ЭНЕРГИЯ ТЕЖАМКОР ТЕХНОЛОГИЯЛАР ВА ҚУРИЛМАЛАР/ ЭНЕРГОСБЕРЕГАЮЩИЕ ТЕХНОЛОГИИ И УСТАНОВКИ/ ENERGY SAVING TECHNOLOGIES AND INSTALLATIONS

SOLAR ENERGY APPLICATION IN MUNICIPAL SOLID WASTE: EXPERIENCE, RESULTS AND EFFICIENCY

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Abstract. *The article proposes a solar installation for the thermal processing of municipal solid waste and presents a technique for the technical and economic analysis of solid waste processing systems based on solar energy. An analysis of the heat balance of the developed solar installation was compiled and carried out, and the energy requirement for the thermal processing of municipal solid waste was determined. A calculation has been made showing the energy efficiency of a solar installation for the processing of municipal solid waste using solar energy.*

Analysis shows that the test data for the control system shows that the time of heating the MSW mass to a temperature of 55-60 ^{0}C is - 15 hours.

Experimental results show, the output of landfill gas in the optimal mode is 12-15 m^3/day.

It has been determined, the landfill gas productivity is 150-200 m^3/t, the working volume of the SI is 1 m^3, the temperature of the MSW mass in the reactor corresponds to the thermophiles mode: 55-60 ^{0}C.

Preliminary calculations and tests show that the developed installation will provide a stable temperature regime for solid waste fermentation and save heat energy consumption by 30-40%.

Keywords: *municipal solid waste, solar energy, solar installation, alternative fuels, heat balance, waste management.*

Our country is pursuing a consistent policy in the field of environmental protection, rational use of natural resources, as well as improving the sanitary and ecological state of the regions.

As part of the reform of the waste management system in the country, consistent work is being carried out to improve the quality of sanitary services, to introduce effective mechanisms for the collection and removal of household waste

Fortunately, almost everything that belongs to municipal solid waste does not pose a danger to our health and consists mainly of packaging and food waste. But this category of garbage is harmless if properly stored and processed. In turn, the rotting or burning of solid waste entails poisoning the soil, groundwater, and atmosphere [1-2].

Municipal solid waste (MSW) - organic and inorganic waste generated as a result of the vital activity of individuals and legal entities, as well as waste generated as a result of natural processes on their territory and landscaping (food and vegetable waste, textiles, packaging) of materials, glass, rubber, paper, plastic, wood waste, household items that have lost their useful properties, as well as waste generated when using solid fuel stoves and heating boilers.

Municipal solid waste is an integral product of human activity and requires regular and timely disposal. Their accumulation can lead to serious problems that will affect not only the ecology of the region but also our health [4].

Any solid waste consists of three components:

Organic and inorganic substances and physical water. Water determines such an important property of solid waste as moisture. An organic substance (combustible mass) is an unconventional renewable energy source, therefore, its study is of particular interest. The elementary composition of MSW is given in table Fig.1.

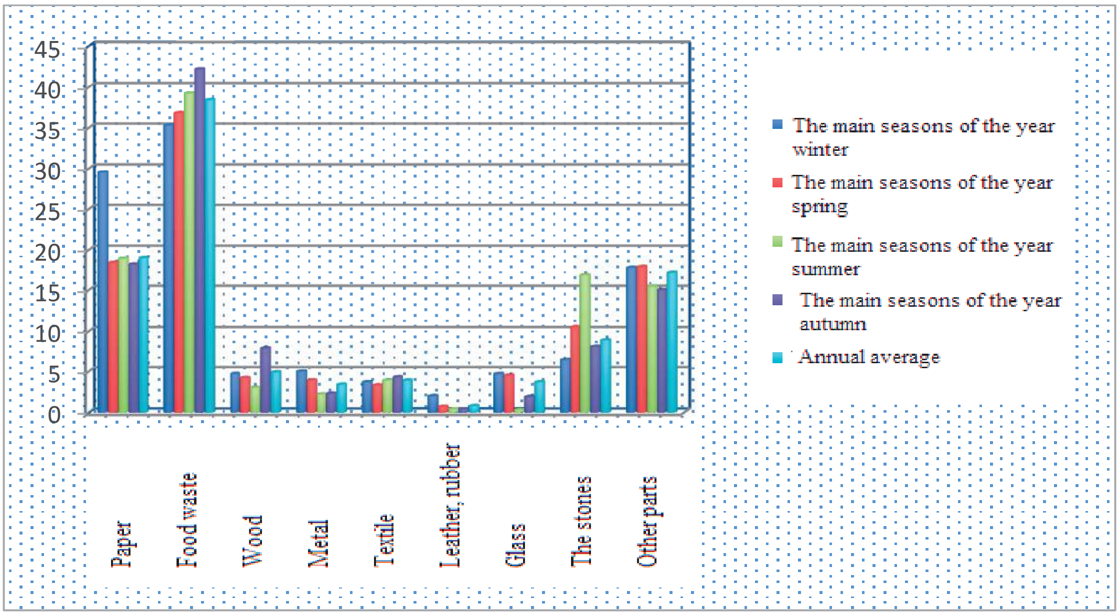


Fig. 1. Average morphological composition of MSW in cities Republic of Uzbekistan (in percentage by weight).

