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Calculation of Energy Efficiency of the Solar Installation for the Processing of municipal Solid Waste

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ABSTRACT: The article presents the developed installations for thermal processing of solid waste using solar energy and presents a technique for the technical and economic analysis of systems for processing household solid waste based on solar energy. Energy saving in systems of solid household waste. The parameters of thermal and anaerobic fermentation of the processes occurring in this installation. A calculation is performed showing the energy efficiency of the installation for the processing of solid household waste using solar energy.

KEY WORDS. Municipal solid waste, solar energy, analysis, temperature, heat,landfill gas.

I.INTRODUCTION

The modern level of development of anaerobic fermentation of municipal solid waste (MSW) makes it possible to cover 30-35% of the thermal energy needs by means of biogas. In modern constructions of MSW reprocessing plants, due to the heating by built-in sources of heat, reliable thermal insulation of reactors and continuous supply of heated fresh MSW, a constant temperature during fermentation is ensured. It provides for the mechanical mixing of the mass of solid waste for the intensification of the digestion and removal of landfill gas [1,2,3,4].

II. SIGNIFICANCE OF THE SYSTEM

We offer, developed the installation that thermal processing of solid waste with the use of solar energy to produce alternative fuel and improve the sanitary-ecological situation [5,6,7,], the experimental installation of which was created at the Department of "Thermal Power Engineering" KarIEI and shown in Fig.1.The proposed installation consists of the following elements: a landfill reactor (2), a mechanical mixer (3), a solar air heater (10), a polycarbonate coating (5), a metal sheet, i.e. absorber (4), receiving hopper (12) and water filter (13).

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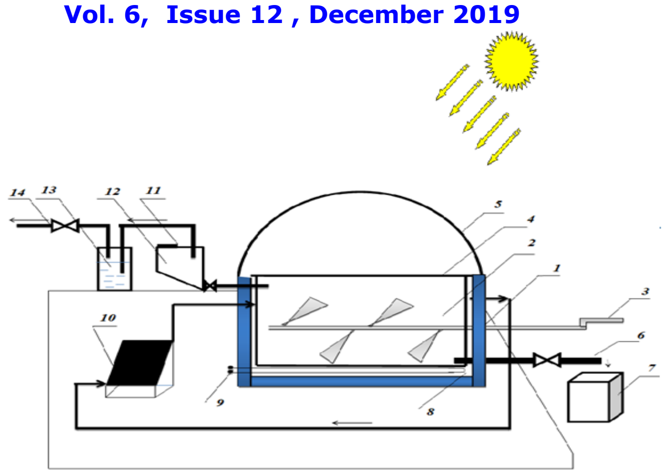

Figure 1.**Solar installation for the processing of municipal solid waste**

1-case; 2-landfill reactor; 3-mechanical mixer; 4-sheet metal (absorber); 5- polycarbonate; 6- exhaust pipe 7- exhaust hopper; 8 air channel; 9- heating element; 10- solar air heater; 11- cover; 12-hopper; 13-water filter; 14th valve

To improve energy efficiency, the device is additionally installed. The electric heater is a backup heater (9). The installation works as follows [2].

Day mode solid household waste is loaded through the receiving bin 12 into the fermentation chamber of the landfill reactor 2 without prior sorting. Every 2-3 hours the mixing of loaded solid household waste in the landfill reactor occurs with the help of a mechanical stirrer 3, driven by hand. Then, the loaded solid waste in the reactor is heated by a solar air heater (SAH) 10 to a temperature of 50-55 ° C. The heater is a backup heater 9 and supports the creation of a stable temperature regime of anaerobic fermentation of solid household waste in the reactor on cloudy days and night mode.This installation is distinguished by the fact that the reactor is covered with a translucent polycarbonate coating 5, which also provides, as a passive solar installation, the required temperature conditions. Thus, the sun rays passing through the polycarbonate glass 5 flows into the installation and heats the metal sheet, i.e. absorber 4 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, heated air to a temperature of 50-60 ° C through the air channel 8 heats the tank and lower parts of the surface landfill reactor.15-20 days occurs during the fermentation process and landfill gas outlets and then the landfill gas is finally sucked into the water filter 13 through the receiving bin 12. The valve 14 is open and part of the landfill gas is sent to consumers through the pipeline from the water filter. After 15-20 days, the fermentation process ends and the waste mass of solid household waste is removed from the landfill reactor through an exhaust pipe 6 in the exhaust bin 7 then the waste mass of solid household waste enters the partially fertilizer storage facility or landfill for solid household waste [3,5,7].

