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Calculation of energy indicators of three-stage bioreactor

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Abstract
The article deals with the energy indicators of a three-stage bioreactor for the technological production of liquid organic fertilizer. The results of the analysis of the basis of single–stage processing and equipment for obtaining biofertilizers are given. The technological parameters of the developed three-stage bioreactor based on the conditions of uniqueness of the similarity theory methods and thermal similarity criteria are substantiated.

Keywords: agriculture, animal husbandry, biofertilizer, processing, substrate, manure, waste, bioreactor, biogas unit, biogas, fermentation, manure removal

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INTRODUCTION

The current level of development of anaerobic fermentation of manure effluents allows to cover by biogas 30-35% of the needs of livestock farms in thermal energy. In modern designs of biogas units due to heating by built-in heat sources, reliable thermal insulation of methane tanks and continuous supply of heated fresh substrate provides a constant temperature during fermentation. Mechanical mixing of the substrate for intensification of fermentation and biogas removal is provided.

Most biogas units are based on the flow principle of action, i.e. the incoming raw materials immediately displace the waste. A fresh portion of manure is supplied continuously in portions (2-10 times a day), and biogas selection and sludge removal are carried out as necessary (Fantozzi and Buratti 2009, MT 2012).

A conventional biogas unit consists of the following elements: intake reservoir, a fermentation chamber (methane tank, reactor), a heating device (heat exchanger), a device for mixing the substrate, a gas holder and a gas water heater.

The raw material from the loading hopper enters the reactor, where it is fermented, resulting in the formation of biogas coming through the water lock into the gas holder. Part of the biogas is sent to the boiler to maintain the required temperature in the methane tank. The biomass is stirred by means of a stirrer driven by an electric motor. The spent raw material from the methane tank enters the storage of biofertilizers.

One of the most promising areas of processing of manure and other organic waste – biothermal transformation by anaerobic fermentation. This fermentation allows you to stabilize the fertilizer potential of raw materials and at the same time to obtain methane.

The following anaerobic digestion technologies are most common: 1) spontaneous fermentation using microflora present in the raw materials themselves in a psychrophilic, mesophilic, and thermophilic regime; 2) technology of effective microorganisms (TEM); 3) technology of immobilization of active microorganisms; 4) three-stage processing of biomass - the main stage of bioprocessing in the methane tank and two stages of processing of "cold" tanks; 5) technology of separation of the acid and alkaline stages of fermentation; 6) the technology of periodic, cyclical submission of the substrate to several reactors with a phase shift of their loading; 7) the technology of the flow of the substrate into the reactor (Fantozzi and Buratti 2009, Luzhkov et al. 2011, MT 2012, Patent DE 10316680 2003).

To meet environmental and sanitary requirements, the following substrate disinfection technologies are used: 1) pasteurization; 2) electrolytic sterilization; 3) disinfection without chemical reagents using electrophysical and electrochemical processing; 4) technology for processing waste into liquid fuels; 5) technology of waste processing by the dry method (Davooabadi and Aghajani 2013, Keshuov and Barkov 2011).

Physico-chemical and biochemical properties of manure allow to apply several methods of preliminary preparation: 1) homogenization of manure and its

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standing at a temperature of the process until the complete consumption of oxygen from the working mixture - this creates microaerophilic conditions for the activation of acid microflora; 2) chemical treatment with weak acid or alkali and standing similar to the first option; 3) treatment with a complex of hydrolytic groups of microorganisms.

The technological parameters of preliminary preparation (Shalimov et al. 2010) manure is produced in thermophilic conditions at a temperature of 50-55 ºC. The most active phase of the formation of volatile acids occurs after 25-35 hours, and their content increases by 60-90% compared to this indicator in the original manure. In the preparation of manure in mesophilic conditions (30-35ºC) the content of volatile acids increases slightly. Treatment of manure with a complex of hydrolytic microorganisms at a temperature of 55 °C can reduce the preparation time to 16-18 hours and increase the rate of biogas production by 30-45%.

To increase the release of biogas «Firm MT-BiomethanGmbH» (Germany) uses the technology of 3-stage fermentation, the main anaerobic digestion in the methane tank, fermentation in the “cold” tank and residual gas release in the storage tank of the finished fertilizer (MT 2012).

As another variant of this technology, by firm «UbitecGmbh» (Germany) proposed a fermentation technology, which consists of 2 stages: the acid stage takes place in the preliminary bioreactor, the alkaline stage takes place in the main reactor (Anonymous n.d.a, Börjesson and Berglund 2007).

In biological redox processes, which include methane fermentation, the concentration of hydrogen ions (pH) significantly affects the activity of enzymatic reactions. Many experts believe that the optimal pH value for methane bacteria is 7.0-7.6, the extension of this interval to 6.5 reduces the biogas yield by 30-40%, and to 6 – almost completely inhibits the development of methane microflora (Anonymous n.d.b, Semblante et al. 2014).

