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ANDRZEJ JĘDRCZAK*, DARIUSZ KRÓLIK*

INFLUENCE OF PAPER PARTICLE SIZE ON THE EFFICIENCY OF DIGESTION PROCESS

Hydrolysis of polymers whose decomposition is difficult, i.e., cellulose and lignin, and even the hydrolysis of decomposable fats, proteins and carbohydrates is generally considered to be as a stage limiting the rate of digestion of sludge and solid wastes. Reduction of particle size and the resulting increase in the area accessible to microorganisms can improve digestion rate and digestion gas production output. The paper presents the influence of waste paper particle size reduction on the efficiency of methane digestion carried out in mesophilic and thermophilic temperature ranges.

1. INTRODUCTION

A proper digestion is greatly dependent on the following factors: substrate type, the presence of relevant populations of microorganisms and environmental parameters affecting their activity and the rate of changes. Various researchers describe in detail how the digestion efficiency is influenced by waste quality, pH, temperature, loading of chambers with organic stuff, digestion time and concentration of nutrients and toxins both in the so-called "wet" as well as "dry" processes, and in the processes that run in single-stage or two-stage systems, in a continuous or periodical way [1], [2], [4], [5], [6].

Information on the influence of the size of waste particles on digestion is very scarce and scant. It is only known that the reduction of particles size and the resulting increase in their specific surface lead to an increase in the hydrolysis rate, the first stage of organic waste digestion [3]. This results in an increase in gas production, especially in the case of digesting the substrates with high contents of slowly biodegradable materials. According to PALMOWSKI and MULLER [7] in the case of small parts whose specific surface is greater than 20 m^2/kg, this influence is rather small, but increases dramatically when the size reduction concerns big parts (particles) whose spe-

* University of Zielona Góra, Institute of Environmental Engineering, ul. Szafrana 15, 65-246 Zielona Góra, Poland.

cific surface ranges from 3 to 20 m^2/kg. An increase in the rate of gas production leads to a decrease in digestion time, which allows the size of the chamber to be reduced without any losses in gas production. A negative effect of particle size reduction is an increase in specific resistance of digested wastes.

The article analyses the influence of waste paper particle size on the efficiency of methane digestion carried out in mesophilic and thermophilic temperature ranges.

2. TEST METHODOLOGY

The tests were carried out on a laboratory scale, in a 12-stand digestion chamber designed for a periodical digestion (figure 1). Reactors (bottles/cylinders) of the volume of 1 dm^3 (6), after having been filled up with a raw material, thorough stirring and removing air were tightly connected with gas burettes (2) and placed in a digestion chamber tub (thermostat) (7). This was a metal tub filled with water, whose level was maintained above the level of the suspended matter in the bottles/cylinders. The water in the tub was heated with two heaters up to the temperature required for the reactors. Pumps for water circulation and two thermometers were fixed on the tube. These thermometer were connected with a control device, which, depending on the thermometers indication, controlled the operation of two heaters (it switched them on or off). Placement of heaters, circulation of water in the tub as well as the construction of the control device guaranteed a uniform temperature of water in the tub as well as its fluctuations lower than 1 °C.

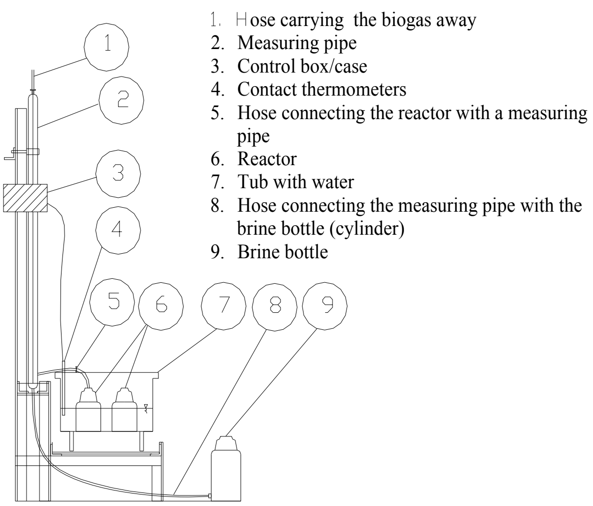

Fig. 1. Scheme of the test stand

2.1. CHARACTERISTICS OF THE RAW MATERIALS

Samples for the tests consisted of the mixtures of the following components (table 1):

- waste paper (grey paper and paper from magazines and papers mixed in the proportion of 1:1) of a various degree of size reduction (table 1), humidity – 3.45%, loss on ignition – 76.55% of dry matter,
- digested sludge from wastewater treatment plant in Gubin-Guben, added in order to inoculate the mixture; humidity – 98%, loss on ognition – 65.8% of dry matter,
- 6% solution $NaHCO_3$ added for the purpose of charge buffering,
- water.