This diagram shows the average composition of solid waste in the Republic of Uzbekistan. The diagram shows that in large cities of the Republic of Uzbekistan, most of all food waste is generated - 40%, paper - 29% and but least of all wood waste - 7%, Least of all, metal waste is generated from 0 to 5%. The diagram also shows that in cities practically no metal and glass are formed, but more organic waste is generated and other parts are 19%.

At the same time, the main trend in the field of waste processing in Western Europe, the USA, Canada, and some Asian countries is the automated fractional sorting of solid waste using mechanized methods of dividing the total stream into separate components, which provides a deep degree of processing of the original waste [2].

More than a dozen technologies for processing solid household waste using various methods have been implemented worldwide. The most common are thermal methods, like combustion, pyrolysis, and gasification.

The main way of liquidation and processing of municipal solid waste in the Republic of Uzbekistan today their burial at landfills remains.

Over the past 5-7 years in our Republics on large technologies of fractional sorting of waste based on manual methods of selection with the subsequent burial of residues ("tails") that are not valuable in the form of secondary material resources have become widespread in urban solid waste landfills.

In the Republic of Uzbekistan, the content of the constituent parts of MSW is not constant and changes according to the seasons, in particular, in summer and autumn, the percentage of food waste in them increases, which is associated with the more frequent use of vegetables and fruits by the population during these periods [4].

Currently, in large cities of the Republic of Uzbekistan, the volume of municipal solid waste is increasing, and the entire volume of generated municipal solid waste is removed and stored without sorting and processing at city dumps. In hot climates, municipal landfills in the city of the Republic of Uzbekistan of municipal solid waste can lead to the formation of various hazardous compounds on them, such as methane, hydrogen sulfide, etc. (NO, NO_2, NH_4, HCl, C, SO_2, H_2S, CO, CoF_3, AgF, ClF_5, CH_4, CH_3, PhMe, C_2H_{10}) (Fig.2). The growth of municipal solid waste has a huge negative impact on the environmental sustainability and health of the population [5-6].

Fig. 2. City landfills in the city of Karshi

This is the oldest solid waste disposal method in the world. Disposal is carried out in the near-surface geological environment [2-6].

Knowing the high sanitary-epidemiological and chemical danger of unorganized collection, storage and storage of municipal solid waste, when choosing a site intended for a landfill, it is necessary to carefully study a number of issues:
- terrain features;
- type (relief) of the area;
- features of the geological composition of the earth's layers of the place, intended for a solid waste landfill;
- features of the surrounding natural landscape;
- the prevailing wind rose.

After a thorough analysis of these factors, carried out by competent professional specialists and an environmental examination carried out by independent professional experts, a site is selected for a solid waste landfill. The main landfills in the Republic of Uzbekistan are indicated.

In landfills, waste is subjected to a daily biochemical decomposition process. As a result, anaerobic conditions are intensively formed, causing bioconversion of organic matter. This produces biogas called landfill gas [2-10].

The waste management infrastructure is being improved, new waste collection points are being built and equipped following the approved programs, and the transport palaces of waste collection and removal organizations are being modernized.

In particular, in 2017-2018, large-scale work was carried out to improve the infrastructure of the solid waste management system, 13 state unitary sewerage enterprises and their 172 branches in districts and cities, as well as 9 municipal treatment facilities. clusters of complex implementation were created. The measures taken made it possible to cover almost half of the population with sanitation services [1-9].

Disposal in the near-surface geological environment remains one of the main ways of utilizing municipal solid waste throughout the world. Under these conditions, solid domestic waste undergoes intensive anaerobic decomposition with the formation of landfill gas.

Recently, there has been an increasing worldwide interest in the development of new designs of energy-saving installations for thermal processing of solid waste under conditions of anaerobic digestion, to obtain alternative fuel (landfill gases) and organic fertilizers or composting in the process of methane fermentation of industrial solid waste, which favorably differs from other methods.

Disposal in the near-surface geological environment remains one of the main ways of utilizing solid waste throughout the world. Under these conditions, solid domestic waste undergoes intensive anaerobic decomposition with the formation of landfill gas.

The following methods of utilization and processing of solid waste have found industrial application in world practice: burial at special landfills; heat treatment (incineration, pyrolysis); biothermal: aerobic composting (producing fertilizer or biofuel) and anaerobic fermentation (producing biogas); sorting (with the extraction of certain valuable components for secondary use, the most suitable technology, ecologically and economically).