III. METHODOLOGY

1. Calculation of structural and technological parameters

Determine the daily intake of MSW m_{MSW} by the formula

$$m_{MSW} = \sum N_{inhab} \; m_{le}, \frac{kg}{day}$$

whereN_{inhab}- the number of inhabitants of the species, people;

m_{le} - daily excrement yield from the inhabitants, $\frac{kg}{person}$. (The norms of MSW accumulation in populated areas per 1 inhabitant should be taken on average at the level of 1.2 $\frac{kg}{day}$)

$$m_{MSW} = 1000 \cdot 1.2 = 1200, \quad \frac{kg}{day}$$

Determined the proportion of dry matter in MSWM_{DM};

ISSN: 2350-0328
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Vol. 6, Issue 12 , December 2019

$$m_{DM} = m_{MSW} \cdot \left[1 - \frac{\varphi_{MSW}}{100}\right], \; \frac{kg}{day}$$

wher φ_{MSW} –humidity MSW,φ_{MSW} =44.2 %.

$$m_{DM} = 1200 \cdot \left[1 - \frac{44.2}{100}\right] = 669{,}6 \; \frac{kg}{day}$$

Determine the proportion of dry organic matter in MSW m_{DOM} by the formula

$$m_{DOM} = m_{DM} \cdot \rho_{DM}$$

whereρ_{DM} - the fraction of organic matter in the dry matter, i.e.

$$m_{DOM} = 669.6 \cdot 0.558 = 373.6$$

Determine the volume of the landfill reactor V_r by the formula

$$V_{landr} = \frac{0.9 \cdot m_{MSW} \cdot t_F}{\rho_{MSW}}$$

wheret_F is the duration of fermentation, days;

$\rho_{MSW}$is the density of fermented MSW$\frac{kg}{m^3}$,

$$V_{landr} = \frac{0.9 \cdot 1200 \cdot 20}{396}$$

Determine the output of landfill gas V_{com}, m^3, with the complete decomposition of dry organic matter

$$V_{com} = m_{DOM} \cdot \eta_{EK}$$

wheren_{EK} *is the MSW output from 1 kg of DOM,* $n_{EK} = 0.14\frac{m^3}{kg}$,

$$V_{com} = 373.6 \cdot 0.14 = 52{,}3 \; m^3$$

Determine the volume of landfill gas V_{lg}, m^3, *with the selected duration of methane fermentation:*

$$V_{lg} = V_{com} \cdot \frac{n_t}{100}$$

wheren_t *is the fraction of landfill gas output for a given fermentation time,*$n_t = 50\%$.

$$V_{lg} = 52{,}3 \cdot \frac{50}{100} = 26{,}15 \; m^3$$

Monthly landfill gas production equals,

$$V_{lg}^{M} = 30 \cdot V_{lg} = 30 \cdot 26.15 = 784.5 \; m^3$$

Annual landfill gas production equals,

$$V_{lg}^{Ann} = 365 \cdot V_{lg} = 365 \cdot 26.15 = 9544.75 \; m^3$$

Determination of the average daily amount of landfill gas produced.

The amount of heat, Q_{heat}, MJ required to heat the mass of MSW loaded to the temperature of the fermentation process:

$$Q_{heat} = m_{MSW} \cdot c_{MSW}(t_{pt} - t_{lm}) \cdot 10^{-3}$$

wherec_{MSW} is the average heat capacity of the mass of MSW, c_{MSW} = 21.9 · W + 2000 = 21.9 · 44.2 + 2000 = 2.97 kJ / (kg · ^{0}C); t_{pt} - fermentation process temperature, ^{0}C; t_{lm}- temperature of the loaded mass of MSW, ^{0}C. It is assumed to be equal to the average daily ambient temperature, if it is less than 30 ° C, then it is assumed to be 30 ° C.

$$Q_{heat} = 1200 \cdot 2.97(50 - 30) \cdot 10^{-3} = 71.3 \; \frac{MJ}{day}$$

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

$$Q_{heatt} = k \cdot F \cdot (t_{pt} - t_{aver}),$$

where k is the heat transfer coefficient, $\frac{W}{m^2 \cdot {}^0C}$;

F is the surface area of the reactor, m^2;

t_{aver} - average air temperature, ^{0}C.

