Energy efficient technology of waste management by micro-cogeneration

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Abstract: The paper considers possible options for energy-efficient waste management technologies using micro-cogeneration. A typology of energy technologies with micro-cogeneration is proposed depending on the main method of disposal, type of reactor, products of the implementation of the main recycling process, as well as processes and equipment of micro cogeneration technology. A brief overview of the current market situation and trends in the development of energy technologies for waste management is presented. The proposed typology and block diagram can be used in choosing rational energy-efficient technologies for waste management.

1. Introduction

In the process of human life, a large amount of production and consumption waste is generated. After preliminary sorting, non-recyclable waste is mainly disposed of at special landfills, which are complex environmental protection structures that protect the atmosphere, soil, surface and ground waters. Landfills and supporting infrastructure require large capital investment at the construction stage, occupy territories that are being withdrawn from land use and subsequently require large restoration costs.

In this regard, nowadays various methods of local waste treatment are used: thermal oxidation or neutralization, gasification, pyrolysis, anaerobic fermentation of organic waste [1], the products of which have a certain energy resource and can be used by means of cogeneration technologies to produce electrical and heat energy, and, if necessary, cold within three-generation technologies.

Due to this, the consumption of fossil fuel resources, whose reserves are not infinite and located in hard-to-reach areas, is reduced, environmental pollution by products of their use, in particular, CO2 emissions, is reduced also. In the “Energy Strategy of Russia for the Period until 2035”, solid municipal waste is assigned to important regional types of fuel resources.

The purpose of the paper is to consider possible options for energy-efficient waste management technologies using micro cogeneration and propose their typology and block diagram, which can be useful for choosing rational waste management schemes.

2. Materials and methods

As the main method for finding the rational options for waste management by micro turbine technologies the authors used creation of its typology, based on the literature review. The typology
was proposed depending on the main method of treatment, type of reactor, products of the implementation of the main treatment process, as well as processes and equipment of micro cogeneration technology (table 1).

Table 1. Energy efficient waste management technologies based on cogeneration

| Treatment method                | Type of reactor                        | Process Products                          | Cogeneration technologies for heat recovery                                                                 |
|--------------------------------|----------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Thermal oxidation (fire neutralization, burning) | Layered, chamber, rotary drum furnaces, furnace devices, cyclone reactors | High temperature flue gases (800–1200°C), ash | Steam boiler, steam engine (steam piston engine, steam screw machine, steam turbine); ORC technology with micro turbines; Hot-water, thermo-oil boiler, thermoelectric generator; Air turbine and gas turbine with reverse sequence technology processes. |
| Gasification                   | Gasgenerators                          | Generator gas with a calorific value of 3.5-6.5-16MJ/m³, ash (slag) | Gas piston, gas turbine engines with heat recovery of flue gases                                           |
| Pyrolysis                      | Pyrolysis Reactors                     | Pyrolysis gas with a calorific value of 15-22 MJ/m³, solid coke residue with a calorific value of up to 30 MJ/kg | Gas piston, gas turbine engines with heat recovery of flue gases                                           |
| Anaerobic Organic Waste Fermentation | Bioreactor                       | Biogas with a calorific value of about 22MJ/m³, fertilizers | Gas piston, gas turbine engines with heat recovery of flue gases                                           |

Considering the suggested typology resulted in creating the block diagram, which can be useful for choosing rational waste management schemes based on cogeneration.

3. Results and discussion
During thermo-oxidative neutralization of waste to ensure their high-quality combustion, the process temperature is maintained at the level of 900 - 1200 °C [1]. In this case, a high temperature flue gas is formed containing solid fly ash particles. Heat generated by cooling to a temperature acceptable for gas purification and removal systems (depending on the purification technology from 300 to 120 °C) can be useful in a steam boiler (PC) for producing saturated or superheated steam. The resulting water vapor enters the steam engine (PD), where, expanding, it performs the work used to drive the electric generator. Wastewater vapors enter the heat consumer. The flow rate and parameters of water vapor
depend on the thermal power of the thermal oxidative neutralization system, power, heat consumption
regimes and type of steam engine (Figure 1).

Wet-steam microturbines with a power of 5 - 30 kW and energy complexes developed on their
basis by the Don Production Technologies Enterprise are quite interesting for use [7].

Figure 1. Structural diagram of possible energy-efficient waste disposal technologies
R - reactor, where the main methods of waste disposal are carried out (burning, gasification, pyrolysis,
aerobic fermentation of organic waste); SB - steam boiler; HW, TOB - hot-water, thermo-oil boiler;
SE - steam engine (steam piston engine, steam screw machine, steam turbine); OCR - Renken organic
cycle technologies; TG - thermoelectric generator; GPE, GTE - gas piston and gas turbine engines;
HR - heat recovery system; E - electric energy; Q - thermal energy

Research in the field of their application in the conditions of a mini-thermal power plant and the
development of a more compact and advanced design are carried out by the joint research group
Promteploenergetika of the Moscow Aviation Institute, the All-Russian Research Institute of
Electrification Agriculture, Royal College of Space Engineering and Technology [3]. Operational
experience of steam piston engines [5] indicates the reliability of their operation on wet saturated
steam at moderate speeds of rotation (up to 3000 rpm), stability of operation with fluctuations in steam
parameters and the appropriateness of their use at low powers.

