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Soil cement as a constructive material for anaerobic bioreactor corps

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One of the promising directions of modern alternative energy is anaerobic biotechnology for the production of biogas (so-called sewage gas). The main problem of hampering widespread use is biogas plants high cost. A new design of an anaerobic bioreactor for the production the biogas is proposed, where soil cement is used as a constructive material of continuous and monolithic construction of the corps bottom and walls. A structural and logical scheme for designing a bioreactor from soil cement for specific capacities of pig farms in geotechnical and climatic conditions has been developed and presented. Also the technological features of object construction by drilling and mixing technology are presented.

Keywords: soil cement, bioreactor, corps ,chink, biomass, substrate, drilling and mixing technology, modifier, climatic parameters, fermenter

Грунтоцемент як конструктивний матеріал корпусу анаеробного біореактора

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Подано нову, енергоефективну й компактну конструкцію анаеробного біореактора каскадного типу, що поєднує в собі ефекти: максимальної площі поверхні для виходу газу; забезпечення умов для механічного перемішування (раціональна форма камер бродіння без глухих кутів); мінімальних енергозатрат на підігрів (мінімальна довжина зовнішнього периметра); можливості централізованого виведення осаду з усіх камер бродіння. Схарактеризовано взаємозв'язок закономірностей щодо прийняття співвідношень діаметра і глибини закладання в ґрунт майбутньої споруди. З'ясовано, що взаємозв'язок між цими параметрами обумовлюється технологічними особливостями виходу біогазу, умовами його перемішування, кліматичними параметрами – промерзання ґрунту (мінімізації витрат на підтримання необхідної температури для анаеробного процесу), технологічними й економічними параметрами влаштування корпуса біореактора буровим верстатом, геологічними та гідрогеологічними параметрами будівельного майданчика й ін. Розроблено і представлено структурно-логічну схему проектування біореактора з ґрунтоцементу для конкретних потужностей свинокомплексу, геотехнічних та кліматичних умов. З метою поліпшення гідратаційних процесів, зниження усадки ґрунтоцементу, зменшення тріщиноутворення та підвищення морозостійкості запропоновано модифікувати ґрунтоцемент ферментним препаратом «Дорзин». Також наведено технологічні особливості зведення об'єкта за бурозмішувальною технологією.

Ключові слова: ґрунтоцемент, біореактор, бурозмішувальна технологія, модифікатор, кліматичні параметри, ферментатор

Introduction. In the context of price constant increases and ecological situation deterioration, more and more attention is being paid to alternative sources of energy supply. Modern alternative energy is represented by a wide spectrum of tools and sources. Their analyze due to the climatic conditions of Ukraine and Kyrovohrad region in particular is very important; the greatest prospect of the biogas technologies and solar energy spread is obvious.

Available in each farm or farmstead, large volumes of organic waste [1] are expedient to be utilized with the maximum total effect of solving complex problems: energy, ecological, farm supply with fertilizers, groundwater contamination prevention etc.

Biological wastes of agricultural production, as a rule, are exported outside the territory of farms and are accumulated for the purpose of natural utilization (degradation). Domestic waste (so-called solid household waste SHW) is exported to landfill solid waste. Both of these types of waste causes pollution, oxidation of the soil, makes it unpropriate for use without the use of high-value measures for the rehabilitation. Fissile material products penetrate into groundwater, lead to emissions of greenhouse gases and many other negative consequences

In the case of household organic waste, the problem of utilization is solved by sorting and subsequent processing. The situation on the agro-industrial enterprises or farms is simpler: sorting is not necessary there because the waste can immediately be recycled by bioreactor.

Analysis of recent sources of research and publications. Biogas reactors in Ukraine have not become widely distributed due to their considerable cost, the capriciousness of methane fermentation technology, and high energy consumption [1 – 4].The deviation of 3°C from the optimum for the process has already slowed down the methanogenesis. Significant influence on the processes of biogas production has environment mobility, stagnant zones absence, thermostabilization. During the cold period, it is necessary to minimize heat loss for substrate heating and equally distribute heat throughout the reactor volume. Practically there are no automation means of biogas production process. But it shoul be remembered that the reactor stop per hour can lead to energy problems in the company, because the process of fermentation is associated with the life of anaerobic bacteria and they restart their activity only for a few days or weeks. The process needs to be adapted to the conditions of Ukraine and permanent automatic monitoring. For Ukrainian conditions, cheap and reliable reactors are needed that is equally effective both in warm and cold seasons.

