Biogas Research Opportunities at Óbuda University

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***Abstract*— Achieving energy safety has become one of the most important goals of developed countries. The production of energy and assurance of energy supply coverage is a key issue not only in Hungary, but throughout Europe and the world. Biogas is one form of renewable energy that has not yet been utilized to its full potential in Hungary. Thorough knowledge of biogas production is the basis for reaching the potential of biogas power plants. The biomass laboratory founded by the University of Óbuda serves these biogas research initiatives.**

I. Introduction

These days, the development of different alternative energy sources is becoming more and more a focus of research. Biogas production has a specific place in the field of renewable energy production. The organic content of the waste can be digested with the anaerobic procedure described here. This technology does not prevent the formation of various wastes, but it is suitable for the prevention of emissions directly into the environment while producing "green energy". The research of economical and efficient methane yield could provide the opportunity for biogas plants to spread widely. The biomass treating laboratory founded at the University of Óbuda can provide the conditions for this type of research and development.

II. Equipment in the Biomass Treating Laboratory

The installation in the laboratory can be divided into three different sections: Biomass production, biomass pretreating, and analytical measurement units.

A. Biogas production units

The anaerobic units are capable of digesting different substrates and the production of biogas. Some of the fermenters are commercially available, but most are custom designed.

The Fermac 320 bioreactor is a complex unit designed to determine the potential gas yield from organic biomass. The physical software of the unit allows process control, monitoring of the process, and data acquisition. Peristaltic pumps are attached to the control unit. These are capable of feeding in chemicals and nutrients. ("Fig. 1,") [1]

Figure 1. Fermac 320

Custom designed double chambered: The double chambered fermenter was custom designed and built in cooperation with the Budapest University of Technology and Economics. Due to the double chamber design, this device can provide both a mesophilic (37ºC) and thermophilic (55-60ºC) environment simultaneously, with each chamber maintaining its own temperature. This pilot scale unit can run either periodically or continuously.

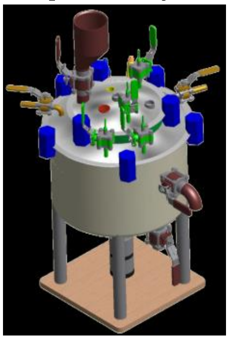

Figure 2. Custom designed double chambered reactor

The inner chamber holds a temperature between 55ºC and 60ºC. This is where the pre-digestion begins. The waste heat from the inner chamber is used to heat the outer chamber to 37ºC. The high temperature of the inner chamber ensures a short hydration time while the low outer chamber temperature for post-digestion provides additional gas yield. ("Fig. 2,")

Custom designed water tempered bioreactor block with internal stirring: The water tempered bioreactor block was custom designed by the research team of the laboratory. The block consists of eight reactors that can be operated side by side. Each reactor is a 1000 ml bottle with four apertures to allow sampling, gas diversion, pH probes, and agitation. The bottles are fixed in place and submerged in a water bath. The water is tempered with a closed-circuit pipeline system. Hot water is circulated by a pump and thermostatically controlled to maintain 37ºC. This water bath is contained in a wooden box with double insulated walls to prevent additional heat loss. (“Fig. 3,”)

Figure 3. Custom designed water tempered bioreactor block with internal stirring

Incubator: The incubator can hold up to twelve reactor units at the same time. It can maintain these reactor units at either the mesophilic or the thermophilic temperate range. The system is capable of periodic agitation; however, the ability to have continuous agitation is still being developed. (“Fig. 4,”)

Figure 4. Incubator

B. *Raw material pretreating equipment*

SHARK: The “Shark” is a wet pretreating machine designed like a cutting mill. The role of this unit is to increase the available surface area by using fluid shearing and collision. The wet media can be recirculated until a sufficient level of crushing is achieved.

Figure 5. Shark

The machine includes a rotating toothed barrel that can accelerate the substrate up to 170 m/s and generate a significant shearing force on the layer’s border area; the substrate during this stage has a maximum total solid content of 8%. The solids in the substrate are broken down by collision impact during this process.

Hydrodynamic pretreating equipment: Cavitation is used to grind the vegetal cells. Small bubbles form and collapse on the surfaces of the solids during cavitation. A wave is generated in the fluid by the asymmetric collapse of the bubbles. This phenomenon results in increased pressure and temperature. [3] The particles, accelerated by the waves, make significant changes in each other’s structure and reactivity resulting in a physical and chemical transformation. (“Fig. 6,”) shows part of the hydrodynamic preheating unit.

