Intensified Anaerobic Organic Waste Disposal under Extreme Natural Temperatures of the Environment

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Abstract. The technology of anaerobic organic waste disposal is presented under psychrophilic conditions using the adjusted mesophilic additive. The evidence justifying the adaptation of the existing biogas technologies for their profitable use at low natural temperatures is provided. Ways for the improvement of waste disposal in biopower plants are developed. The technological process of anaerobic digestion of organic waste that has six stages.

1. Introduction
The pertinence of the publication is determined by the lack of technologies for disinfecting and recycling animal farming waste that could be employed under low natural temperatures in the coldest populated region in the world.

Today organic animal farming waste (deer farming, cattle, horse-breeding) in the eastern sector of the Russian Arctic are not recycled and used die the lack of recycling technologies adjusted to low temperatures [1, 2, 3, 15, 16, 18]. Thus, the waste is not disinfected and there are waste deposits dating back many years next to animal farms. It is known that low temperatures help preserve malignant pathogenic flora and weed seeds in manure, and in spring together with melt water they get into lakes and water bodies, also the thin soil layer is contaminated that ensures the life and sustainability of natural ecosystems in the Arctic. Under such conditions, the natural decomposition of organic waste lasts for about two or three years, while in bioreactors it only takes a month. When the best technology is used, liquid biomass can turn into valuable energy raw materials, and as a result of recycling, it can also be used as organic fertilizer in households (country houses, house plants, landscape design) and for the creation of winter gardens in companies under the conditions of long polar night [9].

What is more, dried substratum that is produced as a result of fermentation in a digestion tank is a valuable feeding additive [6], and can also be used as heat-insulation material.

This is why the introduction of an animal farming waste disposal technology is a pertinent task with scientific and practical value as it would ensure both environmental safety and promote the creation of an energy-saving self-contained production that provides mineralized organic fertilizer enhancing agricultural crop yield, a feeding vitamin additive, and an additional source of power in the form of biogas.

The scientific value of this technology is associated with the following:
- using mesophilic microorganisms adapted to psychrophilic conditions;
- technical solutions as part of an energy saving organic waste disposal technology that ensures
sustainable operation of a biopower plant under the psychrophilic regime.

The innovative nature of the technical devices that support the energy-saving technology for the production of mineralized organic fertilizer is confirmed by five patents for inventions and useful models of the Russian Federation.

The proposed biogas technological line produces on average 0.18 m$^3$ of biogas with the 40-46% of methane. Such biogas without purification can be burnt in household gas ovens. But if taken more rationally, the gas can be purified and harmful impurities can be removed, and then an opportunity to save money on motor fuel also arises.

In our opinion, in Yakutia the most useful way to dispose of organic waste is anaerobic fermentation in biopower plants (BPP) that would produced biofertilizers, feeding additives and a by-product in the form of biogas [12, 13, 14,17]. Finally, in our opinion, the return of the biofertilizer into the farming lands is already an excellent result of waste disposal and natural resource recovery.

Waste recycling in biopower plants will allow to prevent the negative impact associated with the loss of nutrients in organic waste caused by other means of recycling. What is more, the main condition for the efficient use of the fertilizer will be met, namely that is even distribution of dry manure in the soil after its biological ripening. The produced environmentally friendly fertilizers fully retain nitrogen (unlike the classical manure production methods, when 40-50% of nitrogen is lost) in its ammonium form that is the easiest for the plants to absorb.

The existing foreign and Russian technologies of anaerobic fermentation need to be adjusted for their profitable employment in Yakutia due to the following reasons:

1. They are developed to work in milder climates, this is why they can hardly be implemented in Yakutia due to the significant difference between winter and summer temperatures: in summer the temperature reaches +35 °C, and in winter it goes down to -50 °C.

2. The plants work in a mesophilic regime, are automatic and need constant power supply. In remote rural areas there are many communities where power is generated by diesel engines, and therefore electricity is expensive. In communities that are connected to the power grid, power outages are frequent.