Anaerobic bioreactor for biogas and organic substrate production is a a closed container, filled with biological waste without air access at a predetermined stable temperature (from +25 to +55°C). As a result of methanogenesis, biogas and an ecologically safe organic substrate that fall out as solid precipitate, organic fertilizer can be used in agriculture as a material for the body bioreactor traditionally used concrete, metal, polymers.

Selection of previously unsettled parts of the general problem. The disadvantages of known bioreactors are their relatively high cost and lack of concrete structure of a complex curvilinear form techniques installing that provide the best conditions for thermal insulation, mixing, substrate surface crust destruction, providing the maximum area for biogas output from the substrate, periodic removal of solid precipitate, and maintenance. Also, a significant disadvantage is the insufficient durability of bioreactor body, due to corrosion instability.

An option to solve the problem of reducing the bioreactor cost and at the same time to provide body corrosion resistance, soil cement is used as a material for both bottom and walls [5]. There are some advantages for soil cement use in bioreactor body [6–10]:

– positive experience of using soil cement as a material for the construction of sludge cesspool for toxic waste;
– high water resistance W12-14;
– low cost of manufacturing due to natural soil use from the foundation pit;
– high compressive strength, 2 MPa;
– resistance to aggressive components (chemical resistance);
– longevity, lifetime of more than 300 years;
– soil cement is environmentally safe;
– frost resistance within M25;
– the soil cement has ability to become more solid with time.

Problem statement.

1. To propose a new, energy-saving and technological considering ease of operation in Ukraine, the anaerobic bioreactor has been constructed using such constructive material as soil cement, modified soil cement.
2. To develop the structural-logical scheme of designing a bioreactor from soil cement for specific household conditions, in particular, the pig complex LLC «Liga» in the village Company of Kirovograd region.
3. To develop the technological process of building a body bioreactor from soil cement, using. drilling and mixing technology.

Main material and results. The proposed construction of a bioreactor [5] relates to the technology of biogas production by anaerobic decomposition of various biological waste (livestock, poultry, plant growing, food industry, solid household waste, sewage), and can be used in agriculture, food industry, urban solid landfills household waste, sewage treatment plants, organic fertilizer manufacturing plants, such as mulch, substrate.

The purpose of the bioreactor proposed design is to improve the anaerobic bioreactor, ferment-gasholder by installing a solid and monolithic body from the soil cement, the reliability and durability of the bioreactor work, its tightness increases. Moreover the cost reduction and the term of construction under the conditions of natural resources rational use highlights obvious benefits of proposed design.

Fig. 1 shows a top view of a bioreactor installation consisting of loading and pumping unit and directly the bioreactor itself. Where 1 – receiving capacity for biological waste products, 2 – pump, 3 – capacitance - dispenser. Capacities 1 and 3 are formed by walls and bottom of soil cement.

An anaerobic bioreactor for the production of biogas and organic substrate consists of a body 4 of a cylindrical shaped (see fig. 1) with three internal vertical partitions 5, which are arranged relative to one another at an angle of 120 ° and form three cameras for anaerobic fermentation, respectively 6, 7 and 8. Outside of the bioreactor is a collector for mass that brooded 9 formed by the walls and bottom of the soil cement. The cylindrical body 4, the three internal partitions 5 and the joint bottom 10 (fig. 2) are made in a «monolithic» version - as a whole from the soil cement. On the surface of the interior partitions 5, heat exchangers 11 are provided with a polymer tube connected to a heat pump (not shown in fig.). In the fermentation chamber 6, by means of a traverse 12, a biomass mixer is installed, including a hydromotor 13, a reducer 14 with a vertically-mounted shaft, on the bottom of which is a short-base single-shaft polishing screw 15 fixed, and a trapezoid frame with grids 16 for the destruction of the surface crust is fixed in the upper part. In partitions 5 there are openings for overflow pipes 17. The scheme (scanning of bioreactor chambers) of biomass circulation is shown in fig. 3.

Gas accumulation and its initial temporary storage takes place in the cavity of the gasholder 18 formed by a gas cap 19, which is tightly and hermetically installed in the grooves of the soil cement walls of the body 4. In the upper part of the cap 19, which is made of a dark color material for additional heating of the bioreactor from the sun, a means of control and automatic control 20, as well as an outlet gas pipe 21, is installed.

In the lower part of the bioreactor there is provided a reinforced concrete pipe 22 with installed in it, by means of supporting bearings, long-base auger 23 for the removal of a precipitate (substrate). Herewith, the surface of the bottom 10 of the body 4 of the bioreactor in the fermentation chambers 6, 7, 8 and the collector of the fused mass 9 has internal deviations to the apertures with the hydraulic shutters 24 installed therein, through which, periodically and in a definite sequence, the precipitate (substrate) enters the inner cavity tube 22 with screw 23.

