sources of energy recovery, it is necessary to create low-power machines that can recover small amounts of energy streams with low-potential parameters.

This is made possible by microturbines, which expand the range of objects that allow secondary energy recovery. Existing steam and gas turbines have some disadvantages. It is necessary to improve microturbine designs to make them viable energy recovery machines, while simultaneously increasing the efficiency of the transformations.

Existing expansion turbines for natural gas overpressure recovery have two main directions of development. The first type is mostly produced in western countries and has several main features: one radial wheel, single stage, electromagnetic or air bearings, big velocity (20 000 -96 000 rpm). [4, 5].

The second type has some other features: one axial blade, single stage, ball bearings and velocity is about 3000 rpm. Such turbines were designed in Ukraine, Czech Republic and Russia [6-8]. These turbines have smaller efficiency but their purpose is supplying natural gas let down stations with electricity for own needs.

The process of converting overpressure energy into electricity

To understand how to improve and adapt microturbines, it is necessary to understand secondary-energy-source recovery systems. Let us consider the recovery of natural gas overpressure in more detail.

The transformation of the compressed gas energy into work along the adiabatic expansion is accompanied by a decrease in gas temperature – each 0,1 MPa lowers temperature by about 10˚C. At low temperatures, some components of the natural gas mixture change their aggregative state into liquid or solid phases. Heavy hydrocarbons, such as propane and butane, in accordance with the equilibrium isotherm partially liquefy. The result is a mix – a snowy mass, which has a negative impact on the flow passage of the turbine. On the one hand, it increases the irreversible losses by changing the geometry of the guided vane. On the other hand, it reduces the reliability of the unit because of the possibility of accelerated destruction of rotor blades. In addition, natural gas must come to the consumer at a temperature no lower than 5˚C, so it must be heated before or after the turboexpander. Under the existing system, units do not heat the gas because the efficiency is pretty low, or the gas is heated by water at a temperature of 70 – 130˚C. In the latter case, there can be problems with the heating source at a certain temperature [9]. For example if natural gas let down stations is located far away from a town, factory or plant.

Figure 1 shows the various processes of expansion in the PV-diagram, where technical work is represented by the shaded area. Apparently, the multistage expansion allows for the closest approach to the isothermal process, which has the greatest process work. The degree of approximation depends on the number of stages in the turbine.

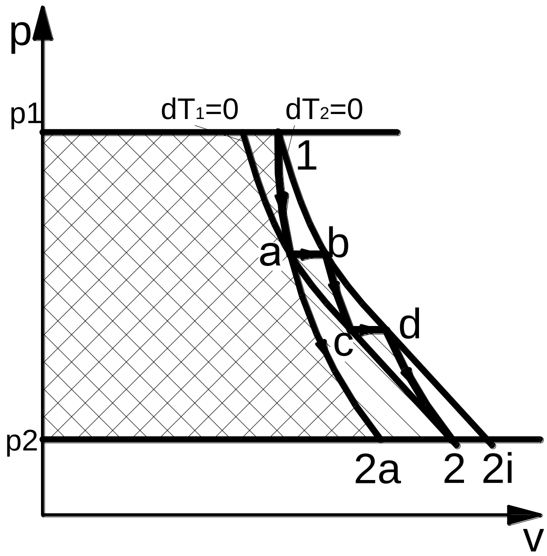

Fig. 1 - The process of ideal gas expansion

1-2a – adiabatic, 1-2i – isothermal, 1-a-b-c-d-2 – multistage.

Heat reduction is proportional to the number of stages of expansion, because it occurs at every stage. Consequently, the energy of the heating process decreases before the beginning of the next stage (Figure 2). It is becoming possible to use cold water, or other low-grade steam, as a heating source. Water from heating system of letdown station, water from heat pumps, industry waste water etc. could be used as a heating source. This is an interesting possibility, but it is complicated by the low temperature potential.

In the past, we have used cheap and reliable units – pressure regulators based on a throttling process with corresponding exergy losses. It is known that the enthalpy of the start and end points of the throttling process is the same, but the course of the irreversible process is unknown. It is depicted in the diagram with the dashed line, labeled i = const.