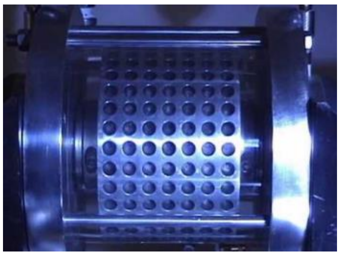

Figure 6. Hydrodynamic pretreating equipment

C. *Analytical units*

The measurement of the quantity and quality of the biogas is done in accordance with VDI 4630 standard, “Fermentation of organic material”. [4]

The quantities are measured by the principle of volume extrusion. The gas is diverted into a bottle filled with water. The gas extrudes the water into a second bottle which can be measured on a digital balance.

The composition of the biogas is analyzed by DANI Master Fast Chromatograph. The chromatograph is calibrated to detect and calculate the level of methane content. *(“Fig. 7”)*

Figure 7. Bio reactor block

D. *Analytical measurements of the raw materials used in experimentation*

The total solids (TS) and total organic solids (oTS) content can be determined using a Nabertherm CE 4/11/R6 furnace. Per the regulation of VDI 4630 the drying process is done at 105ºC with an ignition process at 600ºC. The TS and oTS values of the substrate are very important; the proportion of the materials in the fermentation process are correlated to each other based on these values.

A Satorius AX224 digital balance is used to measure the TS values, oTS values, and the weight of the raw material entering the fermenters.

The pH values are measured at the beginning and at the end of the fermentation process using a Fermac 320 pH probe. The quality of the biogas can be estimated by the pH values.

A Retch AS 200 sieving machine analyzes the particle size distribution.

III. Research Opportunities in the Biomass Treating Laboratory

Laboratory or industry scale biogas research is a field of interdisciplinary research. The production efficiency of biogas greatly depends on the applied technology. The faculty and students of the school of mechanical engineering at the University of Óbuda are focused primarily on the mechanical challenges associated with biogas production.

A. Research of raw material pretreatment

There are further research opportunities related to the Shark and the hydrodynamic pretreatment machines to determine the influence of these units on different raw materials. Both units are only suitable to treat wet media and fluids. [5]

Experiments have been conducted to study the influence of the Shark unit on sludge mixed with straw and received from a wastewater plant. Testing was done on both treated and untreated samples. This testing looked at the impact of the rotation speed, number of recirculation cycles, and the soak time of the wheat straw. These sets are designated as S1-S9. The comparison of the untreated and treated mixture and the results can be found in ("Fig. 8,").

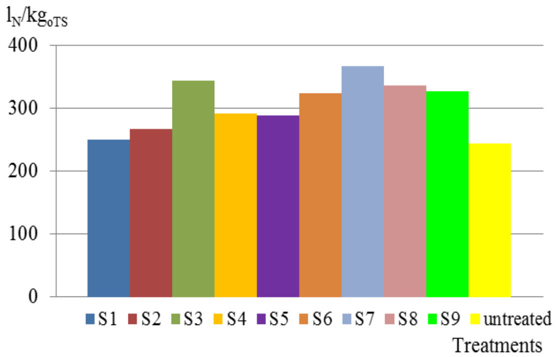

Figure 8. Biogas yield of different pretreatments [5]

The untreated mixture of sludge and wheat straw produced 243 lN/kgoTS of biogas and 118.8 lN/kgoTS of methane. The treated mixtures produced 250-370 lN/kgoTS of biogas. This value corresponded to the value Kaltwasser [6] defined as a median (~200-300 lN/kgoTS). The treated samples produced 4-50% more biogas than the untreated samples. ("Fig. 9,") The optimal parameter set up in this series of tests was S7: 1600 rpm, recirculated 9 times, wheat straw soak time of 15 hours.

