Multi-fuel mini power plant with low-boiling working body based on Tverskoy rotary steam engine

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Abstract. The article presents the results of the development of a multi-fuel mini-power plant with a low-boiling working body based on a rotary steam engine. The description of the structural scheme, design, operating modes, simulation model in MATLAB-SIMULINK are given. The mini-power plant works with both any type of fuel as well as low-potential sources of thermal energy, including thermal solar radiation.

Introduction

Russia is a very huge country with low population density that is why at the moment there is no single centralized power supply system which has united all settlements. Electric power transporting to end-users along these territories is economically unprofitable and technically difficult to implement. Electric power supply of consumers in these territories is provided by autonomous diesel power stations. Delivery of fuel to the remote regions can be also difficult. But all regions have a significant amount of local vegetable fuel which could and should be used for the production of heat and electricity.

This is even more relevant for northern and taiga regions of Russia because of the huge domestic, wood and industrial wastes those rotting is followed by emission of methane and other harmful elements. The environmentally harmful effect degree of methane to the atmosphere is 30 times greater than that of carbon dioxide [1]. The use of these wastes as a fuel for autonomous electrical installations with external heat supply allows solving several problems at once: to utilize waste, to receive electric and thermal energy.

Multi-fuel mini-power plant

The idea of creating cluster and celled systems for the production of electrical and thermal energy implies that large number of remoted energy consumers produce thermal and electric energy for their own needs from local fuels using individual low-power units. This approach leads to a reduction in the number and length of power lines and heating mains, and to reduce energy losses due to the maximum approach of generating units to consumers.

Small local power generation based on the local fuels is one of the alternative ways to power supply of the cottage, country houses and farms.

The idea of small power generation is based on the availability of local fuels, the ability to get electricity anywhere, with the utmost ease of operation, to exclude significant costs for the construction and operation of power lines.
In general, the production and use of power plants running on solid fuel such as firewood or any other fuel, is worthy of attention. An autonomous power plant using any kind of fuel is called a multi-fuel with an external supply of heat.

Multi-fuel power plants use several technologies to generate electricity. The traditional technology is the production of high-pressure steam with subsequent conversion to mechanical energy of the steam expansion machine rotation which shaft is connected with the electric generator.

As thermal expansion machines are used: standard steam turbines, screw turbines, Tesla turbines, axial turbines, rotary-lobed, rotary and steam piston machines, as well as a number of their modifications. Every listed machine class has its own specific features in both design and operation modes. So steam turbines (especially small ones) have a significant disadvantage. Their effective operation is provided only at limits of rotational speeds tens or even hundreds thousands of revolutions per minute. Under the reduction their weight and size the specific power is reduced, the efficiency falls. While the high cost of production and high speed of the main shaft (the need for a reducer) remain. That is why in the field of capacities up to 100 kW, an efficient steam turbine in all parameters is almost impossible to find.

Steam piston machines have a complex design, a large number of friction parts.

Rotational machines are free from these disadvantages. Indicators characterizing the use of energy vapor pressure of the working fluid, metal consumption and performance, in rotary engines are significantly better than others.

Among the class of rotary machines, a special place is occupied by Tverskoy rotary steam engine [2] that has a powerful torque from the smallest revolutions. The engine is able to work efficiently with an average speed of the main shaft (from 1000 to 3000 rpm) at rated load, which makes it possible to carry out autonomous low-power generator units without a reducer and inverter. Autonomous electrical units based on this engine allow generating electricity with the necessary parameters of 50 Hz ± 2% and 380/220 V ± 10%. While an output voltage has pure sine wave form.

Such autonomous electrical units are able to receive electricity and heat energy with minimal energy costs, even in places where there is no supply of power networks at all.

Figure 1. Structural scheme of an experimental multi-fuel mini power plant with low-boiling working body based on Tverskoy rotary steam engine.

The mini power plant consists of 2 main modules: 1. Module of steam generating unit.
2. Rotary-generator module.
In the general cycle of the rotary steam engine operation, it is possible to single out the main working processes as filling, expanding and expelling the vapors of the working body from the working area.

A working body in electrical units with external supply of heat is water or low-boiling substances (for example, Freon gases).

Many researchers around the world have come to the conclusion that the ORC (Organic Rankine cycle) systems with a low boiling working body are effective in converting low-grade heat into useful work and recently this class of plants has been widely studied and applied in many fields [3–9].

Figure 2. Simulation model of the mini power plant in Matlab
The structural scheme of an experimental multi-fuel mini power plant with low-boiling working body based on Tverskoy rotary steam engine is shown in figure 1. The main blocks of the mini power plant are a combustion chamber with a heat exchanger, a steam generator (hot heat exchanger), a hot gas flap with an electric drive, a safety valve, a rotor-bladed expansion machine (Tverskoy rotary steam engine), an electric generator, a rectifier, a fan, a chimney, a freon vapor condenser with a fan, a low boiling point coolant receiver, feeding pump, solenoid valve and controller. Besides, the scheme includes: a gas flap position sensor from the combustion chamber, pressure and temperature sensors at the inlet and outlet of the rotor-bladed

Figure 3. Dependence of the torque on the spindle the rotor-bladed expansion machine on the rotational speed and vapor pressure.