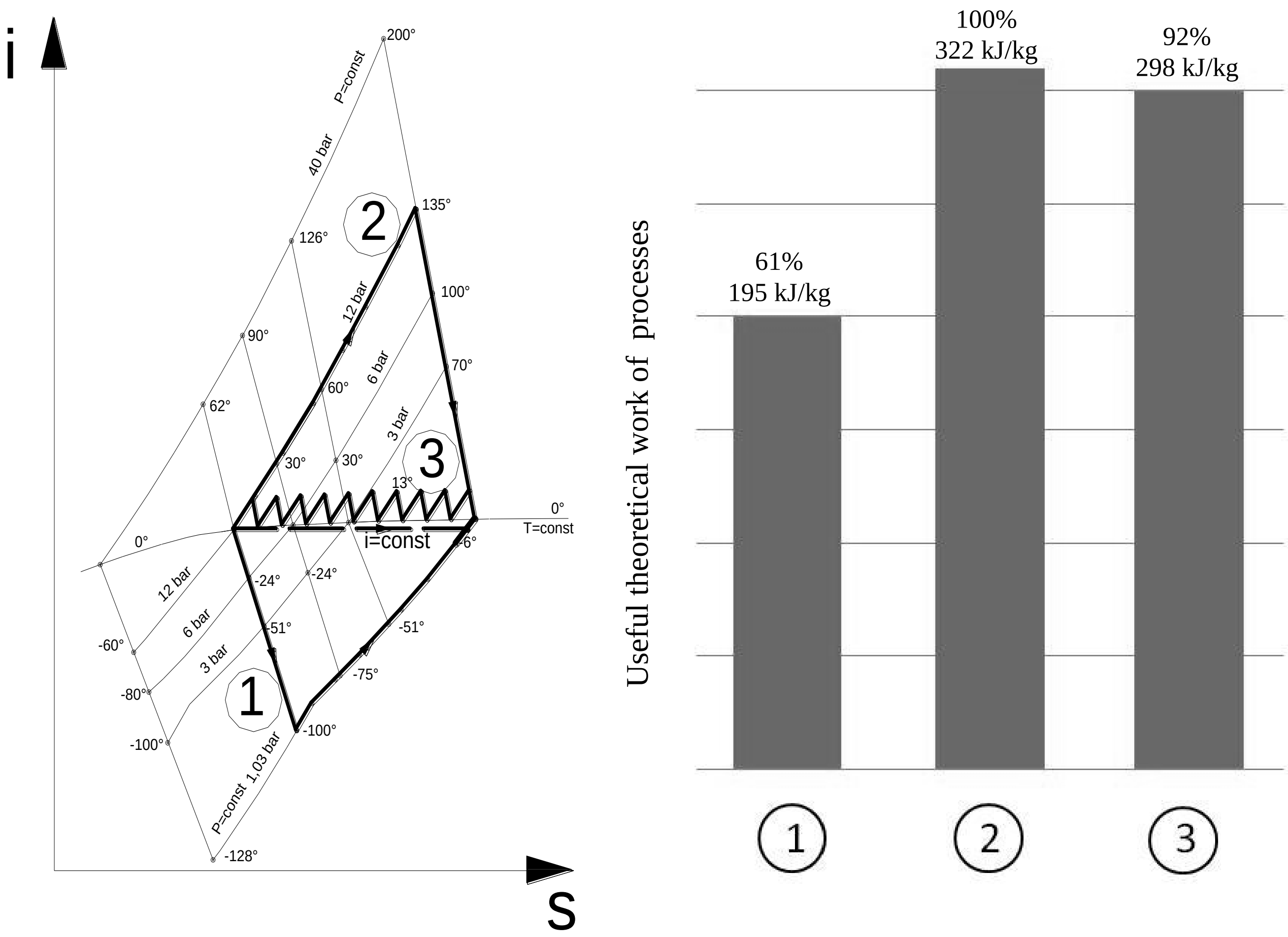

Fig. 2 – expansion processes on the i-s methane diagram and its efficiency

1 – single-stage expansion with subsequent heating, 2 – single-stage heating with expansion 3 – multistage expansion with intermediate heating between stages.

The work of the adiabatic process in the diagram is represented by the projection on the vertical axis. In the case of multistage expansion of the stream consisting of a set of isobaric and adiabatic processes, it is defined by the sum of heat drops at each stage. The second option for implementing this set of processes has the greatest work expansion (Fig. 2, right), which is associated with an increase in the initial temperature. To implement it, however, a high-temperature heating stream is required. The first option for implementing the same set of processes allows the use of heat transfer at relatively low temperatures, but it is characterized by smaller work. On the figure presented theoretical calculation based on is-methane diagram.

