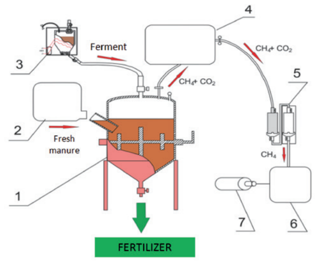
Resource-saving technology for manufacturing of environmentally-friendly organic fertilizers



Tecnología que ahorra recursos para la fabricación de fertilizantes orgánicos respetuosos con el medio ambiente

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RESUMEN

- La relevancia de este trabajo está determinada por la falta de tecnología para la desinfección y el tratamiento del estiércol líquido de ganado vacuno producido en las regiones árticas de Rusia (la República Sakha (Yakutia)).
El objetivo de la investigación es el desarrollo de tecnología para el reciclaje del estiércol con el resultado de fertilizantes orgánicos respetuosos con el medio ambiente en unidades de biogás. La tecnología permite a los agricultores establecer una fabricación autónoma que ahorra energía.
Los principales métodos de investigación son la teoría de la similitud y la teoría del diseño experimental, la programación matemática y los métodos de modelización de simulación. Se utilizaron los programas Excel, Estadística 8 y MathCAD.
Se desarrolló la tecnología de ahorro de recursos para la fabricación de biofertilizantes a partir del estiércol bovino, basada en los microorganismos metanogénicos mesofílicos adaptados a las condiciones psicofílicas. Por lo tanto, se obtuvo por primera vez una tecnología anaeróbica psicotrópica que trabajaba de forma constante a bajas temperaturas.
La introducción de una nueva tecnología en las empresas agrícolas de Yakutia permite producir un promedio de 4.659 toneladas diarias de fertilizantes orgánicos mineralizados; la cantidad esperada de financiamiento de la venta de fertilizantes orgánicos hará 0,056 millones de dólares.
Los materiales del documento pueden ser útiles para estudiantes, profesores e investigadores científicos de especialidades naturales y técnicas, así como para especialistas del complejo agroindustrial y para agricultores.
- **Palabras clave:** estiércol líquido, unidad de biogás, digestión anaerobia, modo psicrófilo, biofertilizante.

ABSTRACT

The relevance of the paper is determined by the lack of technology for disinfection and treatment of the produced liquid cattle manure in the arctic regions of Russia (the Sakha Republic (Yakutia)).

The research objective is the development of technology for recycling of the cattle manure with resulting environmentally friendly organic fertilizers in biogas units. The technology allows agriculturalists to establish energy-saving self-contained manufacture.

The primary research methods are the theory of similarity and experimental design theory, mathematical programming and simulation modelling methods. The Excel, Statistica 8, MathCAD programmes were used.

The resource-saving technology for manufacturing biofertilizer from the cattle manure was developed, based on the mesophilic methanogenic microorganisms adapted to psychrophilic conditions. Thus, a psychrophilic anaerobic technology working steadily under low temperatures was obtained for the first time.

Introduction of a new technology in agricultural enterprises of Yakutia enables to yield on average 4.659 tonnes of mineralized organic fertilizer daily; the expected amount of finance from the sale of organic fertilizers will make 0,056 mln USD.

The materials of the paper can be useful for students, lecturers and research scientists of natural and technical specialties, as well as for specialists of the agroindustrial complex and for farmers.

Keywords: liquid manure, biogas unit, anaerobic digestion, psychrophilic mode, biofertilizer.

1. INTRODUCTION

As of today there is a substantive problem in a crop-growing sector – a deficiency of mineral and quality organic fertilizers. This issue can be softened by means of manufacturing fertilizers from the animal waste – liquid manure [2, 12, 18].

S.V. Melnikov noted that the problem of rational use of manure as an organic fertilizer for creation of the own food reserve with simultaneous compliance with the requirements of environment protection from contamination by animal waste has a national economic significance of utmost importance [19].