The advantage of dividing and extending the process of anaerobic digestion into separate phases or stages is that in each phase optimal conditions for the development and functioning of the microbial population are created, which is necessary to improve the efficiency of biomass fermentation.

Thus, the state analysis of stability and intensity of the methane fermentation process in the bioreactor depends on the balance of all stages of the process, the optimal interaction of all groups of microorganisms in each phase of processing.

MAIN PART

The acceleration of the waste processing process is achieved in the acidic stage of fermentation of the substrate, where strains of effective microorganisms containing Corenebacteriumspecies, Pseudomonasspecies, Arthrodactersimplex in organic acid are introduced into it. The use of a balanced syntrophic association of microorganisms can reduce the period of withdrawal to the operating mode to 2-3 days and start a continuous process with a fairly high daily dose of loading – 30-35%. However, in this case, the introduction of intermediate tanks for growing the required amount of seed material is required, but these costs are recouped due to the intensification of the process by 2-3 times (ETC Energy 2000, Timur et al. 2015).

It is interesting to use the technology of effective microorganisms (TEM), developed by Professor Higa from the University of Okinawa (Japan) (Bruce et al. 1987, Şen et al. 2014). The rate of biochemical reactions increases in proportion to the increase in temperature, for biochemical reactions such dependence is observed to a certain limit. As is known, the fermentation of manure biogas is 2.5-3 times faster in thermophilic conditions (40-55°C) than in mesophilic (25-35°C).

However, the allocation of biogas depends not only on the dose of loading, but also on the method of introducing raw materials into the reactor. With other things being equal, the discrete supply of manure is more efficient than a single, while the amount of decomposed organic matter and the output of biogas is 38-50% higher. It is also possible to accelerate the exit from the reactor to the operating mode by using new efficient associations of microorganisms by introducing them in the form of seed material simultaneously with the prepared manure.

In the results of the analysis of the results of populous research scientists in this area shows that multi-level mixing and forced degassing accelerate the process. With mixing, it is possible to achieve uniform distribution of the loaded manure and microorganisms in the reactor, and with the help of forced degassing to prevent the accumulation of intermediate and final products of metabolism.

In most biogas units, the cleavage processes take place in parallel, that is, they are not separated either geographically or in time. Such technologies are called single-stage (**Fig. 1**). For substrates with rapid cleavage, which because of this tend to oxidation, it is recommended to provide a separate tank for hydrolysis and oxidation, so that decomposition products are dosed out of it at the fermenter (two-stage technology).

The advantage of a multi-stage process is maintaining the efficiency of the bacteria action through the creation of optimal living conditions (primarily the pH level). In this way, greater biogas production can be achieved. In addition, the unused gases due to this section can be separated through the biofilter, thus separating only the gas with high methane content.

