Development of an Experimental Bioreactor

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***Abstract*— This research is based on a customized laboratory bioreactor system with water bath and changing environmental parameters. The effect of the individual environmental elements on the biogas formation was observed. We intended to obtain values of biogas forming in our developed system near the yield values of a former validated laboratory reactor system. To check the development steps we examined the quantity and quality of the biogas forming in the reactors and the deviation of the characteristics.**

I. INTRODUCTION

Hungary's energy vulnerability is very high (above 60% since 2002). Appropriate measures and support schemes should be encouraged to invest in the energy sector. It is advisable to stimulate the exploitation of the underused capacity, which today means only a sort of "reserve".

The development of economies that rely on multiple energy types, and the development of the use of alternative energy sources is an important endeavor. Hungary, thanks to an excellent natural environment has a significant timber industry, agricultural and livestock activities. It is Reasonable to bring to the forefront the exploitation of energy obtained from remaining organic waste in these areas.

The valuable biogas resulting from the anaerobic degradation of carbon-containing waste materials can be a high-potential renewable energy source in our country.

Hungary could reach up to 700 MW, according to estimates based on the available raw materials, which is fifteen times the performance of existing and commercial biogas plants. Increasing the predicted degradation efficiency enhances the intention to install biogas plants, converges on the home exploitability opportunities and increases energy security. Decentralized building sites can reduce domestic energy dependence by even 10-15%.

In our country the sources of biogas production is largely agricultural by-products and energy crops (over 50%). Approx 30% of the production comes from sewage sludge, while the remaining from landfill gases. Renewable energy production, especially agricultural biogas can have the greatest impact on agricultural development. It is planned that by 2020 up to a hundred and fifty agricultural biogas plants can be built.

Biogas is formed by chemical decomposition of organic materials. The degradation process of organic matter takes place in a very complex system, through the close relationship of several bacteria species.

The process of biogas production can be broken down into three microbiological processes, which are based on each other and are inseparable under natural conditions.

The first step is hydrolysis where enzymes degrade the organic material to constituent parts (polymer chains), which are further chopped by the hydrolysis bacteria. Second step, the acetogenic bacteria convert the saccharides, fatty acids, acetic acid and the volatile organic acid is acetate and hydrogen. The third step takes place in strict anaerobic conditions, when the methanogenic microorganisms produce a methane and carbon dioxide mixture, the biogas. The amount of biogas produced for energy purposes is therefore affected by activity of the bacteria food chain.

To optimize the process the following conditions are necessary:

- Oxygen-free environment,
- t = constant temperatures above 20-30 ° C,
- moisture content above 50%,
- pH 7 ~ 7.5,
- satisfactory C / N ratio,
- light isolated environment as far as possible.

To ensure and implement these parameters is dependent on the scope of the technological expectations. On the operating levels these include: technological design (feasibility study, technology fitting raw materials) from the supply of raw materials to the use of required end products

- proper design of the equipment,
- obtaining regulatory approvals,
- purchase, installation and test operation of instruments,
- implementation of appropriate changes (if possible before the commencement of operations) to ensure continued operation.

The purpose of laboratory equipment is the modeling of the technology used in the industry. However, the problem of the biological model is its size of a magnitude is less than that used in the industry and therefore extremely sensitive to environmental influences.

For the laboratory experiments of biogas production well regulated blocks are needed, as according the VDI 4630 - "Fermentation of organic materials" Directive [1] parallel measurements must be done. Commercially found professional-reactor blocks, such as the incubator cabinet or the Fermac bioreactor have good performance, but they are expensive. We proposed the setup of a self-made reactor block which meets the requirements of VDI 4630 and works with small deviation and great performance.

An important aspect was that the intermittent mixing of the raw material - which is impossible in an incubator cabinet.- can be done in the reactors like in the industrial fermenters.

