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Increasing of Utilization Efficiency of the Produced Energy in the Biogas Plant

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Abstract : The current trend not only in the world but also in Slovakia is to increase the share of energy obtained from renewable sources. Biogas stations also participate in the share of energy obtained from these sources. Today it is mostly modern and environmentally friendly technical equipment. They process a wide range of materials or waste of organic origin through the anaerobic fermentation process. Its result is biogas, which can be further utilized for the production of heat and electricity. However, the efficiency of the biogas production process is closely related to technical equipment of biogas plant. Also, biogas plant technology must, to the extent necessary, respect the conditions of its safe and reliable operation. The contribution is oriented to the design of a possible solution for increasing the efficiency of utilization of the produced energy in the biogas station.

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1 Introduction

The biogas plant can be characterized as a set of technological equipment for the transformation of organic materials for biogas production [1]. This transformation takes place most often in the form [2] of fermentation of organic biomass with a large percentage of methane gas, i.e., biogas [3]. In the case of the implementation of managed anaerobic fermentation, both from an economic and ecological point of view, it is a prospective way of using biomass for valuable renewable energy sources [4]. The primary product of anaerobic fermentation is biogas [5]. They are also energy-efficient [6] also the by-products of the anaerobic fermentation process such as digestate i.e. the rigid residue after evisceration and fugate i.e. liquid residue after evisceration.

2 Principle of biogas production based on anaerobic fermentation

Biogas is an organic gas that is obtained through a biochemical process. This is a process also called anaerobic fermentation of biomass [7]. Biomass is transformed to biogas in the tanks so called fermentors in the presence of microorganisms. It´s a biochemical process, those the final result is product called biogas i.e. mixture of methane (CH_4), carbon dioxide (CO_2) and by-products [8]. Organic decomposition (fermentation) occurs without access to air in humid environments by the action of anaerobic cultures of microorganisms [9]. Ideal conditions for these anaerobic bacteria are temperatures close to 50 °C. This is a relatively complex chemical process in which biogas usually occurs in its last phase. Anaerobic fermentation takes place in four phases which are referred to as hydrolysis, acidogenesis, acetogenesis a metanogenesis. The diagram in the figure 1 detailed describes the biochemical process of anaerobic fermentation the result of which is biogas (CH_4+CO_2). The time course of the biochemical process of anaerobic fermentation is closely related to many factors [10]. These include, in particular, constant temperature, because in the case of rapid temperature changes, anaerobic bacteria often die. These include, in particular, constant temperature, because in the case of rapid temperature changes, anaerobic bacteria often die. Another important parameter is a suitable pH. For these purposes, it is advisable to maintain a pH range of 6.5 to 7.5. Next to ensure the presence of trace elements such as iron, cobalt, selenium, molybdenum and tungsten. It is also important to keep the required nitrogen, carbon and phosphorus ratios, as well as the total biomass quality in terms of dry matter content. At present, two approaches are applied to biogas production, i.e. wet and dry process of anaerobic fermentation. A wet process of anaerobic fermentation is considered a technology in which a substrate with a water content of 85% or more is processed. Wet anaerobic fermentation is currently the most common method of anaerobic processing of bio-waste in Slovakia. The following figure 2 shows the diagram of wet anaerobic fermentation process.

In the case of a dry fermentation process, a water content of less than 85% is used. For practical reasons, this technology is currently only used in the Slovak Republic at a minimum. However, it is a technology that has a number of benefits in terms of significantly lower energy intensity of operation, lower sensitivity to the quality of input raw materials and lower balances with material handled. The following figure 3 shows the diagram of dry anaerobic fermentation process.

By complying with the appropriate input conditions, has a biogas obtained dry or resp. wet process of anaerobic fermentation a methane content in the range of 55 to 70% with a calorific value in the range of 18 to 26 $MJ.m^{-3}$.