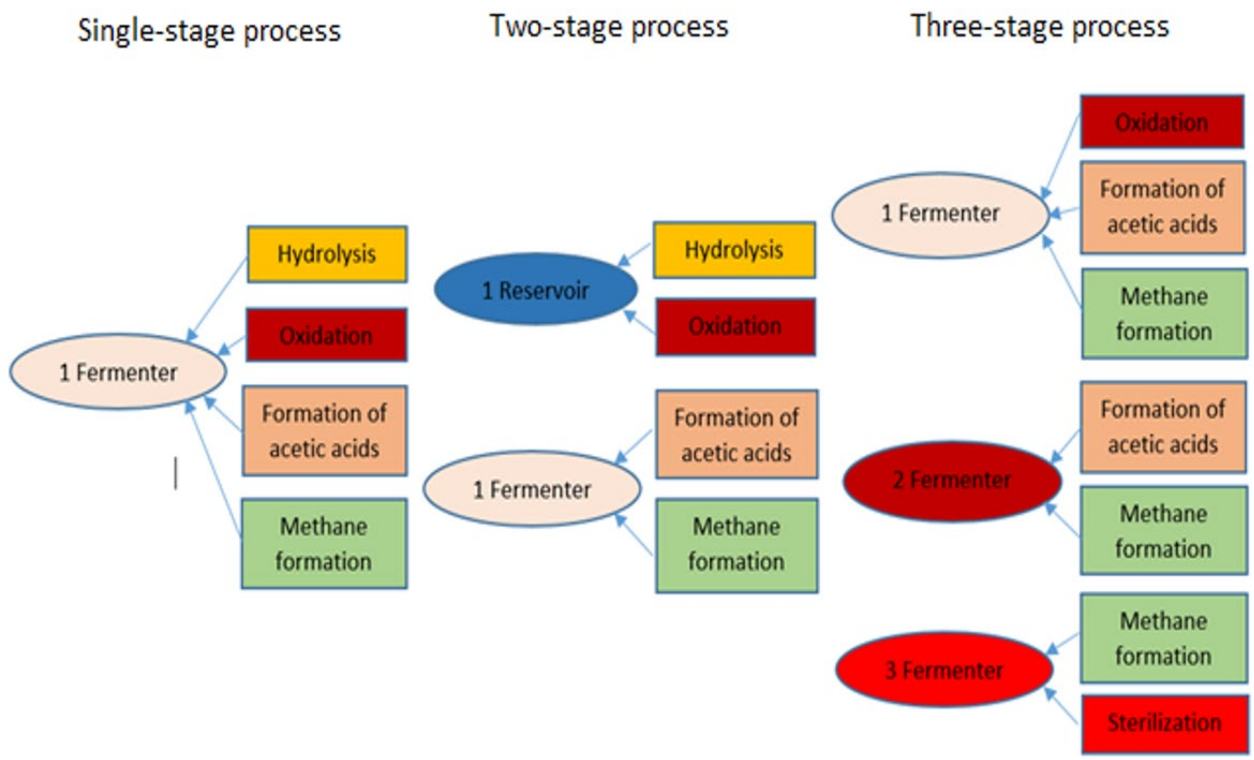


Fig. 1. Single, two and three-stage processes

Although the phase separation best suits the conditions of vital activity of bacteria and has its advantages, such two-stage technologies are not widely used. Additional losses for the second tank, for mixing systems, heating and pumps can be recouped only for certain types of substrates.

On the other hand, in practice it is quite often possible to find two alternately connected reservoirs. In such cases, the first tank is a real fermenter, equipped with heating, agitators, designed for short-term fermentation and the use of rapidly decomposed substrates. In the second tank, added to the first one and, in principle, a fermenter without heating, gas is formed from substrates that decompose not so quickly, and, accordingly, the fermentation process in it lasts longer.

From the point of view, the acceleration of anaerobic fermentation processes and sterilization of harmful microbes in bioreactors is the most effective model of a three-step bioreactor. In contrast to the two-stage, instead of the hydrolysis stage, a three-stage bioreactor is provided with a capacity for preparing the substrate and then 2 fermenters with a heating temperature up to 70°C, providing a thermophilic mode, as well as a sterilizer for an ultra-thermophilic mode, providing sterilization of microbes.

Additional losses for two fermenters and a sterilizer, for mixing systems, heating and pumps can pay off only for certain types of substrates. On the other hand, in practice, quite often you can find many alternately interconnected tanks. In such cases, the tanks act as real fermenters with heating equipment, agitators, designed for short-term fermentation and the use of rapidly decomposable substrates.

The amount of gas that can be produced will be the same with a sufficient amount of fermentation time. There are three typical temperature regimes in which the corresponding strains of bacteria feel well: psychrophilic strains at temperatures below 25°C; mesophilic strains at a temperature of 25-45ºC; thermophilic strains at temperatures above 45ºC.

Most installations operate in mesophilic mode. Due to the large excess heat from the generator for such installations, there is a tendency of high temperatures of the fermenter. In Germany, most biogas units operate at temperatures of 38-42ºC, a psychrophilic mode due to a long fermentation time and low gas production. For our region, installations with a thermophilic mode of operation are increasingly in demand, not least through all large-scale installations they are equipped automated control devices.

The temperature effect of the fermenter on the activity of bacteria is shown in **Fig. 2**. The higher the temperature, the more sensitive the bacteria to its fluctuations, first of all, if they are short-term. This is clearly seen from the relatively narrow maximum of the curve and its rapid fall in the thermophilic regime. While in the mesophilic mode daily fluctuations of 2-4ºC hardly have an effect on bacteria, then in the thermophilic mode such fluctuations should be no more than 1ºC. A one-