II. INTRODUCTION OF THE BIOREACTOR BLOCK

The goal is the realisation of a laboratory device, so for the material of elements contacting biologically active material, glass is used, while for the tubing silicone rubber is recommended. Thus, achieving the biochemical neutrality of the system during the fermentation process. [1] The one-liter reactors have drilled screw caps, sealed by a silicone rubber sheet. During the measurement, this so called septum is perforated by a hypodermic needle connecting a tube. The gas sampling itself is also done through the septum with a syringe because the 20 Shore hardness silicone closes well the resulting holes. The bottle itself is heated by a water bath. (Figure 1) Outside the reactor are two bottles for measuring the volume of the arising biogas using the positive displacement method. [2] [3]

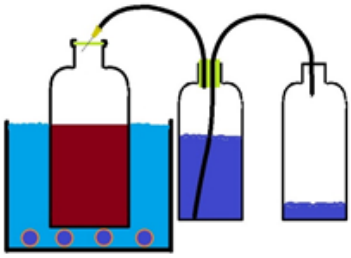

Figure 1. Reactor block and quantity measurement (own pic.)

The constant temperature fluid is held by a standard 600x400x300 mm size food box. The water is in a closed, continuous circulating system – heated by an external heat source, a thermostat - delivers heat to the radiator, which heats the water sustaining the temperature of the reactor tanks. The boxes are double insulated by an outer layer of polyfoam and foam pieces placed on the surface of the water. As a result, the interior light and the evaporation of water are decreasing at the same time. (Figure 2)

Figure 2. Insulated reactor block [5]

The 8 mixing reactors, driven by an individually designed gear box with 8 outputs, mixing plugs and paddles were manufactured for the reactor bottles (Figure 3). The electric motor performs the mixing performance, the gears transmit the drive and a Bowden cable connects the mixing paddle.

Figure 3. Mixing of the bioreactor-block reactor (own pic.)

The reactor block with water stabilised temperature was made, but the test series showed that the gas and methane yield in the system remains low compared to reactors placed in the incubator cabinet at the laboratory. In addition, the values measured in the parallel experiments on eight reactors had great deviation.

III. MEASUREMENT METHOD FOR THE REACTOR OPERATION

The performance of the reactor block was checked mainly by the biogas yield of the reactor bottles. Parallel experiments started simultaneously with the same parameters in the incubator cabinet (Fig.4) and in our reactor-block. Comparing the resulting biogas and methane yields results the development steps were proofed.

Figure 4. System stored in the incubator cabinet (own.pic.)

At the biogas trials the input of the raw materials to the reactor vessel was made under the VDI 4630 Recommendation as the basis of their solids (TS) and organic solids (TOS) content [1]. After, creating an anaerobic space the gas phase was purged with nitrogen, to remove the remaining oxygen from the reactor bottles. In the anaerobic degradation process the oxygen remaining in the system has a negative impact on the biogas yield because of obligate methanogens [2]. After it the reactor system installation was completed and started.

The amount of gas generated from the raw materials was determined by displacement method, analysis of the gas

composition was performed by gas chromatography. The primer was digestum from the South-Pest sewage farm, the raw material was wheat straw and microcrystalline cellulose.

. We determined the pH of the fresh seed sludge and fermented slurry at the beginning and end of the series of experiments. By this we were able to classify the adequacy and health of the bacterial culture in the fresh mud and check the completeness of the fermentation after the experiments.

The bacterial culture activity, the uniformity and quality of gas generation were significantly affected by the light conditions. The ultraviolet radiation within 200 to 400 nm range of the polychromatic light has a germicidal effect, so excessive light input can damage the bacteria, arrest their growth, while the infrared rays within the range of 780 nm - 1 mm can cause some additional heat input, thus affecting the rate of gas production. [4] So the most preferred way was to ensure the greatest darkness of the fermentor tanks to obtain a consistent performance.

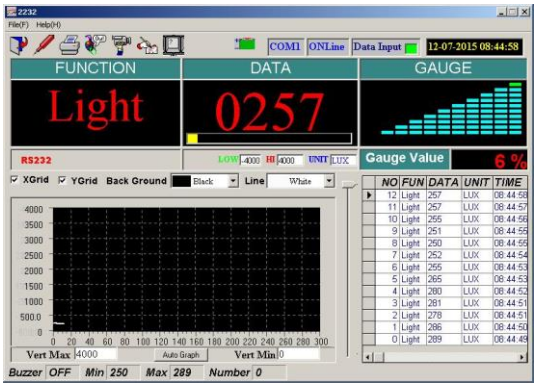

Figure 5. PCE Instruments PCE-222 [6]

