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INNOVATIVE TECHNOLOGY FOR CONTINUOUS PRODUCTION OF BIOGAS FROM LIQUID BIOSUBSTRATES

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Abstract: The article presents an innovative design solution for a bioreactor intended for continuous biogas production from liquid biosubstrate. The proposed device is designed as a hermetically sealed container with a volume of 50–100 m^3, made of heat–insulating material and equipped with spiral heating and cooling pipes. The upper part consists of a conical dome with a mounting flange, a hermetic filling and discharge funnel, while the lower part contains an electric motor–driven scraper for removing sludge. The fermentation process is supported by electric stirrers and an ultrasonic extraction rod, which accelerates the decomposition of complex organic compounds and subsequent methanogenesis. Control is carried out by a computer system with special software that automatically doses enzymes, nutrients, and bacteria based on data from multifunctional sensors. The gas produced is collected in a gas tank under a dome and then fed through a detector and safety valve for energy use. By–products include flotate and sludge, which can be used as organic fertilizer, while the water component can be reused as an inoculation component. The bioreactor enables the efficient processing of various liquid waste from the municipal and industrial sectors, including catering establishments, food processing plants, and waste oils. The main advantages are hermetically sealed continuous operation, high production stability, the possibility of connection to cogeneration units or municipal heating systems, and complete environmental acceptability of outputs. The device represents promising technology for regions without wastewater treatment infrastructure and an important tool for sustainable renewable energy production.
Keywords: biodegradable waste, liquid biosubstrate, anaerobic fermentation, organic fertilizer, device

INTRODUCTION

The production of biogas from biodegradable substances is one of the oldest known forms of renewable energy use. [10] Archaeological finds from historical periods in China confirm the existence of primitive pit reactors, where animal and human excrement was fed through pipes into a closed pit with a tight lid. [14] The resulting gas was then piped to burners, where it was used as fuel. This simple principle of anaerobic fermentation has persisted in various forms for centuries and has become the basis for modern technologies for processing biological waste into energy-usable biogas. [1]

In recent years, biogas production has become increasingly accessible to smaller entities and households. Compact systems such as HomeBiogas (Figure 1) are emerging, transforming various types of organic waste into gas that can be used in the home. [4] Such equipment allows, for example, cooking with biogas for 2 to 4 hours a day, while producing 5-8 liters of liquid organic fertilizer suitable for use in gardens. [2] This approach represents a significant shift towards decentralized and sustainable management of biodegradable waste. [6]

In addition to domestic systems, agricultural biogas plants, which mainly process manure, poultry manure, and straw manure from livestock farming, play an important role. [5]

Figure 1 . HomeBiogas [11, 12]

A smaller proportion is made up of organic waste from households and various businesses, such as kitchen and grease waste. Including it in the fermentation process has a double effect: it increases biogas production and generates financial savings or income from waste disposal for producers, canteens, and restaurants. [13] The gas produced is most often used to generate electricity and heat in cogeneration units, with surplus electricity being fed into the public grid.

The development of biogas technologies is closely linked to advances in reactor design. In practice, horizontal flow reactors, such as the Darmstadt system, are used, which take the form of a steel or plastic cylindrical tank with thermal insulation. [15] These reactors, often with a volume of 50–100 m^3, are mounted on concrete bases with a slope of 3–5 % and allow slow mixing of the contents using blades driven by a low-energy motor. [16] The gas produced accumulates in the upper part of the reactor and is discharged into a gas tank, while heating is usually provided by a pipe distribution system or integrated directly into the mixing mechanism. This type of reactor is mainly used for the fermentation of denser waste, such as poultry manure or sludge with a higher straw content. [8]

Vertical reactors, on the other hand, are based on standard steel or concrete slurry tanks. Their conversion into a bioreactor requires gas tightness and thermal insulation, using common building materials such as high-quality concrete, polystyrene, or glass wool. [17] The advantage is mass production, which reduces the price per unit of volume. Such reactors usually have volumes ranging from 250 to 600 m^3, but there are also devices with capacities of up to 1200 m^3. In some cases, they serve a dual function - during the year, they are used for fermentation and as slurry storage tanks, optimizing operation according to seasonal needs. [3]