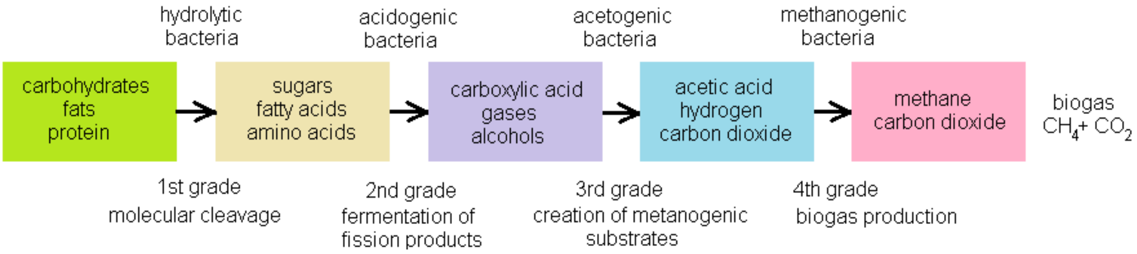

Figure 1 Biochemical process of biogas production through anaerobic fermentation

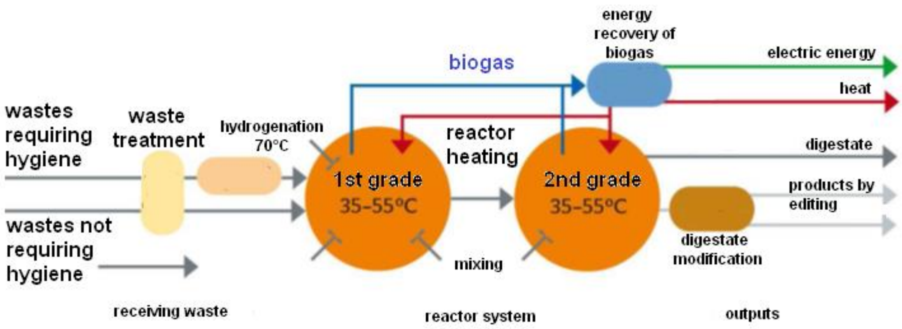

Figure 2 The diagram of the wet anaerobic fermentation process

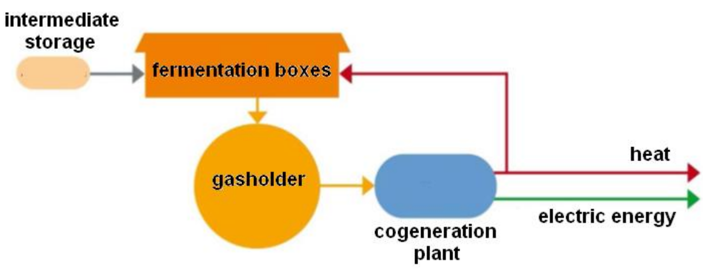

Figure 3 The diagram of the dry anaerobic fermentation process

Table 1 Chemical composition and selected properties of biogas

Chemical composition of biogas								
Biogas component	Methane	Carbon dioxide	Water vapor	Nitrogen	Oxygen	Hydrogen	Ammonia	Hydrogen sulphide
volume %	40 – 75	25 – 55	0 – 10	0 – 5	0 – 2	0 – 1	0 – 1	0 – 1
Selected properties of biogas								
Parameter	Calorific value	Density	Density in relation to air density	Ignition temperature	Range of flammable gas concentration in air		Theoretical need for air	Maximum flame rate in air
Biogas	6 $kWh.m^{-3}$	1,2 $kg.m^{-3}$	0,9	700°C	6 – 12%		5,7 $m^3.m^{-3}$	0,25 $m.s^{-1}$