The reactors ambient lighting conditions were measured with the PCE-222 type instrument for ambient conditions manufactured by PCE Instruments, in light measuring mode, with computerized data collection. (Figure 5)

IV. EXPERIMENTAL RESULTS AND STEPS OF DEVELOPMENT

A. Condition survey of the reactor block

The fundamental problem is the excessive lighting of the reactor tanks, so before the experiments light metering was performed on several zones in the interior and exterior space of the block. To compare we had to measure the light environment of the incubator cabinet too. (Figure 6)

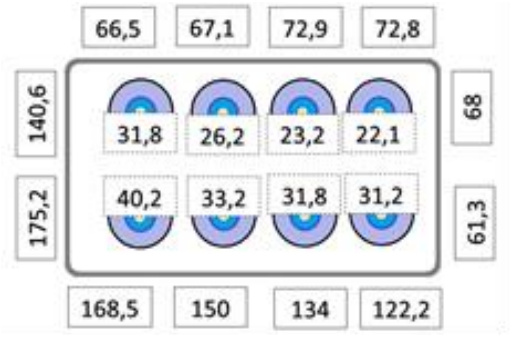

Figure 6. Illumination maps in the reactor block [lux][6]

In addition to the difference between light conditions we assumed the shortfall can be caused by the metering bottles operating on the displacement principle in the incubator cabinet were placed in a 37-degree space. Therefore, in the first experiment two of the eight bottles of the reactor block were placed in the water bath with the metering bottles.

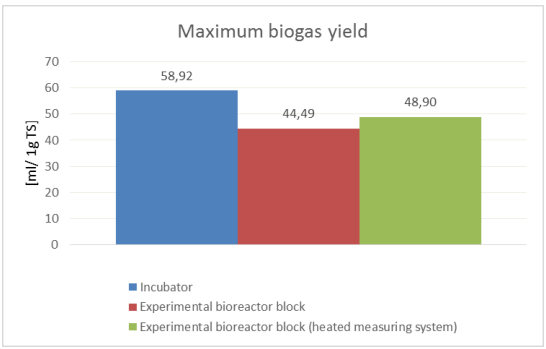

Figure 7. Maximal gas yields

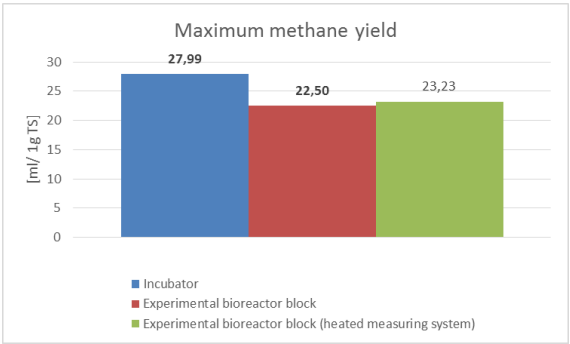

Figure 8. Maximal methane yields

The above chart shows the positive effect of placing the reactor in the same space with the measuring system on the gas yield. The standard deviation values also supported the need to improve the water system box. The standard deviation values of biogas and methane in the incubator cabinet was 2.00 and 1.08 ml / GTS, in the water box-reactor block was 5.17 and 3.34 ml / GTS. (Figure 7-8)

B. The use of external insulation box

An exterior insulated wall was needed, we chose a wooden, double-wall box. The external wall was made of sheets of pine, the inner of poplar plywood sheet. The space between the two walls was filled with polyurethane foam for the right thermal insulation, the surfaces was coated with linseed oil, and then with matt black paint. So both thermal insulation and light insulation problems were solved. (Figure 9-10)

Figure 9. Coated box (own pic.)

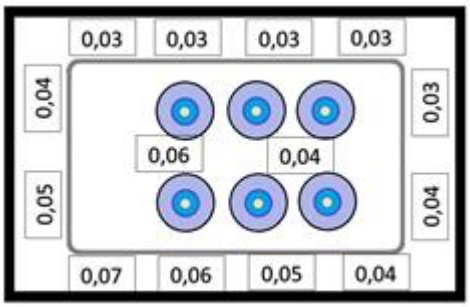

Figure 10. Coated box, illumination [6]

During the development the waste heat of the water in the reactor block was used to create the internal climate. The light insulation testing was performed on the basis of the measurement methodology previously reported. (Figure 5)

The conversion only partially brought the expected results. The crate had an increased gas yield, the surplus yield was reduced in the incubator cabinet, the stabilized environment, good heat and light insulation had a positive effect on the fermentation. However, the differences due to the imperfections intensified within the system, the standard deviation was significantly higher between the reactors. The standard deviation values of biogas and methane in the incubator cabinet was 1.36 and 1.40 ml / GTS, in the water box-reactor block was 12.20 and 7.31 ml / GTS.

