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THE ANAEROBIC DIGESTION OF SHEEP MANURE IN SELF-DESIGNED LOW-COST BIOGAS REACTOR

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ABSTRACT

One of the possible utilisation methods for organic wastes is anaerobe decomposition (fermentation). The main product of this process is biogas which is usually used for energy purposes due to its composition (mainly methane and carbon dioxide). The residual solid material after fermentation can be used as soil conditioner.
Lab-scale fermentation can be carried out using the "VDI 4630 – Fermentation of organic materials Characterisation of the substrate, sampling, collection of material data, fermentation tests" standard. Based on the conditions described in the standard, a small-scale low-budget reactor system were prepared. The temperature during the holding time was controlled with water bath and the gas production was determined with fluid displacement method. A peristaltic pump was used for the recirculation of the gas to mix the base material. Furthermore, the temperatures of the environment, the water baths and the inside of each reactor was automatically registered on a data collector.
Based on the gathered data, the system is applicable for biogas production from sheep manure. The produced biogas quantities were between 0.01-0.15 m^3/kg TS and the methane content was 24-63 vol% during the experiment at various temperatures, using different inoculants.

Keywords: biogas reactor, fermentation, sheep manure, slurry

1. INTRODUCTION

The natural degradation of organic material by microorganisms under anaerobic conditions results in the production of biogas. During anaerobic digestion, organic material is converted into biogas, a renewable fuel. Biogas, due to its high CH_4 content, could be used to produce electricity, heat or vehicle fuel. Recently, the anaerobic digestion of agricultural and industrial wastes, municipal organic waste, sewage sludge, etc. has become a commonly used method for renewable energy production. The volume yield of Biogas production is affected by several factors, not only the origin and composition of the base material, but the temperature variation, pH and concentration of total solid and total organic etc. can have significant effect on the quantity and quality of the produced gas [1, 2].
Temperature is one of the key factors, as three kinds of microorganisms can be distinguished based on the temperature intervals they can produce biogas [3]. As a result, the applied technology can be operated in three temperature intervals as well: psychrophilic (environmental temperature), mesophilic (optimally 32-42 °C) and thermophilic (<50 °C) [3]. As the temperature is increased, the gas yield per time unit is expected to increase and the time of the process to decrease. However, higher reactor temperature means additional costs. Generally, wet technology is used for biogas production, during which the maximum dry matter content of the used material is 15% [4]. Using such dry matter content, the base material is still easy to mix and pump. The gas production capability of the base materials can be examined under laboratory conditions using the standard "*VDI 4630 – Fermentation of organic materials Characterisation of the substrate, sampling, collection of material data, fermentation tests*". According to the standard, a climatic chamber or temperature-regulated water bath is necessary to keep the anaerobic digesters at a constant temperature.
The aim of the experiments was to develop a low-budget biogas reactor that based on this standard, and the application of a water bath was chosen. The system, beside meeting the criteria in the standard, can mix the base material and record the temperatures. It is capable of parallelly operating reactors at various water

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bath temperatures. For the tests, environmental temperature (psychrophilic conditions), 34 °C (mesophilic conditions) and 50 °C (thermophilic conditions) were used.
Sheep manure was used to test the system, which is a low-quality base material, according to literature [5]. The gas yield was around 0.1-0.4 m^3/kg dry base material [6, 7, 8], the methane content of the produced gas was expected to be 40-65 vol% [7, 9, 10, 11, 12]. Thus, the biogas should be applicable for energy purposes.

2. MATERIALS AND METHODS

2.1. Materials

The digester system vas tested using sheep manure. The dry matter content (TS) was decreased to 18 wt.% for better mixing and homogeneity. During the experiments, 0, 10 and 20 wt.% digested cow manure (DCM) was added as inoculant. The properties of the base material are summarised in Tab. 1.