The regional peculiar feature of crop-growing in conditions of permafrost is that low soil temperatures (for which the following characteristics are typical: the maximum seasonal thawing does not exceed 100 cm, the sum of average daily temperatures in summer is about 300°C, the temperature of the warmest month at the depth of 20 cm is 1°C, the active temperature in the soil is absent, the temperature above 5°C is only set in the upper 5 cm-layer [15]) are instrumental in preservation of malignant pathogenic microflora and weed seeds in manure bulks which get to the lakes and wetlands in spring together with melt water. Grounds of settlements and surface water bodies are heavily contaminated by the organic and biogenic matters of the livestock manure. Untreated liquid manure has a destructive impact on the fragile nature of the Arctic regions of Russia, aggravated by the reverse reaction of the permafrost.

Moreover, the situation is worsened by the fact that the level of natural fertility of cryogenic soils is insufficient to use the incoming solar energy to the fullest extent. In permafrost soils of the agricultural zone the content of nitrate nitrogen varies from 1 to 10 mg/kg. The content of mobile phosphorus in soils is 30-260 mg / kg; exchange potassium – 140-200 mg/kg [15]. Mineral nitrogen is not enough, and the content of labile phosphorus is low to feed plants; only the reserve of exchange potassium is sufficient except for sandy loam soils [15]. Practice has shown that half of the vegetables and potato yield in Yakutia can be obtained only due to application of fertilizers.

Low temperatures of the soil crossover of cryogenic soils, short vegetation period, and close occurrence of the permafrost confining beds bind to be careful in evaluating fertilizer quantity. The unused fertilizer remains can cause soil and products contamination; it regards primarily nitrogen fertilizers, then organic fertilizers as a nitrogen source. Small volume of cryogenic soils (absorption capacity up to 40 mg-eqiuv. with the calcium content of 50 to 80%, magnesium 10-30%, sodium 3-10%), lack of percolative regime, and limited horizontal runoff predetermine accumulation of remains of unused nitrates of undecomposed pesticides above sanitation standards [14].

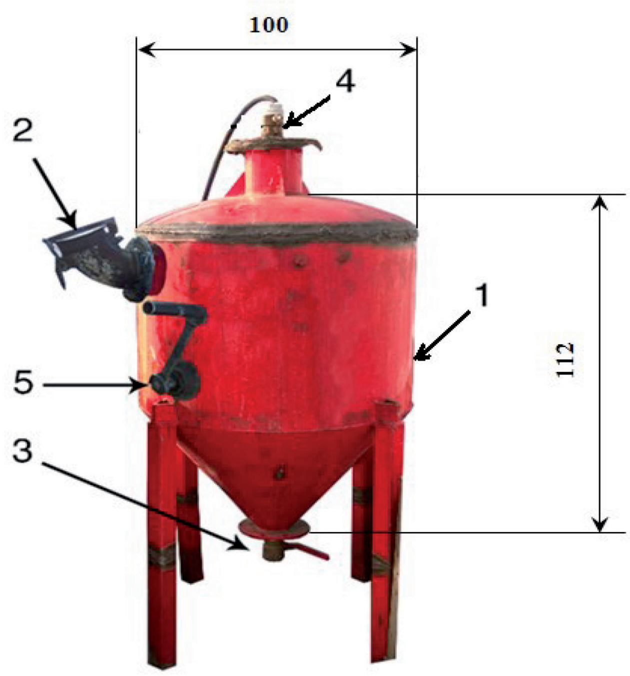

Fig. 1: Psychrophilic anaerobic digester: 1 – steel cylindrical tank with conical bottom; 2 – loading spout for fresh manure; 3 – unloading spout for treated substrate (sludge, effluent); 4 – biogas outlet; 5 – hand-driven agitator

Therefore, the development of technology for recycling the liquid cattle manure ensuring not only environmental performance, but also contributing to the establishment of the energy-saving self-confined manufacture (with the resulting mineralized organic fertilizer enabling to increase crop yield) is a crucial objective of scientific and practical interest.

Point of the problem. There are different methods of the liquid cattle manure treatment [22]. However, anaerobic digestion in biogas units is best suited for the natural and climatic conditions of Yakutia [3]; still, the issue is what digestion mode and what equipment will ensure the maximum efficiency of the process at minimum cost, and it requires special research.

Scientific hypothesis. Reliable and smooth operation of the biopower plant can be achieved by means of using such technology and process equipment that ensure stable process of anaerobic digestion of the organic matter of manure to condition of mineralized fertilizer under less energy-consuming temperature mode.

Research objective is to develop the technology for manufacturing environmentally-friendly organic fertilizers from the liquid manure of cattle in biogas units.