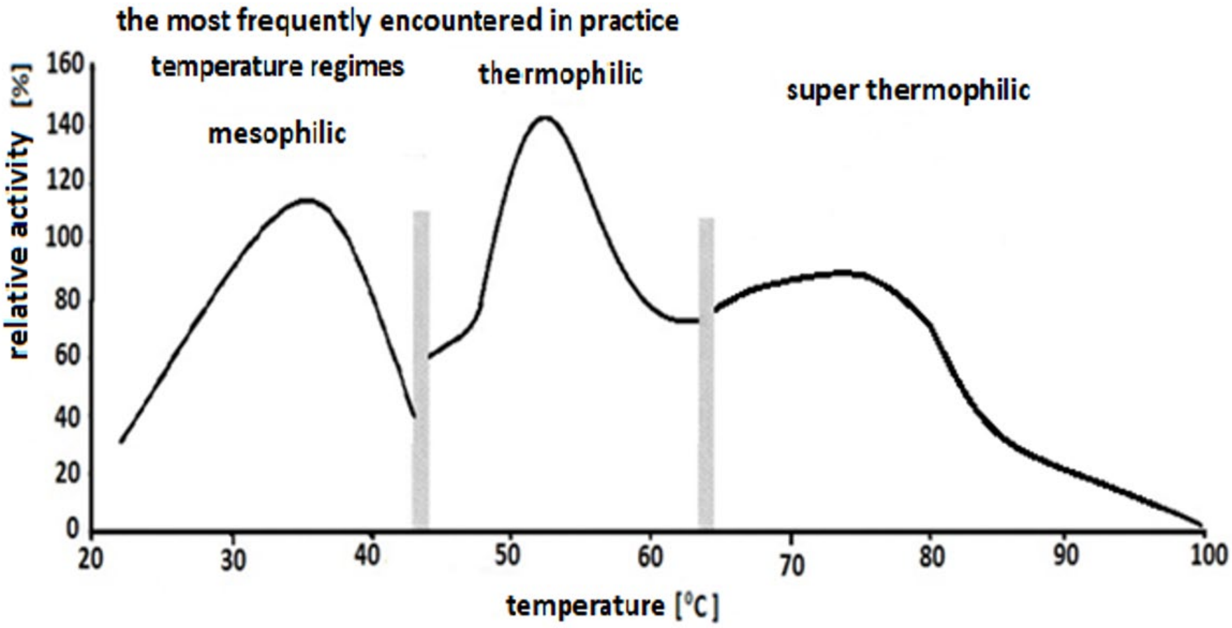


Fig. 2. The effect of temperature on the activity of bacteria with medium acidity

time placement of poorly compacted material (with a large amount of oxygen) or a large amount of very cold material, as well as stopping the operation of the agitator for several hours (primarily in winter), can cause such a temperature change of 1ºC.

Interestingly, in installations, operating on renewable raw materials, higher temperatures are observed than was indicated for the construction of heating. At the same time, the anaerobic process, unlike composting, is not exothermic; much more energy will accumulate in methane.

A large amount of easily processed substrate, which is a vegetable, leads to irreversible oxidation reactions with a corresponding heat release, this effect of course reduces the heat consumption of the installation and should be observed for each installation separately and be taken into account the specifics of the installation.

Operation at high temperatures requires the installation of special automation systems and precise control of the biogas unit. In our time, when it comes to the full integration of biogas units into the daily work of an agricultural enterprise, the mesophilic regime creates simply less difficulties. Today, the trend is that work in higher temperature conditions of the fermenter, as the operation of the installation has become a separate activity and requires appropriate personnel. For a long period of time (1 month or more), the bacteria get used to the new temperature regime, so that each company can choose the best option.

One of the ways to increase the biogas yield is the use of various stimulating exogenous additives: methanol, acetate, cellulose, etc. Addition of ascorbic acid to the substrate in combination with CA-L-ascorbate, according to the technology developed by firm SchmackBiogasGmbH (Germany). As an indicator of the efficiency of anaerobic fermentation, the Redox potential is determined, which is an electrochemical criterion (Dochain and Vanrolleghem 2001, Shalimov et al. 2010). The introduction of exogenous additives reduces the time of withdrawal of the methane tank to the operating mode up to 3-5 days.

Current trends in the development of biogas technologies and ways to improve the efficiency of biogas units of organic waste methane fermentation in anaerobic conditions. In the future, it is necessary to investigate methods of controlling the activity of microorganisms in the anaerobic decomposition of organic waste with the extension of the time of simultaneous continuous processing. This allows to form microbial communities with a given physiological activity, directed to regulate the metabolism of microorganisms and the depth of substrate decomposition.

Method of Determination of Energy Indicators

Energy assessment - the consumption of thermal energy and biogas for technological needs, the amount of thermal energy obtained by burning biogas, thermal power and heating elements; specific energy capacity of the process.

The basis of the method of production tests are the standards of RK OST 102.1-97 “Technical expertise” and GOST 31343-2007 “Machines and equipment for processing and disinfection of liquid manure. Test method”.

Operational-technological assessment – the time of heating the biomass in the reactor, the temperature of the biomass, the amount of processed bio-waste, the average daily production of organic fertilizers; average yield biogas, evaluation of productivity and technical level of the bioreactor is carried out in accordance with R–50–605–65–94, STP 5-98 and GOST 31343-2007.

The volume of effluents, entering the processing, is determined by the calculation method according to the average daily yield of manure and consumption of process water. The consumption of process water is determined by the water meter with a measurement error of ±0.001 m.

The temperature and relative humidity of the ambient air, the presence of hydrogen sulfide, ammonia, carbon dioxide in the air is determined before the equipment starts operating and at the end at three points on the diagonal of the room at the level of 0.3 m from the floor. Type of organic waste (manure) - according to GOST 20432.

The method for determining the dry residue in organic waste is determined according to GOST 26713. The density of manure is determined by weighing it in a container with a capacity of at least 0.008 m. The experiment is repeated three times. The weighting error is ± 0.1 kg, the average measurement value is calculated with rounding to the first decimal place.

Acidity of organic waste (manure) is determined according to GOST 27979.