Table 1

Characteristics of the test samples

Specification	Sample number (reactor)					
	P-1	P-2	P-3	P-4	P-5	P-6
Waste paper, kg	–	0.011				
Size reduction, mm	Control sample	Reduction max. around 1	2.5	5	10	15
Specific surface, m^2/kg	–	30.0	27.0	26.0	25.5	25.3
Sludge, dm^3 (kg d.m.)	0.700 (0.0140 M and 0.0136 T)*					
Solution of $NaHCO_3$, dm^3	0.133					
Water, dm^3	0.167	0.156				
Sample volume, dm^3	1.000					
Dry matter of sludge and wastes, %	1.35 (T) 1.40 (M)	2.46 (T), 2.50 (M)				

* M – mesophilic digestion, T – thermophilic digestion.

2.2. PROCESS RANGE AND CONTROL

Mesophilic and thermophilic digestion were monitored for 25 days at the temperature of around 36 °C and for 21 days at the temperature of around 55 °C. The process of methane digestion was controlled by measuring each day the volume of the biogas produced and periodically by measuring methane and carbon dioxide content in the biogas. The gas composition was determined with ALTER WAG-1 device, after it had been accumulated in the column in the amount allowing measurement.

The characteristic features of the digested material were determined both before and after the digestion. They were as follows: dry matter, loss on ignition, pH, oxidation-reduction potential, COD_{Cr}, TOC, organic and ammonia nitrogen, as well as volatile fatty acids (VFA). The determinations were made according to the methods specified by the Polish Standards.

3. RESULTS

3.1. EFFICIENCY OF BIOGAS PRODUCTION BASED ON WASTE PAPER OF VARIOUS SIZE PARTICLES

Figure 2 shows the results of measuring a daily biogas production during mesophilic and thermophilic digestion of waste paper mixtures of various size particles with sludge (in dm^3/kg d.m.).

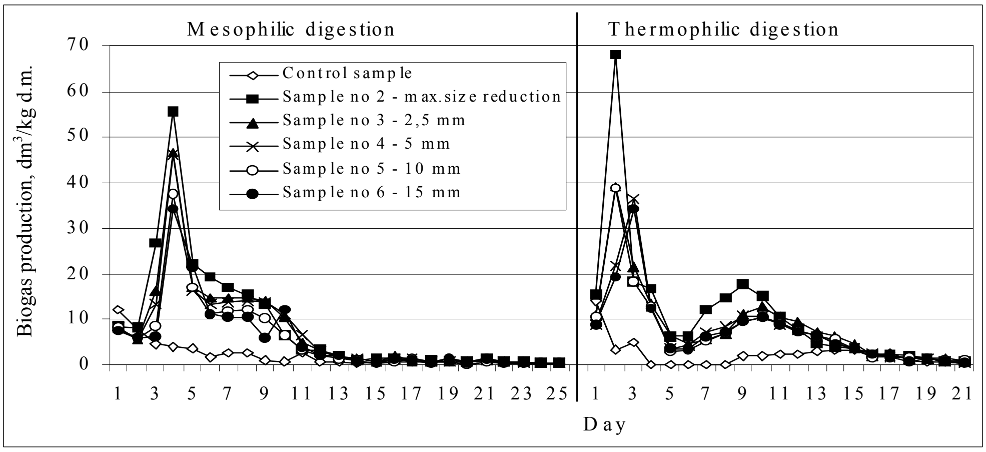

Fig. 2. Daily production of biogas generated by mesophilic and thermophilic digestion of waste paper of various particle sizes