A specific group are tanks with a hermetically sealed membrane roof, which allow biogas to be stored directly above the fermentation mixture. Double membranes are also used, into which air is blown to maintain the pressure required for further use of the gas. Such solutions are used, for example, in German biogas stations, where one-third of the facilities combine the function of a fermenter and a biogas storage tank. [19]

Biogas production also plays an important role in Slovakia. According to available data, as of October 2, 2020, there were 113 biogas plants in operation with an average capacity of 1 MW and a total installed capacity of 115 MW. [18] Despite the slowdown in new installations after 2014, this segment remains promising, especially in terms of innovations in the field of sophisticated bioreactors. Demonstration facilities, such as the biogas plant of the University Agricultural Enterprise of the Slovak University of Agriculture in Kolíňany, prove the long-term sustainability and efficiency of this type of technology in Slovak conditions.

The current state of the renewable energy market, growing demands for the recovery of biodegradable waste, and technological advances in fermentation equipment are creating opportunities for new design solutions. [9] The aim of this article is to present a modern type of bioreactor designed for the continuous production of biogas from liquid biosubstrate, which combines the advantages of existing systems and offers new possibilities for the efficient and environmentally acceptable processing of various types of biological waste. [20]

DESCRIPTION AND ESSENCE OF THE TECHNOLOGICAL SOLUTION

Since 2020, employees of the Department of Mechanical Engineering at the Technical University of Košice have been developing bioreactor technology for the continuous production of biogas from liquid biosubstrate. This technology is currently protected by utility model No. 9637, issued by the Industrial Property Office of the Slovak Republic in Banská Bystrica on July 13, 2022. [7]

The bioreactor technology for the continuous production of biogas from liquid biosubstrate consists of a sealed container with a volume of 50 to 100 m^3 made of heat-insulating material, reinforced with a spiral heating/cooling pipe, with inputs and outputs for connecting the cooling/heating medium, brine, and which stands on a solid above-ground foundation structure.

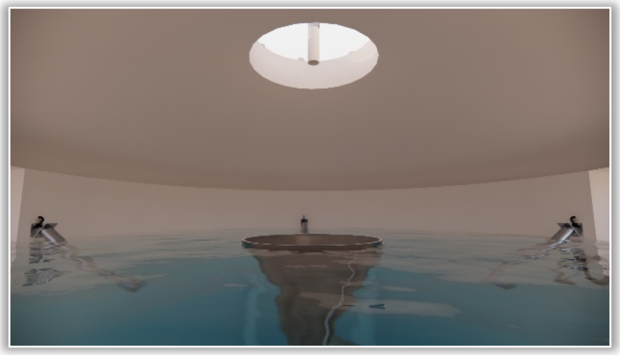


Figure 2 Biogas detector

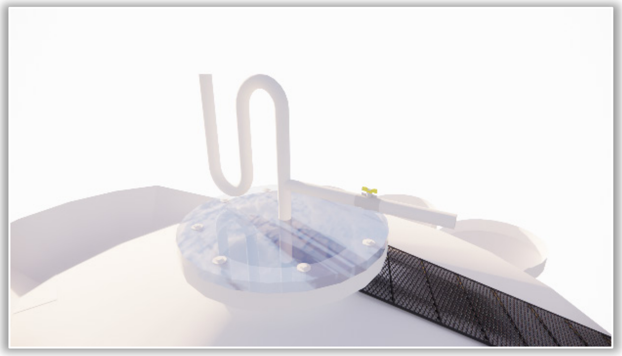


Figure 3 View of the pipeline through the gas discharge valve and safety valve

The bioreactor is covered from above by a conical dome with a transparent mounting flange. A recessed funnel with a neck and a drain below the level of the biosubstrate, controlled by a level gauge, is used to fill it with liquid biosubstrate. [7] Under the reactor dome (above the flotate level) there is a space – a gas tank equipped with a biogas detector (Figure 2).