2. MATERIALS AND METHODS

The research was conducted in the laboratory of alternative energy sources of the Road Construction Department at Ammosov North-Eastern Federal University of Sakha Republic (Yakutia).

Experimental studies were conducted on the laboratory equipment, which structure ensured acquisition of the estimates of biogas units operation processes under various modes of anaerobic digestion of the cattle manure.

Psychrophilic and mesophilic digestion modes were investigated. In this case the biopower plant was represented in two variants: without heating of digested substrate and with a heating device.

The utility model patent No. 142699 as of October 18, 2013 was received on the anaerobic digester (Fig. 1).

The anaerobic digester is loaded with fresh substrate at 2/3 of the total volume, the remaining 1/3 is left for biogas accumulation.

The anaerobic digester lid has a Ø 20 mm biogas outlet (4) with a tap. The lid tightness is provided by a weld seam. Loading spout (2) is located sidewise. In order to unload the treated substrate, there is an opening in the conical bottom of the anaerobic digester with an outlet pipe of Ø 50 mm (3) with a tap. In order to mix the digested substrate there is a mechanical hand-driven agitator (5).

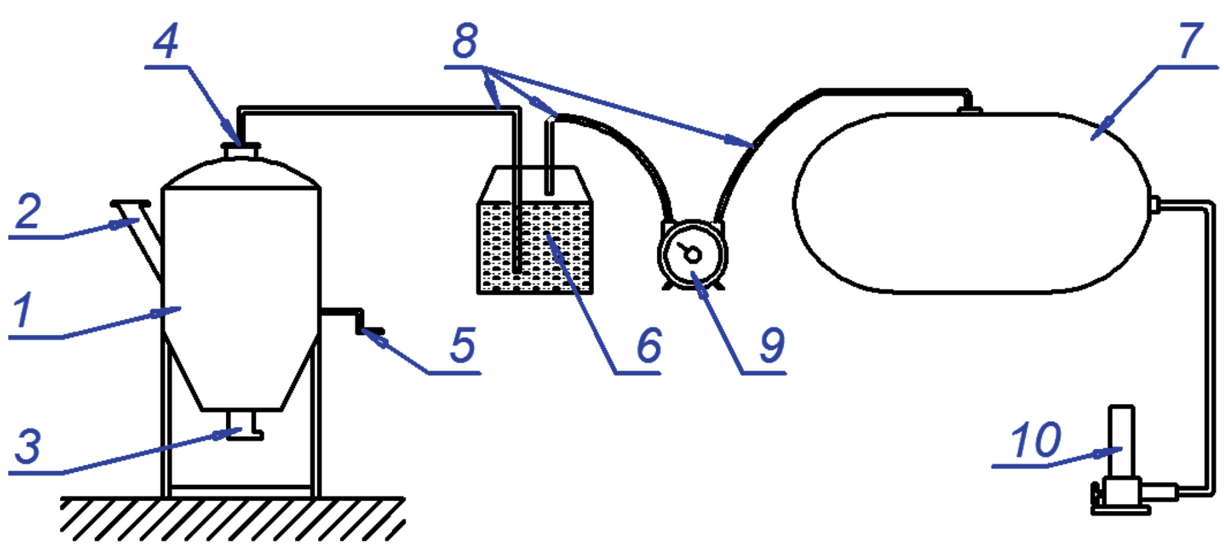

Fig. 2: Flow chart of the experimental biogas unit in psychrophilic mode: 6 – water trap; 7 – dry gas-holder; 8 – gas hose; 9 – gas meter GSB-400; 10 – burner

For the procedure of anaerobic digester actuation in a psychrophilic operation mode, see Fig. 2.

1. Dilute fresh manure with hot water with the temperature of 70…80 °C to humidity of 92-93%, thus digestible substrate is obtained.
2. Homogenate the digestible substrate thoroughly and load to the anaerobic digester (1) through the side loading spout (2). The mass of the substrate prepared for digestion is 140 kg, which corresponds to the 2/3 filling of the anaerobic digester volume.
3. The gas hose Ø 20 mm (8) is connected to the outlet (4) and treated with sealing material.
4. Low-pressure compressor KPP-230-24 is used to remove air from the anaerobic digester through the gas hose (8), thus anaerobic environment is established.

