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DOI: 10.15199/180.2021.4.3

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CONSTRUCTIONAL AND TECHNICAL INFRASTRUCTURE OF BIOGAS PRODUCTION

INFRASTRUKTURA BUDOWLANA I TECHNICZNA W PRODUKCJI BIOGAZU

***Summary**: The aim of the present solution – according to inventories no 224455 and 218837 is the description of biogas production technology in family and producer farms, running the litter system of animal management, especially of cattle and pigs. The submitted technology of biogas production consists in accumulation of manure with 20% content of dry matter on the plate which – after filling – is covered with the hermetic shield, constituting the preliminary chamber I. It serves for washing out the liquid and organic mass and its transportation to the main fermentation chamber II where the process of gas obtaining at temperature of 30–40°C is carried out (mesophilic fermentation). To ensure the appropriate temperature of mesophilic fermentation, the solar collector was employed. The main fermentation chamber is equipped in agitator for unification of substrates subjected to methane fermentation, and in screw feeder, enabling supplementation of substrates with energetic additives.*

***Keywords**: substrates, methane fermentation, biogas, solar collector, biogas desulphurization device, tank for biogas storager*

***Streszczenie**: Celem niniejszego rozwiązania – według inwentarzy nr 224455 i 218837 jest opis technologii produkcji biogazu w gospodarstwach rodzinnych i produkcyjnych, prowadzących system ściółkowy chowu zwierząt, zwłaszcza bydła i trzody chlewnej. Przedstawiona technologia produkcji biogazu polega na gromadzeniu na płycie obornika z 20% zawartością suchej masy, który po napełnieniu przykryty jest hermetyczną osłoną, stanowiącą komorę wstępną I. Służy do wypłukiwania masy płynnej i organicznej oraz jego transport do głównej komory fermentacyjnej II, gdzie odbywa się proces pozyskiwania gazu w temperaturze 30–40°C (fermentacja mezofilna). Aby zapewnić odpowiednią temperaturę fermentacji mezofilnej, zastosowano kolektor słoneczny. Główna komora fermentacyjna wyposażona jest w mieszadło do unifikacji substratów poddawanych fermentacji metanowej oraz w podajnik ślimakowy, umożliwiający uzupełnienie substratów dodatkami energetycznymi.*

***Słowa kluczowe**: substraty, fermentacja metanowa, biogaz, kolektor słoneczny, urządzenie do odsiarczania biogazu, zbiornik do magazynowania biogazu*

Introduction

Production of agricultural-origin energy from agricultural farms, especially of those specialised in animal production gives a chance to diversification and increase of agricultural incomes and energetic safety of rural areas, and also to the improvement of environmental protection.

The development and implementation of biogas installations and the possibilities of their adaptation to the structure of agricultural farms in Poland brings the universal possibilities and chances for the improvement of agricultural production effectiveness and of environmental conditions. The submitted solutions give also a chance to meet the requirements of criteria in respect of sustainable production and fulfilling the economic and environmental requirements as well as animal welfare and social needs.

The described solutions satisfy the above mentioned criteria and give the possibility of developing the small and medium-size agricultural farms [1, 6].

Biogas – producing plant for solid and liquid substrates

Within the frames of the studies, the idea of biogas installation, enabling the independent or coherent methane fermentation of two types of substrates [4] was developed. Fig. 1 illustrates the biogas installation, satisfying the mentioned assumptions. Chamber I is adapted to fermentation of solid substrates, including manure, and hydraulic installation ensures the possibility of washing out the organic matter to chamber II. In chamber II, the second degree fermentation of liquid manure and of organic mass, washed out from chamber I, is carried out. Additionally, the solid substrate with dry matter content above 20% may be added to chamber II.

According to the described above biogas installation, fermentation of methane and independent biogas production may be carried out in two versions, and namely:

— simultaneously, in the chambers for solid and liquid substrates;
— irrespectively of the delivery of solid and liquid substance.