The technology of processing municipal solid waste at solid waste landfills, where 90-95% of the total solid waste flow of the housing stock is received, is based on the spontaneous decomposition of the organic part of the waste in the landfill body.

Thus, landfill disposal is environmentally hazardous and economically unprofitable in terms of environmental payments, land costs, and the need to finance its reclamation.

The method of utilization of municipal solid waste using pyrolysis technology consists in their irreversible chemical change under the influence of elevated temperature without access or with limited access to oxygen with the release of combustible pyrolysis gas (pyrolysis gas). According to the degree of temperature impact on the combustible mass of waste, pyrolysis as a process is conditionally divided into low-temperature (up to 650 °C) and high-temperature (650-900°C). In the case of supplying a limited amount of air and water vapor to the reactor, the gasification process takes place [11-13].

The work uses the methods of the theory of heat and mass transfer and body balances of heat power and solar installations. The created solar installation for thermal digestion of solid waste to obtain landfill gas and biofertilizers has been investigated. Balance methods of numerical and experimental studies of solid waste fermentation were used to analyze the results.

As a result of the anaerobic decomposition of the organic fraction of municipal solid waste, 40-70% of the total amount of methane that enters the atmosphere annually is formed as a result of anthropogenic activity, more than 20% of which falls on solid waste disposal facilities. It is estimated that about 150-200 m^3 of landfill gas is generated from one ton of municipal solid waste [1].

In Uzbekistan, the disposal of municipal solid waste to obtain alternative fuel is also a relevant and promising direction.

The solar installation developed by us for the processing of municipal solid waste using solar energy (Fig. 1) can be used in the landfill of solid waste in small settlements, to prevent environmental pollution, disturb the ecological balance, obtain alternative fuel (landfill gas), and organic fertilizers.

At the same time, the presence of some problems with the collection and removal of municipal solid waste in the regions hinders the formation of an effective waste management system and the further development of the industry.

The sun is a giant source of "clean" energy, not polluting the environment. Efficient use of solar energy can significantly reduce the consumption of natural resources. Climatic and weather conditions in the south of Uzbekistan create wide opportunities for the efficient use of solar energy in the Kashkakdarya region. Using solar energy, it is possible to solve the problems of thermal processing of municipal solid waste [1-8].

The results of measuring the local climate meteorological parameters in the conditions of the city of Karshi in Kashkadarya region are shown in the following pictures.

Direct radiation is of primary importance in the radiation balance. Scattered radiation is solar radiation that has undergone scattering in the atmosphere. The diagram shows the data of direct, scattered solar radiation (W/m^2) and average monthly outdoor temperatures (^0C) for Karshi ($\varphi = 39^0$) and Kashkadarya region ($\varphi = 38 \dots 40^0$) (Fig.4-8).

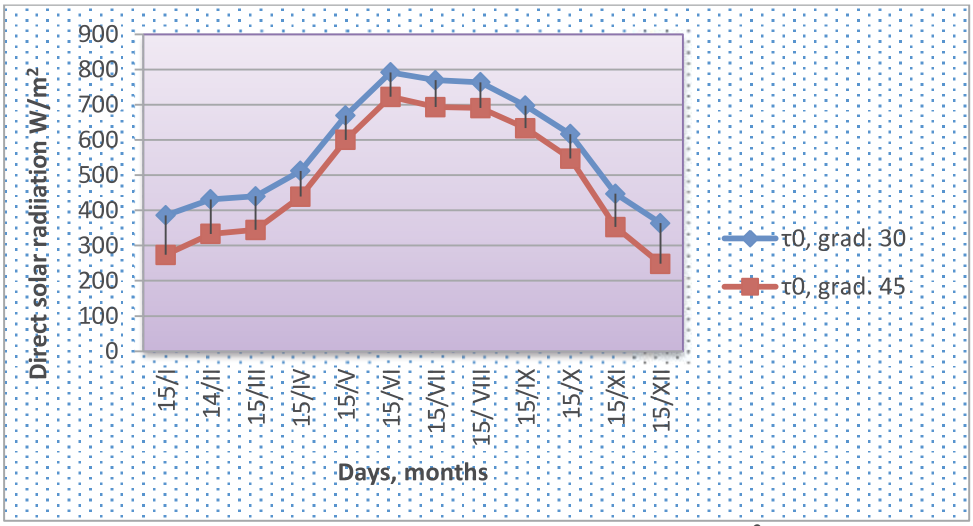


Fig.4. Direct solar radiation, W/m^2.