The anaerobic bioreactor for the production of biogas and organic substrate works in the following way. By tape conveyor, tractor and loader, the raw material of biological origin is fed into a tank 1, there they add water and mix with a screw mixer to the required consistency. Subsequently, the pump 2 supplies the biomass to the dosing tank 3 and controls the required temperature of the mixture (within +25…+55°C) and maintains the required biomass level in the tank 3. Herewith, the excess biomass (fig. 3) through pipeline 17 enters the lower part of the bioreactor in a fermentation chamber 6 where it is heated by a biomass heater 11 and mixed with a short-base empty auger 15. The fermentation process begins. The superficial crust of solid elements formed on the surface of the biomass in the chamber 6 is destroyed by trapezoidal grids 16, which allows gas bubbles to enter the cavity 18 of the gas cap – gasholder 19 without interference.

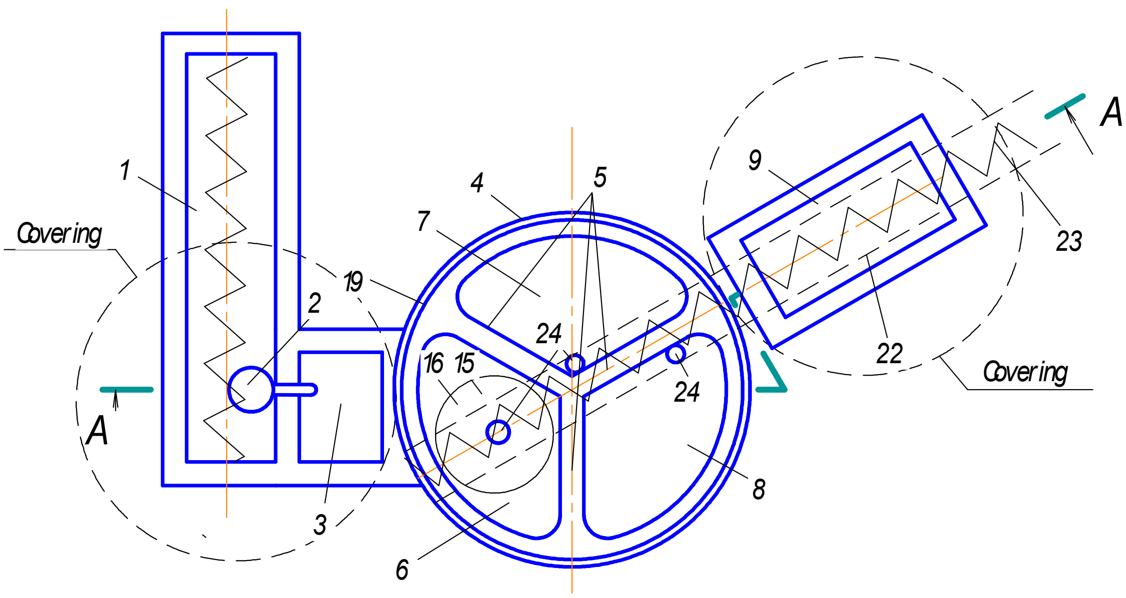

Figure 1 – Bioreactor installation (top view) [5]