3. Under the conditions of permafrost, construction of a facility, in particular one with large floor area, call for piles foundations to defrost the soil, and it is a costly measure.

4. The majority of plants have high-capacity fermentation tanks and their efficiency is ensured by the processing of large continuous flow of waste, namely the waste produced by big animal farms. This industry in the region is represented mainly by small farms. Due to huge distances between communities and lack of roads, there is no possibility to construct a centralised biogas station. This is further complicated by the lack of mechanization of labour-intensive processes and poor qualification of small farmers.

The biochemical conversion process that turns organic matter into methane during anaerobic fermentation according to [4, 5, 10, 11, 19, 20] is influenced by a large number of factors that have a varying degrees of importance.

In our opinion, all the factors can be divided into compulsory ones, the ones constant in time, and the controlling ones and random ones [7]. The compulsory factors are the following: availability of organic matter and free water, lack of air and light, symbiotic relations of micro-organisms that can support acid and methane generation, stable temperatures.

Factors that influence the technological operations (stages), are evaluated by the quality of their implementation with minimal power and financial costs. According to these indicators, the adequate technological processes should ensure high technical and economic effect.

The conducted analysis shows that the BPP disposal technology can improved by:

- constructing a permanent plant to produce adapted mesophilic additive (AMA), disseminated methane generating micro-flora that is adapted to psychrophilic conditions with a view to add it to the fermented biomass to boost the anaerobic decomposition in the fermentation tank (FT);

- less expenditures on heating the fermented raw materials by using improved psychrophilic fermentation regime;
- development of a geometrical form of the fermentation tank that would be easy to manufacture, operate and maintain; cheap; small in size with a view to install it directly in the household and family farms;

2. Methods that intensify the processing in a biopower plant

Perfect conditions for anaerobic fermentation can be created in the fermentation tank that has an egg-shaped fermentation tank, but in practice such tanks are too expensive [12]. This is why cylinder steel fermentation tanks are widely used.

We also propose to use such a fermentation tank in private household farms. To ensure the operation of a BPP, only constant temperatures are needed, but not its timely even distribution in the operating space, this is why we propose to eliminate heating devices.

Under the conditions of low natural temperatures, we propose to use psychrophilic fermentation regime, at the same time using the following methods for boosting the process:

1. In terms of construction and technology, we propose a fermentation tank with small volume \( V_M \leq 1 \text{ m}^3 \) that would allow to cut the costs, simplify the production, operation and maintenance.

2. When a fermentation tank is turned on, ferment with mesophilic methane generating microorganisms that are adapted to the psychrophilic conditions (hereafter referred to as the adapted mesophilic additive, AMA) should be added to the fermented substrate.

The AMA should be produced beforehand in a special permanent machine. At the same time, the permanent machine at 36°C creates comfortable conditions for breeding, growth and generating of mesophilic methane generating microorganisms. Further, by slowly reducing the temperature, mesophylls are adjusted to low temperatures and are now living in the psychrophilic regime, and when in the end of the fermentation the temperature falls to 10°C, the organisms adapt to the psychrophilic regime. Then the ferment with adapted microflora is placed into the fermentation tank, new fermented substrate is loaded on the AMA.

When loaded, new substrate gets into the environment that contains a colony of methane generating microorganisms. Therefore, the process of psychrophilic decomposition is intensified by the introduction of AMA into the fermented substrate, the kinetics of anaerobic fermentation in the BPP fermentation tank is improved.

The loading regime of new substrate is recurrent. When launched, the operational volume of the fermentation tank is filled by 2/3 with homogeneous mixture that consists of AMA and disposed new substrate. Anaerobic conditions are created, the substrate is slowly mixed every day at the same time. After the processing is over, the fermented substrate (effluent) is not fully unloaded from the fermentation tank, some part of the effluent is left there and becomes the ferment for the new launch of the BPP.

Thus, the dynamic model of the main line of the anaerobic processing has the following operational form, that differs from the existing ones because it has a machine for the adaptation of mesophilic micro-organisms to psychrophilic conditions [8].