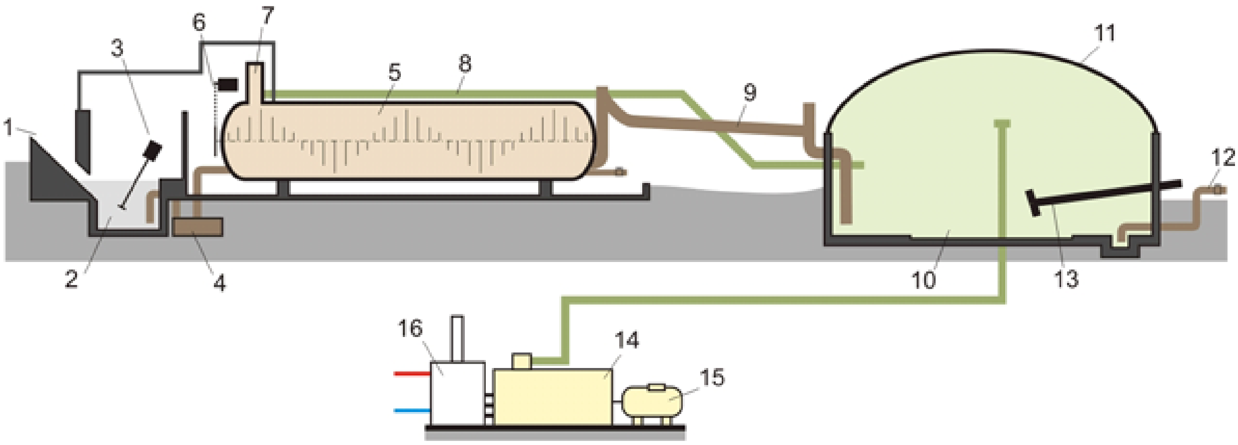

Figure 4 Basic structure of a conventional biogas

1 – hopper; 2 - homogenisation tank; 3 - propeller stirrer; 4 - sludge pump; 5 – fermentor; 6 - mixing fermentor; 7 - gas dome; 8 - gas pipeline; 9 - overflow pipeline; 10 - final storage tank; 11 - membrane gas; 12 - drain pipeline of digestate; 13 - propeller stirrer; 14,15 - cogeneration plant; 16 - heat exchanger.

The table 1 described a chemical composition and selected properties of biogas.
The basic qualitative parameter of biogas is the percentage of methane [11]. The obtained biogas can replace natural gas in practice. It can therefore be used, for example, by means of convection technology equipment for the production of electric or thermal energy [12].

3 Basic technological equipment of biogas plant

For reliable and safe operation of biogas plant technology [13] it is necessary to ensure its quality parts and a suitable monitoring and control system. By using appropriate technical equipment combined with a high-quality monitoring and control system it is possible to achieve its semi-automatic, resp. automatic operation. Current approaches in biogas plant technology are also closely linked to user requirements [14]. Therefore, in addition to safe and reliable operation, the priority is also a long service life. The following figure 4 shows the basic structure of a conventional biogas plant.
The biogas production process begins by dosing the substrate into the dispenser. After adding the required amount of input substrate, it is transferred to the homogenization tank by means of the conveyor. In the homogenization tank, the input substrate is diluted with water. After homogenization to the required density, the substrate is pumped into the fermenter, where the biogas production process begins when the required temperature is reached. In the final phase, the substrate is pumped from the fermenter into the after fermentor and then to the final storage.

4 Weaknesses of current approaches in biogas station technology solutions

In practice it has been observed several deficiencies which concern the biogas plant technological equipment. One of the deficiencies is concerns into the absence of monitoring the density of the substrate in the homogenization tank and the fermentor [15]. Substrate density is one of the important parameter which is associated with the consumption of own electricity produced in a biogas plant. Another major deficiency of current approaches to biogas plant technology solutions is the absence of elements of the monitoring system [16]. It is for example absence of monitoring water flow which is pumped from the collection tank into the homogenisation tank. Water is used to dilute the solid substrate. The amount of water required to dilute the substrate is generally determined only by an estimate of the personnel who must perform the inspection visually. There is often also a missing of monitoring of the amount of liquid residue after fermentation (Fugate). Another problem of the operation of biogas stations is the deficiency of altimeters in fermenters, which serve to monitor the height of the pumped substrate level. During mixing of the substrate in the fermenter, it often happens that the blender throws a piece of substrate over the surface level and the altimeter records it by performing an error message in the monitoring system. A separate group represents a deficiency that is directly related to the energy utilization of the biogas produced [17]. The produced biogas is during a longer shutdown of the cogeneration plant ineffectively burned with a safety burner. In case when the cogeneration plant is shut down and the biogas in the fermenters exceeds the determined fill value then biogas is burned with a safety burner so-called “fakel”. This means that biogas is not used and the operator of the process equipment thus loses profit.

5 Designing and implementation changes to eliminate deficiencies in the biogas plant operation

In the event of a complex solution of the above mentioned problems of the biogas station operation it is necessary not only to modernize the technological equipment, but also to innovate the elements of the monitoring and control system. Figure 5 shows innovation proposal of the elements of the monitoring and control system of the biogas plant.

