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Feasibility Study of the Use of Plasma Gasification for Residential Complexes

Nikolay Romaniuk[1,*] Olga Novikova[2]

[1] *Higher School of Engineering and Economics, Peter the Great St. Petersburg State University, Saint Petersburg, Russian Federation*
[2] *Higher School of Nuclear and Thermal Power Engineering, Peter the Great St. Petersburg State University, Saint Petersburg, Russian Federation*
[*] *Corresponding author. Email: nickolai.romaniuk@yandex.ru*

ABSTRACT
In modern conditions of international economic and environmental aspects of energy, there is a need to introduce innovations in Russia and in other countries from the point of view of synchronizing energy policy with the international community. The study of the resource base of solid municipal waste can serve as a basis for assessing the prospects for the development of plasma gasification technologies. The article considers the possibility of developing the concept of sustainable development through the expansion of technologies for the energy processing of MSW. Taking into account the new integration processes of Russia and Belarus, the authors considered this problem from the point of view of both states.
Based on the proposed algorithm for selecting a power plant for processing MSW, it is proposed to analyze the prospects for the development of decentralized energy of individual residential complexes.
The study presents the results of the economic justification of the effectiveness of the project implementation from the point of view of the minimum technical and economic interaction of the research object with external participants. The Authors evaluated the influence of factors on the final result and the possibility of using technology for residential areas.
The results of the study are proposed to be used in the development of strategic plans for sustainable development at the microeconomics level of residential complexes in different countries and regions. The proposed approach will expand the resource base of the fuel and energy complex and minimize the negative environmental effect of waste disposal.

Keywords: *Municipal solid waste (MSW), Plasma gasification, Economic efficiency, Electricity generation, Utilization rate, Maximum permissible concentration (MPC), Processed products, Rational nature management, Resource saving, General household needs.*

1. INTRODUCTION

The level of environmental pollution due to large volumes of waste and inefficient methods of their disposal is increasing catastrophically rapidly. That is why it is necessary to introduce technologies for their processing based on the principle of returning to the resource cycle with minimal logistical costs. This requires consideration of circular economy projects with the maximum use of waste from one process in the form of resources of another process at the place of their formation.

Taking into account the new integration processes of Russia and Belarus, the authors considered this problem from the point of view of both states. Dynamics of municipal waste production in Russia, Europe and Belarus are shown in Figure 1, according to Rosstat, Eurostat and Belstat. Also, taking into account the dynamics of changes in the number of population, the figure shows the specific values of waste production per capita.

At the moment, Russia lags behind European and North American countries in terms of utilization, but this problem has begun to be covered at the federal level, projects have been adopted to change the situation. The largest is the National project “Ecology”, which includes 9 federal projects. The work is carried out in five directions – waste, water, air, biodiversity and technology. The implementation period is until 2024.

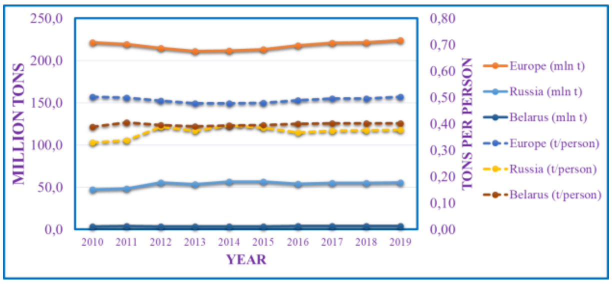

Figure 1 Dynamics of municipal waste production and production per capita in Russia, Belarus and Europe.

According to the hierarchy of MSW management in the Republic of Belarus presented in the National Strategy for the Management of Solid Municipal Waste and Secondary Material Resources in the Republic of Belarus for the period up to 2035, the energy use of MSW is completely absent at the moment. The Strategy does not consider the technology of plasma gasification, the widespread use of which can ensure more effective implementation of the goals.

The volume of MSW generation in Belarus in 2019 amounted to 3.8 million tons, from which 3.8 billion m^3 of synthesis gas can be obtained by plasma gasification technology [1]. As a result of the implementation of waste, the received electricity can amount to 1.9 billion kWh per year, which is 4.8 % of the annual electricity generation. Herewith, the total electricity generation in Belarus in 2019 was 39.8 billion kWh. In Russia, the generation of MSW in 2019 amounted to 55.4 million tons, what can be an additional source of 27.7 billion kWh per year, which is 2.6 % of the annual electricity generation. At the same time, the total electricity generation in the Unified Energy System of Russia in 2019 amounted to 1.080,6 billion kWh.