Table 1. Ultimate and proximate analysis of the base material

	In relation to the dry matter							In relation to the feed material	
	Nitrogen	Carbon	Hydrogen	Sulphur	Oxygen	Ash	HHV	Moisture	pH
	wt%						MJ/kg	wt%	-
Sheep manure	2.59	29.28	3.85	0.70	17.17	46.42	9.87	15.1	7.68
Digested cow manure (DCM)	2.25	37.70	5.27	0.71	20.07	33.00	11.30	79.2	8.81

2.2. Fermentation setup

The three main parts of the developed system are the temperature-regulated water bath to keep the reactors at the examined temperature intervals, the anaerobic digester system for biogas production the and the data logger to continuously monitor the temperatures at various parts of the system.
The temperature-regulated water bath system can be observed in Fig. 1. The temperature of the water bath is controlled by a W1209 digital thermostat (Fig. 1/1). To reach the 34 °C water temperature, an Atman 100 W aquarium heater was used, but a 600 W immersion heater was necessary to achieve 50 °C water temperature (Fig. 1/2). The water for the bath (Fig. 1/3) was held in a 40 litres polypropylene harvest crate (Fig. 1/4). To monitor the temperature of the bath, an NTC temperature sensor was added (Fig. 1/5) to the system which was directly connected to the heater. The circulation of the water bath was achieved with an aquarium pump with 300 l/h performance (Fig. 1/6). Due to the evaporation of the water bath, approximately 1-2 litres per day water should be replenished. When the water level was low according to the liquid level sensor (Fig. 1/7), the liquid level controller (Fig. 1/8) proceeded the automatic water replenishment from a container (Fig. 1/9) using a 240 l/h performance submersible pump (Fig. 1/10). To minimise the rate of evaporation from the 50 °C warm water, polystyrene sheets were put on the surface of the water.

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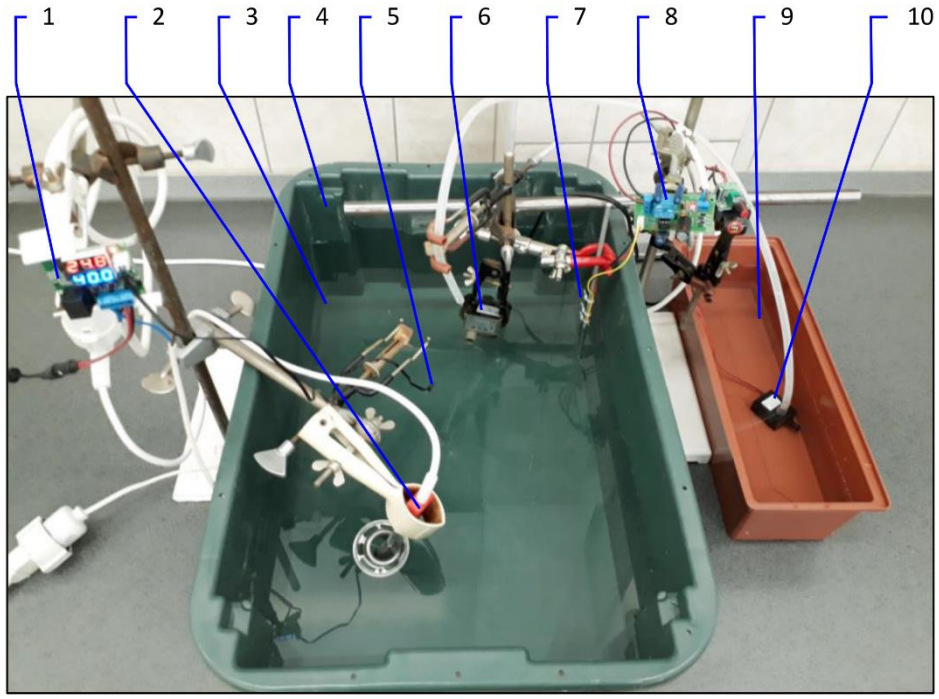

Figure 1. The temperature-regulated water bath system (1 – W1209 digital thermostat; 2 – immersion heater; 3 – water bath; 4 – PP harvest crate; 5 – NTC waterproof temperature sensor; 6 – aquarium pump; 7 – liquid level sensor; 8 – liquid level controller; 9 – replenisher for the water bath; 10 – submersible water pump)