To eliminate the disadvantages of both of these options, we should consider the multistage expansion with an intermediate heat supply after each step (the third option), which makes the process closer to isothermal and increases the useful work. In this case, heat drops at each stage, and the required grade of heating process reduces in proportion to the number of stages of the expansion. Therefore, it is possible to use a low-grade heating source. However, the cost and space required for the recovery unit will increase rapidly.

A multistage design with several expanding machines and heat exchangers is possible, but it is complicated and very expensive. Atlas Copco Inc. implemented such a scheme by using two to six turbines (compressors) and the same number of heat exchangers in between. The high-speed radial wheel of each turbine rotates a common shaft of the gear, which, in turn, then rotates an electric generator. The unit capacity is from 500 to 20.000 m^3/h [10].

Microturbines with one blade wheel are the most practical, so they present the most interest. Such turbines can be axial or radial. A radial turbine that has a blade wheel with a small diameter has a much higher velocity, which makes it more complicated to produce and to connect to the low-speed generator. Axial microturbines have a low-velocity wheel, and it is rational to use a partial supply of working fluid. A few examples of this concept exist. Curtis, an American engineer, designed a single-wheel axial turbine with speed stages. Likewise, the Kinast turbine allows for the same amount of steam to flow through the blade wheel three times in a row.

Based on the foregoing, the most rational option is the design of microturbines with one blade wheel, several stages of expansion, and gas heating between stages. That was the reason for developing a new type of microturbine, which we have called the TurboSphere.

TURBOSPHERE – MULTISTAGE MICRO TURBINE FOR SECONDARY ENERGY SOURCES RECOVERY

The TurboSphere simultaneously combines several units, such as a turbine, a heat exchanger, and a power generator. It has only one blade wheel, and its multistage gas-flow expansion is performed by heating gas between stages.

Heat flow occurs repeatedly, in accordance with the number of stages of expansion, while it moves from one sector to another. The gas flows in a circular spiral inside the channels that form a spherical surface. The channels are formed by rows of curved tubes of appropriate diameter, and the heating liquid moves between the tubes.

The TurboSphere (Fig. 3) consists of a detachable outer frame (1), one wheel (2) with blades (3), allowing the gas to move alternately from both sides of the wheel through the set of nozzles and confusers (4) located on both sides of the wheel. The blade wheel is provided with labyrinth sealing. Gas channels (5, 6) encircle the inner spherical case (7).

The gas stream enters the TurboSphere through the pipeline (8), passes through the first-stage nozzles, and then goes into the blade wheel and enters the gas tubes (5). From there, it flows to the second-stage nozzles on the opposite side of the wheel. After passing the second-stage nozzles, it goes through the gas tubes (6) and then enters the third stage, and so on. Sequentially, it moves a few steps through the channels until it reaches the desired final pressure, and then it leaves the turbine through the pipeline (9). The gas stream moves on a spherical spiral through various channels, combined into a sphere. This way, a single blade wheel performs a multistage stream expansion, which is made possible by the partial supply and two-way stream flow. It is getting possible because of symmetric blades. On one half of the wheel there is gas moves from the nozzle through the blades in one direction, and in the second half of the wheel - in the opposite direction. The maximum amount of stages in TurboSphere is thirty. Modern microturbines do not exceed five stages.

In the TurboSphere, the working fluid is heated between stages. Working fluid moves within the channels, and heating liquid enters through the pipe (10) to the annular space between channels and heats the expansion stream. The cooled liquid is drained through the pipes (11).

The TurboSphere is supplied by an automatic control system (12), which allows it to change the number of expansion stages in the turbine. The automatic control system controls the drops in pressure, mass flow, and temperatures of the working and heating fluids.

The power generator (13) is located within the TurboSphere. The blade wheel has direct flange connections to the rotor. The TurboSphere's hermetically enclosed frame permits the use of flammable gases as a working fluid. The electrical output (14) of the generator does not disturb the leakproof nature of the TurboSphere.