ISSN: 2350-0328
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Vol. 6, Issue 12 , December 2019

Heat transfer coefficient k, $\frac{W}{m^2 \cdot {}^0C}$ is determined by the formula

$$k = \frac{1}{\frac{1}{\alpha_1} + \sum \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_2}}$$

where $\frac{1}{\alpha_1}$ is the resistance to heat absorption, $\frac{W}{m^2 \cdot {}^\circ C}$;

$\frac{1}{\alpha_2}$– resistance to heat transfer, $\frac{W}{m^2 \cdot {}^\circ C}$;

δ_i – is the thickness of the i-th layer of the fence element, m;

λ_i – is the coefficient of thermal conductivity of the i-th layer of the fence element, $\frac{W}{m \cdot {}^\circ C}$.

The surface area of the reactor is determined from the expression:

$$F = S_{SIDES} + 2 \cdot S_{BASEA}, m^2$$

where S_{SIDES} + - side surface area of the reactor, m^2;

S_{BASEA} - reactor base area, m^2.

$$S_{SIDES} = 2 \cdot c \cdot (a + b) = 2 \cdot 3(6 + 3) = 54, m^2$$

$$S_{BASEA} = a \cdot b = 6 \cdot 3 = 18, m^2$$

$$F = 54 + 2 \cdot 18 = 90, m^2$$

Take a concrete reactor with a thickness of 0.1 m, the insulation is made in the form of slag concrete (0.1 m). Then the heat transfer coefficient will be equal to

$$k = \frac{1}{0{,}05 + \frac{0{,}1}{1{,}83} + \frac{0{,}1}{0{,}06} + 0{,}05} = 0{,}43, \quad \frac{W}{m^2 \cdot {}^\circ C}$$

The amount of heat Q_{heatt} equals,

$$Q_{heatt} = 0{,}43 \cdot 54 \cdot (50 - 30) = 464{,}4, \frac{kW}{day}$$

Let us translate the amount of heat lost to the environment in $\frac{MJ}{day}$:

$$Q_{heatt}^{en} = 3.6 \cdot 10^{-3} \cdot Q_{heatt} \cdot t_{wh}, \frac{MJ}{day}$$

where t_{wh} - work hours per day, t_{wh} = 12 h.

$$Q_{heatt}^{en} = 3.6 \cdot 10^{-3} \cdot 464.4 \cdot 12 = 20, \quad \frac{MJ}{day}$$

The total energy consumption for preheating the mass of MSW through heating element in the Q_{EE} reactor is determined by the formula

$$Q_{EE} = q_{norm} \cdot z, \quad kW \cdot day$$

where q_{norm} is the specific load on the heating element, $q_{norm} = 2.5, \frac{kW}{hours}$;

z - the duration of heating heating elements, z = 4 hours per day.

$$Q_{EE} = 10 \cdot 4 = 40, \quad kW \cdot day$$

We translate the values obtained in MJ:

$$Q_{EE}^{aver} = 3.6 \cdot 10^{-3} \cdot Q_{EE} = 3.6 \cdot 40 = 0.144 \; \frac{MJ}{day}$$

For the use of solar energy is mainly used polycarbonate coating (absorber) to heat the mass of MSW. The Q_s solar energy flux absorbed by the polycarbonate coating by the absorber surface is:

$$Q_s = \tau_{sur} \cdot \alpha_{ab} \cdot A_{sq} \cdot G \cdot z, \quad W$$

where G is the absorber irradiance, $\frac{W}{m^2}$, $G = 400 \; \frac{W}{m^2}$;

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International Journal of Advanced Research in Science, Engineering and Technology

Vol. 6, Issue 12 , December 2019

A_{sq} - area of the illuminated surface, m^2 $A_{sq} = 18\, m^2$;