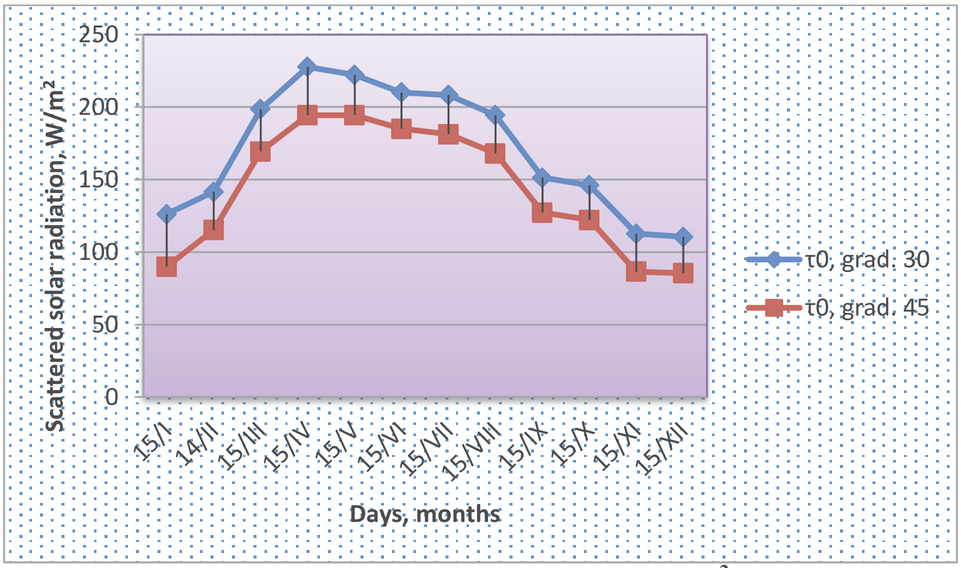


Fig.5. Scattered solar radiation, W/m^2.

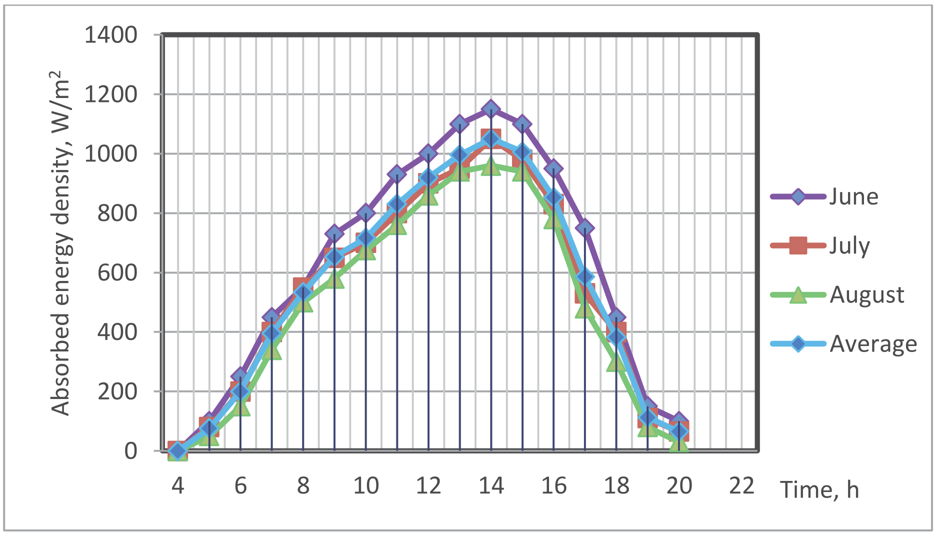
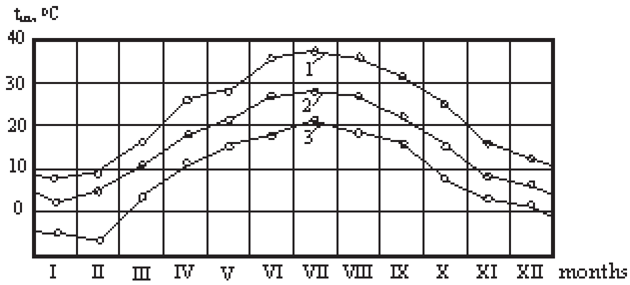


Fig.6. The density of the absorbed flux of solar energy for a surface installed at an angle of 39° to the horizon on clear days of summer months in the city of Karshi, Republic of Uzbekistan.



1 - average maximum; 2 - medium; 3 - average minimum.
Fig.7. Average monthly outdoor temperatures.

