Recycling of municipal solid waste using solar energy

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Abstract. The article proposes a solar installation for thermal processing of municipal solid waste and presents a method of technical and economic analysis of systems for processing municipal solid waste based on solar energy. The object of the research is a solar installation for thermal processing of municipal solid waste. The analysis of the heat balance of the developed solar installation was compiled and carried out, and the energy requirement for thermal processing of municipal solid waste was determined. 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 anaerobic fermentation of solid waste to obtain landfill gas and bio fertilizers has been investigated. Balance methods of numerical and experimental studies of anaerobic fermentation of solid waste were used to analyze the results. A calculation has been made showing the energy efficiency of a solar installation for the processing of municipal solid waste using solar energy. Based on the research carried out, it was found that at an average heating temperature of 50-55 °C, 200-250 m³ of landfill gas was obtained from one ton of household waste.

1. Introduction

Municipal solid waste (MSW) - unsuitable for further use food and municipal items or goods that have lost their consumer properties, the largest part of consumption waste. MSW is also divided into waste (biological solid waste) and municipal waste proper (non-biological solid waste of artificial or natural origin), and the latter is often referred to the municipal level simply as waste [1 – 3].

In the Republic of Uzbekistan, the content of the constituent parts of municipal solid waste 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 (Fig. 1) [4 – 9].
Currently, in large cities of the Republic of Uzbekistan, the volume of solid municipal waste is increasing, and the entire volume of generated solid waste is removed and stored without sorting and processing at city dumps. In hot climates, municipal solid waste dumps in the city of Karshi can lead to the formation of various hazardous compounds, such as methane and hydrogen sulfide (Fig. 2).

![Average morphological composition of MSW in the city of Karshi](image1)

**Figure 1.** Average morphological composition of MSW in the city of Karshi.

![City landfills in the city of Karshi](image2)

**Figure 2.** City landfills in the city of Karshi.

The State Committee for Ecology in the period from 2013 to 2017 in the district centers and rural settlements of Uzbekistan covered only 6% of the population with services for the collection and removal of municipal waste. Today this figure has reached 57%, but for the rest of the population, the lack of waste disposal remains a significant problem [4-9].

As part of the reform of the waste management system in the regions of the country, 13 state unitary enterprises "Tozahudud" with 174 regional and city branches were created. Business entities are involved in the sphere through a transparent mechanism for securing territories on the basis of electronic competitions. In 2017-2018, 414 additional units of special equipment were purchased at the expense of budget funds [4, 9].
Today in Uzbekistan there are 183 enterprises and 9 clusters engaged in the processing of solid household waste. The total production capacity allows to process 894 thousand tons of waste per year, which is only 9% of the total mass of waste produced in the country [4, 9, 17].

In recent years, the mass of MSW constantly entering the environment has reached universal proportions and tends to 500 million tons per year. MSW pollutes the surrounding nature. They also serve as a source of harmful biological, chemical, and biochemical substances entering our environment. These substances cause significant harm to the life and health of people on Earth, as well as to subsequent generations. In addition, solid waste must be presented as a source of a number of valuable substances necessary for use in the most developed industries. The solution of the accumulated problems in the processing of solid domestic waste is of paramount importance, as well as a result of the gradual depletion of such sources of natural raw materials as oil, coal, ferrous and non-ferrous metal ores, for most types. For the national economy, the use of various types of solid waste in full volume. Most advanced economies are coping with these challenges, especially in the USA, Japan, the Baltic States and Germany. The market economy is ahead of the industrialists and researchers, state bodies are faced with the task of creating the most harmless technologies and the full use of all types of solid waste, i.e. approaching the emergence of waste-free technologies [5 – 8]. Therefore, the problem of recycling solid waste in order to obtain alternative fuels is an urgent scientific and technical task of our time.

The purpose of this work is to develop a solar installation for thermal processing of solid waste in urban landfills, to study the heat balance of the installation and to estimate the yield of landfill gas depending on the parameters of the installation and the environment [10 – 14].

2. Methods

In world practice, the following methods of utilization and processing of solid waste have found industrial application: burial at special landfills; heat treatment (incineration, pyrolysis); biothermal: aerobic composting (to obtain fertilizer or biofuel) and anaerobic fermentation (to obtain biogas); sorting (with the extraction of certain valuable components for secondary use, the most suitable technically, ecologically and economically) [3, 4, 9, 15, 16, 17]. The technology of processing household 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 household waste by pyrolysis technology consists in their irreversible chemical change under the influence of elevated temperature without access or with limited access of 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 conventionally 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 [3]. One of the main methods for the disposal of solid waste throughout the world remains disposal in a subsurface geological environment [17 – 28]. Under these conditions, municipal solid waste is subjected to intense anaerobic decomposition with the formation of landfill gas [6].