The main part of the installation for biogas production from manure with the addition of energetic plants of organic waste is

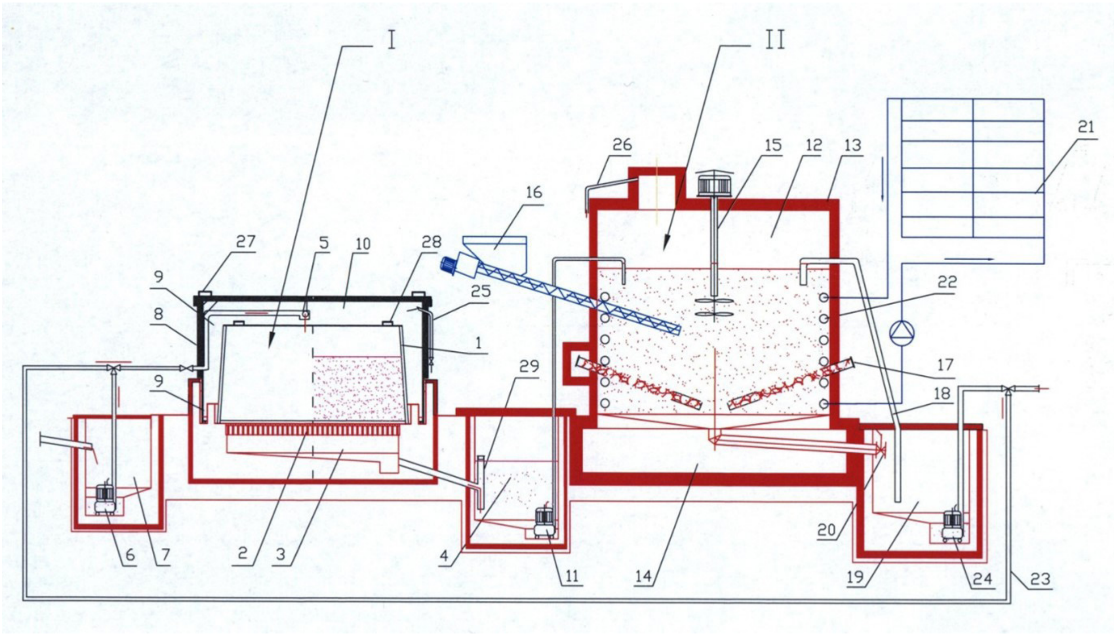

Fig. 1. Biogas installation for substrates with dry matter content above 20% (device for production of biogas from manure)

I – chamber I, II – chamber II; 1- internal container in a form of truncated pyramid; 2 – grid; 3- channel for effluent of organic matter; 4- tank for effluent from chamber I and for fresh liquid manure; 5 – sprinkler; 6 – pressure pump; 7- tank to which slurry is delivered; 8 – external container in a rectangular shape, with thermal insulation; 9 – liquid ring; 10 – hermetical chamber; 11 – pump; 12 – fermentation chamber; 13 – thermal jacket; 14 – thermally insulated strip foundation; 15 – propeller agitator; 16 – screw transporter - feeder; 17 – pipe perforated containers with expanded clay aggregate (granules); 18 – overflow siphon of post-fermentation mass; 19 – tank; 20 – sediment drain valve; 21 – solar collector (panel); 22 – tubular heat exchanger; 23 – thermally insulated pipeline; 24 – pump; 25 – gas pipeline; 25 – holder; 28 – holder; 29 – inflow of liquid manure [4]

hermetic chamber I, constituting the subject of patent no 218837. The essence of the mentioned inventory is the equipment for production of biogas from solid agricultural waste, especially of manure, having a thermal fermentation chamber of a heater, equipped in sprinkler, outflow of the excess of liquid manure and outflow of gas, wherein the fermentation chamber is made from thermal ring with the fixed upper cover whereas the bottom part of thermal ring is hermetically embedded in liquid ring, shaped in the bottom cover, on which there is embedded the container which is found in the interior of the fermentation chamber, and the said contained has a shape of truncated pyramid, being open at the bottom and at the top and having the openwork side walls. The mentioned walls are created from the inclined carrying pillars, connected with the plates. The holders are fixed to the upper part of the container and to the upper cover of the chamber. The equipment ensures the efficient loading of the fermentation charge, the run of fermentation process and unloading of the utilized material. The construction of the fermentation chamber, furnished with the holders, being embodied in hermetical channel ensures the tightness and the possibility of its lifting and lowering according to the needs of loading and unloading of the fermentation material to the container. The container with the openwork walls, as situated inside the fermentation chamber facilitates the effective utilization of the placed charge, with the utilization of sprinkler and heater, depending on the needs of fermentation as well as it enables, owing to the holders, lifting the container and unloading of the used charge from the bottom of the fermentation chamber. The effective emptying of the container from the charge, consisting of solid particles, is ensured owing to its inclined openwork walls.