The temperature of the liquid manure entering the biological processing is determined by thermocouples at the entrance to the installation at regular intervals washed down constantly per shift. Measurement error - ±1 °C. Repeat the experiment three times. The average value of the measurements is calculated by rounding to the nearest whole number.

The effectiveness of disinfection by the presence of weed seeds E_s, %, is calculated by the formula:

$$\mathbf{E_s = K_1 - K_2}$$

where K_1 - the germination of weed seeds in the source material; K_2 - the germination of weed seeds in the final product, in (%).

The effectiveness of disinfection by the presence of bacterial contamination, helminth eggs and weed seeds is calculated with rounding to an integer.

Research Results

The basis for controlling the biosynthetic activity of microorganisms - the reaction of the microbial cell to changes in external conditions. Therefore, for the development of technological modes of cultivation of microorganisms, it is necessary to study, how the state of the system affects the kinetics of methanogenesis. This will provide the initial data for the development of design and technological scheme of high-performance equipment.

To calculate the energy indicators, the substrate temperature of the three-stage bioreactor t_{PR} is set, necessary for the implementation of the technological process, then the total energy consumption for maintaining the Q_T process is taken as an unknown quantity, and the temperature t_{PR} is an independent input.

The technology of controlled three-stage anaerobic and thermal neutralization allows to reduce costs, and the complex of automatic control and management minimizes the involvement of personnel and allows obtaining a stable quality of liquid fertilizers (Aldabergenov and Orynbayev 2015).

The technology of controlled three-stage anaerobic digestion and thermal neutralization allows to reduce costs, and the complex of automatic control and management minimizes the involvement of personnel and allows obtaining a stable quality of liquid fertilizers (Aldabergenov and Orynbayev 2015).

Submission of the substrate to the first reactor is carried out by a pump, where the process of fermentation begins, of anaerobic fermentation at temperatures up to 50°C. The substrate with the temperature (t_{PR1} = 46°C) from the first reactor is pumped to the second reactor, where the process of fermentation continues, anaerobic fermentation with a higher temperature - about 70°C, which results in accelerated decomposition of organic waste.

The substrate with the temperature (t_{PR2} = 66°C) from the second reactor is pumped to the third reactor, where the high-temperature processing process with a temperature (t_{PR3} = 96°C) continues, which results in accelerated neutralization of organic waste. The substrate in the bioreactors is mixed automatically to a uniform consistency for 15 minutes, every 4 hours.

The solution of the problem in this formulation can be carried out within the framework of both the stationary and non-stationary thermal conditions. In the first case, it boils down to determining the estimated total energy consumption of the energy Q_T to maintain the process, the second - the law of the time variation of the loading temperature t_{LOAD1}, t_{LOAD2}, t_{LOAD3} and the temperature in the three-stage bioreactor t_{PR1}, t_{PR2}, t_{PR3}.

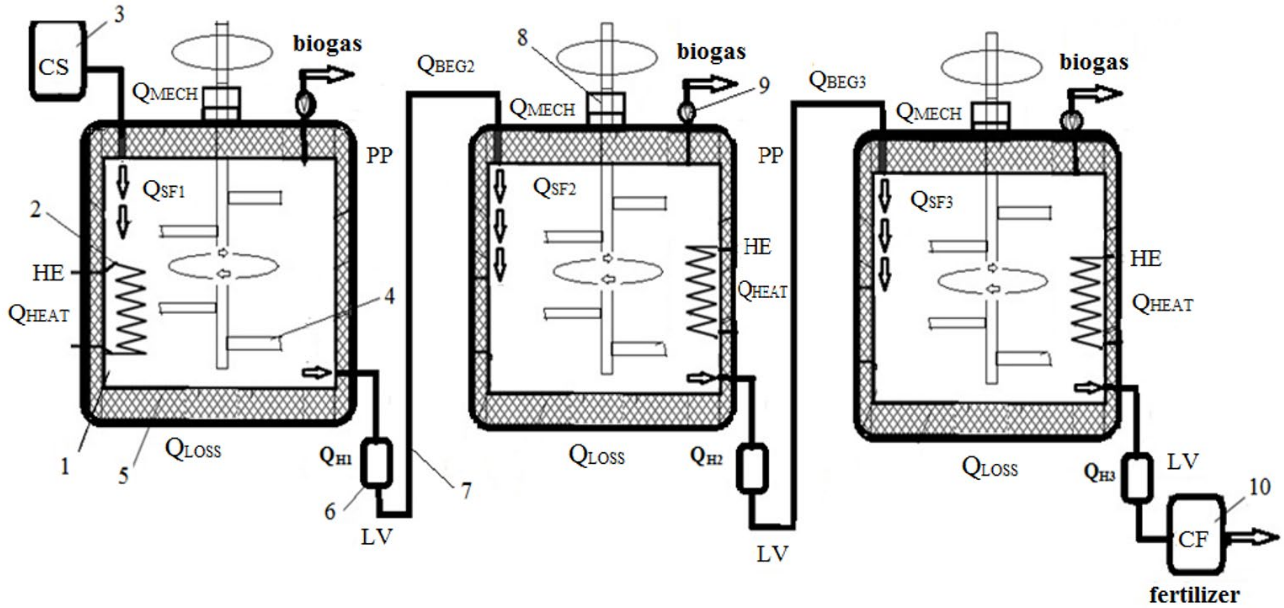
Heat fluxes of biogas unit are shown on the schematic diagram of heat exchange of its elements (**Fig. 3**). On the basis of the above, the equations of the analytical model of the biogas unit are formed.