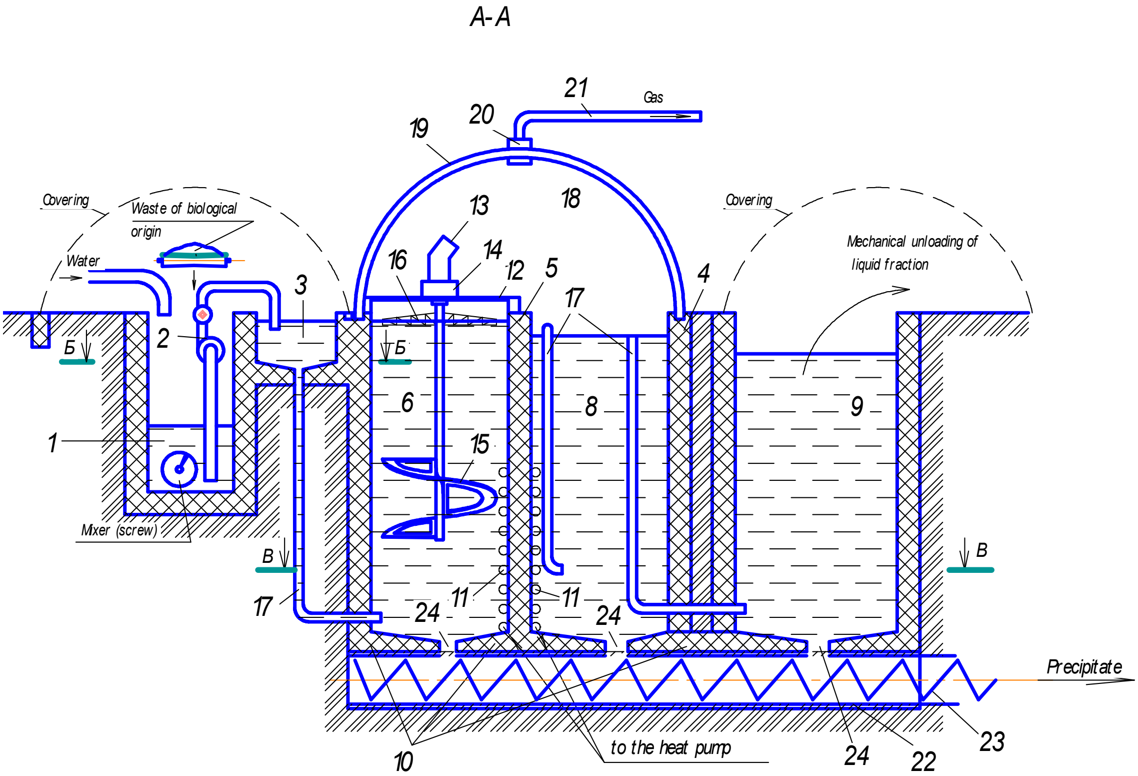

Figure 2 – Slash A-A bioreactor from Fig. 1 [5]

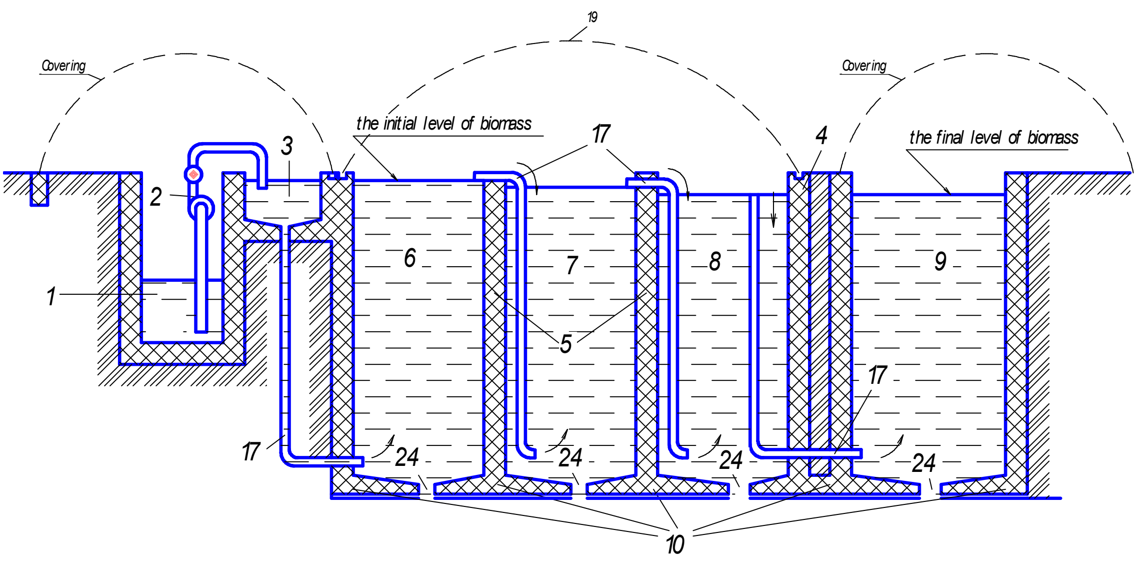

Figure 3 – Scheme (bioreactor chamber scanner) of biomass circulation [5]

Partially burnt out, the biomass that takes position in the upper part of the fermentation chamber 6 enters the transient pipe 17 into the lower part of the intermediate fermentation chamber 7, stirring and heating from the partition 5 with heaters 11. There is a continuation of the fermentation of biomass in the intermediate chamber of fermentation 7 and biogas production, which freely flows into the cavity 18 of the gas cap of the gasholder 19. As the chamber 7 is filled, the biomass from the upper part enters through the intermediate pipe 17 between the chamber 7 and the chamber of final fermentation 8 in its lower part, mixing and heating from the partition 5 with the heaters 11. There is a final fermentation of biomass in the chamber 8 with emission of biogas into the cavity 18 of the gas cap – of the gasholder, 19 where the gas is stored, it's kept for a certain period and, by means of automatic devices 20, given up by pipe 21 to places of longer storage, purification or direct use.