The anaerobic digestion was carried out with and without mixing the base material. The anaerobic digester system equipped with mixer can be found in Fig. 2. In this case, a motor speed controller (Fig. 2/1) is used regulate the speed of the peristatic pump (Fig. 2/2) which is connecter to the reactor with two silicone tubes. With the help of the pump, biogas from the headspace can be mixed to the bottom of the slurry, providing homogeneity and the liberation of the gas from the slurry. If no mixer is used, the abovementioned parts are not included in the system. In both cases, the system can be flushed with inert gas before the digester is started using the flushing tube (Fig. 2/3). Brown glass bottles (Fig. 2/4) which can hold up to approximately 1 kg base material were used as reactors. Thus, the microorganisms were not exposed to light. The anaerobic digesters operate on the principle of fluid displacement: the produced gas leaves the reactor through a tube (Fig. 2/5) and displaces an amount of confining liquid through the overflow (Fig. 2/9) from the container (Fig. 2/10) equal to the volume of the gas. 1.5 l soft drink bottles were used as confining liquid containers, filled with 6M NaCl solution.

The quantity of the produced gas can be measured daily by reading off the amount of displaced liquid. Then, the container can be refilled with confining liquid from a 50 ml syringe barrel (Fig. 2/6) without air entering the system using the 3-way stopcock (Fig. 2/7). For this, the overflow should be closed off and the flow from the barrel opened with the stopcock. Then, the directional control valve (Fig. 2/8) can be used at the end of the flushing tube to let the liquid from the barrel enter the container. As the level of the liquid starts increasing in the container, some of the gas is transferred through the flushing tube. At this point, samples can be taken for further analyses.

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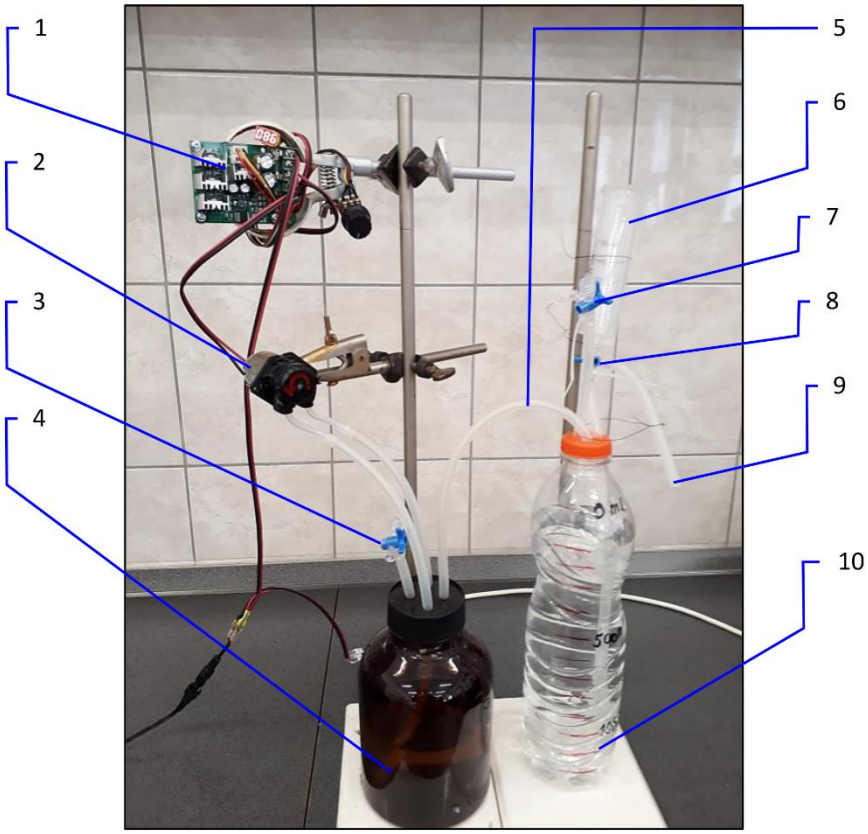

Figure 2. The anaerobic digester system equipped with mixer (1 – motor speed controller; 2 – 12V DC motor with peristaltic pump; 3 – flushing tube with stopcock; 4 – reactor; 5 – tube for biogas departure; 6 – a barrel of a 50 ml syringe to refill the confining liquid container; 7 – flushing tube with a stopcock; 8 – directional control valve; 9 – confining liquid overflow; 10 – confining liquid container)

The temperature can be measured at several places in the prepared system which are registered in a data logger (Fig. 3).