Biogas is discharged by overpressure into a service pipe through a gas discharge valve, and the overpressure is secured by a safety valve (Figure 3). Propeller electric mixers are mounted tangentially on the inner shell of the vessel, where an ultrasonic extraction rod (Figure 4) is also mounted at an angle in a centripetal direction.

Figure 4 Ultrasonic extraction rod

An innovative design feature of bioreactor technology are hermetically sealed additive funnels, at least three in number, with lids and an electric motor-driven dosing flap, which dose ingredients into the fermentation process based on information from a biogas detector, a multifunctional sensor. After fermentation, the flotate from the surface of the biosubstrate is drained from above through a discharge funnel with a fecal outlet suitable for transport by fecal vehicles for further use (Figure 5).

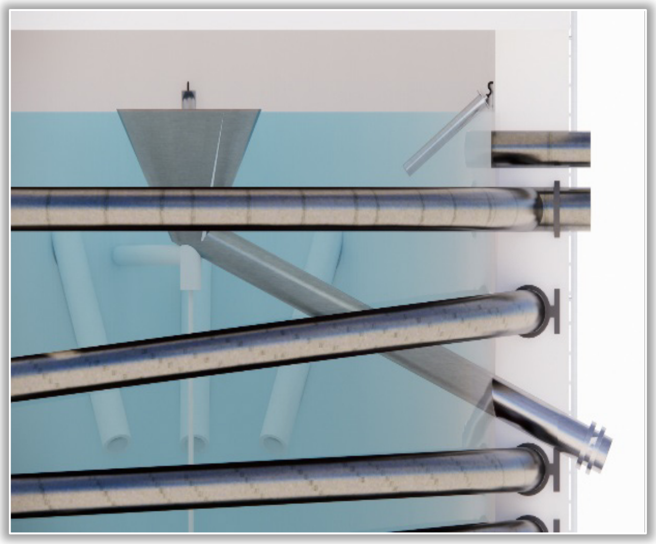


Figure 5 View of the discharge funnel with fecal end

The second output from the bioreactor is sludge, which is pushed by a scraper into a sludge removal pipe, terminated with a fecal lever end piece, for discharge directly into prepared containers. The movement of the scraper (Figure 6) is ensured by a mechanism with a shaft and an electric motor. The structural elements of the bioreactor also include a ladder located on the side of the container, a door at the entrance to the space under the container, and an electrical control box in that space for the placement of electrical distribution circuit breakers and a control system distribution box (Figure 7).