From the chamber of final fermentation, biomass, through the transfer tube 17, enters the collector of mass that brooded 9, from which it is mechanically removed by a clamshell, a noria, etc.

At the same time, the process of fermentation and the location of biomass in chambers 6, 7, 8 and collector of fermented mass 9 is accompanied by the fall of a biomass precipitate (substrate). The sediment accumulates at the bottom of 10 chambers 6, 7, 8, and 9, and due to internal deviations it gets more concentrated in a joint with a concrete pipe 22 openings with hydro shutters 24 and is given by a screw 23 to the place of collection, packaging. The frequency, sequence, opening time of the hydraulic shutters 24 and the activation of the screw 23 may occur, both manually and automatically, in accordance with the bioreactor control program.

An anaerobic bioreactor for the production of biogas and organic substrate is designed to work both continuously and discretely at any time of the year.

Bioreactor designing. Depending on the initial conditions, namely: the type and daily output of biological waste, calculate the internal volume of the reactor.

Suppose the farm has 10 heads of cattle, 20 pigs and 35 chickens. In the course of the day, the excrement will be: 55 kg from 1 cattle; 4,5 kg from 1 pig; 0,17 kg from 1 chicken. The mass of daily waste is:

$10 \times 55 + 20 \times 4{,}5 + 0{,}17 \times 35 =$

$= 550 + 90 + 5{,}95 = 645{,}95$ kg.

The optimum moisture content of raw materials for loading in a bioreactor is 85%.

Humidity of fresh excrement of pigs, cows is 86%, and chickens excrement 75%. To bring the moisture content of chickens excremant to 85%, add about 0,5 liters of water (about 0,5kg). Then the daily load of the reactor will be 646 kg.

The daily loading of the reactor is allowed to be no more than 10% of its full load.

Then the complete loading of the reactor:

10×646 kg = 6460 kg $\approx$ 6,5 ton

For LLC «Liga» smt. Kompaniyivka Kirovograd region the calculation is carried out for 5,3 thousand heads (the industrial capacity of the enterprise is 6 thousand heads.) The reducing number of livestock may be explained by the presence of piglets, seasonal variations, etc.

Then the mass of daily waste will be:

m = 5300 × 4,5 = 23850 kg.

Full load of the reactor:

m = 10 × 23850 kg = 238500 kg = 238,5 t.

According to [11], the bulk weight ρ of fresh pigs excretes varies within ρ = 1013…1400 kg/m^3.

Reactors volume: $V = \dfrac{238500}{1200} = 198{,}75 м^3$

The result of the previous calculations is that reactor must be with a useful volume of 200 m^3.

The issues of the ratio of diameter and depth of laying to the ground of the future construction remains. The interconnection between these parameters is determined by the technological features of the biogas output, the conditions of its mixing, the climatic parameters - freezing of the soil (minimizing the cost of maintaining the required temperature for anaerobic process), technological and economic parameters setting up of the bioreactor with a drilling machine, geological and hydrogeological parameters of the construction site and other. This is a complex optimization task.

It should be noted that the diameter of the bottom of the reactor is the greater part of the conditional foundations of the future structure (fig. 4), and the accepted value of the outer diameter of the container must satisfy the condition $P_{ум} \le R$ (the second group of boundary states, the calculation is carried out according to the classical methods). The adoption of the minimum value of the outer diameter of the reactor body is based on calculations for the designing of foundations [12, 13] and depends on soil, hydrogeological, climatic conditions and loads from the structure and substance in it. An increase in the diameter of the tank will positively affect the reduction of the pressure under the $P_{ум}$ structure, the gas outlet area and the liquid *grad p* pressure gradient, but will increase the outer perimeter, which, in the presence of overlying soils in the upper layers will cause «frost heave». Minimal effects are the occurrence of additional internal uneven tensions in the body of the soil cement tank, which can lead to loss of integrity and tightness. To solve this problem, it would be advisable to create anti-friction collars at the depth of the seasonal freezing, insulation of the upper perimeter, the arrangement of drainage.

Placing the reactor vessel below the level of the daily surface, using three radially installed through 120° internal partitions and filling the inner cavity by the substrate can minimize the load on the walls and bottom. In the working and long-term position, walls and bottom of the reactor, passive pressures from the substrate $P_{суб}$ and the external natural soil of the undisturbed structure of the $P_{гр}$ are perceived, which can be assumed to be equal in the first approximation. The thickness of the bottom and walls will be determined by the value of: the filtration coefficient; passive pressure on the wall in the sectors between the partitions; technological possibilities of mixing working equipment to provide a continuous and homogeneous enclosure structure from soil cement. A value that satisfies all conditions is accepted.