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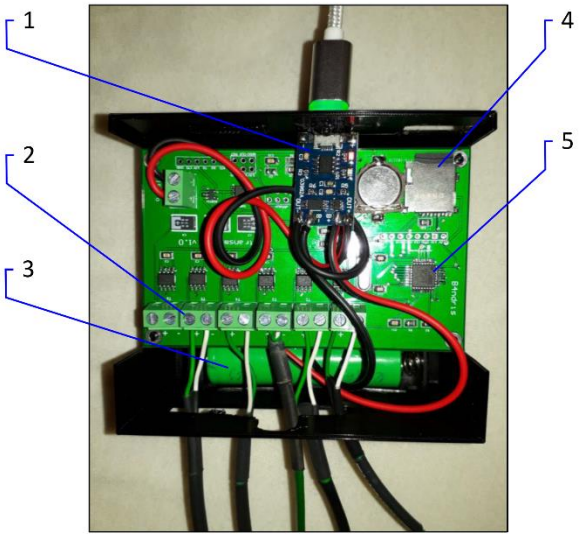

Figure 3. Temperature data logger (1 – battery charger; 2 – connectors of K-type thermocouples; 3 – battery; 4 – microSD card holder; 5 – Atmega328p microchip)

The data logger has been developed at our department for special requirement in different experiments. It consists of an Atmega328p microcontroller and uses special purpose ICs for K-type thermocouple measurements. The data logger also has an RTC (Real Time Clock) IC. Thus, the acquired data stored on the microSD memory card also contains time and date stamps. The data acquisition preferences as data collection interval for example, can be re-programmed to the perquisites of the experiments. The amount of data is only limited by the size of the memory card and it is stored in CSV files. Therefore, it is possible to store several thousands of data points in a 1 MB memory space. The device also contains a rechargeable Li-Ion battery and the ultralow power design provides several months operation on a single charge.
The assembled system can be observed in Fig. 4.

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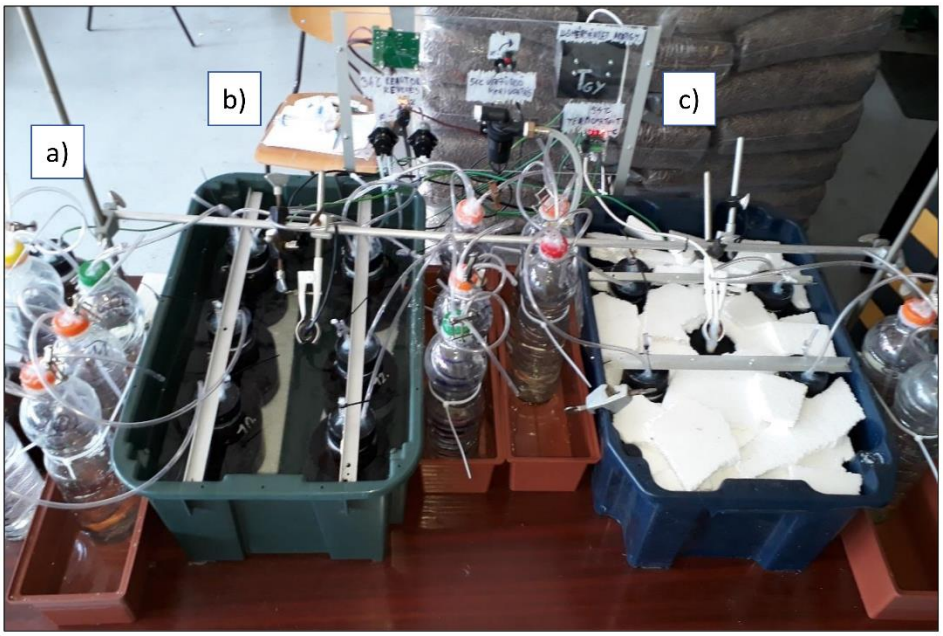

Figure 4. The assembled fermenter system with 2 reactors operating at room temperature (a), 6 at 34 °C (b) and 4 at 50 °C

2.3. Analytical methods

A Mettler Toledo HB43-S moisture analyser equipment was used to determine the moisture content. The ash content was determined by burning the samples at 820 °C to constant weight. Elemental analysis was carried out with a Carlo Erba EA 1108 elemental analyser. The higher heating value (HHV) was examined with a Parr 6200 isoperibolic bomb calorimeter. An Agilent 490 Micro-GC with a COX module was used for the analysis of CH_4, CO_2, CO, C_2 and O_2.