The object of the inventory concerning the solution of hermetic chamber of biogas installation for solid substrates is illustrated in Fig. 2 where the equipment is presented in longitudinal cross-section and upper projection.

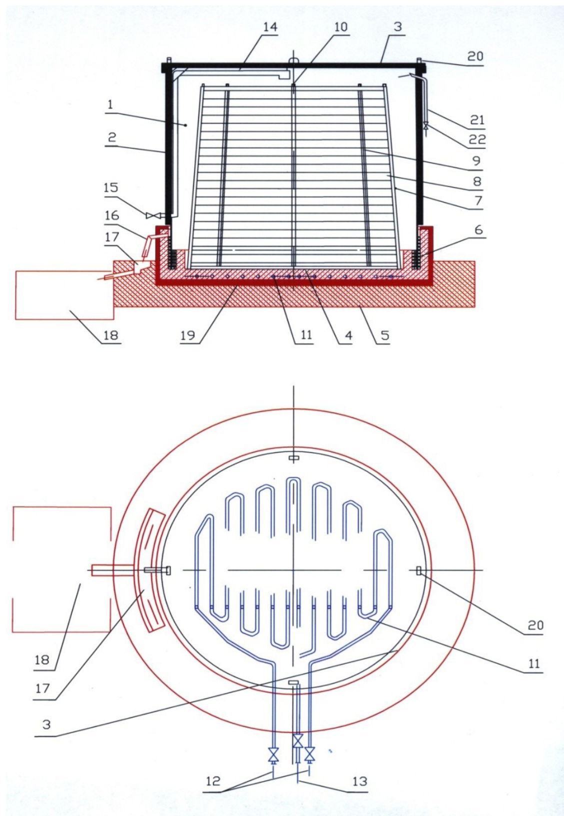

Fig. 2. The scheme of hermetic chamber of biogas installation for solid substrates
1 – fermentation chamber; 2 – thermal wall ring; 3 – upper cover; 4 – bottom cover; 5 – strip foundation; 6 – liquid ring; 7 – container; 8 – inclined carrying pillars; 9 – plates; 10 – carrying holders; 11- tubular heater; 12 – feeding valves; 13 – outflow valve; 14 – sprinkler; 15 – valve; 16 – outflow opening; 17 – outflow gutter; 18 – tank; 19 – thermal insulation; 20 – carrying holders; 21 – biogas outflow pipeline; 22 – valve [4]

The equipment consists of fermentation chamber 1, created from thermal wall ring 2 assembled with the upper cover 3. At the bottom, the fermentation chamber has a cover 4, embodied on strip foundation 5. In the bottom cover 4 there is a liquid ring shaped 6 in which the liquid hermetically tightens the lower walls of thermal wall ring 2 of the fermentation chamber 1. The container 7 is constructed in a form of truncated pyramid open at the bottom and at the top, having the openwork side walls, made of inclined carrying pillars 8 combined with the plates 9. At the upper part, the container 7 has the assembled holders 10 serving for positioning of the container on the bottom cover 4. In the wall of the bottom cover 4 there is installed a tubular heater 11, supplied with the heating agent of the pipeline, having the feed valves 12 and outflow valve 13. In the fermentation chamber 1, there installed the sprinkler 14 with the valve 15, supplying the liquid manure. In the lower part of the wall ring 2 of the fermentation chamber 1 there is a outflow opening 16 of the liquid manure which ensures obtaining the level of the liquid up to the height of the position of the said opening. The outflow opening 16 is assembled with the outflow gutter 17, combined with the tank 18. Between the bottom cover 4 of the fermentation chamber 1 and the strip foundation 5, the thermal insulation 19 is fixed. To the top cover 3, the assembling holders 20 are affixed. In the upper part of the thermal ring 2 of the fermentation chamber 1, there is fixed the biogas outflow pipeline 21 with valve 22