The most efficient production of biogas in mesophilic digestion was reached on the fourth day of the process. The greatest amount of biogas was generated in the sample containing paper of the smallest particles – 55.6 dm^3/kg d.m., slightly smaller amount from the samples P-3 – 46.6 dm^3/kg d.m. and P-4 – 46.2 dm^3/kg d.m, and the smallest amount was found in P-1 – 3.9 dm^3/kg d.m. Within the period from the sixth day to the tenth day of the experiment the daily biogas production was still high and ranged from 6.4 to 19.2 dm^3/kg d.m. After the eleventh day of the process the gas production in all the samples declined significantly and did not exceed 6.4 dm^3/kg d.m. Analyzing the curves that represent the changes in daily biogas production depending on the digestion time it was found out that they were almost identical in the case of the samples P-3 and P-4 as well as P-5 and P-6.

The curves representing the relationship between the daily gas production and the time of the thermophilic digestion have two characteristic maximum values (figure 2). The first was found on the second or the third day of the process and the other one on the ninth or tenth day of the experiment.

The largest amount of biogas of all the samples was reached during the first maximum. This day the largest amount of biogas was produced by the sample containing paper of the particles of the smallest size (P-2) – 68.1 dm^3/kg d.m., slightly less gas was found in the samples P-3 and P-5 – 39.0 and 38.8 dm^3/kg d.m., respectively. The samples that had their maximum on the third day produced 36.6 (P-4) and 34.1 (P-6) dm^3/kg d.m. of biogas.

After reaching the maximum the biogas production fell dramatically in all the samples. It increased up again between the ninth and twelfth day, excluding the control sample, up to the value of 7.1–17.5 dm^3/kg d.m. (the day of the second maximum). Beginning with the thirteenth day of the experiment the biogas production continuously declined and on the eighteenth day it did not exceed 2.0 dm^3/kg d.m. in any of the samples.

3.2. METHANE CONTENT IN THE BIOGAS

Table 2 shows the content of methane in the biogas samples under analysis. During the mesophilic digestion a chemical composition of biogas was measured four times, on the third, fourth, seventh and the last days of the process. In the first measurement, we analysed only the biogas from the sample P-2, in the second and the third measurement – the biogas from P-2 to P-6, whereas on the last day the biogas from all the samples was analyzed.

Table 2

Average methane content in the biogas produced by mesophilic and thermophilic digestion, % (v/v)

Number of sample	Consecutive days													
	Mesophilic digestion								Thermophilic digestion					
	1	2	3	4	5	6	7	8–25	1	2	3	4	5–10	11–21
1	75								80					
2	50			28	43			69	23		32		69	89
3	38				44			62	32		27		63	82
4	37				43			62	31		25		62	83
5	42				43			64	27		29		63	83
6	46				41			69	28		27		55	79

During the thermophilic digestion a chemical composition of biogas was measured 4 times on the second, fourth, tenth and the last days of the experiment. For the first three measurements the biogas from the samples P-2–P-6 was taken, whereas in the fourth measurement all the samples were checked (table 2).

4. DISCUSSION OF THE RESULTS

Figure 3 presents the curves representing a global single production of biogas (in dm^3/kg of dry matter) from waste paper of various particle sizes on consecutive days of the mesophilic and thermophilic digestion process.