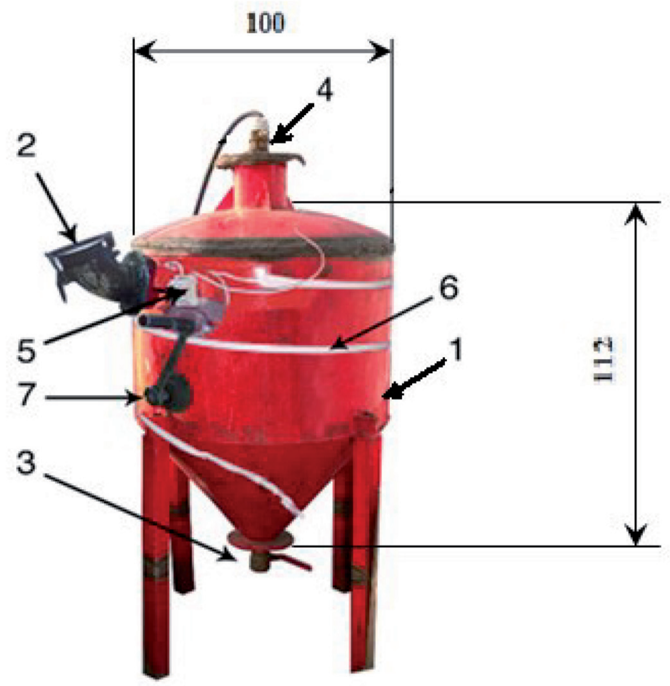

Fig. 3. Mesophilic anaerobic digester: 1 – steel cylindrical tank with conical bottom;2 – loading spout for fresh manure; 3 – unloading spout for processed substrate (sludge, effluent); 4 – biogas outlet; 5 – controller with temperature sensor; 6 – heating tape; 7 – mechanical agitator.

5. The end of the gas hose Ø 20 mm (8) is lowered to the water trap (6). The process of biogas generation in the anaerobic digester can be observed by the output of gas bubbles in the water trap. Junctions of the gas hose are also sealed.
6. The gas hose Ø 20 mm (8) from the water trap is connected to the gas meter GSB – 400 (9).
7. The biogas is supplied from the gas meter (9) to the dry gas-holder (7) where it accumulates.
8. The quality of anaerobic digestion is controlled by the burner (10) –biogas maintaining the burning process testifies the favorable course of the manure recycling process.
9. The digested substrate is mixed in the anaerobic digester using the hand-driven agitator (5) daily at one and the same time. Reduced impact load is applied to avoid layering of the digested substrate and to prevent crust formation.

For the anaerobic digester in a mesophilic operation mode, see Fig. 3.

Digestion temperature is sustained by the heating tape ENGL-1 for 0.46 kW (6) with a heat control unit ART – 18 – 5H0 – 60 (6). Heat control unit enables to set the required temperature gradient in the working space of anaerobic digester, turns the heat control unit on when the temperature drops and off when the temperature grows (Fig. 3).

For the procedure of biopower plant actuation in mesophilic operation mode (Fig. 4).

1. Load fresh substrate with humidity of 92-93% and mass of 140 kg to the anaerobic digester through the loading spout (2) to fill 2/3 of the anaerobic digester volume.
2. Lower the temperature sensor of the heat control unit (12) through the gas outlet (4) to the substrate.
3. The gas hose Ø 20 mm (8) is connected to the outlet (4), whereas the other end of the hose is lowered to the water trap (6).
4. Low-pressure compressor KPP-230-24 is used to remove air from the anaerobic digester through the gas hose (8), thus anaerobic environment is established.
5. The gas hose Ø 20 mm (8) from the water trap is connected to the gas meter GSB – 400 (9).
6. The biogas is supplied from the gas meter (9) to the dry gas-holder (7) where it is stored and accumulated.