When working on saturated water vapor at a steam flow rate of 3.6 tons of steam or more, it is also
advisable to use steam screw machines [6]. Research and development conducted by Eco-Energy
CJSC and Peter the Great University show that when steam pressure is triggered 0.3 - 0.6 MPa and
steam consumption is 6-50 t/h using a steam screw machine, one can get an electric power of 200 -
1500 kW [2,6].

If there is no need for water vapor, the heat of cooling of the flue gases can be used advantageously
in a hot water boiler (WB) to produce hot water, the required parameters, or in a thermo-oil boiler
(TOB) for heating thermal oil. The useful heat obtained in this case can be used in cogeneration using
ORC - technologies that implement the Renken thermodynamic cycle on organic liquids boiling at
lower temperatures compared to water [8,9,10]. Infinity Turbine developed microturbines operating on
organic working fluids with an electric power of 2 kW or more [9]. CALNETIX [10] developed the
TGX100 steam turbine power plant with an electric power of 125 kW, operating on the R245 FA
working fluid. At the same time, to obtain an electric power of 125 kW, 750 kW of heat in the form of
hot water at a temperature of 110 °C are required.
When using a thermal oil boiler, hot oil with a temperature of 280–300 °C can be supplied to the thermoelectric generator modules to generate electrical energy [11]. Such a system was introduced at the Bio Kibor power plant with an electric power of 5 kW to 1 MW produced by the KIBOR plant.

Also, air turbines and gas turbines with the reverse order of processes, technological schemes, the analysis of energy and environmental efficiency of which we described earlier, can be used to utilize the heat of cooling of flue gases [12].

In the process of gasification of organic waste in the reactor (P), combustible gas [13] and a solid residue are obtained. The composition of the generator gas depends on the type of gasified waste and the gasification method, the heat of combustion can reach 3.5–6.5-16 MJ/m3. Generator gas can be burned in boiler furnaces to produce water vapor or hot water, or in gas reciprocating, gas turbine engines to produce electrical energy. [13,14,15,16,17,18]. The gas energy complexes include a gas generator, a gas treatment system, and a gas reciprocating or gas turbine power plant with heat recovery devices. The gas-generating energy complexes GEC - 001 - GEC -1 are proposed, operating on wood, briquetted organic waste with a moisture content of 6 to 20%, based on gas piston engines with an electric power of 3 to 350 kW and a thermal power of 100 to 1000 kW, a waste flow rate of 4 up to 400 kg / h, generator gas from 13 to 1300 m3/h [16]. CATERPILLAR manufactures gas-piston power plants with electric power from 70 to 6520 kW [14]. GEIbenbacher gas piston power plants can run on heavy types of gaseous fuels (associated petroleum gas, biogas, pyrolysis gas, etc.). Their electric power ranges from 330 to 4034 kW, respectively, thermal power from 363 to 3634 kW [15]. In MSTU under the name of N.E. Bauman a gas-turbine energy converter with the production of electric energy was developed for an installation for utilization of solid household and industrial wastes of an unconventional scheme that does not require the purification of gases from solid particles in front of a turbine that runs on clean high-temperature air heated in a gas-air heater by the products of combustion of generator gas [17].

Using gas microturbines Capstone electric power from 30 to 200 kW [18]. In cogeneration mode, in addition to electricity, heat can be obtained with a capacity of 84.7 to 394.5 kW. To do this, they must be equipped with devices that utilize the heat of flue gases. Capstone microturbines can run on gaseous fuels with a calorific value of 10,475 kJ/m3 (biogas, low-calorie gases).

When disposing of waste by the pyrolysis method, it is generally possible to obtain heating oil, pyrocarbon, and pyrolysis gas [19, 20]. Moreover, pyrocarbon with a calorific value of 25 -31 MJ/kg can be used directly as solid fuel or in the form of coal water. Pyrolysis plants of KB Klimova LLC allow processing from 3 to 25 tons of waste per day. When the reactor is operating in gasification mode with generating times from the processing of solid waste and garbage in the amount of 5000 kg / day, an electric 150 kW and a thermal 200 kW power can be obtained using a gas piston engine [19]. The Safe Technologies industrial group (St. Petersburg) developed pyrolysis plants for the thermal destruction of continuous heat treatment units with a capacity of up to 1,500 kg / h, which allow processing various types of waste [20,21]. The tests of the UTD-2-200 installation showed that the pyrolysis gas generated in this process can be used in cogeneration technologies based on Capstone microturbines and the FAS gas piston engine (Fasenergomash LLC, Russia) [22].

4. Conclusion

Obtained from anaerobic fermentation of organic waste biogas can be rational to use in cogeneration after additional preparation on the basis of the previously listed gas reciprocating and gas turbine engines with a waste heat recovery system for flue gases. The feasibility study of a cogenerator based on the small-sized gas turbine unit GTES-200 manufactured by Kaluga Engine using the technology of microbiological utilization of municipal solid waste [22] confirms a payback period of no more than three years, which allows us to consider this technology as cost-effective.

The results of studies of trends in the development of the energy technology market with microcogeneration, the proposed typology and block diagram can be used to select rational energy-efficient technologies for waste management.
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