As you can see, the implementation of plasma gasification technologies can have a greater positive impact on electricity generation in Belarus than in Russia, which will significantly increase export opportunities and unlock the potential for energy saving through the use of internal reserves. The second important indicator for assessing the state of the industry is the coefficient of municipal waste recycling. According to the national project “Ecology”, in Russia, the share of MSW not directed to disposal in the total volume of solid municipal waste generated in 2019 was only 3.8 %. Herewith, the recycling rate of MSW in the European Union is steadily growing and is already 48 %, and in Belarus 22.5 %. The increase in the share of MSW processing occurs using various technologies and environmental solutions. For example, recycling, composting and incineration technologies are of particular importance in the EU countries. For a number of countries, the energy use of MSW may become relevant. The construction of these installations on the territory of residential complexes can reduce the amount of garbage transported by roads and improve the energy efficiency of facilities. In this case, the possibility of creating unauthorized landfills will decrease, the environmental situation will improve. Currently, there is no large-scale use of MSW recycling plants in the places of their generation.

The object of research in this work is the process of returning to the resource cycle of a part of the waste generated during the operation of residential areas, as well as obtaining electricity from the remaining mass with the subsequent sale of processed products. The subject of the study is the use of plasma gasification technology for the power supply of residential complexes using MSW.

The purpose of this work is to assess the economic feasibility of using a plasma gasification plant for the disposal of residential complex waste. We use system analysis as a research method.

To achieve this goal, it is planned to identify factors and evaluate the economic and environmental indicators of the technology of energy processing of MSW, as well as to justify the possibility of using the installation with the definition of operating conditions for residential areas on the example of a specific project.

2. LITERATURE REVIEW ON THE TOPIC

Based on the results of the analysis of articles [2, 3, 4, 5, 6, 7] it can be concluded that garbage recycling is the most acute, global and most urgent environmental problem in our time. Scientists from many countries are engaged in the topic of the economic benefits of recycling MSW, projects are being created and implemented and actual results are being evaluated. Some companies offer ready-made modular solutions.

Group of articles [8, 9, 10, 11, 12] describe waste recycling methods. In developed countries, it has been possible to achieve a high degree of utilization with satisfactory profitability of recycling plants, which is an important point for the development of this industry without state subsidies. The most common and proven is the traditional incineration of solid waste on grate grates [13], at the same time, the most environmentally efficient technologies are high-temperature pyrolysis and plasma gasification plants with a utilization rate of up to 94 %. Articles devoted to plasma gasification lack studies of economic efficiency based on operation under certain conditions.

The economic efficiency of technologies that increase the energy efficiency of various facilities are considered by authors from different countries [14, 15, 16, 17, 18].

Earlier in the authors' article [19] the classification of technologies was presented and the limitations and selection criteria were determined, which makes it possible to recognize the use of high-temperature pyrolysis and plasma gasification technologies as the most appropriate for these facilities. Based on the results of the analysis of a group of articles [8–19], it was decided to base the study on plasma gasification technology due to good performance, ease of operation and availability of technology on the Russian equipment market. The studied articles do not fully disclose the subject of the sale of sorting and processing products as a result of the operation of the plasma gasification plant, as well as the assessment of the influence of factors on the final value of the payback of the project. In this article, based on the data for the territory of St. Petersburg, the solution of the above tasks is presented.

In this study, it is proposed to consider low-power installations from the point of view of not only environmental, but also economic efficiency. The installations are located near the residential complex and partially provide electricity for its general household needs. The advantage of this concept against the background of large factories is that there is no need to build a high-voltage power grid, as well as long-term transportation of MSW to their disposal sites. Therefore, economic calculations for distributed waste disposal plants are no less important than for large plants. Currently, there is a lack of practical assessments of economic efficiency based on up-to-date data, and since Russia and Belarus are currently integrating energy, common approaches and justifications for the introduction of these technologies can be useful to both sides.