3. RESULTS

The system was tested with 2 reactors operating at room temperature, 6 reactors at 34 °C and 4 reactors at 50 °C. 2 of the reactor operating at 34 °C were equipped with mixers, and the inner temperature of the reactors operating at room temperature was measured with putting thermocouples in the slurries. The inner temperature of the room temperature reactors and the temperature of the room can be seen in Fig. 5, while the temperatures of the 34 and 50 °C warm water bathes are illustrated in Fig. 6.

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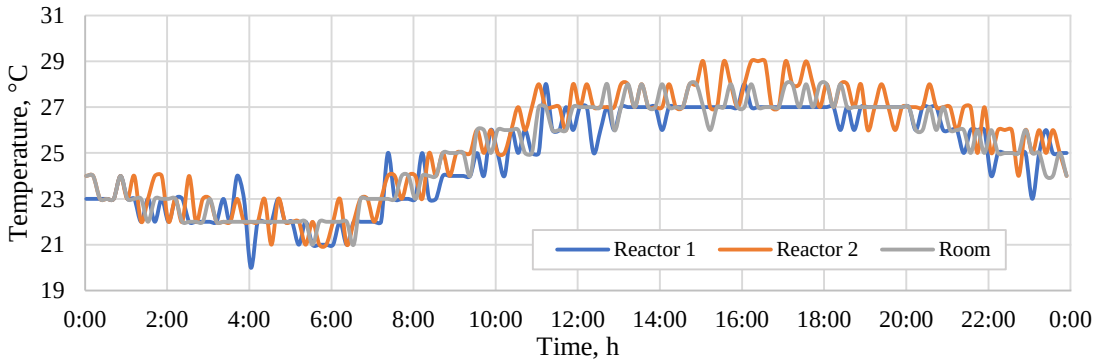

Figure 5. The temperature of the room and the inner temperature of the two room-temperature reactors

Examining the temperatures of the two room-temperature reactors and their environment (Fig. 5) it can be stated that the inner temperatures were often slightly higher than the room. This slightly increased temperature indicates the fermentation process. Fermentation was increased during the day (at higher temperature) than at night.

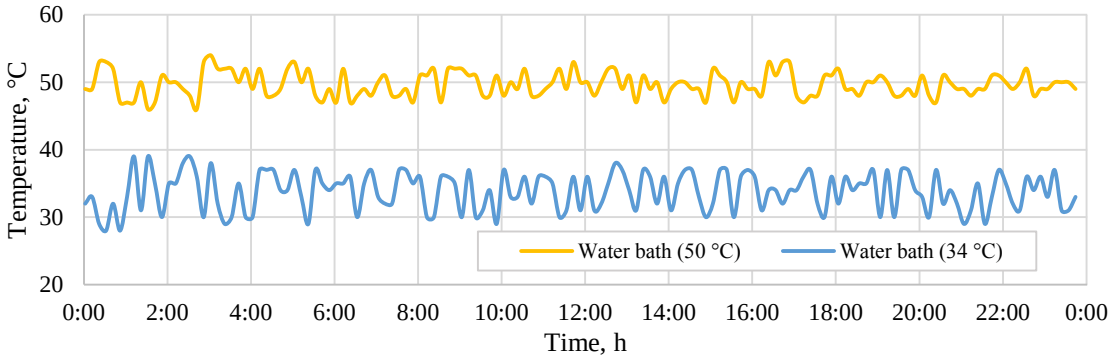

Figure 6. The temperatures of the two water baths

An aquarium heater was used for the 34 °C water bath, which proved to be a cheaper but worse solution than the use of a digital thermostat and immersion heater. The previously set thermostat temperature of 50±0.2 °C resulted in 46-52 °C water temperature, but the aquarium heater which was set to 34 °C only resulted in 28-39 °C water temperature.