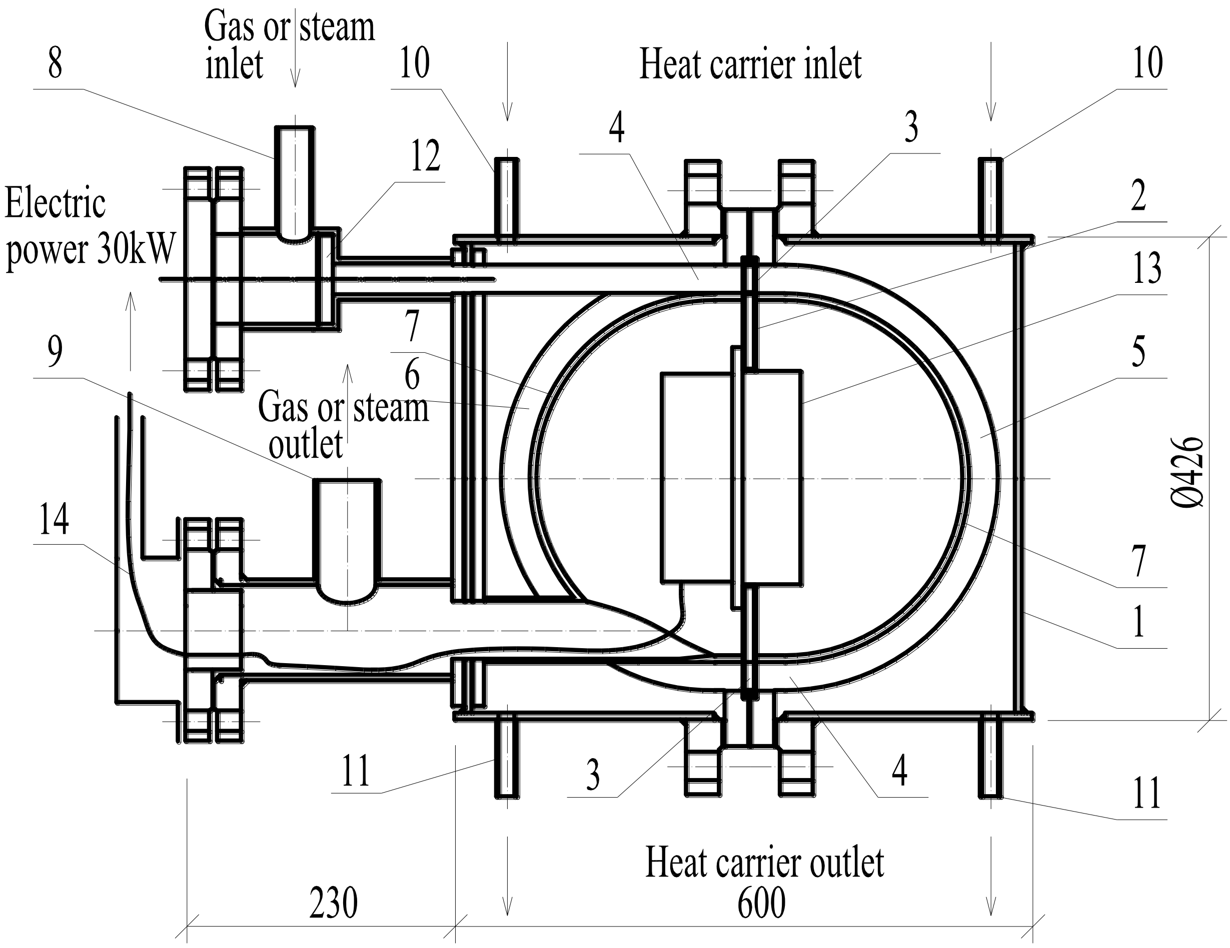

Figure 3 - Schematic diagram of the TurboSphere

The TurboSphere can be applied as a turbo engine for fans and other devices. For this reason the shaft will be outside of the turbine.

The electrical power of the turbines ranges from 5 kW to 500kW, depending on the characteristics of the energy sources. The TurboSphere is a compact machine (figure 4), with only one moving part - a blade wheel with a diameter from 300 mm to 700 mm. This blade wheel's rotational velocity can reach 3000 rpm or more. It requires neither a high-velocity electric generator nor a reduction gear. Its dimensions allow for the TurboSphere to be placed indoors or outdoors.

The main technical features of the TurboSphere's prototype are presented in the table 1.