3. RESEARCH METHODOLOGY

For example, consider the projected residential complex in St. Petersburg. Next, we will propose a methodology and calculate the economic efficiency of the return to the resource cycle of the untreated part of the waste of the facility with the production of energy for partial compensation of household expenses due to the use of plasma gasification technology. Economic efficiency is estimated based on the amount of incoming and saved funds during the implementation of the project. Importation price 1m^3 garbage in the city of St. Petersburg is equal to 550 ruble (p_{ex}). According to the initial data, the generation of garbage in the residential complex is 16 425 m^3 per year the price of removal of this amount of garbage per year, according to the tariffs, will be 9 million rubles (S_w) or 1115 rubles per person per year (93 rubles per month). When using a plasma gasification unit, these costs (9 million rubles) are not available. The calculation is made according to Equation (1).

$$S_w = Q_{gen} \cdot p_{ex} = 9 \cdot 10^6\,RUB \text{ per year} \quad (1)$$

According to the Territorial scheme of waste management of production and consumption of the city of St. Petersburg, glass occupies 8.9 % of the total mass (ω_{gl}), this is a non-recyclable part, so it is possible to significantly increase the degree of processing by collecting glass containers. Now pots cost from 1 ruble to ten, depending on the volume. For a bottle at the glass container reception point, the price ranges from 0. 15 to 0.9 rubles. With rare exceptions – 1 ruble. Let's take the average value – 0.8 rubles (p_b) for a glass product weighing 400 g (m_b). Weight of MSW per year – 3092 ton (Q_{gen}), calculated value of the glass mass – 275 ton or 688 000 bottles. In case of sale – 0. 55 million rubles (S_{gl}). The calculation is made according to Equation (2).

$$S_{gl} = {(\omega_{gl} \cdot Q_{gen})}/{m_b} \cdot p_b = 0{,}55 \cdot 10^6\,RUB \text{ per year} \quad (2)$$

The complex generates 3092 tons per year, while, according to the Territorial Scheme, as part of MSW – ω_{nfm} = 3.8% nonferrous metal (m_{nfm} = 117. 5 ton) and ω_{fm} = 0.8% ferrous metals (m_{fm} = 24.7 ton). Price for ferrous metal – p_{fm} = 31.4 rubles per kg (0.78 million rubles.), and for nonferrous metal – on average p_{nfm} = 140 rubles per kg (16. 5 million rubles). Taking into account the density of scrap metal ρ_m = 3 ton per m^3, the volume of metal collected per year is approximately 47. 4 m^3 (V_m). When exporting once a month, there will be enough space in volume 5m^3 (to generate V_{mm} = 3.95 m^3 per moth). The calculation is made according to equations (3, 4, 5, 6).

$$S_{nfm} = \omega_{nfm} \cdot Q_{gen} \cdot p_{nfm} = 16{,}5 \cdot 10^6\,RUB \text{ per year} \quad (3)$$

$$S_{fm} = \omega_{fm} \cdot Q_{gen} \cdot p_{fm} = 0{,}78 \cdot 10^6\,RUB \text{ per year} \quad (4)$$

$$V_m = {(\omega_{nfm} + \omega_{fm}) \cdot Q_{gen}}/{\rho_m} = 47{,}4\text{m}^3 \text{per year} \quad (5)$$

$$V_{mm} = {V_m}/{12} = 3{,}95\text{m}^3 \text{per mth} \quad (6)$$

Plasma gasification technology has a degree of processing of more than 93 %, while slag formed in quantities not exceeding ω_s = 7 % the original mass (minus sorted glass and metals), it is represented by oxides and carbonates of metals and silicon. Molten slag is collected for use as a composite material in construction. At the price p_s = 1.1 ruble per kg we get the implementation price of the annual production volume at the level of 0.2 million rubles Slag density ρ_s = 2 ton per m^3 will represent the volume 93. 6 m^3

(V_s). When exporting once a month, there is enough space in volume 8–9 m^3 (to generate V_{sm} = 7.8 m^3 per month). The calculation is made according to Equations (7, 8, 9).

$$S_s = \omega_s \cdot Q_{gen} \cdot p_s = 0,2 \cdot 10^6\, RUB \text{ per year} \quad (7)$$

$$V_s = \omega_s \cdot Q_{gen} / \rho_s = 93,6 \text{m}^3 \text{per year} \quad (8)$$

$$V_{sm} = V_s / 12 = 7,8 \text{m}^3 \text{per mth} \quad (9)$$

With plasma gasification technology, residual electrical energy for sale and third-party use ranges from 1 kWh to 3.8 kWh per 1 kg of waste per hour according to data based on various recyclable substances when using the PLAZARIUM MGS installation. Based on the low power of the installation and the work on MSW after sorting, we will take the value – 0.5 kWh per 1 kg (k_{el}), since the mass fraction of substances amenable to combustion is about half of the total mass [20]. Then we get a daily output equal to 4 235 kWh (or 1 545 775 kWh per year). Tariff price for kWh in St. Petersburg it is 4. 98 rubles per kWh on a single-rate electricity tar (p_{el}). We get savings of 7.7 million rubles per year (S_{el}). The calculation is made according to Equation (10).

$$S_{el} = k_{el} \cdot Q_{gen} \cdot p_{el} = 7,7 \cdot 10^6\, RUB \text{ per year} \quad (10)$$

We use specific indicators of plasma gasification technologies on the example of WPC – for power installation 45 m^3 per day we get the volume of investments – 128.5 million rubles (I_{pl}).