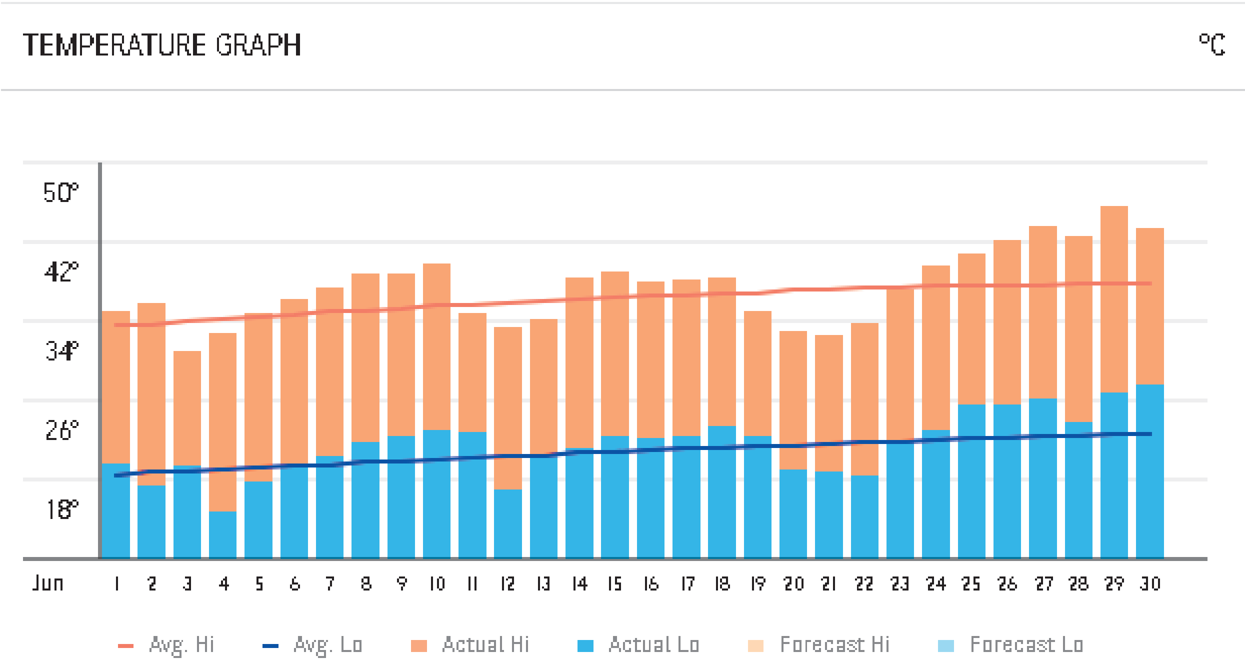


Fig.8. **Graph of change of ambient temperature in Karshi city in June 2022**.

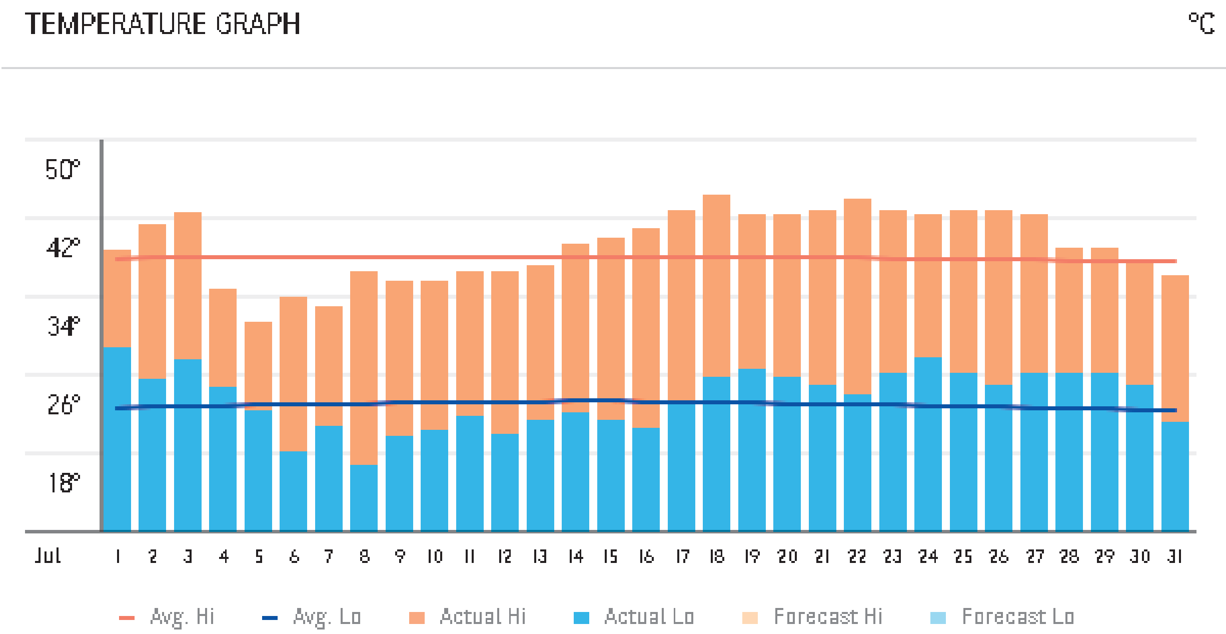


Fig.8. **Graph of change of ambient temperature in Karshi city in Jule 2022.**

An experimental solar installation is designed to produce alternative fuel and biohumus from the municipal solid waste by anaerobic digestion. The solar installation provides processing of municipal solid waste and reducing environmental pollution and increasing the degree of environmental safety.