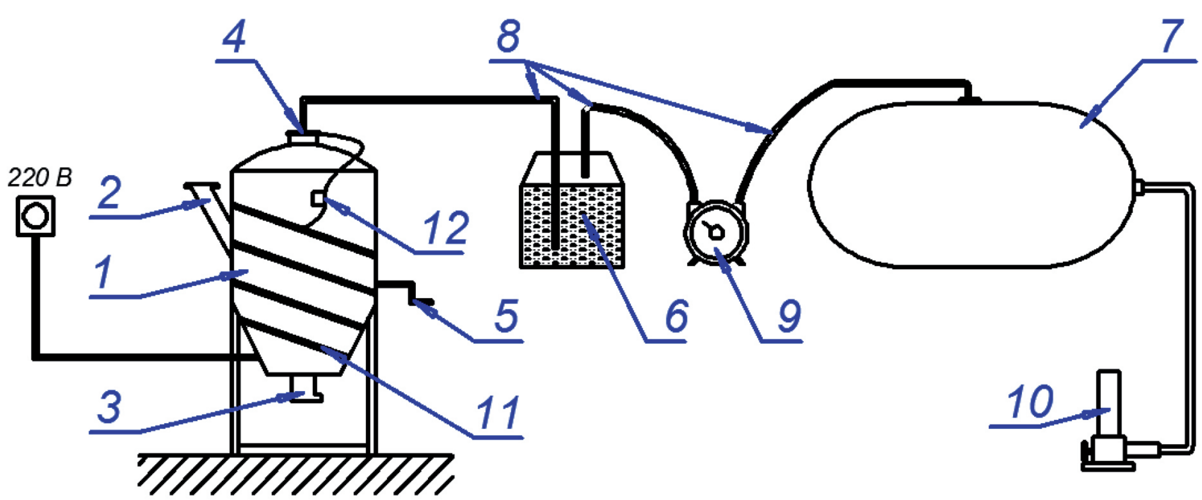

Fig. 4. – Flow chart of the experimental biogas unit in mesophilic mode: 1- anaerobic digester; 2 – side loading spout; 3 – unloading spout; 4 – gas outlet; 5 – hand-driven agitator; 6 – water trap; 7 – dry gas-holder; 8 – gas hose; 9 – gas meter GSB -400; 10 – burner; 11 – heating tape ENGL – 1 for 0.46 kW; 12 – heat control unit with temperature sensor