For PLAZARIUM MGS mobile plasma gasification and waste disposal units, the average maintenance cost is from 3 to 5% of the installation cost per year (k_{ser}). The average cost of operating the installation is from 3 to 5 % of the installation cost per year (k_{exp}), which corresponds to values from 3.9 to 6.4 million rubles. Let's assume the average value of the amount of maintenance and operation costs – 10.3 million rubles per year ($C_{exp+ser}$). The calculation is made according to Equation (11).

$$C_{exp+ser} = k_{exp} \cdot I_{pl} + k_{ser} \cdot I_{pl} = 10,3 \cdot 10^6\, RUB \quad (11)$$

To calculate the linear amortization, we will take the useful life of 20 years (T_{use}). With investments amounting to 128.5 million rubles, amortization will be 6.4 million rubles per year (A). The calculation is made according to Equation (12).

$$A = I_{pl} / T_{use} = 6,4 \cdot 10^6\, RUB \text{ per year} \quad (12)$$

Additional spaces are planned to be emptied once a month and sent for sale. The calculation of the required dimensions was made above.

The received data on income, savings and expenses for the year are presented in the Table 1.

Table 1. Costs, savings and income

Source of costs, savings or income	Value, million rubles
Garbage collection (per year)	9
Glass Delivery (per year)	0.6
Delivery of non-ferrous metals (per year)	16.5
Delivery of ferrous metals (per year)	0.8
Molten slag (per year)	0.2
Electricity generation (per year)	7.7
Volume of investments	128.5
Operating and maintenance costs (per year)	10.3
Amortization (per year)	6.4

We get an approximate payback period (basic) of the plasma gasification project for the city of St. Petersburg – 7 years (T_{pbb}). This value corresponds to the profitability of the project – 10.3 %. In this calculation, it is assumed that the appreciation of each element will correspond to inflation, thus, when adopting a single discount rate, it is possible to calculate the payback without using the discounted cash flow method. Thus, the calculation is made according to Equation (13), using the average annual profit.

$$I_{pl} / (S_w + S_{gl} + S_{nfm} + S_{fm} + S_s + S_{el} - A - C_{exp+ser}) = 7,1 \quad (13)$$

This calculation does not take into account the construction of an electric grid, landscaping and the cost of building additional structures, as it most depends on the specific conditions, the wishes of the customer and the distance from consumers of electric energy. It is also possible to receive additional profit in the case of subsidies or performing additional functions.

Let's take the entire volume of unaccounted costs and revenues as the value X. Write it down in the lower part of the fraction, we get the following Equation (14):

$$T_{pb} = 128,5 / (18,1 - X) \quad (14)$$

The characteristic of the dependence of the payback period on the value of unaccounted costs and income is shown in the Figure 2.

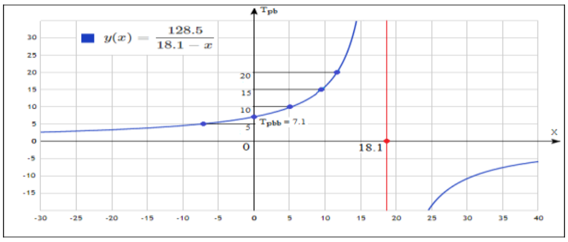

Figure 2 Characteristics of the dependence of the payback period on the value of unaccounted costs and income.

As you can see from the figure, when additional costs approach the level of 18.1 million rubles, the project will show unprofitability. Based on the obtained patterns, it is possible to estimate the allowable additional costs in the conditions of a specific project. In our case, when agreeing on a payback period of up to 15 years, it becomes possible to carry out additional expenses and provide accelerated amortization, which will lead to better maintenance and accelerated equipment renewal.

Next, we will assess the impact of initial costs on the final result. With one planned payback period, consider three options in Figure 3.