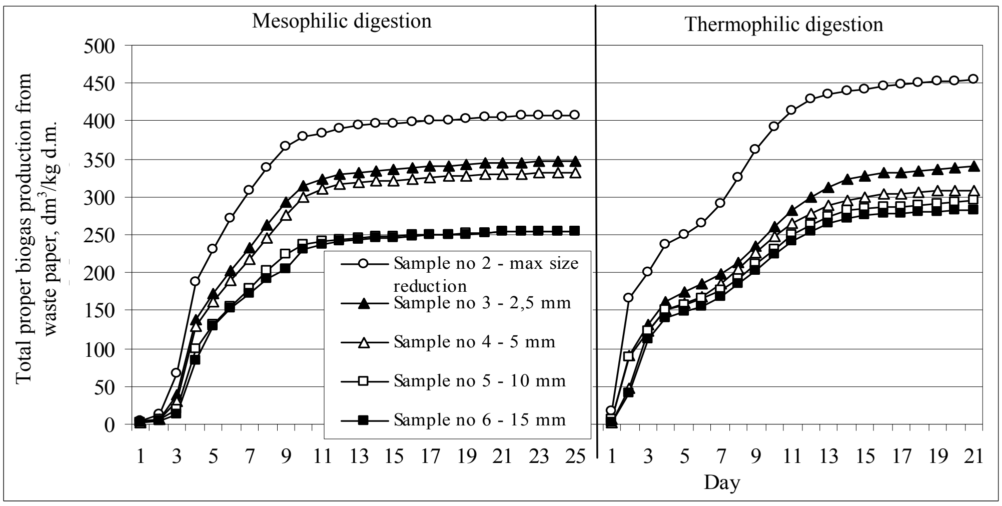

Fig. 3. Total proper biogas production from paper of various particle sizes in mesophilic and thermophilic digestion, dm^3/kg d.m.

Biogas production in all the samples proceeded similarly. Analyzing the curves representing the mesophilic process, it is possible to distinguish

- the period of the digestion initiation – the first three days,
- the period of maximum production – the 4th day,
- the period of stable, high biogas production – from the 5th to 10th days,
- the period of biogas production falling – from the 11th day to the end of the experiment.

On the last day of the experiment a maximum total amount of biogas (408 dm^3/kg d.m.) was produced from waste paper consisting of the smallest particles (figure 4). The bigger the particles of the paper, the smaller the biogas production. For the samples with the particle size of 10 and 15 mm the biogas production was approximately by 39% smaller than the biogas production for the samples consisting of the smallest particles.

During thermophilic digestion there was no the process initiation, which occurred in the mesophilic digestion. On the other hand, a decrease in the process rate was clearly noted from the 4th to the 6th days of the experiment.

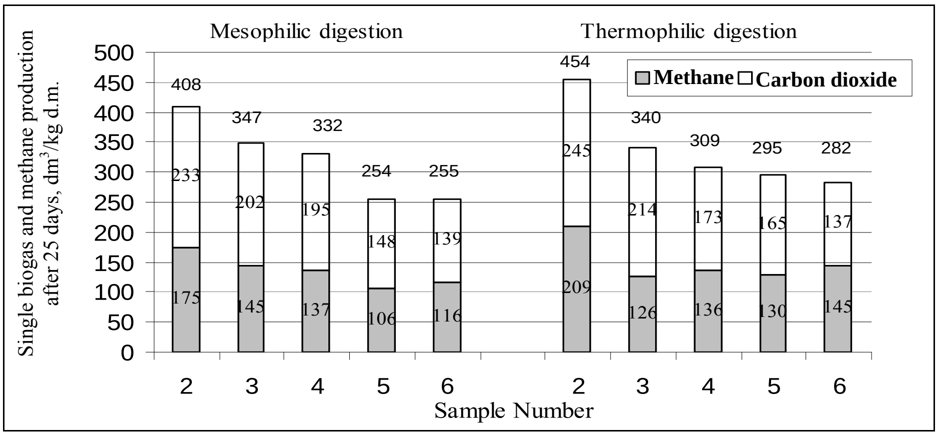

Fig. 4. Piece biogas production in waste paper mesophilic and thermophilic digestion, dm^3/kg d.m.

The waste paper pulp of the maximum reduction of particle size allowed the production of 454 dm^3 of biogas/kg dry matter (figure 4). The bigger the waste paper particles, the smaller the biogas production. For the samples of 2.5-mm particle size the production was by 25% smaller than for the sample of the maximum size reduction, and for the other samples it was from 25 to 38% smaller (309–282 dm^3/kg of dry matter).