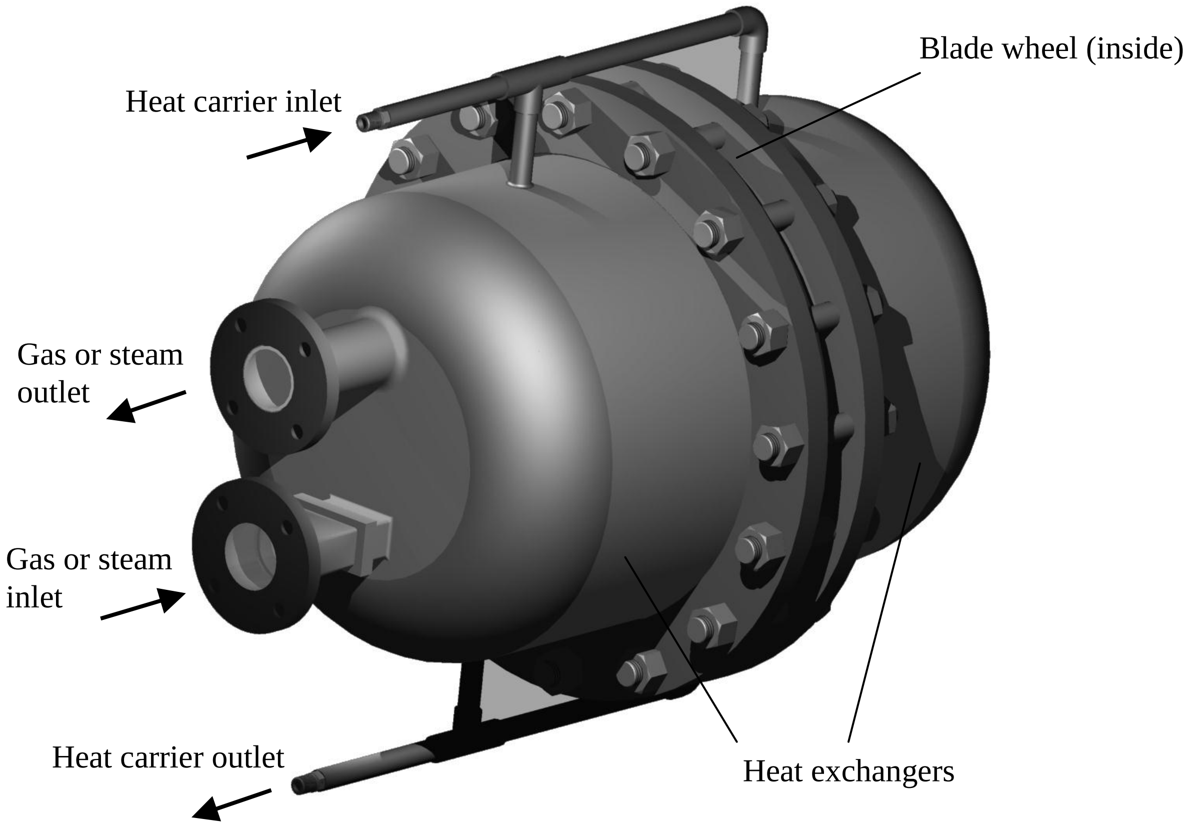

Figure 4 – 3D diagram of the TurboSphere

Table 1 - Theoretical feature of the TurboSphere prototype

Electric power	kW	3,7	9,8	18,0	30,5	44,2
Velocity	rpm	3000				
Number of expansion stages	-	10				
Axial blade wheel diameter	mm	300				
Voltage	V	380				
Frequency	Hz	50				
Size	mm	600x600x600				
Weight aprox.	kg	300				
Working fluid:		air				
- Mass flow	kg/s	0,09	0,24	0,44	0,74	1,08
- Inlet pressure	MPa	0,16	0,6	1,2	2,1	3,1
- Inlet temperature	^oC	20	20	20	20	20
- Outlet pressure	MPa	0,005	0,18	0,43	0,8	1,2
- Outlet temperature	^oC	7	0	0	0,2	1
- Outlet temperature (without heating)	^oC	-16	-16,5	-16	-16	-16
- Pressure losses in the heatexchanger	%	18	17	17	16	16
Heating liquid	-	water				
- Mass flow	kg/s	0,4	0,4	0,4	0,6	0,6
- Inlet temperature	^oC	20	30	40	45	60
- Outlet temperature	^oC	15	17	16	18	18

The turbine's original design and concept allow for earlier implementation of complicated power cycles. Allowing the use of any type of steam or gas as a working fluid, this process creates a wide spectrum of input and output characteristics, including flow rate, pressure, and temperature.