The gas yield was registered daily. The gas production expressed in relation to 1 kg base material can be seen in Fig. 7. By increasing the temperature to 34 °C, the gas yield increased but it decreased after further temperature increase. The possible explanation is that the limit temperature of the thermophile zone is 50 °C [13] but the temperature of the water bath was between 46-52 °C (Fig. 6). It can be assumed that this temperature was not optimal for the thermophile bacteria, so the gas yield below the data found in literature [13]. The addition of inoculant had positive effect on the produced gas quantity in all cases.

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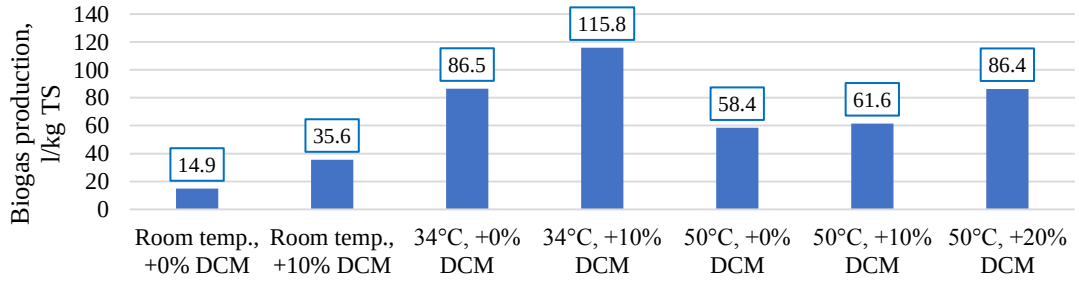

Figure 7. Biogas production

The changes in the examined gas composition during an experiment (34 °C reactor temperature and 10% DCM) can be observed in Fig. 8. In the presented case, the CO_2 content continuously decreased, while the CH_4 content slowly increased till the end of the experiments, when it reached approximately 60 vol%. No H_2 and CO was detectable in the samples. The trend of the gas composition was similar in case of each experiment.

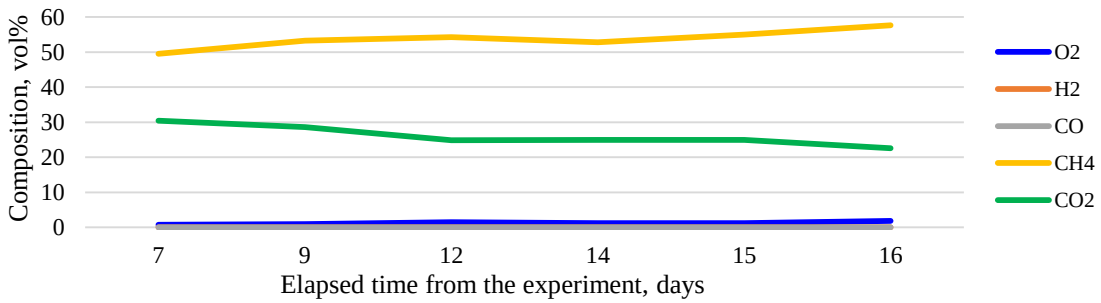

Figure 8. The changes in the examined components of an experiment (34 °C reactor temperature, +10% DCM)

The examination of the maximum methane content of the produced biogas samples (Fig. 9.) revealed that the biogas produced at room temperature without inoculants had the lowest methane content. In comparison, both the temperature increase and the addition of inoculants increased the amount of the most valuable gas component. If no inoculant was added, the highest methane content was achieved at 34 °C.

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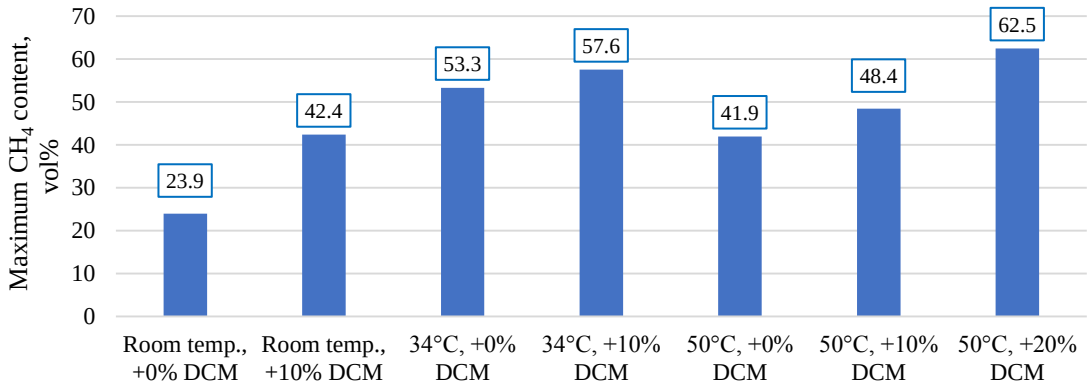