The main criterion for calculating the thickness of the bottom and walls of the reactor vessel is the value of the filtration of moisture from the substrate, which is assumed to be zero. The well-known formula A. Darcy may be adopted as a basis: $Q = k_ф \dfrac{\Delta H}{\Delta l} F$, that, taking into account the coefficient of permeability for different substances, k (P.G. Nutting) $k = d_{еф}^2 Sl(m, \varepsilon)$ will take the form: $v = \dfrac{k}{\mu} \dfrac{\Delta p}{\Delta l}$ and will represent the equation of L.S. Leibenzon:

$$v = \frac{d_{еф}^2 Sl(m,\varepsilon)}{\mu} \frac{\Delta p}{\Delta l},$$

where $d_{еф}$ – is the effective diameter of the particles (the diameter of the particles of equivalent fictitious soil, the hydraulic resistance of which is equal to the hydraulic resistance of the real breed); *Sl(m,ε)* – is the Slighters number (dimensionless), as a function of the coefficient of porosity *m* and the structure of the porous space *ε* (under the structure of the porous space understand the shape and size of individual pores, their quantitative ratio and compatibility); *μ* - is the dynamic coefficient of viscosity of the liquid.

The establishment of climatic parameters in the design of a future bioreactor can be carried out according to the proposed method [14] for determining the climatic loads at a given geographic point must be used data of the local network of weather stations (fig. 5).

The area equation, which reflects changes in the climatic factor *Z* in the vicinity of the design point, can be written as:

$Z = A + BX + CY$,

where *X, Y* – coordinates of the meteorological station or the design point;

A, B, C – Parameters determined according to the network of meteorological stations.

Parameters *A, B, C* are determined by the least squares method according to the data from all weather stations by the point of the design point, which can be implemented in any environment of any computing complex, in particular, Microsoft Excel. The coordinates of the meteorological stations and the design point *X, Y* can be given in the form of rectangular coordinates in kilometers relative to the conventionally selected center, or the values of longitude and latitude of the terrain in degrees published in meteorological guides, determined from maps of Google Maps or other cartographic systems.

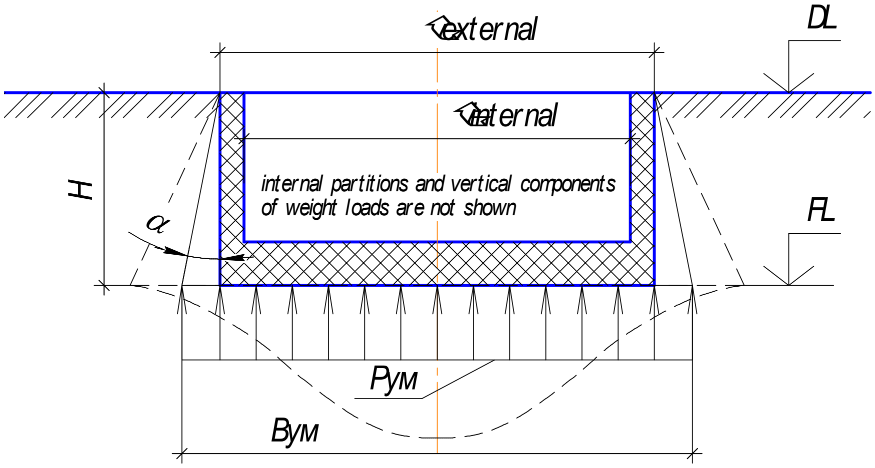

Figure 4 – The scheme of pressure transfer to the ground due to the resistance of the soil on the side surfaces and under the bottom of the fermentor

Figure 5 – Network of weather stations in the region [14]

Geological parameters of the construction site. Ideally, the soil for laying the bottom and walls of the soil cement tank should have at least 25–30% of cohesive colloidal particles (that should passing through a sieve with a cell size of 0,07 mm) and contain a minimum of large granular particles such as gravel. That is, it should be clayey or dusty soil: clay, or loam. Modification of soil cement by the introduction of the enzyme preparation «Dorsin» [15] in the most optimal amount (to 0,05%), improves hydration processes, significantly reduces shrinkage of soil cement, reduces cracks formation, increases frost resistance. A well-known positive experience with the use of enzyme modifier for clay soils Dorsin in road construction.

The enzyme preparation «Dorsin» is a composition of substances that were mainly formed during the cultivation of microorganisms (yeasts of the genus Saccharomyces) in a complex nutrient medium with some additives. The basis of the nutrient medium is beet molasses.