Functioning of installation for biogas production

After lifting of the upper cover 3 with thermal ring 2 using the holders 20, the container 7 is filled with the charge e.g. manure. Then, the upper cover 3 with the wall thermal ring 2 is put on the container 7 and the bottom part of the said ring 2 is situated in the liquid ring 6 of the bottom cover 4 what causes hermetical tightening of the fermentation chamber 1. As a result of the fermentation of the charge with the utilization, depending on the needs, of the heater 11 and sprinkler 14, the obtained biogas is evacuated by pipeline 21 for utilization according to the needs. The excess of the liquid from the fermentation chamber 1 is discharged by outflow gutter 17 to the tank 18. After ending the process of fermentation and cessation of biogas evolution, a mobile part of the fermentation chamber 1 is risen up by the holders 20 and then, the container 7 is lifted by the holders 10. The utilized charge is removed from the bottom cover 4 of the strip foundation 5. The described above installation of the fermentation chambers for biogas obtaining is supplemented with the following parts of installation: set for treatment of biogas from hydrogen sulphide and water and biogas tank for its storage.

Biogas produced in the installations, being found in the agricultural farms is transferred to the reservoirs where it is stored under a constant pressure and delivered to current-generating aggregate or to the household facilities. There are known the so-called wet gas reservoirs, constructed from cylindrical container with two walls between which the liquid is found. In the reservoir, between its walls, there is a mobile bell. The tightness of the reservoir is ensured by the liquid, present between the walls of the reservoir. Other known reservoirs are built from the elastic fabric in a shape of roller or rectangular form and are situated in the casing with rectangular walls and a gable roof. There are also the reservoirs in shape of sphere or roller with flexible walls pressured with the charging plate in order to ensure the constant pressure.

Installation for production of biogas from natural fertilizers (manure), together with the appropriate instrumentation

The constructed installations need the reservoirs which are simple in construction and effective in operation. The essence of utility model includes construction of reservoir for biogas storage under the constant pressure, delivered from the agricultural farm and destined especially for the supply of household facilities. The mentioned construction has a flexible container, pressurized with the plate form the top, being equipped in inflow, outflow and safety gas valves. The installation for production of biogas from manure is presented in Fig. 3.

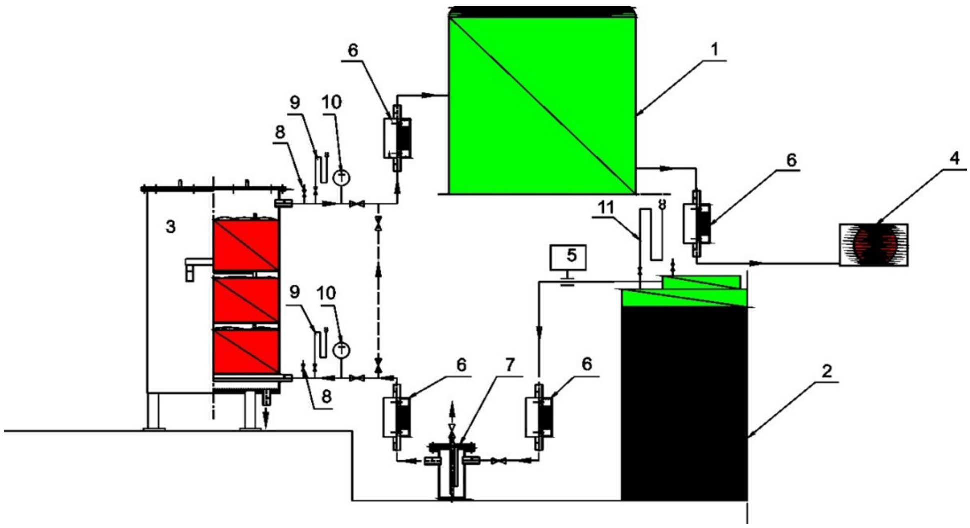

Fig. 3. Installation for production of biogas from natural fertilizers, especially from manure, with the employed system for biogas treatment – removal of H2S:

1 – biogas reservoir; 2 – fermentation chamber; 3 – desulphurisation facility; 4 – cogeneration aggregate; 5 – gas counter; 6 – flame interrupter; 7 – dewatering device; 8 – gas sampler; 9 – manometer; 10 – thermometer; 11 – safety valve [2, 5]

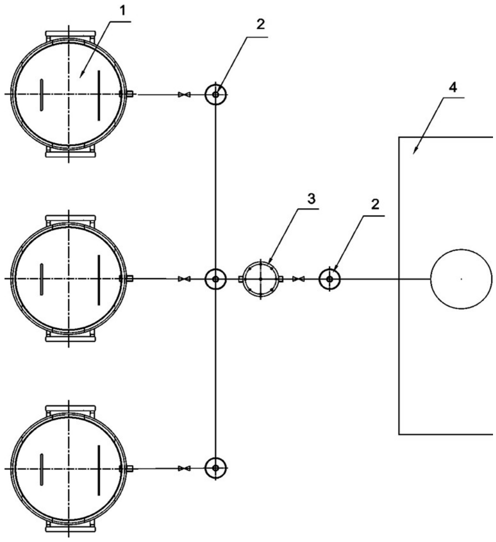

Fig. 4. Scheme of biogas producing plant with the system of three desulphurization devices: 1 – desulphurisation device; 2 – dewatering devices; 3 – flame interrupter; 4 – biogas producing plant with the chambers for solid and liquid substrates [3]

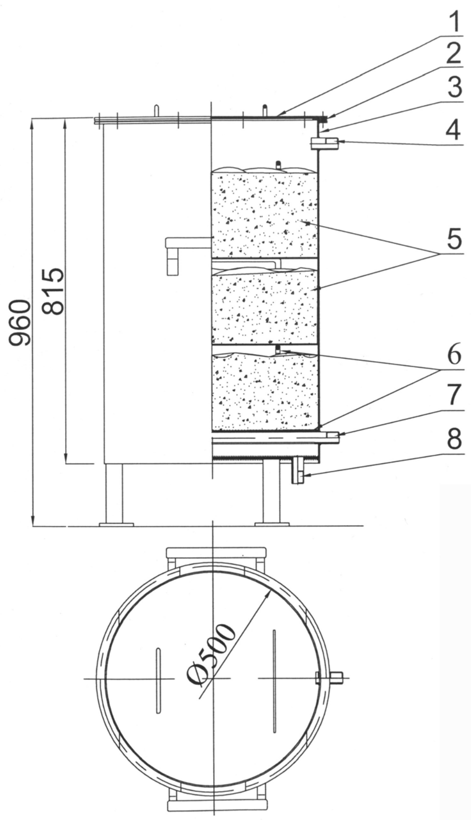

Fig. 5. Desulphurisation device adapted to removal of H2S in the biogas installation with the power below 20 kW: 1 – cover; 2 – seal; 3 – reservoir of sulphur recovery device; 4 – connection – gas entrance; 5 – bed of bog iron ore; 6 – bracket with perforated plate; 7 – connection – gas exit; 8 – connection for condensate removal [3]

Additionally, the submitted construction has also floor foundation with three vertical slideways, furnished with distance sleeves, on which two rubber (lower and upper) ring reservoirs are placed; on the mentioned ring reservoirs, the pressure plate with the fixed leading sleeves is situated. The sleeves are put on vertical slideways, the upper terminals of which are linked with the bonding element. The reservoir rings are connected with the installation by flow-through system, with the use of three tees: inflow tee, outflow tee and control-measuring tee, situated between the walls of the reservoir rings. Pressing the reservoir rings from the top with the pressure plate, lowered down on the slideways to the level of upper distance terminals of the sleeves and the simultaneous observation of manometer, linked to the pipeline with the control-measuring tee, enables obtaining of the correct, constant pressure, under which biogas is transferred to receivers of the household facilities. In the periods when the biogas is not supplied to the reservoir from the biogas plant – what may cause the drop of the pressure which can cut off the gas delivery to the receivers (by reaction of cut-off valve, attached to the pipeline with outflow valve) – the pressuring plate may be additionally charged with the charger in order to increase the insufficient pressure [3].

Fig. 4 and 5 show the desulphurization devices, and Fig. 6 illustrates flame interrupter. The both devices are the elements of the submitted installation.