C. The use of eleveted bioreactors

The reactors had increased scattering (deviation) values due different temperatures caused by the heating pipe (Figure 11). To compensate this a perforated platform was placed at the bottom of the chest, above the heating pipes, so the heat pipes are not in the direct vicinity of the reactor. The thermal inertia of the water could be exploited to minimize the temperature differences. (Figure 12) The surface of the platform grid allowed testing the system with 6 reactors.

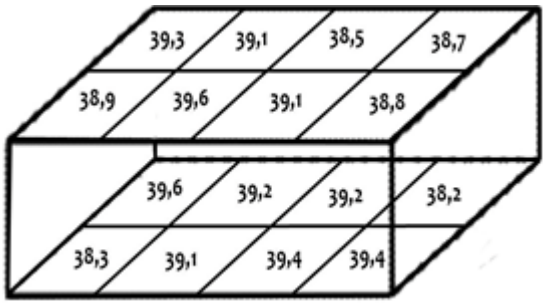

Figure 11 Thermal map of the insulated box [6]

Figure 12. Arrangement of the insulated box (own pic.)

Based on the results of biogas experiment we found the objectives set by the development are achieved. (Table 1) Both biogas and methane yields of the box were very close to the incubator cabinet values, but more importantly the deviation also decreased significantly for the laboratory equipment.

TABLE 1.

YIELD AND DEVIATION VALUES COMPARED TO THE INCUBATOR CABINET VALUES

Compared samples	Biogas yield shortfall	Methane yield shortfall	Biogas deviation	Methane deviation
compared to incubator cabinet box	8,85%	11,15%	same	1,38×

D. The application of mixing and the result of the biogas reactor block development

Our designed temperature control box can receipt mixing spirals too, so hoping the larger and more uniform gas yield bioreactors with intermittent mixing units was also tested.

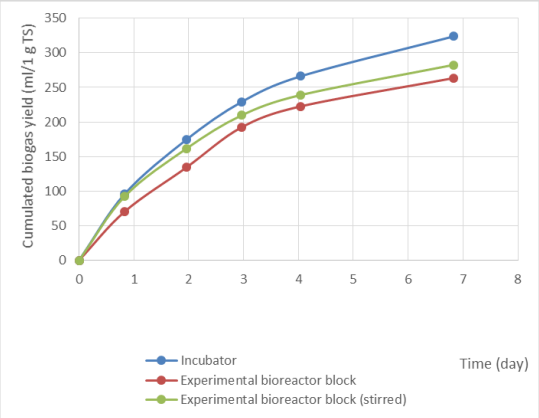

Figure 13. Biogas yields

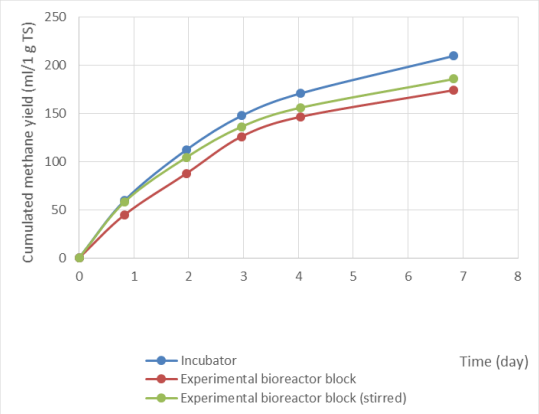

Figure 14. Methane yields

The differences in biogas and methane yields decreased, 329 ml/gTS and 209 ml/gTS in the incubator cabinet, while 282 ml/gTS and 185 ml/gTS values was measured in the mixed reactor block unit. (Figure 13-14.)