Developed, and in fig. 6, a structural-logical block diagram of the design of a bioreactor from soil cement is presented.

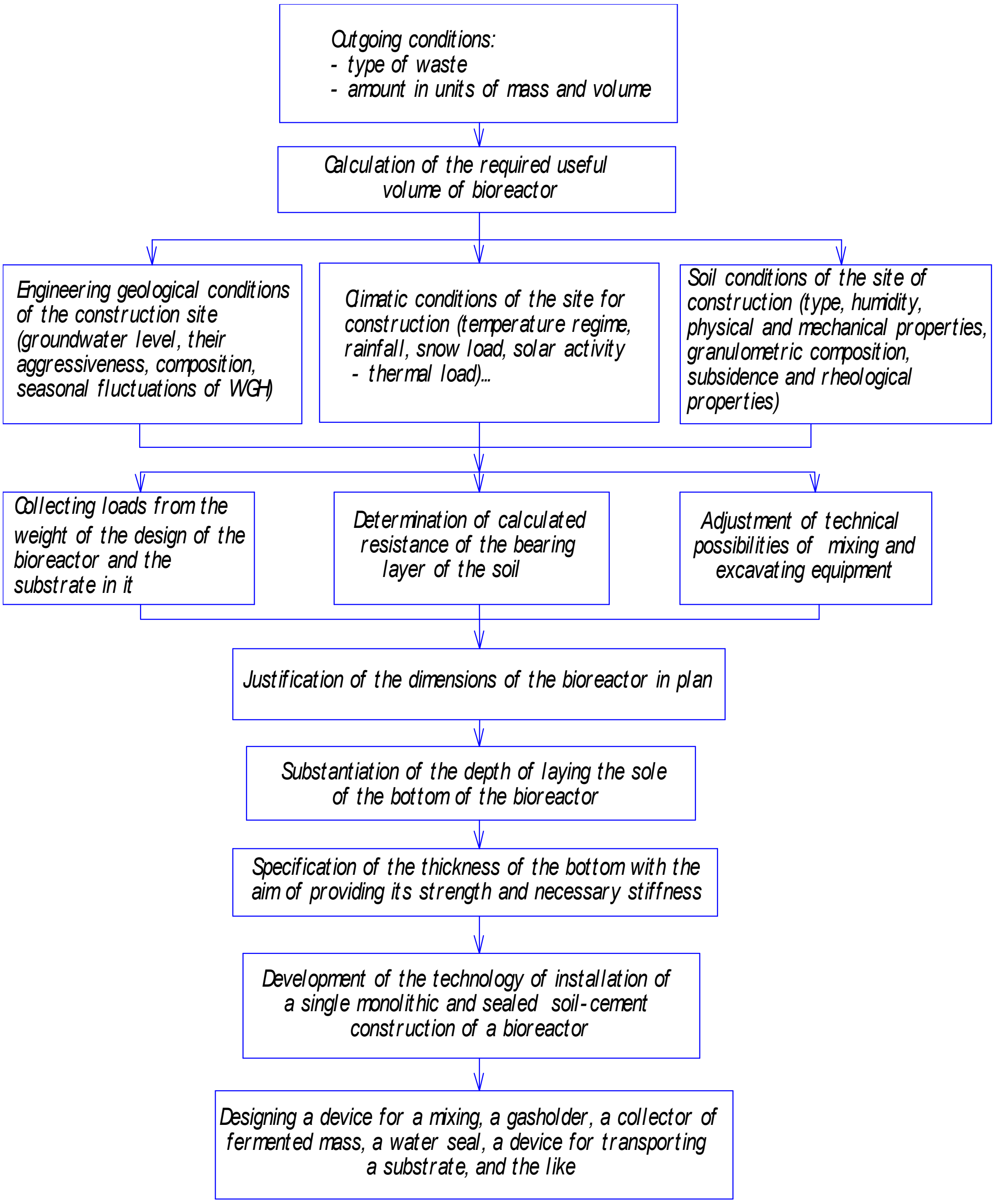

Figure 6 – **Structural and logical block diagram of designing bioreactor from soil cement**