As mentioned above, a separate area of deficiencies in the biogas plant operation is represented deficiencies, which are related to the efficiency of the energy utilization of the produced biogas. These are in particular losses that are caused by the long downtime of the cogeneration plant e.g. turbine generator or power line faults [18]. In this case, the biogas produced is fired by a safety burner due to the safety of the operation of the biogas plant. This burning is necessary to perform in the moment, when the level of the biogas produced in the gas tank above the fermentor is exceeds the limit value. Emergency combustion of biogas has no energy use in that mode and is therefore reported as a loss.

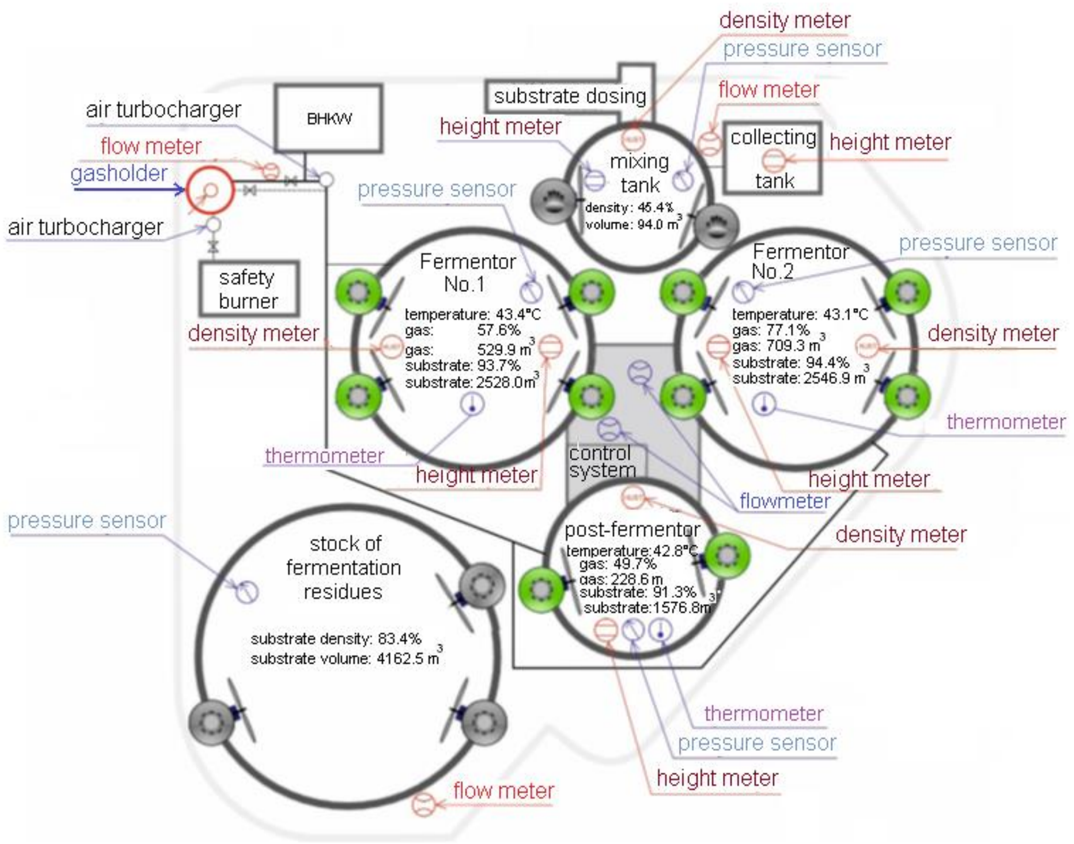

Figure 5 Innovation of the elements of the monitoring and control system of the biogas plant

For eliminate this deficiency must be implemented additional elements of the technological equipment into the system [19]. The main element will be represented by three-membrane gas-holder. The gas pressure in the gas-holder is maintained by air, which is blown between the membranes by the turbocharger. Input air has two functions. The first function maintains a gas overpressure and the second function maintains the permanent shape of the outer membrane, what it creates protection against weathering. The gas-holder size is dependent on the amount of biogas produced in the fermentor per unit time and the time required to cover the downtime of the biogas plant technological equipment intended for the consumption of the biogas produced. The figure 6 shows a three-membrane ball-shape gas-holder.