Figure 9. The maximum methane content of the samples

The comparison of the carbon content of the slurry before and after digestion can be observed in Fig. 10 and Fig 11 indicates the decrease of the carbon content of 1 kg base material after the 16-day fermentation. It can be stated that the addition of 10% DCM increased the carbon conversion (gas production), but there was no further increase in case of 20% DCM addition. Moreover, the raw material conversion decreased. The reason for this might be that the digested material had low organic carbon content. Thus, the amount of inoculant was disadvantageous to the reaction.

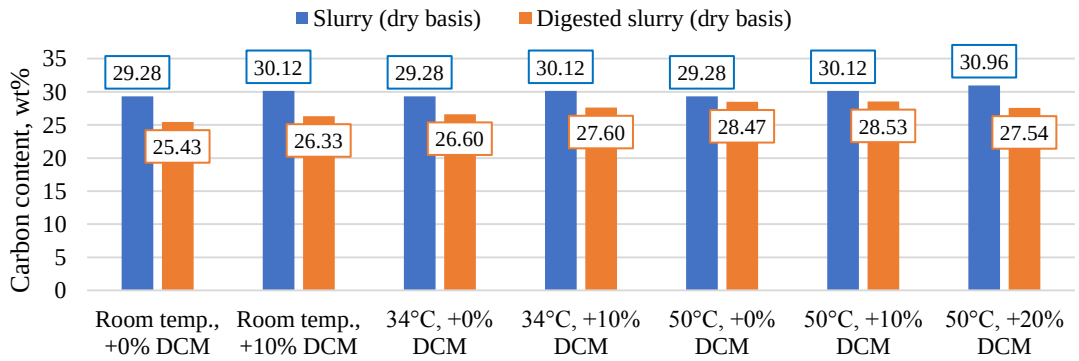

Figure 10. The carbon content of the slurry before and after digestion

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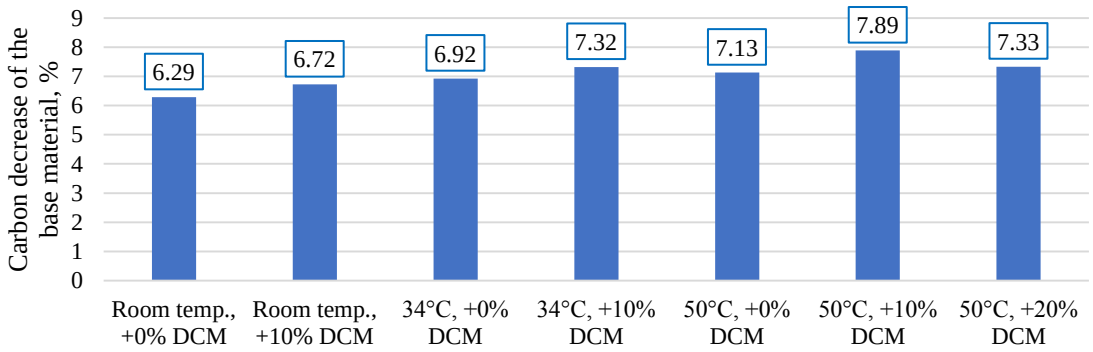

Figure 11. The decrease of the carbon content of 1 kg base material

4. CONCLUSIONS

The developed system was suitable for fermentation experiments. The system is capable to operate at various set temperatures and as mixing is also possible, the effect of the mixing intensity and periodicity can also be examined.
Sheep manure was used to test the system with the addition of cow manure as inoculant. Experiments were carried out at room temperature, 34 and 50 °C. The most gas quantity was produced at 34 °C, and the methane content of the gas was the highest in this case as well (without inoculant and with +10% DCM). The addition of 10% DCM was advantageous on the quantity and quality of the produced gas. However, the use of 20% DCM has lower effect on the decrease of the carbon content of the raw material.

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