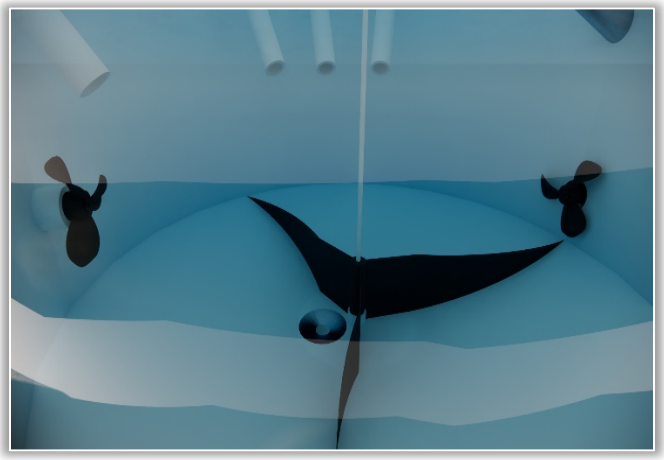


Figure 6 Movement of the scraper

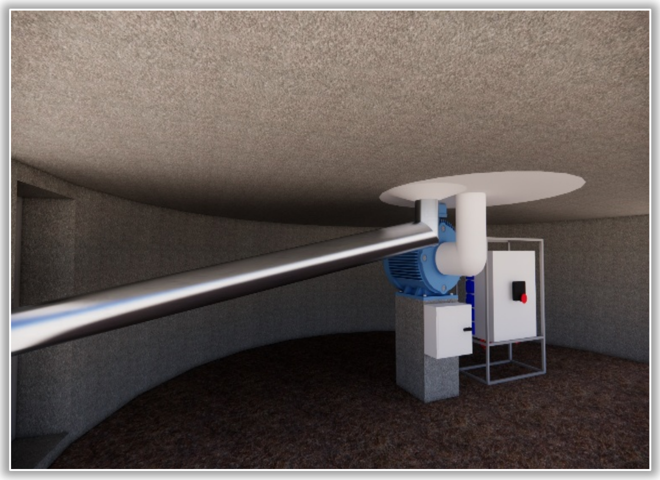
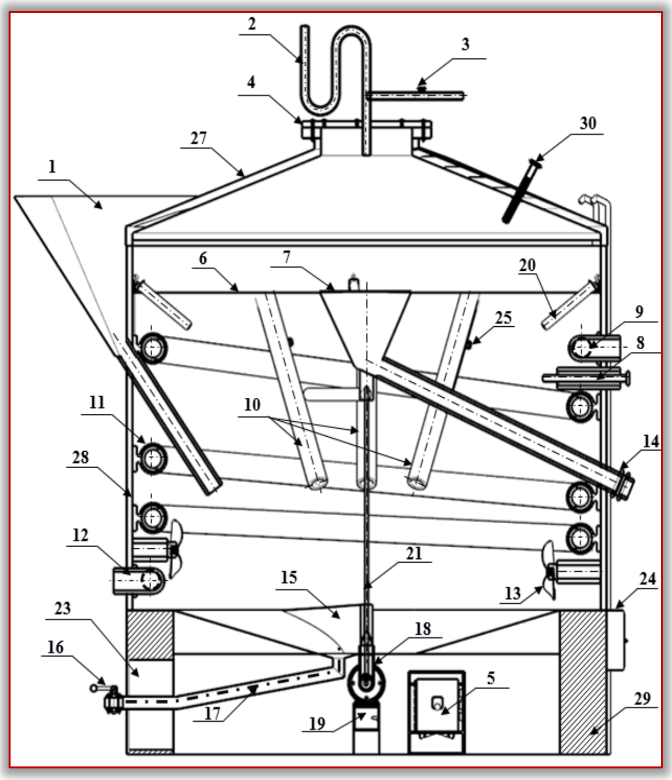


Figure 7 Entrance door to the space under the container with electrical control and management box

The main advantage of this bioreactor technology is the continuous, hermetically sealed filling and emptying of the biosubstrate after fermentation, which does not produce digestate. Another advantage is the high biogas yield, but also the possibility of connecting to other technical equipment, such as the municipal heating system, a cogeneration unit, as well as the processing of dewatered flotate and sludge by bagging and subsequent shipment of fertilizer.

The figure 8 shows a cross-section view of a bioreactor for the production of biogas from liquid biosubstrate.



Legend: 1 – feed hopper, 2 – gas safety valve, 3 – gas outlet valve, 4 – mounting flange, 5 – distribution box, 6 – level gauge, 7 – outlet hopper, 8 – multifunctional sensor, 9 – cooling/heating medium inlet, 10 – additive funnels, 11 – cooling/heating pipe, 12 – cooling/heating medium outlet, 13 – propeller electric mixers, 14 – fecal outlet, 15 – scraper, 16 – fecal lever outlet, 17 – desludging pipe, 18 – electric motor, 19 – electric control box, 20 – ultrasonic extraction rod, 21 – shaft, 22 – ladder, 23 – door, 24 – control system, 25 – flap with electric motor, 26 – hatch with filling opening, 27 – dome, 28 – container, 29 – base structure, 30 – biogas detector.

Figure 8 Cross–section view of a bioreactor for the production of biogas from liquid biosubstrate

The figure 9 below shows a top view of a bioreactor for producing biogas from liquid biosubstrate.