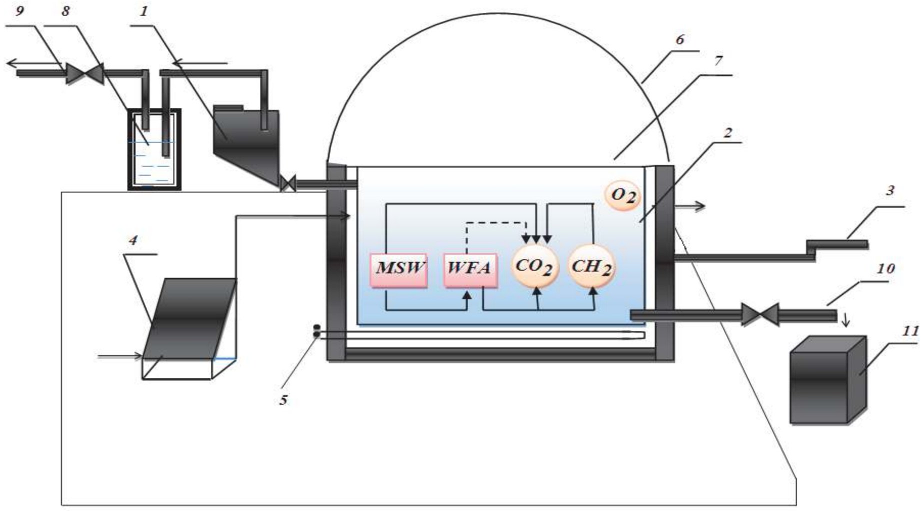


Fig.9. Solar installation for the thermal processing of municipal solid waste.

Fig.10. Experimental solar installation for the thermal processing of municipal solid waste.

1-receiving hopper, 2-landfill reactor, 3-mechanical mixer, 4-solar air heater, 5-electric heater, 6 polycarbonate coating, 7-absorber, 8-water filter, 9-valve, 10- exhaust pipe, 11-exhaust hopper.

The experimental solar installation for the thermal processing of municipal solid waste (ESITPMSW) is made of a half-cylinder with a base in the form of a rectangular parallelepiped. The working volume of the reactor is 1 m^3 (Fig.9 and 10).

The proposed installation works as follows. In the daytime mode, municipal solid waste is loaded through the receiving hopper 1 into the fermentation chamber of landfill reactor 2 without prior sorting. Every 2-3 hours, the mixing of the loaded municipal solid waste in the landfill reactor occurs using a mechanical stirrer 3, driven manually. Loaded solid waste in the reactor is heated by a solar air heater (SAH) 4 to a temperature of 50-55 °C. The electric heater 5 is a backup heater and supports the creation of a stable temperature regime of anaerobic fermentation of municipal solid waste in the reactor during cloudy days and at night. This installation is characterized in that the reactor from above is covered with a translucent polycarbonate coating 6, which also provides, as a passive solar installation, the required temperature regime. Thus, the sun's rays passing through the polycarbonate glass 6 flow into the installation and heat the metal sheet, i.e. the absorber 7 and due to thermal conductivity, heat is transferred to the internal volume of the reactor. In addition, through the active system of the solar air heater, air heated to a temperature of 50-60 °C through the air channel heats the side and lower parts of the surface of the landfill reactor.

The reactions that occur in loaded solid waste under aerobic conditions can be schematically represented as follows:

$$\mathrm{CH_3COOH \rightarrow CH_4 + CO_2} \quad (1)$$

$$\mathrm{4CH_3OH \rightarrow +3CH_4 + CO_2 + 2H_2O} \quad (2)$$

With further oxidation, the transformation of the cellular substance begins:

$$\mathrm{C_5H_2}NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 3H_2O + AH \quad (3)$$

$$NH_3 + O_2 \rightarrow HNO_2 + O_2 \rightarrow HNO_3 \quad (4)$$

In the reactor, the process of aerobic oxidation most often ends with the formation and accumulation of high concentrations of fatty acids, which limits the process of aerobic decomposition.

Anaerobic biodegradation requires the presence of microorganisms of different species that make up the mixed population. A group of hydrolytic or acidogenic bacteria provides the initial hydrolysis of the substrate to low molecular weight organic acids and other compounds, including methane [13-29].