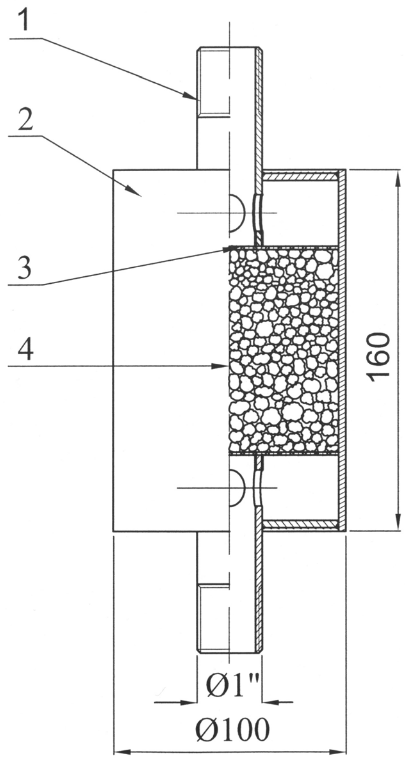

Fig. 6. Flame interrupter for biogas installation (vertical situation): 1 – connection; 2 – reservoir; 3 – perforated bottom; 4 – filling (fine gravel) [3]

Reservoir for storage of biogas, constructed from flexible cylindrical rings (utility model of 24.08.2012)

Biogas produced in the installations, being found in the agricultural farms is transferred to the reservoirs where it is stored under a constant pressure and delivered to current-generating aggregate or to the household facilities.

There are known the so-called wet gas reservoirs, constructed from cylindrical container with two walls between which the liquid is found. In the reservoir, between its walls, there is a mobile bell. The tightness of the reservoir is ensured by the liquid, present between the walls of the reservoir. Other known reservoirs are built from the elastic fabric in a shape of roller or rectangular form and are situated in the casing with rectangular walls and a gable roof. There are also the reservoirs in shape of sphere or roller with flexible walls pressured with the charging plate in order to ensure the constant pressure.

The constructed installations need the reservoirs which are simple in construction and effective in operation. The essence of utility model includes construction of reservoir for biogas storage under the constant pressure, delivered from the agricultural farm and destined especially for the supply of household facilities. The mentioned construction has a flexible container, pressurized with the plate form the top, being equipped in inflow, outflow and safety gas valves.

The discussed installation has a floor base with three vertical guide bars, furnished with distance sleeves, on which two rubber (lower and upper) ring reservoirs are placed; on the mentioned ring reservoirs, the pressure plate with the fixed leading sleeves is situated. The sleeves are put on vertical slideways, the upper terminals of which are linked with the bonding element. The reservoir rings are connected with the installation by flow-through system, with the use of three tees: inflow tee, outflow tee and control-measuring tee, situated between the walls of the reservoir rings. The reservoir has a relatively simple construction and is easy in operation. Pressing the reservoir rings from the top with the pressure plate, lowered down on the slideways to the level of upper distance terminals of the sleeves and the simultaneous observation of manometer, linked to the pipeline with the control-measuring tee, enables obtaining of the correct, constant pressure, under which biogas is transferred to receivers of the household facilities. In the periods when the biogas is not supplied to the reservoir from the biogas plant – what may cause the drop of the pressure which can cut off the gas delivery to the receivers (by reaction of cut-off valve, attached to the pipeline with outflow valve) – the pressuring plate may be additionally charged with the charger in order to increase the insufficient pressure.

Fig. 7. Prototype of the biogas reservoir, consisting of flexible rings [archive of the Institute]

The idea of the solution, constituting the utility model is presented in Fig. 7 where the prototype of the biogas reservoir has been constructed from three cylindrical rings (rubber tubes). Fig. 8 shows two rings.