Figure 4. Experimental sample of the multi-fuel mini power plant on low-boiling working body with the rotor-bladed expansion machine.
expansion machine, a voltage sensor at the generator terminals, an airflow sensor in the condenser heat exchanger, and a combustion sensor, safety valve triggering sensor. An important feature of a multi-fuel power plant is the need to maintain a constant correspondence between the electrical load and the amount of thermal energy supplied to the working body (Freon gas) necessary for its supply. In the scheme the amount of heat energy supplied to the working body is regulated by means of a damper regulating the amount of flue gases (figure 1, blocks 1,2) supplied to the hot heat exchanger. The mass flow of the working body is regulated by an electric feeding pump and an solenoid valve.

The operation of all mini-power plant systems is controlled by the digital control block in accordance with the programmed algorithms for performing logical operations.

To study the operation modes of an autonomous power plant for an active load and when charging a battery, a simulation model was created in the MATLAB-SIMULINK (figure 2). The rotor-bladed expansion machine is modeled by a set of characteristics that reflect the dependence of the developed shaft torque on the rotation speed. Characteristics are given as a functions depending on two arguments (figure 3). Electric generator block with load is made in the form of standard elements.

Figure 4 presents an experimental model of a multi-fuel mini power plant with a low-boiling working body and a rotor-bladed expansion machine, on which operating modes are investigated.

The generator is a permanent magnet synchronous generator. The three-phase output voltage is rectified and applied to the load. Using a rectified voltage allows to connect a single-phase load and evenly load three phases of the generator. The load is 12 incandescent bulbs of 95 watts. Each lamp is switched on by a separate switch. The values of the output voltage and current are monitored by measuring devices. The steam pressures before and after the rotor-bladed expansion machine are also monitored.

Figure 5 shows the calculated graphs of the output power of an autonomous mini power plant at a different rotational speed of the spindle the rotor-bladed expansion machine and different parameters of the vapor pressure of the low-boiling working body.

![Figure 5. Graphs of the output power at different shaft speeds of the the spindle the rotor-bladed expansion machine and at different parameters of the vapor pressure of the low-boiling working body.](image-url)
Graphs of power, output voltage and load current, depending on the magnitude of its resistance (an operating pressure of Freon gases is 7 atmospheres) are shown in figure 6.

**Conclusion**

A multi-fuel mini power plant based on a low-boiling working body solves several problems: firstly, it gives an possibility to get electricity almost anywhere from any kind of fuel; secondly, while it is a source of heat for cooking or heating the home; thirdly, it allows to recycle woods and others waste.

Summing up we can confidently say that autonomous mini power plant with low-boiling working body based on Tverskoy rotary steam engine will be quite effective in their simple construction and cost affordability; and it can get the widest distribution.

**References**

[1] Greenhouse effect [https://en.wikipedia.org/wiki/Greenhouse_effect](https://en.wikipedia.org/wiki/Greenhouse_effect)

[2] Tverskoy rotary steam engine [http://www.rotor-motor.ru/page06.htm](http://www.rotor-motor.ru/page06.htm)

[3] Sapozhnikov M B and Timoshenko N I 2005 The marginal efficiency of power plants on low-boiling working bodies *Heat and power engineering* vol 4 p 68

[4] Grinman M I and Fomin V A 2009 Prospects for the use of power plants with low-boiling working bodies *Collection of reports All-Russian Power Engineering Conf. of Reconstruction of Energy* – 2009 (Moscow: Open Company Intehekspo) pp 27–30

[5] Bukholdin Yu S, Zinchenko Yu, Levashov V A and Sidorenko D 2008 Low-temperature radial-axial turbine for the utilization power plant *Gas Turbine Technologies* 3 14–18

[6] Grinman M I and Fomin V A 2006 Prospects for the use of low-power power plants with low-boiling working bodies *Power Engineering* 1 63–69

[7] Bileka B, Vasiliev E, Kabkov V, Izbash V, Kolomeev V and Kostenko D 2002 Recycling of waste heat of GPU in power plants with low-boiling working bodies *Gas Turbine Technologies* 5 6–10

[8] Ogurechnikov L A 2007 Combined generation of electrical and thermal energy in low-temperature binary power plants *International Scientific Journal for Alternative Energy and Ecology* 5 (47) 68–72

[9] Sukhotin A M, Semerikova I A, Moskvicheva V N and Petin Yu M 1973 *Use of Freons in Power Plants* ed V N Moskvicheva (Novosibirsk: Institute of Thermal Physics) pp 4–28