It is also known that methanogenic bacteria synthesize methane as a result of the restoration of the methyl group of acetic acid and methyl alcohol:

$$\mathrm{C_5H_2}NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 3H_2O + AH \quad (5)$$

$$NH_3 + O_2 \rightarrow HNO_2 + O_2 \rightarrow HNO_3 \quad (6)$$

In anaerobic digestion, the enzymes are exoenzymes (cellulosome, protease, etc.) from a number of bacteria, protozoa, and fungi [10].

$$\text{organic waste} + \mathrm{H_2O \rightarrow} \text{monomers} + \mathrm{H_2} \quad (7)$$

During acidogenesis, soluble monomers are converted into small organic compounds, such as short chain (volatile) acids (propionic, formic, lactic, butyric, succinic acids – see Reaction 8), ketones (glycerol, acetone), and alcohols (ethanol, methanol – see Reaction 9).

$$\mathrm{C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O} \quad (8)$$

$$\mathrm{C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2} \quad (9)$$

The acidogenesis intermediates are attacked by acetogenic bacteria; the products from acetogenesis include acetic acid, CO_2, and H_2. The reactions 10-13 shows the reactions that occur during acetogenesis:

$$\mathrm{CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2} \quad (10)$$

$$\mathrm{C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2} \quad (11)$$

$$\mathrm{CH_3CH_2OH + 2H_2O \rightarrow CH_3COO^- + 2H_2 + H^+} \quad (12)$$

$$\mathrm{2HCO_3^- + 4H_2 + H^+ \rightarrow CH_3COO^- + 4H_2O} \quad (13)$$

The last phase of anaerobic digestion is the methanogenesis phase. Several reactions take place using the intermediate products from the other phases, with the main product being methane. Reactions 8-13 show the common reactions that take place during methanogenesis:

$$2CH_3CH_2OH + CO_2 \rightarrow 2CH_3COOH + CH_4 \quad (14)$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (15)$$

$$CH_3OH \rightarrow CH_4 + H_2O \quad (16)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (17)$$

$$CH_3COO^- + SO_4^{2-} + H^+ \rightarrow 2HCO_3 + H_2S \quad (18)$$

$$CH_3COO^- + NO^- + H_2O + H^+ \rightarrow 2HCO_3 + NH_4^+ \quad (19)$$

As a result of ensuring the required temperature regime of municipal solid waste, the process of anaerobic fermentation, like the above chemical processes, takes place.

Within 15-20 days, the process of fermentation and the release of landfill gas takes place, then the landfill gas is finally sucked into the water filter 8 through a receiving hopper 1 for cleaning gases from impurities. Here, the gas is cleaned of dust particles and unnecessary impurities (for example, sulfur and water mixture). Having passed the water filter 8, the landfill gas, through the open valve 9, is directed through the pipeline to consumers. The fermentation process ends within 15-20 days and the spent mass of municipal solid waste is removed from the landfill reactor through the exhaust pipe 10 to the exhaust hopper 11, then the spent mass of municipal solid waste is transferred to the storage facility from where it is partially used as fertilizer or transferred to the solid household landfill waste.

To estimate the energy consumption for the processing process, the heat balance of solar installation for the thermal processing of municipal solid waste was calculated in the following order.

In July 2022, the maximum level of solar radiation was recorded for the entire experimental research period. These results of computational and experimental studies are presented in Table 1.

Table 1. Results of an experimental study of SAH in the mode of heating air and waste oil (July 2022).

The local time	Inlet air temperature, t_{out1}, ^0C	Air flow, G_{air}, m^3/s	Outlet air temperature, t_{in2}, ^0C	Waste oil temperature, t_{hwo}, ^0C	The intensity of the total solar radiation flux on the SAH area, Q_r, W
5:00	18	0,04	20	21	200
6:00	20	0,04	25	26	250
7:00	23	0,04	30	34	450
8:00	25	0,04	36	39	550
9:00	27	0,04	38	44	730
10:00	30	0,04	44	46	800
11:00	34	0,04	52	53	930
12:00	36	0,04	58	65	100
13:00	40	0,04	60	73	1100
14:00	44	0,04	65	78	1150
15:00	42	0,04	62	75	1100
16:00	38	0,04	60	70	950
17:00	32	0,04	51	65	750
18:00	27	0,04	45	55	450
19:00	22	0,04	40	48	150
20:00	20	0,04	28	37	100
21:00	18	0,04	24	27	20
22:00	16	0,04	22	22	15

Experiments with different compositions of solid waste were carried out in the experimental installation in order to obtain landfill gas. The experimental results are shown in Fig.11,12 and