This innovative turbine performs the following tasks:

1 Power generation from waste heat using the Organic Rankine Cycle (ORC);

2 Electricity production from low-potential fuel, such as trash and wood;

3 Recovery of natural gas overpressure at gas stations;

4 Conversion of steam overpressure energy into electricity during steam throttling, minimizing energy loss [11-13].

It is possible to integrate the TurboSphere into sources of alternative energy, such as geothermal and solar energy.

The energy market requires small, cheap, and highly efficient micro turbines for the recovery of secondary energy sources. In addition to having these traits, the versatile TurboSphere will be compatible with a wide range of energy sources and their necessary parameters.

CONCLUSIONS

It is important to aspire to use all energy sources rationally. One of the most available sources of "free energy" could be found in of secondary energy.

Through the use of suitable overpressure turbines, called turboexpanders, it becomes possible to take advantage of overpressure energy sources. The turbine units that currently exist are large. Many consumers need microturbines, capable of operating with low flow rates and low-grade energy sources. Existing units have certain disadvantages that limit their utility.

Through a new look at turbomachinery, the TurboSphere is designed to eliminate these disadvantages. The main difference of the TurboSphere is the minimization of the gap between the adiabatic expansion and the isothermal process, due to the large number of stages of expansion and the heating between stages. This process is performed on a single blade wheel in one unit, which combines a turbine, a heat exchanger and an electric generator simultaneously. Microturbine units will increase the energy efficiency of industrial manufacturers and will reduce the consumption of primary fuels.

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REFERENCES

1 B. Khrustalev, V. Sednin, and others; Ed. prof. A. Nesenchuk. Systems of production and distribution of energy industry, Part 1, Minsk "Tehnoprint", 2005.

2 Energyland [electronic resource]. - 2012. - Mode of access: http://energyland.info/analitic-show-65723 - Date of access: 16.03.2012.

3 An Overview of Industrial Waste Heat Recovery Technologies for Moderate Temperatures Less Than 1000ºF / Carolyn J. Roos, 2009 – Access mode: http://www.chpcenternw.org/– Access date: 13.10.2011.

4 H. Bloch, C. Soares. Turboexpanders and Process Applications. Gulf Professional Publishing, 2001.

5 Gas expansion turbines, Turboexpander MTG // RMG Regel + Messtechnik GmbH [electronic resource]. - 2007. - Mode of access: http://www.rmg.com/en/rmg-products/expansion-turbines/mtg-radial-turbine.html - Date of access: 19.10.2011.

6 Utilizing energy turboexpander units «Turbogaz», Kharkov, Ukraine [electronic resource]. – 2008. – Mode of access: http://www.turbogaz.com.ua/equipment/turbodetandr/utdu.html – Date of access: 21.01.2009.

7 Turboexpander "Gazelektropribor", Kharkov, Ukraine [electronic resource]. – 2005. – Mode of access: http://www.gep.com.ua/turbo.htm – Date of access: 12.06.2008.

8 Turboexpander "Gascontrol", Czech Republic [electronic resource]. – 2007. – Mode of access: http://www.gascontrol.cz/ru/produkty/expanzni-turbina.html – Date of access: 15.02.2009.

9 K. Levkov. Energy-saving potential of the natural gas stream // Research and development in the field of engineering, energy and - IX International Scientific Conference of students, masters and PhD students, p.414-417, Gomel GGTU, 2009.

10 Atlas Copco Gas and Process Solutions // company Atlas Copco [electronic resource]. - 2011. - Mode of access: http://www.atlascopco-gap.com/download_file.php?id=323 - Date of access: 11.10.2011.

11 K. Levkov. Conversion of low grade energy sources into electricity. Belarusian-German seminar. «Scientific and technical cooperation and technology transfer in the sphere of power efficiency and waste processing». Minsk, 2012.

12 K. Levkov. Research and development high efficient microturbine units for secondary energy sources recovery. Russia-Belarus-Skolkovo: united innovative space: Minsk, 2012.

13 K. Levkov. «TurboSphere» –multistage micro turbine for secondary energy sources recovery / «TurboPower» conference, «Volvo Aero» Trollhatten, Sweden, 2012.