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The efficiency of conversion of cattle manure into biogas by the use of chosen physical pretreatment methods at the pilot scale

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SE.Biomethane: Small but Efficient – Cost and Energy Efficient Biomethane Production

Partnerzy:

Sweden

SLU- Swedish University of Agricultural Sciences
JTI – Swedish Institute of Agricultural- and Environmental Engineering
Triventus Biogas AB (SME)
Ultuna Egendom, Lövsta Biogas plant (SME)

Poland

UMW- University of Warmia and Mazury
Institute of Energy Ltd. (SME)

Germany

DBFZ- Deutsches Biomasseforschungszentrum gemeinnützige GmbH
Ventury (SME)

CBEO-UWM Olsztyn – responsible for WP4 (task 4a i 4b); and task 1c within WP1

The aim of the study was to determine of ultrasounds desintegration and hydrodynamical cavitation influence on organic substrate used in methane fermentation process in static condition. The researches were concentered on relation between energy dose introduced to biomass and effectiveness of biogas production and methane content.
The experiments were carried out in technical scale at the Agriculture Biogas Plant in Bałdy.

The Didactic and Research Station in Bałdy

Substrates:

Catle manure with wheat straw:

Dry mass	24,4% - 26,5%
Organic dry mass content	68-76 % (dry mass)
Nitrogen (N)	3,4 -7,2 %
Amonium	0,22-2 %
Phosphorus	1 – 1,5 %

The Didactic and Research Station in Bałdy covers 482 ha, of which 422 ha are cereal, maize and grass crops.
There are about 360 head of dairy cattle and 40 horses.

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Ultrasound pre-treatment – laboratory scale

sample	Desinty of energy [kJ/l]	Temperature [°C]	Time [s]
1.	50	23,1	4,41
2.	100	30,0	8,82
3.	150	44,8	13,07
4.	200	51,3	15,81
5.	250	44,3	21,23
6.	300	52,5	25,95
7.	350	56,5	31,29
8.	400	69,0	42,47
9.	450	71,3	47,71
10.	500	67,2	54,14

Ultrasound disintegrator UP400S
Hielscher Ultrasonics

Power of ultrasound - 400 W
Frequency - 24 kHz

Catle manure with wheat straw:
Dry mass 6,2% ± 0,3%

Analysed parameters:
In liquid phase: COD, TC, TOC, IC, $N_{tot.}$
In solid phase: TC, $N_{tot.}$ dry mas, dry organic mas

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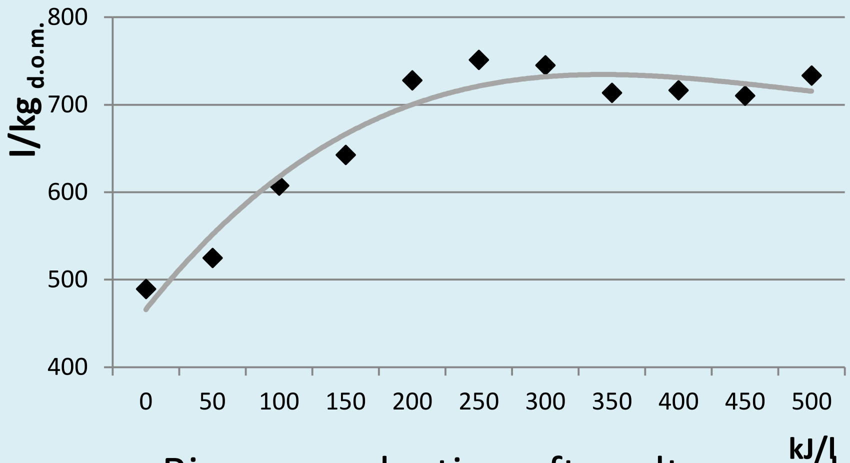
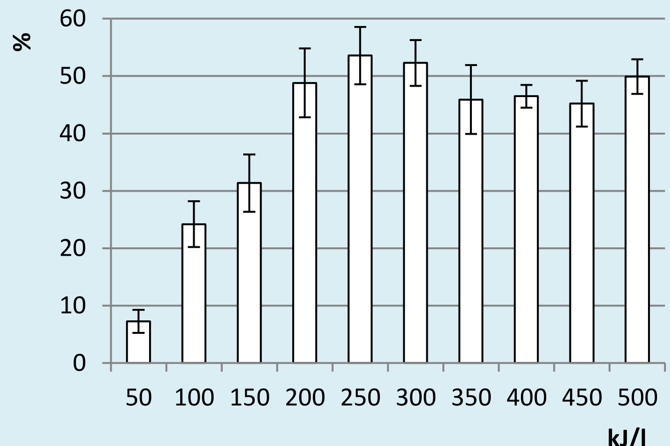
RESULTS