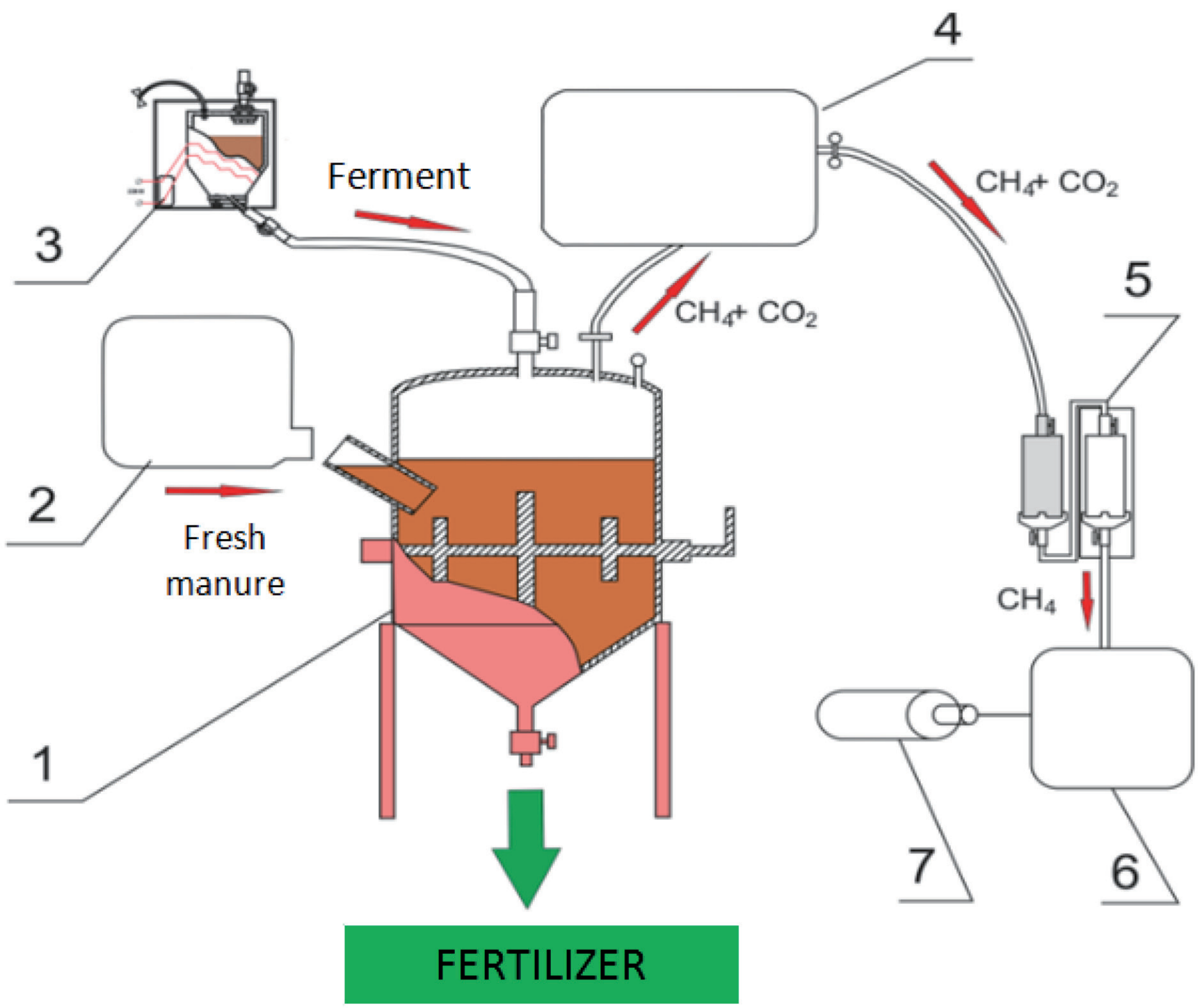

Fig. 5 – Basic diagram of the proposed technology for anaerobic treatment of the liquid cattle manure: 1 – anaerobic digester; 2 – tank for homogenization of manure with water; 3 – adaptation unit; 4 – dry gas-holder; 5 – biogas filter; 6 – high-pressure compressor; 7 – gas cylinders

7. Temperature sensor (12) is plugged in and set for the temperature of the mesophilic mode at 36 °C.
8. The quality of anaerobic digestion is controlled by the burner (10) – biogas maintaining the burning process testifies the favorable course of the manure recycling process.
9. Substrate is mixed once a day using the hand-driven agitator 7 in partial rotation mode.

	Indicators	values
1	Period of the biopower plant operation, days	24 -26
2	Mass of the recycled fresh manure with humidity of 93%, kg	88
3	Mass of AMF in anaerobic digester for the next start of the biopower plant, kg	50 – 52
4	The expected mass of the fertilizer obtained, kg	80 - 81
5	Housing season, days	240
6	Mass of the recycled manure of cattle during the housing season, kg	704
7	Mass of fertilizer predicted during housing season, kg	655 – 669
8	Cost of 1 kg of biofertilizer, rubles	5(0,09 USD)
9	Income from biofertilizer sale, rubles	3275 - 3345
10	Increase of crop yield, %	10

Table 1. Effect from the biopower plant use with one anaerobic digester

3. RESULTS

The flow chart of the process of anaerobic digestion of the liquid cattle manure in the psychrophilic periodic mode is presented in Fig. 5.

At the beginning of the process mesophilic methanogenic microbes are adapted to psychrophilic conditions in unit 3, and the ferment accelerating the process of anaerobic digestion of the fresh cattle manure is prepared.

	Indicators	Test method	Cattle effluent
1.	Humidity,%	GOST 13496.3-92	60.0
2.	Crude protein, g/kg	GOST 13496.4-93	87.5
3.	Potassium, g/kg	AAS emission method	10.789
4.	Sodium, g/kg	AAS emission method	44.704
5.	Calcium, g/kg	AAS emission method	5.773
6.	Phosphorus, g/kg	AAS emission method	7.174
7.	Ferrum, g/kg	GOST 30692-2000	1.180
8.	Manganese, mg/kg	GOST 30692-2000	59.25
9.	Zinc, mln^{-1}(mg/kg)	GOST 30692-2000	148.92
10	Copper, mln^{-1}(mg/kg)	GOST 30692-2000	37.98
11	Lead, mln^{-1}(mg/kg)	GOST 30692-2000	-
12	Cadmium, mln^{-1}(mg/kg)	GOST 30692-2000	0.062
13	Arsenium, mln^{-1}(mg/kg)	GOST 30692-2000	0.085

Table 2. Chemico-toxicological investigation of effluent

Tank 2 is used to homogenate the initial components of manure and water, and prepare fresh manure for treatment.