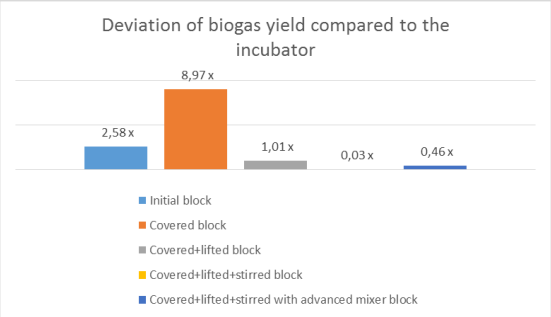

Figure 15. Relative comparison of biogas deviations

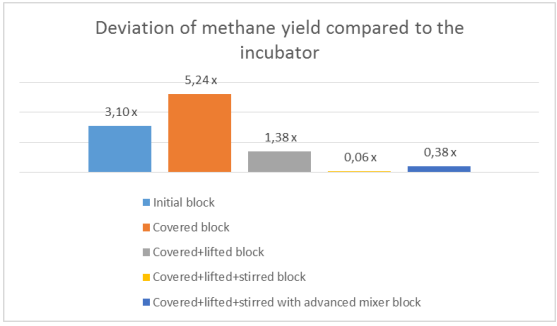

Figure 16. Relative comparison of methane deviations

The differences also continued to improve relative to the incubator cabinet deviation values. (Figure 15- 16.)

It is apparent that the effects of engineering and other changes in the reactor block brought on the expected results. In terms of the variance values the results were better than expected. In view of reactor yield performance we approached the incubator cabinet values, the difference almost halved.

V. FURTHER DEVELOPMENT OPPORTUNITIES

We reached the goals determined at the beginning of the bioreactor-block development. The test results confirmed changes and revisions to the accuracy of the technology.

However, the further developments arising from the use of laboratory biogas reactor block and other requirements of the existing solutions are inevitable.

These trends include the fact that during operation the requirements of gas tightness must be achieved with greater security. To do this, you need to redesign the agitator shaft stopper and to select the optimal bearings and seals.

The requirement of the reactor block mobility also emerged as possibility. This is necessary because the analytical measuring systems are permanently installed in each laboratory. To determine the gas composition by the gas chromatograph can affect the environment

So the goal is that the gas is injected into the sample injector reactors in the shortest possible path. This could be achieved by designing a strong scaffolding and support it with rollers.

During the measurements the cover of the thermal insulation double-wall boxes proved difficult and cumbersome to move. So a hinge side, ease of opening and fixing would make adaptability easier.

VI. CONCLUSIONS

The development steps modeled those used in the industry; however examples included other natural anaerobic environments. The targeted, cost-effective, yet suitable for real laboratory measuring bioreactor block has been constructed. Taking into account the costs without quantifying the block requires significantly lower investment as the series-built ones.

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REFERENCES

[1] VDI 4630 – Szerves anyagok fermentálása - A szubsztrátum jellemzése, mintavételezés, lényeges adatok gyűjtése, fermentációs tesztek, Verein Deutcher Ingenieure, Düsseldorf, 2006

[2] Drégelyi – Kiss Ágota, Horváth Miklós, Bagi Zoltán: Biogáz gyártás mérési eljárásai, Óbudai Egyetem, Budapest, 2012, ISBN 978-615-5018-51-0

[3] R. B. S. Chowdhury, D. J. Fulford: Batch and semi-continuous anaerobic digestion systems, Renewable Energy Vol.2. No. 4/5, pp. 391-400, 1992

[4] Tasneem Abbasi, S. M. Tauseef, S. A. Abbasi: Biogas Energy, Springer New York Dordrecht Heidelberg London, New York, 2012, ISBN 978-1-4614-1039-3

[5] Kormos Klaudia: Kevert, szakaszos biogáz fermentáció vizsgálata, Tudományos Diákköri Dolgozat, Óbudai Egyetem Bánki Donát Gépész és Biztonságtechnikai Mérnöki Kar Gépszerkezettani és Biztonságtechnikai Intézet, Budapest, 2013

[6] Kiss Zsolt, Vízfürdő temperálású bioreactor-blokk teljesítményoptimalizálása, Budapest, 2016. január, Óbudai Egyetem Bánki Donát Gépész és Biztonságtechnikai Mérnöki Kar Gépszerkezettani és Biztonságtechnikai Intézet, Szakdolgozat