To clarify the energy indicators of the three-stage bioreactor, we determine the amount of heat (Dochain and Vanrolleghem 2001, IWA Task Group for Mathematical Modelling of Anaerobic Digestion Processes 2002, Vachagina and Karayeva 2009), Q_{HEAT}, kW, required for heating the loaded mass to the temperature of the fermentation process taking into account the parameters obtained as a result of measurements in the laboratory installation:

For the first reactor $Q_{HEAT1} = m_{BM1} \cdot c_{BM} (t_{PR1} - t_{LOAD1})$;

For the second reactor $Q_{HEAT2} = m_{BM2} \cdot c_{BM} (t_{PR2} - t_{LOAD2})$;

For the third reactor $Q_{HEAT3} = m_{BM3} \cdot c_{BM} (t_{PR3} - t_{LOAD3})$;



1 - bioreactor; 2 - heating element (HE); 3 - container for substrate preparation (CS); 4 - blade of substrate mixer; 5-thermal isolation; 6-electric pump-substrate shredder (LV); 7-process pipelines (PP); 8-mixer; 9-valve for gas;10-container for accumulation of finished fertilizer (CF)

Fig. 3. Structural model of laboratory installation of three-stage bioreactor

where c_{BM} - the average heat capacity of biomass, c_{BM} = 4.18 kJ/(kg ^{0}C); t_{PR} - the temperature of the fermentation process, ^{0}C; (t_{PR1} = 46^{0}C, t_{PR2} = 66^{0}C, t_{PR3} = 96^{0}C); t_{LOAD} – the temperature of loaded biomass, ^{0}C. Shall be equal to the average monthly ambient air temperature, if less than 5^{0}C, was adopted (t_{LOAD1} = 5^{0}C, t_{LOAD2} = 46^{0}C, t_{LOAD3} = 66^{0}C); m_{BM} – general biomass, kg (m_{BM1} = 47 kg, m_{BM2} = 45 kg, m_{BM3} = 43 kg).

$$Q_{HEAT} = \sum Q_{HEAT1} + Q_{HEAT2} + Q_{HEAT3}$$

Heat loss Q_{LOSS}, kW, lost in the process of heat transfer through the wall of the bioreactor into the environment:

For the first reactor $Q_{LOSS1} = k_1 F_1 (t_{PR1} – t_{AV1})$,

For the second reactor $Q_{LOSS2} = k_2 F_2 (t_{PR2} – t_{AV2})$,

For the third reactor $Q_{LOSS3} = k_3 F_3 (t_{PR3} – t_{AV3})$,

where k - the heat transfer coefficient, W/(m$^{2}\cdot{}^0$C); F - the surface area of the methane tank, m^2; t_{AV} - the average monthly air temperature, ^{0}C.

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

$$k = \frac{1}{\frac{1}{\alpha_1} + \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_2}}$$

where 1/α_1 - heat perception resistance, 1/α_1 = 0.05 (m$^{2}\cdot{}^0$C)/W; 1/α_2 - heat transfer resistance, 1/α_2 = 0.05 (m$^{2}\cdot{}^0$C)/W; i - the thickness of the i-th layer of the fence element, m; i - the coefficient of thermal conductivity of the i-th layer of the fence element, m^{0}C/W. δ_1 - thickness of wall layer and insulation, λ_1 - coefficient thermal conductivity of the layer.

$$Q_{LOSS} = \sum Q_{LOSS1} + Q_{LOSS2} + Q_{LOSS3}$$

The total energy consumption for the mechanical mixing of the substrate in the reactor Q_{MECH} is determined by the formula

$Q_{MECH} = q_{norm} \cdot V_R \cdot z$, kW·h,

$$q_{norm} = 50 \frac{W * h}{m^3}$$

For the first reactor $Q_{MECH1} = q_{norm} \cdot V_{R1} z_1$, kW·h,

For the second reactor $Q_{MECH2} = q_{norm} \cdot V_{R2}\, z_2$, kW·h,

For the third reactor $Q_{MECH3} = q_{norm} \cdot V_{R3} z_3$, kW·h,

where q_{norm} - specific load on the mixer; V_R - reactor volume, m^3;

z - the duration of the operation of the mixer, z = 1.5 hours per day.