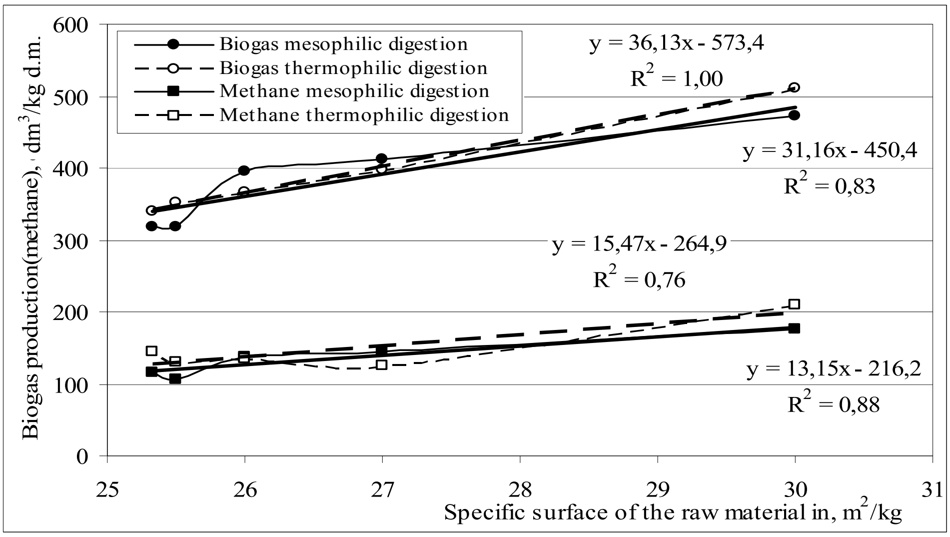

Fig. 5. Relationship between a piece biogas production and methane production
and the waste paper specific surface

According to IMHOFF [4] the biogas production from paper is 220 dm^3/kg of dry matter at methane content of 63% (v/v). The samples under analysis produced much more biogas. In the mesophilic and thermophilic processes, this amount was 1.2–1.9 and 1.3–2.1 times bigger, respectively. However the gas produced was much poorer in methane. An average methane content in the samples within a thermophilic temperature range was 45% (v/v), whereas in the mesophilic process it reached 43% (v/v). The production of methane higher than that reported in literature was obtained only in the samples containing the pulp of the maximum reduction of size particles both in the mesophilic as well as thermophilic processes. For the samples containing bigger particles it was comparable with the production reported by other researchers or even significantly smaller (samples P-5 and P-6, mesophilic range).

Figure 5 presents the relationships between a piece biogas production and methane production from waste paper and the specific surface of the raw material. In the analyzed range of particle sizes, the biogas and methane production increased linearly with an increase in the specific surface of the waste paper during both the mesophilic and thermophilic digestion.

Waste paper is a specific material. Its characteristic feature is small thickness, approximately 0.1 mm, which causes that the specific surface of the waste paper before its change into pulp is approximately 25 m^2/kg. The reduction of the size of waste paper particles, whose diameters are smaller than 10 mm, increases its specific surface only by about 2% (that is by 0.5 m^2/kg). On technological scale the size of waste particles is not reduced to the particles smaller than 25 mm. Thus the results obtained are of no practical use. They can only confirm that reduction of particle size and the resulting increase in their specific surface lead to the increase in the rate of digestion of organic wastes, especially those which are easily biodegradable. This leads to an increase in the production of gas, especially in the case of digestion of substrates with high content of fibrous materials, which are not easily biodegradable [3].

Higher efficiency of digesting wastes of smaller particle sizes leads to decomposition of a greater amount of wastes. In mesophilic and thermophilic digestion, the dry matter of wastes of the smallest particle size declined by approximately 25% (P-2), whereas in the case of the samples with the particle size of 10 and 15 mm – by less than 20%.

5. CONCLUSIONS

The tests carried out confirm a positive influence of solid waste particle size reduction (paper waste) on their biodegradability under anaerobic conditions. Biogas production increased linearly with an increase in a specific surface of the waste paper during both mesophilic and thermophilic digestion. As a result, a greater amount of the biogas and a smaller amount of solid wastes after digestion are obtained.

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WPŁYW ROZDROBNIENIA PAPIERU NA WYDAJNOŚĆ PROCESU FERMENTACJI

Hydroliza polimerów trudno ulegających rozkładowi takich jak celuloza i ligniny, a nawet podatnych na rozkład tłuszczów, białek i węglowodanów, jest generalnie uznawana z etap limitujący szybkość fermentacji osadów i odpadów stałych. Zmniejszenie wymiaru cząsteczek i wynikające z tego zwiększanie powierzchni dostępnej dla mikroorganizmów może poprawiać szybkość fermentacji oraz wydajność produkcji gazu fermentacyjnego. W artykule przedstawiono wpływ stopnia rozdrobnienia makulatury na wydajność procesu fermentacji metanowej prowadzonej w mezofilowym i termofilowym zakresie temperatury.