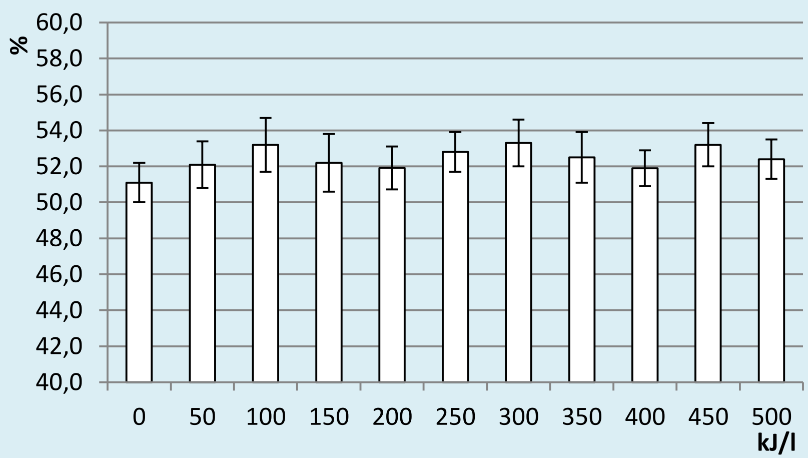
Ultrasound pre-treatment – laboratory scale



Biogas production after ultrasound pretretment



Percentage increase of biogas production



Methane content in biogas

Hydrodynamical cavitation pre-treatment – laboratory scale

sample	Desinty of energy [kJ/l]	Temperature [°C]	Time [min]
1.	50	32,5	4,02
2.	100	37,5	8,29
3.	150	45,5	13,08
4.	200	50,0	18,03
5.	250	48,5	22,4
6.	300	57,5	27,43
7.	350	64,5	32,34
8.	400	67,0	37,10
9.	450	72,0	41,35
10.	500	75,0	46,11

Catle manure with wheat straw:

Dry mass 6,2% ± 0,3%

Analysed parameters:

In liquid phase: COD, TC, TOC, IC, $N_{tot.}$

In solid phase: TC, $N_{tot.}$ dry mas,
dry organic mas

Laboratory cavitation pump
Volume - 5 l
Power - 1,2 kWe

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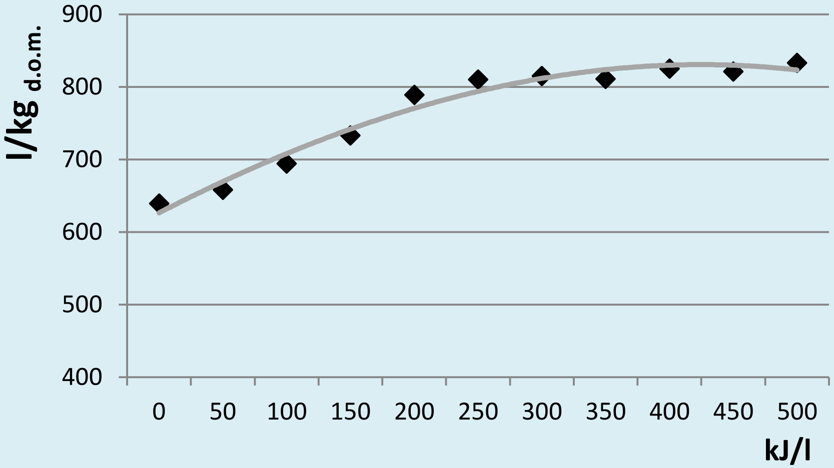
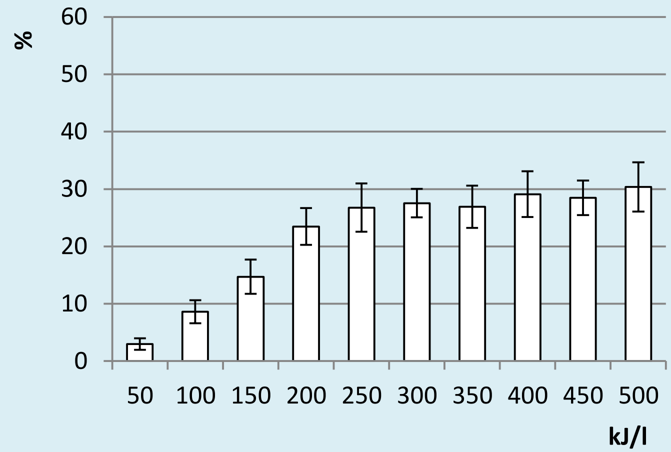
RESULTS