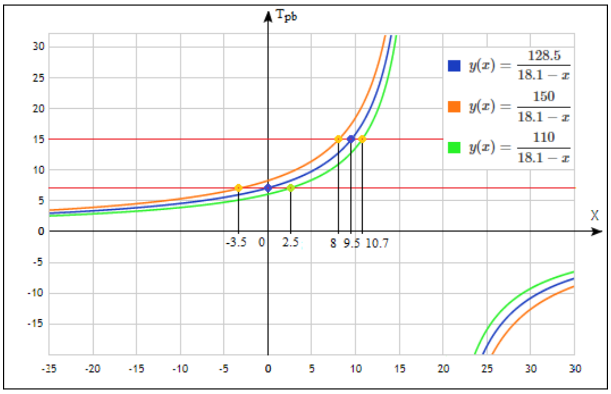

Figure 3 Initial cost analysis.

According to the figure – with long payback periods embedded in the project, initial investments have a lesser impact on the result. So to compensate for the increase in initial investments by 21.5 million rubles (up to 150 million rubles) with a payback period of 15 years, the allowable increase in annual spending by 1.5 million rubles is less than the base scenario. For a payback period of 7.1 years, this value will be -3.5 million rubles – that is, without finding new sources of income, the project will not reach the planned payback period.

Let's estimate the effect of the changes in the above calculated components of the average annual profit on the final result. Let's assume that the tariffs for electric energy in region N are lower than the one under consideration, while due to the peculiarities of the plant's operation on a certain composition of MSW, more energy was actually needed for the plasma gasification process, as a result of which there was a shortage of electricity In this case, less electricity is sold at a reduced price relative to the base scenario. Let's put the effect of reducing this income item at the level of 40 % (4.62 million rubles per year). Let’s represent the result obtained in the Figure 4.

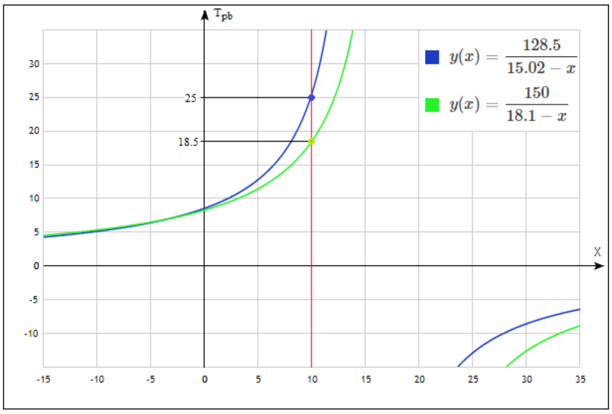

Figure 4 Annual cost analysis.

Modifications in the structure of annual costs have almost no effect on the payback of the project with a small or negative (profitable) value of unaccounted costs. With the value of unaccounted annual costs at the level of 10 million rubles, a 40% reduction in income from electricity sales increases the payback period by 6.5 years.

Minimization of negative environmental impact and prevention of exceeding the TLV is a prerequisite for the technology. The threshold limit value (TLV) of pollutants in the atmospheric air of urban and rural settlements are presented in GN 2.1.6.3492–17.

The list of pollutants that fall under the control of the government is presented in the order of the Government of the Russian Federation dated 08.07.2015 №. 1316-r (Ed. From 10.05.2019).

For the PLAZARIUM MGS installation, the complete environmental friendliness of the waste disposal process with complete destruction (99.99%). Absence of resins, dioxins and furans. The maximum permissible emissions (MPE) comply with governmental standard (GOST) Sanitary Rules and Regulations 2.2.112.1.1.567–96 and the standards of the EC Directive.

Thus, the absence of a negative impact of the MGS installation on the environment is its strong competitive advantage in comparison with other recycling technologies.

4. CONCLUSION

The exploitation of the PLAZARIUM MGS plasma gasification plant for the disposal of MSW of multi-storey buildings has a commercial and environmental effect. Full utilization of the generated MSW is ensured, thereby there is no need for export, while sorting metals and generating electricity increase the economic performance of the installation. The peculiarity of this study is the possibility of adapting calculations to a specific region, as well as the possibility of introducing additional factors and conditions. In this case, it is necessary to select and add the actual values and, using the method described above, perform calculations.

For a more in-depth study, you can add an assessment of the construction of an electric grid, landscaping, the implementation of additional work, as well as calculate the payback based on expectations for the rise in price of the elements used based on forecasts in the region under consideration. Due to the high individuality and volatility, these factors were not considered in this article, since the main task is to develop a calculation methodology.

As a result of the study, the theoretical profitability of plasma gasification technology and payback for 7.1 years when used for waste disposal of residential areas are proved, the possibility of using this technology in the fulfillment of certain environmental safety conditions and the method of location is also justified.

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