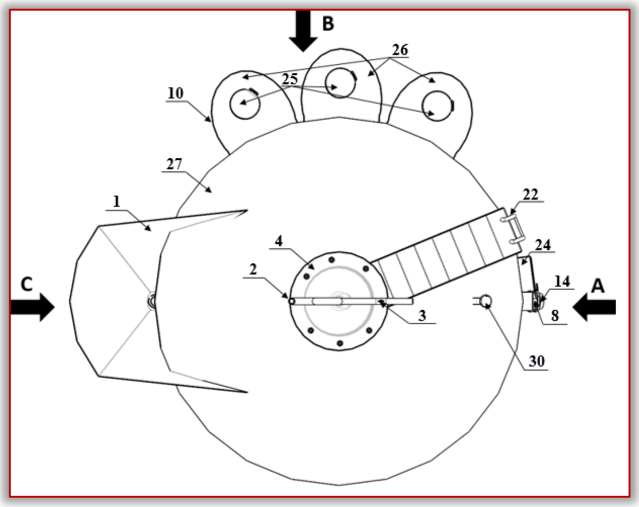


Figure 9 Top view of a bioreactor for biogas production from liquid biosubstrate

The figure 10 shows a view in direction A of a bioreactor for the production of biogas from liquid biosubstrate.

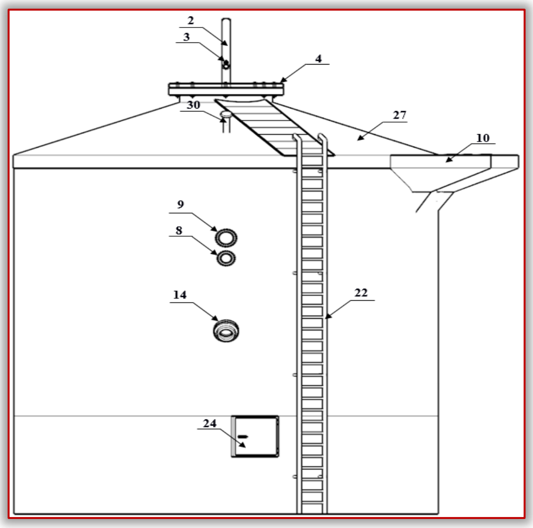


Figure 10 View in direction A of a bioreactor for the production of biogas from liquid biosubstrate

View in direction b of the bioreactor for biogas production from liquid biosubstrate is shown in the following figure 11.

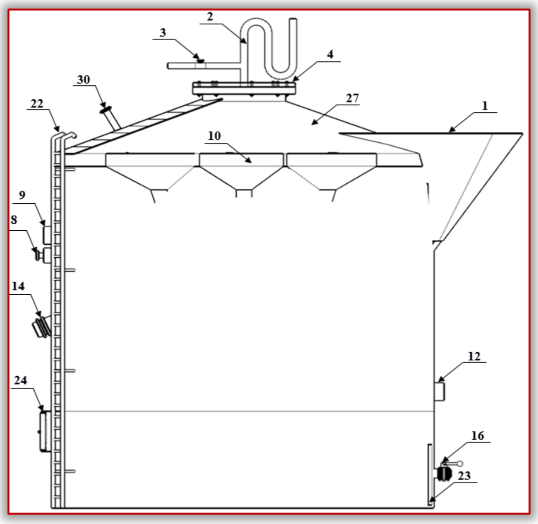


Figure 11 View in direction B of the bioreactor for the production of biogas from liquid biosubstrate

View C of the bioreactor for biogas production from liquid biosubstrate is shown in figure 12.

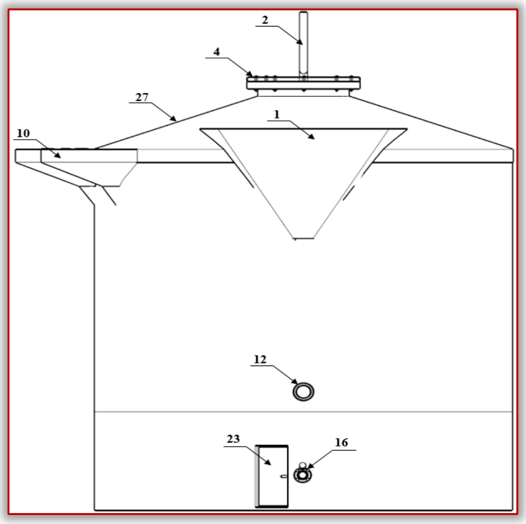


Figure 12. View in direction C of the bioreactor for biogas production from liquid biosubstrate