$Q_{MECH} = \sum Q_{MECH1} + Q_{MECH2} + Q_{MECH3}$;

The energy of the process of the substrate fermentation in the Q_{SF} reactor is determined by the formula

$Q_{SF} = (0{,}1 Q_{HEAT})$, kW;

The total energy costs of maintaining the process:

$Q_T = Q_{HEAT} + Q_{LOSS} + Q_{MECH}, + Q_{SF}$ (kW/day),

Specific energy consumption per unit of production, liquid fertilizer

$$q_{FERT} = \frac{Q_T}{G_{FERT}}, (kW/l)$$

Specific energy consumption per unit of product, biogas

$$q_{BG} = \frac{Q_T}{G_{BG}}, (kW/m^3)$$

As a result of measurements made in the laboratory installation of a three-stage bioreactor (**Fig. 4**), energy indicators were established.

Fig. 4. Laboratory installation of a three-stage bioreactor

In the reactors, liquid level control sensors are installed, which provide a stable level of the substrate, when triggered, affect the pump shut-off, as well as a temperature controller sensor, that maintains a stable temperature in the reactor and when the temperature of the substrate increases or decreases, turns off and turns on the heating elements (Aldabergenov and Orynbayev 2015).

Laboratory facility, other than the above, is also equipped with a gas and electrical energy meter to measure the produced biogas and the consumed electrical energy for heating, mixing and pumping the substrate.

During the operation of the installation, automatic control is provided in the first reactor to provide a mesophilic mode with a substrate temperature (t_1 = 39-51°C), in the second reactor a thermophilic mode with a substrate temperature (t_2= 56-65°C), as well as in the third (sterilizer) over a thermophilic mode with a substrate temperature (t_3= 79-91°C).

The technological assessment of the process of fertilizers' production in a laboratory installation is determined by the time of heating the biomass in the reactors in different modes, the temperature of substrate t_{PR}(°C), the intensity of the substrate circulation, volume of substrate(l), the average daily production of organic fertilizers; the average daily biogas yield (m^3/h), and also consumed electrical energy (kW).

According to the results of the calculation and experimental study, a graph of the average daily energy consumption and the temperature of the substrate to the stages (reactors), depending on the duration of processing (**Fig. 5**).

And the results of the study were used to chart changes in specific energy consumption for unit of liquid fertilizer production q_{FERT} and biogas q_{BG}, by stages depending on the duration of processing (**Fig. 6**).

Energy analysis indicators of the thermo-biological processing processes of the substrate in a three-stage bioreactor due to the sequence of the stage of the substrate processing, the anaerobic process is accelerated. Change in the average daily energy consumption indicators depending on the duration of processing (**Fig. 5**), shows a gradual increase from 6.8

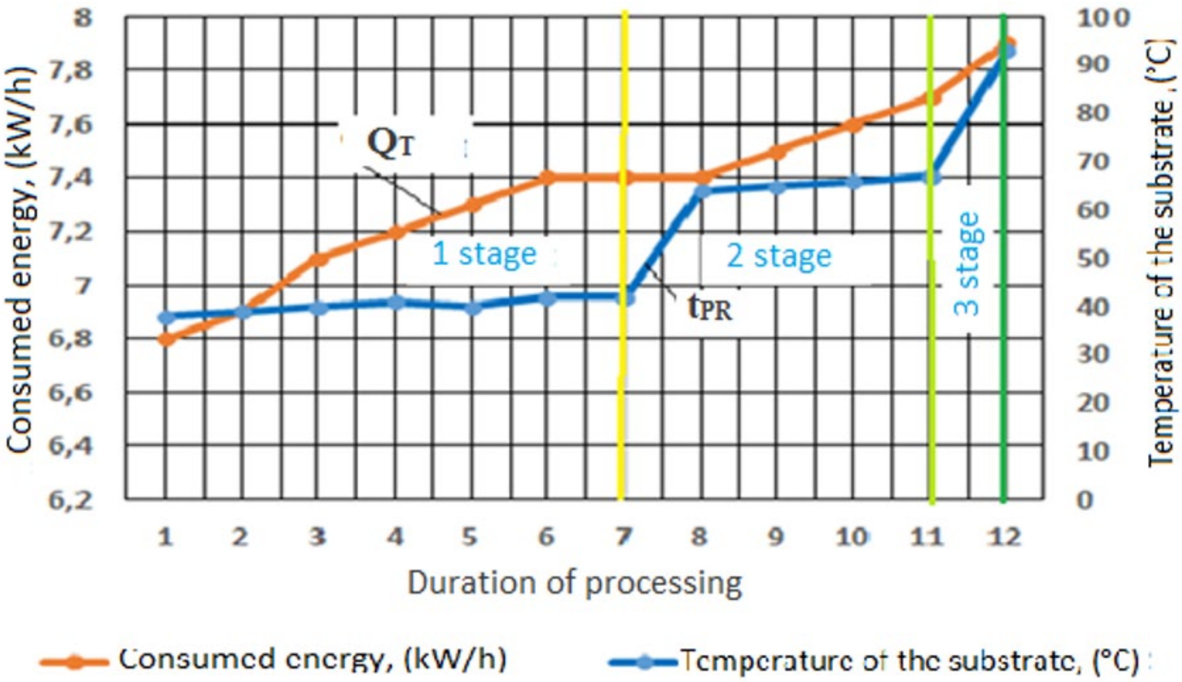


Fig. 5. Changes in the average daily energy consumption and substrate temperature depending on the duration of processing