Next, the adapted mesophilic filler (AMF) is supplied from unit 3 to anaerobic digester 1, and prepared fresh manure is loaded from tank 2 on AMF.

The digested substrate – effluent, the primary product of anaerobic technology, is a quality organic fertilizer [7, 8, 9, 10, 11].

The effect of using a biogas plant with a single anaerobic digester was calculated (Table 1), and the effluent produced was analyzed (Table 2).

4. DISCUSSION

According to prior information, the obtained organic fertilizer provides increase in the crop yield by minimum 10% and reduces soil acidity. 1 litre of such fertilizer is enough to treat 2-15 m^2 of soil [24, 25, 26, 27, 28].

Application of cattle manure and poultry droppings to the soil has the following aspects:

1) fertilizing, since they contain fertilizer elements;
2) environmental, since recycling of manure and droppings as a fertilizer prevents environment pollution;
3) biospheric-geochemical, since when animal wastes are applied to the soil as fertilizers, the circulation of elements and energy contained in them is not interrupted; whereas when manure is piled up as waste, the organic waste of animals is excluded from the natural circulation of elements and energy for a long time.

The organic fertilizers have a number of advantages over the mineral ones:

- they are compound and contain not only all macronutrients, but also micronutrients;
- the major part of the nutrients is connected in form of organic compounds which become available for crops gradually as their organic forms become mineralized;
- the microflora contained in them improves soil bioactivity;
- they are an additional source of the carbon dioxide required to crops for photosynthesis.

According to the authors [1, 2, 3, 4, 5, 6] nutrients of liquid manure differ by enhanced solubility compared to straw-based manure. Thus, nitrogen from liquid manure is soluble for more than 50%, and potassium for almost 100%. It is important to take into account that phosphorus from liquid manure is taken up by crops better than the one from mineral fertilizers. Apart from the three primary crop nutrients, liquid manure contains many microelements.

Melnikov S.V. writes in his paper [20] that the issue of manure recycling as a whole is among the most difficult ones, since its solution is at intersection of various technical-science disciplines (biology, animal science, veterinary science, amelioration, chemistry, physics, medical science, mechanization, agricultural science, etc.). Comprehensive and efficient solution to this problem demands a system approach, including the consideration of processing operations in reference to each other throughout the whole production line: from the animal stall to the site of complete sale of manure with due account for environmental requirements and for ensuring necessary hygiene and sanitary operation conditions [3, 16, 17, 20, 21].

Currently biopower plants operating in the mesophilic mode of digestion are widely spread and used throughout the world [19]. However, upon temperature fluctuation in the range of $\pm 2\ ^0C$ mesophilic methanogenic microbes die, and the process damps. Therefore, it is not expedient to use such plants in Yakutia.

It is proposed to apply the psychrophilic periodical mode of the biopower plant operation with a small anaerobic digester from 1 m^3 and less [13, 14, 23] due to the following significant reasons:

- currently manufactured plants operate in mesophilic mode and are equipped with the high-current automated system;
- unstable electric power supply in rural settlements of Yakutia;
- small farms in terms of the number of livestock;
- lack of technologies for mechanization of labour-intensive processes and treatment of the produced manure;
- shortage of fertilizers that resulted in meadows and pastures exhausting;
- environmental pollution, growth of hazardous exposure of untreated manure on the human health.

5. RECOMMENDATIONS FOR MANUFACTURE

It is recommended to manufacture the anaerobic digester from the steel plate or previously used metal tank cisterns. The required volume of anaerobic digesters shall be selected depending on the livestock number according to the Table 3.

These anaerobic digesters can hold only a daily amount of manure, corresponding to the standard time of fermentation, i.e. the biopower plant is conserved for 24-26 days. Therefore, in order to ensure continuous treatment of the total amount of fresh manure produced during the housing period farms will have to install additional 25 anaerobic digesters which will cause unreasonable growth of financial expenses.