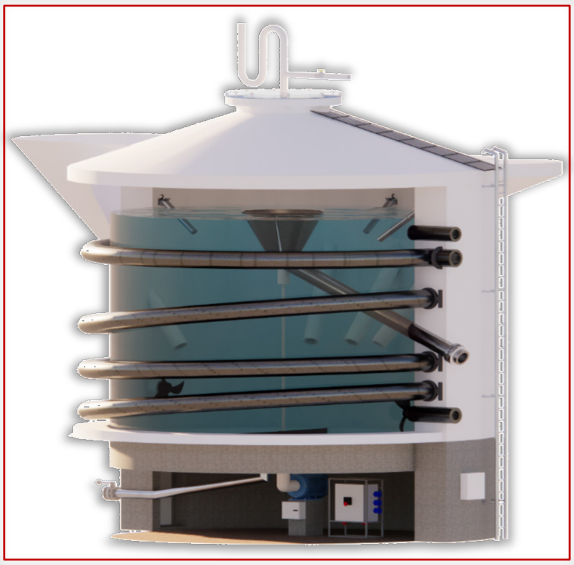


Figure 13. 3D cross–section view of a bioreactor for biogas production from liquid biosubstrate

INDUSTRIAL APPLICABILITY OF TECHNOLOGY

A bioreactor for the continuous production of biogas from liquid substrate can be advantageously used where there is no wastewater treatment plant and where it is necessary to transport domestic and commercial municipal wastewater from cesspools over long distances for disposal, but especially liquid waste from catering establishments, food and processing industries, but also waste oils. The decomposition process of bio-waste in such a composition is at various stages, so it is necessary to homogenize it by mixing, including ultrasound, analyzing it, and adjust the fermentation process so that the optimal amount of biogas is extracted. For this purpose, multifunctional sensors are used to measure temperature, pH, chemical elements, organic substances, and microbiological processes in the fermentation process, such as fatty acids (formic, acetic, propionic, lactic, valeric, etc.), the load on FOS/TAC fermenters, and biogenic elements (phosphorus, nitrogen, potassium, calcium, sodium, magnesium, etc.) in settings according to the composition of the biosubstrate.

This composition and conditions are served by software for dosing ingredients, which are mainly methanophilic bacteria in a wide spectrum (order Methanobacteriales, order Methanococcales, order Methanomicrobiales, etc.) and nutrients in an acidic and alkaline environment.

The biogas produced is also used to heat the biosubstrate to the temperature set by the control system within the optimal range. The discharged flotate and sludge after dewatering serve as high-quality fertilizer, and the water returns to the reactor as a high-quality inoculation ingredient.

By processing biomass in a bioreactor, large amounts of waste from small sources, which would otherwise be a burden on the environment, can be effectively utilized. In addition, biogas production in a bioreactor does not produce its own waste, as all outputs are environmentally acceptable for further use.

CONCLUSIONS

The presented bioreactor technology for the continuous production of biogas from liquid biosubstrate represents a significant step forward in the field of biodegradable waste processing. The combination of a hermetic solution, precise control of the fermentation process, and innovative design elements such as an ultrasonic extraction rod and multifunctional sensors achieves high biogas yield while maintaining stable operating conditions.

A significant added value is the possibility of effective use of by-products - flotate and sludge - as organic fertilizers, thus closing the material cycle and minimizing environmental impact. Technology also allows connections to heating systems or cogeneration units, which increases its economic and energy efficiency.

The equipment is particularly promising for areas without wastewater treatment infrastructure and for entities processing various liquid wastes from the municipal and industrial sectors. The implementation of this technology is therefore an effective tool for the sustainable management of biological waste and also contributes to the development of renewable energy sources.

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