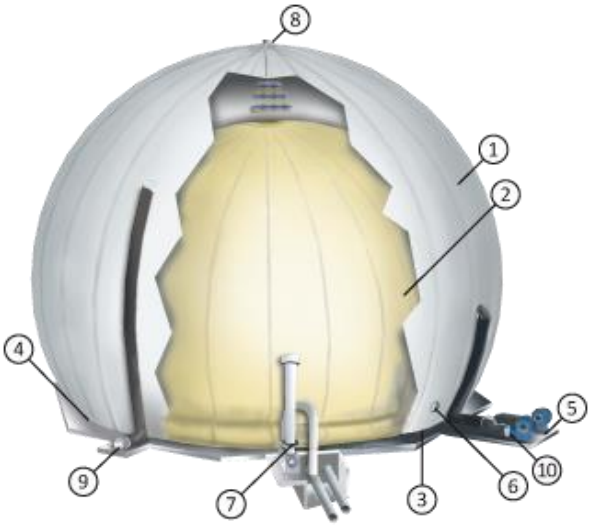

Figure 6 Ball-shape gasholder [21]

1 - outer membrane; 2 - inner membrane; 3 - floor membrane; 4 - anchoring frame; 5 - supporting turbocharger; 6 - peephole; 7 - liquid fuse; 8 - measurement of filling; 9 - regulation valve; 10 - return valve

In the event of a cogeneration plant shutdown, biogas will be transported from the fermentor into the gas-holder using a stainless steel pipeline. The direction of the biogas flow will be controlled by means of a three-way valve. The first branch represents the original solution. The second branch represents an innovative part which will be connected via a turbocharger to a back-up three-membrane gas-holder. In the case of a forced shutdown of the cogeneration plant the control unit sends a signal to the three-way valve to close branch no. 1 and opening of branch no. 2 along with the launch of the turbocharger. Only after the backup gas-holder has been filled and the still persisting shutdowns of the cogeneration plant the biogas will be burned with a safety burner. Figure 7 shows a flowchart which describes the upgrading of the biogas plant operating mode.

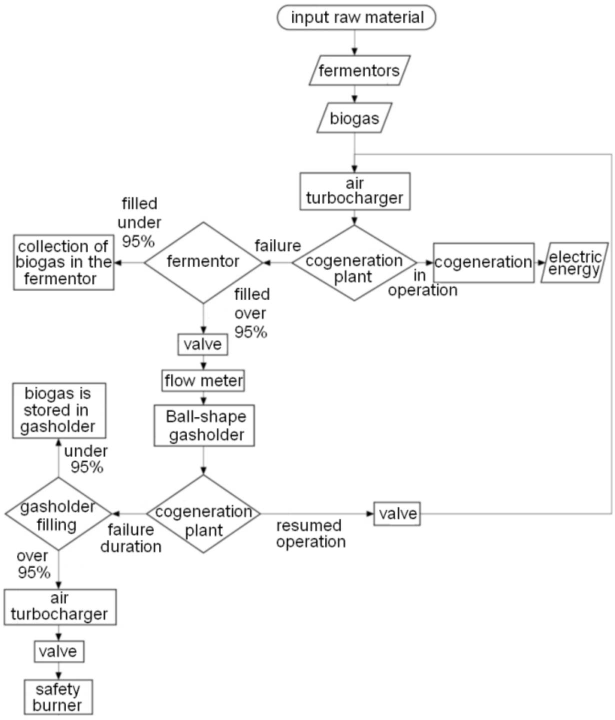

Figure 7 Flowchart proposed of designed innovation of the biogas plant operating mode

After reintegration of the cogeneration plant it is possible the biogas from a backup gas-holder use in case of a lack of biogas production in the fermentor. At the same time, the proposed solution will contribute to higher stability and efficiency of the biogas plant operation.

Conclusions

The aim of the paper was to propose an innovation of the current approach in the technical solution of the technological equipment configuration of the biogas plant in order to increase the economic efficiency of their operation. Innovation also involves the design of suitable sensors necessary for monitoring and control of the upgraded biogas station operating mode. Implementation of the proposed technical solution in practice can reduce losses which arise as a result of the cogeneration plant failure. The proposed solution also allows for the continuous operation of the cogeneration plant even in case of a failure or maintenance fermentor. With these innovations, an operator of a biogas plant can reduce its losses in case of failure on a cogeneration plant or a fermentor and also increase the amount of electricity and heat produced. In case of innovation the monitoring and control system of the biogas plant, almost unattended operation can also be achieved, which also contributes to a significant improvement in economic indicators.

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