Execution of bore-mixing works can be carried out by the drilling machine BM-811м on the basis of the car URAL [16, 17]. Cylindrical construction is non-technological in terms of convenience, accuracy of the positioning bore-mixing body and the displacement of the drilling machine. One solution, adopt a linear scheme of the reciprocating motion of the drilling machine, shown in fig. 7. In this case, it is necessary to arrange 682 wells with a depth of 4,0 m, a diameter of 0,5 m with a distance between adjacent wells 0,4 m. The main lines show the wells where the injection of cement occurs throughout the depth of the well, auxiliary - thickness of the bottom of the reactor - 0,9 m. Works on soil reinforcement are performed in three changes within 10 days. The average length of installation of one borehole is about 25 minutes. As a normative source, a document of the RF (Code of the rules of joint venture CP 291.1325800.2017 Structures of cement reinforced, designing rules was used. [18]. Cement outgoings ranges from 500 to 700 kg/m^3 and depends on the type and granulometric composition of the soil. The set of strength of the soil cement acording to the project lasts for 28 days, after which by the excavator with the equipment «reverse shovel» or «grab» holdings perform excavation of soil from three chambers and then perform a manual cleaning. The total duration of works is 40 days.

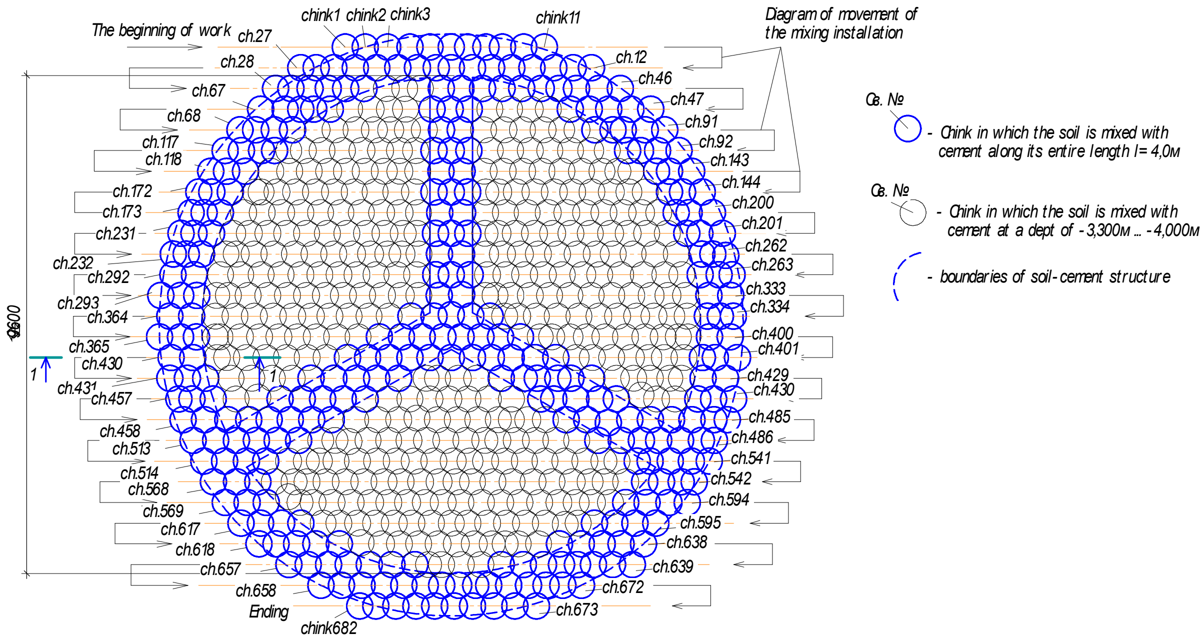

Figure 7 – Technological sequence of drilling and mixing works

Conclusions:

1. Expediency of soil cement use for the arrangement of ferment anaerobic bioreactor that produce biogas and organic substrate is proposed and determined.

2. A new, energy-efficient and compact anaerobic bioreactor design is introduced, which combines such effects as maximum surface area for gas outlet; provision of conditions for mechanical mixing (fermentation chambers rational form without deafening angles); minimum energy consumption for heating (minimum length of the outer perimeter), the possibility of sediment centralized outflow from all fermentation chambers.

3. Bioreactor design proposed design application enables to solve a number of significant problems: the rational use of natural, including renewable energy sources; ecological utilization of wastes; rational use of natural resources for construction; obtaining environmentally friendly fertilizers for agrocomplex.

4. The structural-logical block diagram of bioreactor designing from soil cement has been developed. The starting data are the type of biological waste and the daily amount of waste in units of mass and volume.

5. It was designed and given the recommendations for the bioreactor location for a particular company in the data engineering geological and climatic conditions.

6. Recommendations on the technological sequence of fermentor placement from soil cement cylindrical elements by the bore-mixing technology have been developed.

7. Perspective is to establish the appropriateness of soil cement use for constructing the bottom of artificial reservoirs and as separate foundations for solar cells.

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