Characteristics of flows according to the plan of technological operators equal:

\[
L = \sum_{i=1}^{n} L_i
\]

\[
L_i = f (j_i; U_i; \text{pH}_i; \text{NPK}_i; t \text{ and etc.})
\]

where \( L_1 \) is the flow of native substrate;
\( L_2 \) is the flow of technical water for homogenization;
\( L_3 \) is the flow of the fermented substrate;
\( L_4 \) is the flow of heat losses into the environment;
\( L_5 \) is the flow of losses of NPK substrate;
\( L_6 \) is the flow of spoil;
\( L_7 \) is the flow of biogas;
$L_8$ is the results of the analysis (humidity, substances, temperature, biogas quality and other indicators)

![Diagram](image)

**Figure 1.** Operational plan of the developed technological line of the anaerobic fermentation:
1 - substrate feeding container and homogenizer; 2 - device for the adaptation of mesophilic microorganisms to the psychrophilic conditions; 3 - fermentation tank; 4 - spoil collection reservoir; 5 - gas container; 6 - agricultural chemical lab; 7 - gas purification biofilter; 8 - ICE; 9 - equipment for the production of vitamin additive; 10 - container for the collection and storage of the fertilizer.

The quality evaluation of the anaerobic processing of the organic substrate are represented by the following agrotechnical indicators:
- humic substances;
- nitrogen, phosphorus, potassium;
- pH of the environment;
- colour of the spoils;
- pathogenic micro flora, weed seeds;
- biogas output from $1 \text{ m}^3$ of the fermentation tank;
- ration of $\text{CH}_4$ to $\text{CO}_2$ in the biogas.

In accordance with the operational plan, the proposed technological process of anaerobic fermentation of cattle manure can be divided into six main stages (Figure 2).

The first stage - AMA pretreatment by the adaptation of mesophilic methane generating microorganisms to psychrophilic conditions. The second stage - preparation of new biomass by mixing the native manure with warm water, homogenization. Third stage - loading AMA to the fermentation tank with adapted micro-flora and fermented substrate; creating best possible conditions for anaerobic fermentation. Further we have the IV stage - the process of anaerobic degradation of the fermented substrate. V stage - production of by-product biogas, its purification and use. Final VI stage - production of the main product, high-quality organic fertilizer.
3. Conclusions
In comparison to the popular mesophilic fermentation regime, the new technology has the following advantages:
- it efficiently works at the temperature of 10 °C in a cattle barn as the mesophilic micro-organisms are adapted to the temperature fluctuations;
- the volume of the fermentation tank \( V_M = 0.2\ldots1.4 \text{ m}^3 \) allows to reduce its cost by 3.4 times in comparison to Russian and foreign analogues and simplify the production technology, launch, operation, maintenance and repair of biopower plants;
- small volume of devices ensure multiple capacity building of the BPP on the basis of module introduction of fermentation tanks;
- organic fertilizer from BPP contains bound nitrogen, phosphorus and potassium. The chemical components have the following ration \[83\]: total nitrogen - 4.0,7.0, including ammonium nitrogen - 2.54.0; phosphorus (P_2O_5) - 7.012.0; potassium (K_2O) - 1.03.0; micro-elements, mass concentration mg/l - copper - 3.0 (micro-elements, mass concentration mg/l); cobalt - 5.0; zink - 23.0; water – 8595 and ensures better crop yields by more than 10%.
- processing in BPPs of at least 10% of the annually produced organic waste allows to produce 112 million tons of fertilizer every year. With the standard consumption of the fertilizer of 3 ton per hectare, 37 mln hectares of land can be fertilized, e.g. 2.2% of all the agricultural land;
- recycling one ton of substrate using the new technology costs 1065 rubles, while processing the same amount in the mesophilic regime would cost 26854 rubles. Thus, operational costs of the new energy-saving technology are 25.2 times lower than that of the currently used one.

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