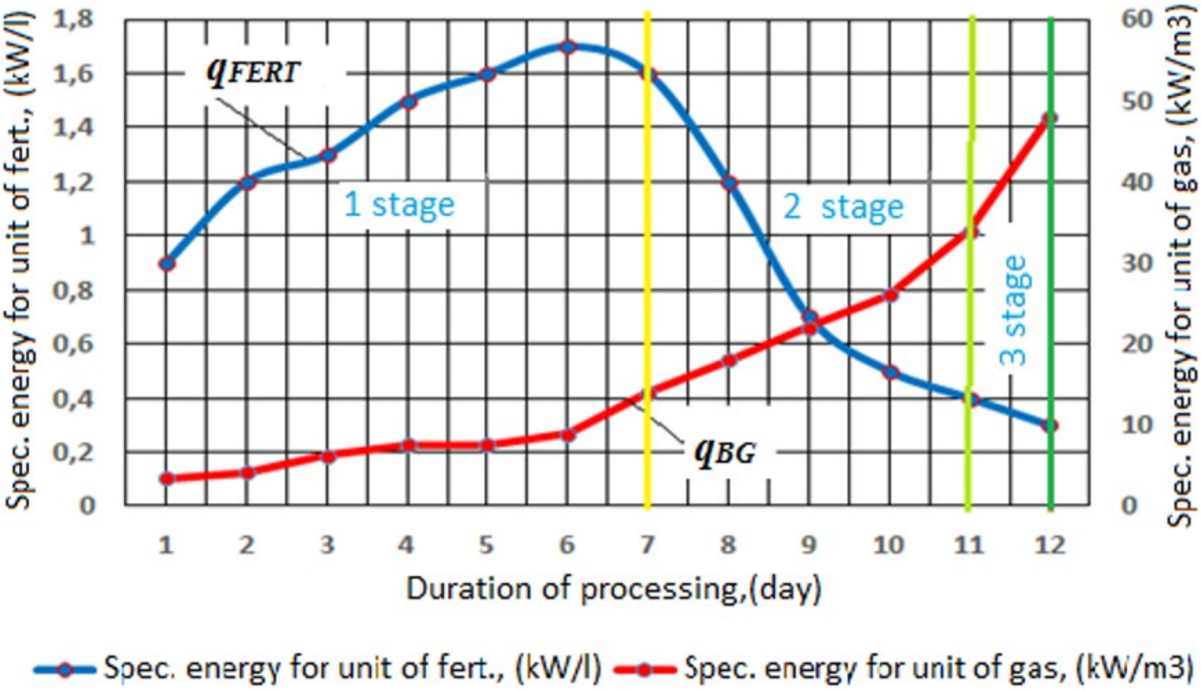


Fig. 6. Change in specific energy consumption per unit of product depending on the duration of processing

to 7.4 kW/h, at the beginning of the first stage for 6 days, stabilization at the level of 7.4 kW, at the end of the first and the beginning of the second stage for 3 days, as well as an increase to 7.8 kW at the end of the second and third stage for 4 days. The change in the indicators of the average daily temperature of the substrate shows its gradual increase in the first stage about 50^0C, in the second stage about 70^0C, in the third stage about 90^0C.

Changes in the specific energy consumption indicators per unit of liquid fertilizer production q_{FERT} (**Fig. 6**) in stages depending on the duration of processing, shows an increase in the first stage from 0.8 to 1.6 kW/l, within 7 days, in the second stage decrease from 1.4 to 0.4 kW/l, and in the third stage a decrease from 0.35 to 0.4 kW/l. Specific energy consumption per unit of biogas production q_{BG}, shows a gradual increase in the first stage from 0.1 to 0.4 kW/m^3 within 7 days, in the second stage increase from 0.4 to 1kW/m^3 for 4 days, and in the third stage increase to 1.4 kW/m^3. The increase in specific energy costs for biogas production is associated with a decrease in the volume of gas yield.

The results of the analysis of the energy indicators of the processes of the substrate thermo-biological processing in a three-stage bioreactor due to the continuity of the processing stage of substrate proves the acceleration of the anaerobic fermentation process by 3 times. The use of a three-stage bioreactor allows continuous production of liquid organic fertilizers with high energy efficiency.

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