The necessity of using small anaerobic digesters is determined by the cattle management technology in Yakutia – the majority of farms contains from 5 to 10 animals. For the purposes of ensuring and maintaining the optimum temperature inside the stalls during winter, they are built as very compact; the maximum ceiling height is around 2 m.

The optimal volume of the anaerobic digester will be with height *(h)* equal to diameter *(d)*. For the anaerobic digester to have the least weld length *(l)* upon manufacture, the height *(h)* shall be ϖ times larger than the diameter [14]

In view of the above, the following variants are recommended in terms of anaerobic digesters volumes:

Cattle, ea.	5	6	7	8	9	10	11	12
Volume of anaerobic digester, m^3	0.7	0.85	1	1.2	1.3	1.4	1.6	1.7
Cattle, ea.	13	14	15	16	17	18	19	20
Volume of anaerobic digester, m^3	1.85	2	2.15	2.3	2.45	2.6	2.7	2.85
Cattle, ea.	21	22	23	24	25	26	27	28
Volume of anaerobic digester, m^3	3	3.15	3.3	3.4	3.6	3.7	3.85	4

Table 3. The volume of anaerobic digester depending on the cattle livestock

1st variant: In order to ensure treatment of the whole amount of produced manure, it is recommended to apply the modular approach – arrange a sequence of 10 anaerobic digesters.

2nd variant: Install a 1.85 m x 1.85 m anaerobic digester regardless of the livestock number. In this case the unit volume will be 4 m^3.

Since farms with cattle livestock numbering 5-10 animals currently prevail in cattle-breeding complexes of Yakutia, the procedure of the biopower plant operation is proposed as follows (Table 4):

Process indicators	Livestock of the farm, N, animals	
	5	10
Mmanure,kg/day	125	250
Mwater,kg/day	110	220
Vreactor, m3	4	4
Number of digesters, ea	2	4
Loading procedure	daily	daily
Unloading procedure	in 25 days	in 25 days
Unloading amount, kg/day	125	250
Gas yield, m3/year	4200	8400
Fertilizer yield, kg/year	30 000	60 000
AMF mass, kg	74	148
Periodicity of AMF loading	Every other day	Every other day

Table 4. Biopower plant operating procedure

Biopower plants should be located right in the livestock building. Thus, the best conditions are created to preserve the warmth of the manure mass loaded to the anaerobic digester, as the main condition for efficient operation of the biopower plant is anaerobic digester tightness. Moreover, the probability of loading fresh manure to anaerobic digester is larger, at the same time the labour of the stock breeder is facilitated, and heat leakage from the livestock building is reduced. The vertical arrangement of anaerobic digester allows saving manufacturing areas.

6. CONCLUSIONS

The efficiency of the developed energy-saving technology is as follows:

1. Recycling of one tonne of cattle manure using a new technology costs 18.4 USD. At the same time the biopower plant in mesophilic mode (36 ºC) located in the livestock building with the air temperature of 10…12 ºC is energy-consuming and not financially viable. Treatment of one tonne of manure in mesophilic mode costs 463 USD. Thus, operating expenses of the new energy-saving technology are 25.2 times cheaper than the widespread mesophilic treatment.
2. Introduction of the biopower plants to all cattle farm enterprises of Yakutia enables to receive on average 4,651.8 tonnes of a quality organic fertilizer on a daily basis. At the cost of 0,09 USD/kg the amount of money received from sales of organic fertilizers will be 19,3 mln USD, ideally. Treatment of at least 10% of the annual produced cattle manure in a biopower plant will allow manufacturing 112 M. tonnes of fertilizer annually. The application standard being 3 t/ha, 37 M.ha of soil could be fertilized, i.e. 2.2% of the total area of farming lands.
3. The cost of anaerobic digester manufactured in Yakutsk is 1431,0 USD, which is 3.4 times cheaper than the Russian and foreign alternatives without the account of forwarding charges.
4. The organic fertilizer from the biopower plant contains nitrogen, phosphorus and potassium in a bonded form. The ratio of chemical components is as follows [10]: total nitrogen – 4.07%, including ammonium nitrogen 2.54; phosphorus (P_2O_5) – 7.012; potassium (K_2O) – 1.03; microelements (mg/l): copper – 3.0; cobalt – 5.0; zinc – 23.0.

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