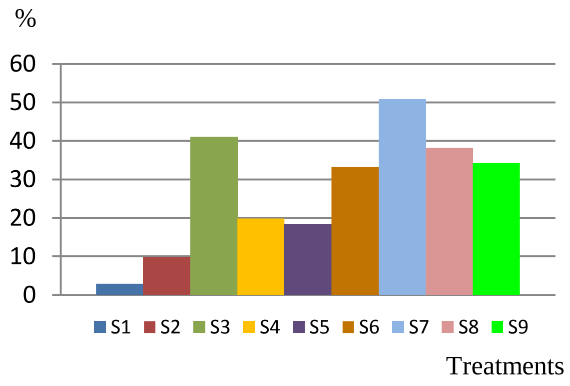

Figure 9. Increment biogas yield percentages with different pretreatments compared to the untreated sample [5]

The results from this testing indicate that preheating has a significant impact on the degradation time, biogas yield, and methane yield. The most efficient number of recirculation cycles is three, once the energy balance was fine tuned. ("Fig. 10,") [7]

Potential testing to be pursued is a system that combines two pretreating machines, so that one pretreat machine feeds a second pretreat machine. Due to the number of variables offered by this arrangement, a Design of Experiment (DoE) with statistical analysis would be required.

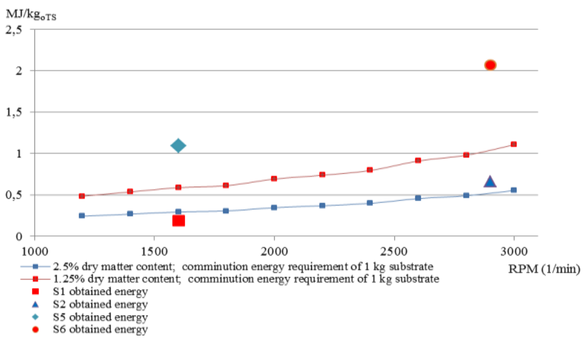

Figure 10. Energy balance – circulated 3 times[7]

Statistical analysis can be used to determine the value of the variables of the experiment. This is the design of experiment [8]. Variance analysis can be used to analyze the results and set up a mathematical model for further experiments [9].

The operation of the machine and the different settings of the pretreatment were tested with both materials. On the basis of the cross-effect figure the joint investigation of effects of the other factors was also carried out. ("Fig. 11,"). [7]

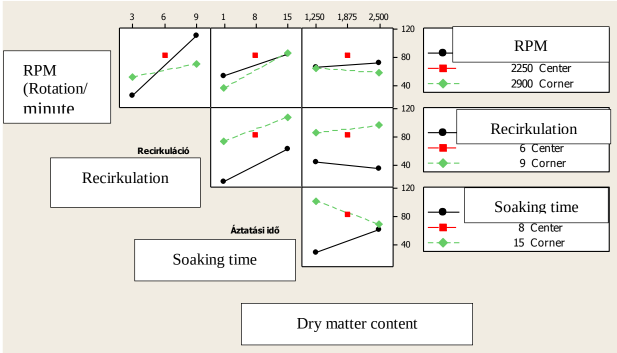

Figure 11. Cross-effect after 16 days [7]

B. Design of a laboratory reactor

The University's Biomass Treating Laboratory provides the space and the equipment to build and test machines based on new innovations.

The water tempered bioreactor block with internal stirring was custom built piece of equipment. By designing and building a customized bioreactor block, it was possible to create the needed equipment for testing multiple samples in parallel and maintain a testing budget. This equipment does, however, still have room for improvements, such as mobility and improvements to the stirring system.

Our current project is a horizontal bioreactor. This reactor is compatible with the Fermac 320 unit's control system which can provide data vital to further testing and analysis. The volume of the new reactor is identical to the existing one to ensure they are comparable. It has a heavily modified stirrer inside the chamber compared to the commercially available version. This is the first prototype, the first step in a long development process to reach the final stage. ("Fig. 12,")

Figure 12. Horizontal reactor

There is a great industrial demand for higher biogas and methane yield. The efficiency of the digestion can be improved by the increased available surface area of the raw material. There is also a demand at the University to design and build a surface increasing mechanical treating machine suitable for wet and dry materials. [10]

C. Modeling the industrial biogas production

The Fermac 320 bioreactor can be used for modeling industrial scale biogas production. It can simulate different environments by adjusting the pH level, temperature, and agitation. The impact of these parameters can be monitored, captured, and analyzed to allowing a full understanding of the critical design settings.

IV. CONCLUSION

The equipment of the Biomass Treating Laboratory and the possible research projects are summarized in the chapters of this article. This article was written from the engineering point of view. This is an interdisciplinary field of research. Many researches can be found in the fields of microbiology, energetics, analytics, and chemistry.

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