τ_{sur} - transmittance of transparent coating protectingreceiving surface from the wind, with a single glazing is taken 0.9;

α_{ab}-the absorption coefficient of the receiving surface of solar radiation, 0.85 - 0.9;

z is the duration of heating by the polycarbonate coating, z = 8 hours per day.

$$Q_s = 0{,}9 \cdot 0{,}8 \cdot 18 \cdot 400 \cdot 8 = 41{,}472, \frac{kW}{day}$$

We translate the values obtained in MJ:

$$Q_s^{aver} = 3{,}6 \cdot Q_s = 3{,}6 \cdot 10^{-3} \cdot 41{,}472 = 0{,}149 \frac{MJ}{day}$$

Determine the consumption of heat, W, for heating the air by the formula:

$$Q_{AH} = 0{,}278 \cdot G_a \cdot c_p \cdot (t_c - t_{amt}) \cdot z, W$$

where, G_a - air flow, 5; c_p is the specific heat of air, 1; t_{amt} - ambient temperature, 25 ºC; t_c - air temperature at the outlet of the collector, 55 ºC; z is the duration of the heating of the high-voltage regulator, z = 8 hours per day.

$$Q_{AH} = 0{,}278 \cdot 5 \cdot 1 \cdot (55 - 25) \cdot 8 = 333{,}6\; kW \cdot day$$

We translate the values obtained in MJ:

$$Q_{AH}^{aver} = 3.6 \cdot 10^{-3} \cdot 333.6 - 1.2\; \frac{MJ}{day}$$

Total energy costs to maintain the process per day:

$$Q_{costs} = Q_{heat} + Q_{heat}^{en} + Q_{EE}^{aver} + Q_{AH}^{aver}, = 71.3 + 20 + 0.144 + 1.2 = 92.793, \frac{MJ}{day}$$

The amount of landfill gas required to maintain the process:

$$V_{\lg r}^{aver} = \frac{Q_{costs}}{q_{lg}} = \frac{92.793}{25} = 3.71\,, \frac{m^3}{day}$$

The amount of landfill gas $Q_{\lg am}^{aver}, \frac{m^3}{day}$ equals

$$V_{\lg am}^{aver} = V_{lg}^{aver} - V_{\lg r}^{aver} = 26.15 - 3.71 = 22.44, \frac{m^3}{day}$$

The annual sales amount of landfill gas $V_{\lg am}^{ann}, \frac{m^3}{year}$, equals

$$V_{\lg am}^{ann} = V_{\lg am}^{aver} \cdot 365 = 22.44 \cdot 365 = 8190.6, \frac{m^3}{year}$$

Calculation of energy efficiency indicators

The potential energy of landfill gas Q_{GEN}, generated for the year is determined by the formula

$$Q_{GEN} = V_{lg}^{ann} \cdot q_{lg} = 9544.75 \cdot 25 = 238618.7, MJ$$

The energy effect of the landfill plant for the year equals

$$E_{eff} = V_{\lg am}^{ann} \cdot q_{lg} = 8190.6 \cdot 25 = 163812, MJ$$

Installation marketability ratio

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 6, Issue 12 , December 2019

$$К_{am} = \frac{E_{eff}}{Q_{GEN}} \cdot 100 = \frac{163812}{238618{,}7} \cdot 100 = 68{,}6\ \%$$

Annual savings of equivalent fuel will be:

$$B_{t.c.f.} = \frac{E_{eff}}{29300} = \frac{163812}{29300} = 17{,}62\ t.c.f.$$

IV. CONCLUSION AND FUTURE WORK

On the basis of the performed calculations, it was obtained that the use of this installation allows to save 17.62 t.c.f. on heat supply of a pigsty.

Preliminary calculations and tests show that the developed facility ensures a stable temperature regime for the fermentation of solid waste and saves thermal energy by 30–40%.

In general, the proposed developed solar installation for the processing of municipal solid waste, both in cities and waste from plant growing and livestock farming, eliminates landfills, as they are now called sanitary-ecological landfills, and will transform the municipal services of settlements from unprofitable to profitable and the environmental situation will improve significantly.

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