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 plant for anaerobic fermentation of solid waste to obtain landfill gas and biofertilizers has been investigated. Balance methods of numerical and experimental studies of anaerobic fermentation of solid waste were used to analyze the results. An experimental solar installation for the thermal processing of municipal solid waste (SITPMSW) was created, which is made of a semi-cylinder with a base in the form of a rectangular parallelepiped, with dimensions: length 1.2 m, width 1 m and height 1 m. The working volume of the reactor is 1.2 m³ (Fig. 3.).
Figure 3. Solar installation for thermal processing of municipal solid waste: 1-receiving hopper, 2-landfill reactor, 3-mechanical mixer, 4-solar air heater, 5-articulated reflector, 6-air channel, 7-electric heater, 8-polycarbonate cover, 9-solar reflector, 10-absorber, 11-water filter, 12-valve, 13-exhaust pipe, 14-exhaust hopper.

In the daytime mode, municipal solid waste is loaded through the receiving hopper 1 into the fermentation chamber of the landfill reactor 2 without preliminary sorting. Every 2-3 hours, the mixing of the loaded municipal solid waste in the landfill reactor takes place with the help of a mechanical stirrer 3, driven manually. Then, the loaded municipal solid waste in the reactor is heated by a solar air heater (SAH) 4 from 20 to 55 °C. An articulated reflector (5) is additionally installed in the solar air heater to increase the efficiency of the installation and to ensure that the air is heated from 55 to 65 °C. In addition, the air heated from 20 to 65 °C through the air channel (6) heats the tank and lower parts of the landfill reactor surface through the active system of the solar air heater. The electric heater is a backup heater 7 and supports the creation of a stable temperature regime for anaerobic fermentation of municipal solid waste in the reactor during cloudy days and at night. This solar installation differs in that the reactor is covered on top with a translucent polycarbonate coating 8 and solar reflectors (9), which also provides the required temperature regime as a passive solar installation. Thus, the sun's rays passing through the polycarbonate coating 8 flow into the interior of the installation and heats the metal sheet, i.e. absorber 10 and due to thermal conductivity heat is transferred to the inner volume of the reactor. Within 12 days, the process of fermentation and landfill gas exits takes place, and then the landfill gas is finally sucked into the water filter 11 through the landfill reactor 2. Through the open valve 11, part of the landfill gas is sent to consumers through the pipeline from the water filter 12. After 12 days, the fermentation process ends and the spent masses of municipal solid waste are removed from the landfill reactor through the chimney 13 into the exhaust hopper 14, then the spent masses of municipal solid waste are supplied to the storage partly as fertilizers or to the solid waste disposal site.

3. Results and Discussions
To estimate the energy consumption for the processing process, the heat balance [14, 15] of solar installation for the thermal processing of municipal solid waste was calculated in the following order. The loaded mass of solid waste is determined by the formula:

\[
m_{MSW} = V \cdot \rho_{MSW}, \text{ kg (1)}
\]

\[
m_{MSW} = 1.2 \cdot 250 = 300 \text{ kg}
\]
The output of landfill gas $V_{COM}$, m$^3$, when the solid waste mass is completely decomposed, is determined by the formula:

$$V_{COM} = m_{MSW} \cdot \eta_e, \text{ m}^3$$  \hspace{1cm} (2)

where $\eta_e$ is the output of solid waste from 1 kg MSW, $\eta_e = 0.2$ m$^3$/kg, then

$$V_{COM} = 300 \cdot 0.2 = 60 \text{ m}^3$$

Draw up the heat balance of the installation in the following form:

$$Q_{RE} = Q_{FER} + Q_{LOS} - \sum Q_{R} - Q_{REF} - Q_{SAH}, \text{ W}$$  \hspace{1cm} (3)

where $Q_{RE}$ is the required thermal energy for the thermal processing of municipal solid waste, W; $Q_{FER}$ - heat consumption for heating municipal solid waste, W; $\sum Q_{R}$ - solar radiant energy passing through the translucent part of the installation, W; $Q_{SAH}$ - heat flow coming from the SAH, W; $Q_{LOS}$ - loss of thermal energy through heat transfer to the environment, W.

The amount of heat, $Q_{FER}$, kJ, required for heating the solid waste mass to the temperature of the fermentation process:

$$Q_{FER} = m_{MSW} \cdot c_{MSW} (t_{FER} - t_{MSW}) \cdot 3.6 \cdot 10^{-3}, \text{ W}$$  \hspace{1cm} (4)

The amount of heat $Q_{LOS}$, W, lost in the process of heat transfer through the wall of the reactor to the environment:

$$Q_{LOS} = k \cdot F_{tot} \cdot (t_{FER} - T_{AVER}), \text{ W}$$  \hspace{1cm} (5)

where $k$ is the heat transfer coefficient, W/(m$^2$·°C); $F_{tot}$ - total heat transfer area, m$^2$; $T_{AVER}$ - average air temperature, °C.