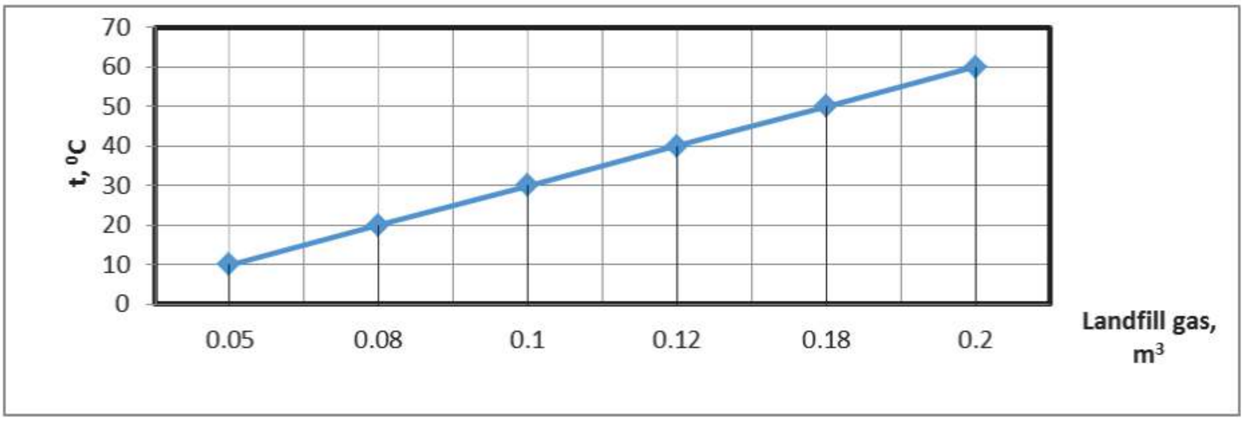


Fig.11. Changing the internal temperature in the solar system and the waste gas outlets.

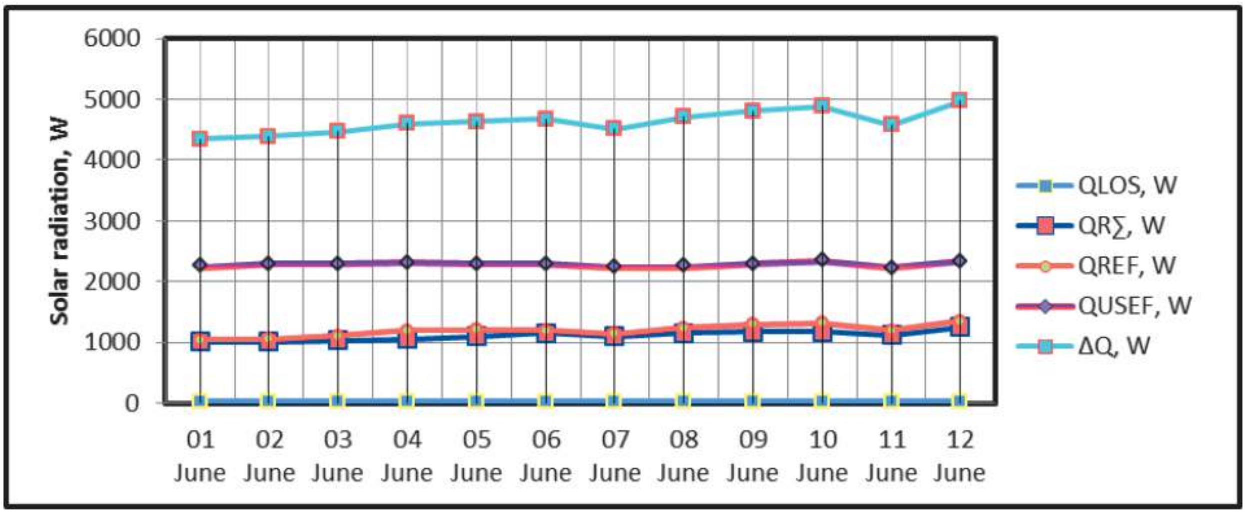


Fig.12.The results of calculating the heat balance of the *ESITPMSW*.

Experimental results Landfill gas outlet.

№	MSW weight, *kg*	Average temperature solar heating, ^0C	Landfill gas, m^3	Biohumus, *kg*
1	300	55	65	130
2	300	53	62	120
3	300	50	60	125
4	300	52	62	128
5	300	54	64	132

Analysis of the test data for the control system shows that the time of heating the MSW mass to a temperature of 55-60 ^{0}C is - 15 hours. The output of landfill gas in the optimal mode is 12-15 m^3/day.

The landfill gas productivity is 150-200 m^3/t, the working volume of the SI is 1 m^3, the temperature of the MSW mass in the reactor corresponds to the thermophiles mode: 55-60 ^{0}C.

Preliminary calculations and tests show that the developed installation will provide a stable temperature regime for solid waste fermentation and save heat energy consumption by 30-40%.

In densely populated points (places) with a large number of municipal solid waste generated and the absence of landfills, there is a high possibility of processing solid waste. Demand for this kind of renewable fuel resource will grow over time and there will be an opportunity to save traditional fuel and energy resources.

The developed solar installation for the processing of municipal solid waste can provide, without energy consumption, the production of landfill gas for its own technological needs.

The use of landfill gas in technological production at the expense of solar energy makes it possible to ensure its summer and autumn production with the greatest efficiency, which is especially important in areas cut off from large energy centers due to river spills, impassability (in mountain villages distant from the center), etc.

The output of landfill gas when using solar energy to heat the mass of solid waste in the reactor in summer and autumn will increase.

Modernization of the installation using solar energy will reduce the weight of specific capital costs and increase the profitability of solar installations.

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