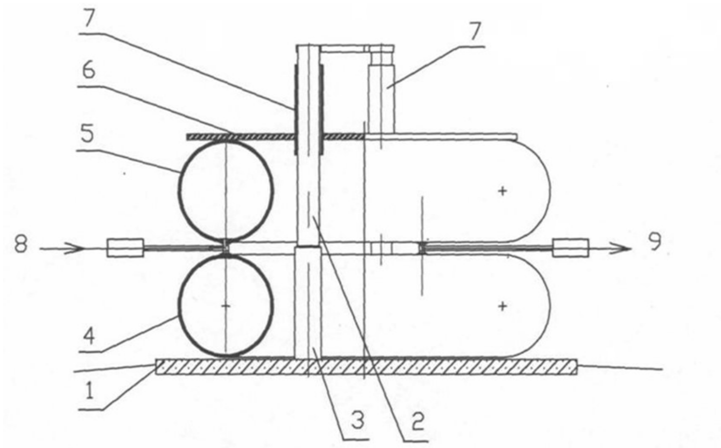

Fig. 8. Scheme of biogas reservoir made from flexible (rubber) rings, suitable for application in laboratory biogas devices or small biogas plants
1 – base; 2 – slideway; 3 – foot; 4 – cylindrical (flexible) lower ring; 5 – cylindrical (flexible) upper ring; 6 – upper pressuring plate; 7 – sleeve of slideway; 8 – inflow of biogas; 9 – outflow of biogas [own development]

Operating costs of the suggested installation

The annual maintenance cost:

$$K_{utrz} = \frac{K_i}{T_i} + K_u = \frac{450\,000}{20} + 0{,}2 \cdot \frac{450\,000}{20} = 27\,000\ \text{PLN} \cdot \text{year}^{-1}$$

where:

S – coefficient – 0,2

K_{utrz} – maintenance cost

K_i – cost of investment

T_i – time of investment utilizing

K_u – insurance cost: $\frac{K_i}{T_i} \cdot S$

$K_{uż}$ – The operating costs

$K_{uż} = K_r + K_{ee} + K_n$ = 10 600 PLN • year^{-1}

K_r – labour cost;

K_{ee} – costs of electric energy;

K_n – costs of repairs 0.3 $\frac{K_i}{T_i}$

The quantity of the produced biogas – 112 thousand m^3/year^1.
The quantity of the produced electric energy – 212 MWh · year^1.
The quantity of the produced thermal energy – 246 MWh · year^1.

The operating costs:

$$K_e = K_{utrz} + K_{uż} = 27\,000\ \text{PLN} + 15\,450\ \text{PLN} = 42\,450\ \text{PLN} \cdot \text{year}^{-1}$$

The cost of electric energy production:

$$K_{ce1}=\frac{27\,000+15\,450}{212+172}=110.55\ \mathrm{PLN{\cdot}MW\,h^{-1}}$$

The calculations did not consider 30% of thermal energy which is used in heating of biogas plant.

The cost of thermal energy production:

$$K_{ce2}=\frac{27\,000+15\,450}{212}=200.23\ \mathrm{PLN{\cdot}MW\,h^{-1}}$$

The annual consumption of raw material (substrate) for biogas production:

$$2.9\ \mathrm{t{\cdot}d^{-1}{\cdot}365\ d}=1058.5\ \mathrm{t}$$

When assuming the price of raw material (manure, droppings) in amount of 10 PLN for 1 t, the annual cost of the raw material is:

$$1058.5\ \mathrm{t}\times 10\ \mathrm{PLN{\cdot}t^{-1}}=10\,585\ \mathrm{PLN}$$

The real cost of electric energy production:

$$K_{ce3}=\frac{27\,000+15\,450+10\,585}{212+172}=138.11\ \mathrm{PLN{\cdot}MWh^{-1}}$$

The real cost of thermal energy production:

$$K_{ce4}=\frac{27\,000+15\,450+10\,585}{212}=250.16\ \mathrm{PLN{\cdot}MWh^{-1}}$$

The mentioned above elements of installation were taken from own authorial developments for the needs of the project BIOSTRATEG BIOGASEE/WP1/1/ZEBW/B/D02 for biogas installation of 20 kW size, with fermentation chambers 2 x 100 m^3.

Summing up

The submitted solutions of technological installation for biogas obtaining from substrates with dry matter content above 20% as well as from liquid substrates with 5–8% dry matter content allow the universal utilization up to ca. 200 LSU (Livestock Units) in agricultural farms specialized in animal production.

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Article reviewed
Received: 29.11.2021 r./Accepted: 12.12.2021 r.