The heat transfer coefficient $k$, W/(m$^2$·°C), is determined by the formula[20,21,22,23,24]:

$$k = \frac{1}{\frac{1}{\delta_1} + \frac{1}{\delta_2} + \frac{1}{\lambda_1}} \cdot \text{W/(m}^2\text{·°C)}$$  \hspace{1cm} (6)

Where $\frac{1}{\delta_1}$ is the resistance to heat perception, W/m$^2$·°C; $\frac{1}{\delta_2}$ - heat transfer resistance, W/m$^2$·°C; $\delta_1$ is the thickness of the i-th layer of the fence element, m; $\lambda_1$ is the thermal conductivity coefficient of the i-th layer of the fence element, W/m·°C.

A concrete reactor with a thickness of 0.1 m was installed, thermal insulation made in the form of glass wool (0.1 m).

The flow of solar energy passing through polycarbonate glass is $\sum Q_R$ [21,22,24]:

$$\sum Q_R = q_r \cdot \alpha_{ab} \cdot \tau_{tr} \cdot F, \text{ W}$$  \hspace{1cm} (7)

where $q_r$ is the average total solar radiation, W/m$^2$; $\alpha_{ab}$ - absorption coefficient of the receiving surface of solar radiation, 0.85 - 0.9; $\tau_{tr}$ - transmittance of a translucent coating, with a single glazing is adopted 0.9; $F$ - area of the illuminated surface, m$^2$.

The energy received by the receiver from the Sun through the reflector can be determined by the equation:

$$Q_{REF} = R_{REF} \cdot A_{ref} \cdot E_{REF} \cdot F_{REF}, \text{ W}$$  \hspace{1cm} (8)

where, $E_{REF}$ -is the irradiation of the mirror reflector, W/m$^2$; $F_{REF}$ -surface area of the mirror reflector, m$^2$; $R_{REF}$ - reflectivity of the mirror reflector; $A_{ref}$ - absorption coefficient of the receive.

Useful thermal energy (heat production) of the SAH is equal to:

$$Q_{USEF} = Q_{SAH} = G_w \cdot \rho_a \cdot c_p \cdot (t_{a2} - t_{a1}), \text{ W}$$  \hspace{1cm} (9)

$$Q_{USEF} = Q_{SAH} \cdot Q_{REF}, \text{ W}$$  \hspace{1cm} (10)

where, $G_w$ - volumetric air flow, m$^3$/sec; $\rho_a$ - air density, kg/m$^3$; $c_p$ - specific heat of air, kJ/(kg·°C); $t_{a1}$ and $t_{a2}$ -
air temperature at the inlet and outlet of the SAH, ºC.

If we assume that it is \( Q_{FER} + Q_{LOS} \) equal to \( Q_{CONS} \) the total heat consumption, then,

\[
Q_{FER} + Q_{LOS} = Q_{CONS},
\]

(11)

Accept that \( Q_{R}^{\Sigma} + Q_{REF} + Q_{SAH} \) equal to \( Q_{inc} \) then

\[
Q_{R}^{\Sigma} + Q_{REF} + Q_{SAH} = Q_{inc}
\]

(12)

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.4,5 and Table 1.

**Figure 4.** Changing the internal temperature in the solar system and the waste gas outlets.

The results of calculating the heat balance of the solar installation are shown in Fig.5.

**Figure 5.** The results of calculating the heat balance of the SITPMSW.

**Table 1.** Experimental results Landfill gas outlet.

| №  | MSW weight, kg | Average temperature solar heating, ºC | Landfill gas, m³ |
|----|----------------|--------------------------------------|------------------|
| 1  | 300            | 55                                   | 63               |
| 2  | 300            | 50                                   | 55               |
| 3  | 300            | 54                                   | 60               |
| 4  | 300            | 52                                   | 58               |
| 5  | 300            | 54                                   | 61               |
4. Conclusions
The cycle of studies of the anaerobic fermentation of solid waste, carried out on the experimental solar installation, confirmed the possibility of obtaining landfill gas and high-quality biofertilizers.

Based on the results of numerical and experimental studies, a modern, effective and environmentally friendly clean energy-saving technology of anaerobic fermentation of solid waste using solar energy has been developed.

The presented option is promising, because solar energy is used to heat and maintain the temperature of the anaerobic fermentation of the mass of solid waste in the SITPMSW of various sizes.

Thus, the problem of solid waste disposal is currently really relevant, therefore our presented solution prevents the threat to the health and life of the population, as well as disruption of the ecological balance and makes it possible to obtain alternative fuel and organic biofertilizers. The proposed solar installation can be used in public utilities, agriculture and other industries.

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