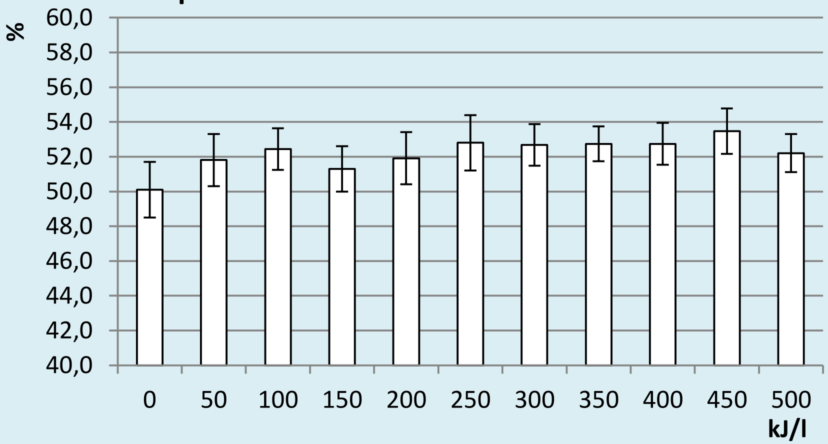
Hydrodynamical cavitation pre-treatment – laboratory scale



Biogas production after cavitation pretretment



Percentage increase of biogas production

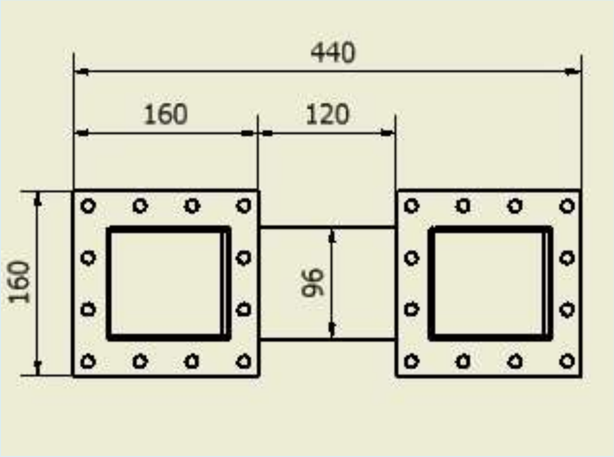


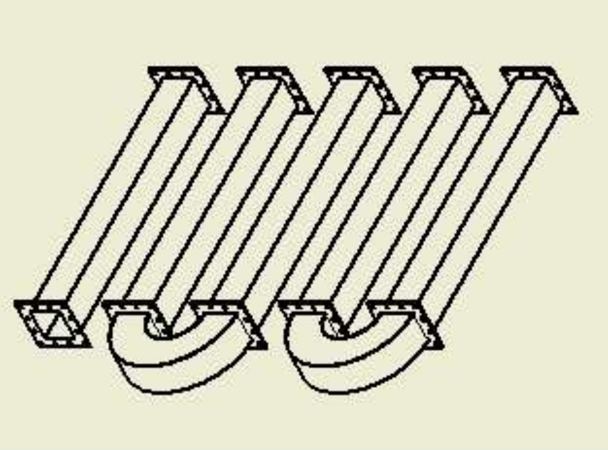
Methane content in biogas

Research was performed on an industrial scale using a model agricultural biogas plant installations in the research station in Bałdy.

- First, the influence of ultrasonic disintegration of organic substrates for biogas plant efficiency. Ultrasonic disintegrator used his own design, which has been incorporated into the existing technological system of biogas plants.
- Second, measurements of efficiency biogas-powered desintegrated substrate using hydrodynamic cavitation generator.
- Shown energy efficiency of the use of these methods disintegration in relation to the size of the obtained biogas production.

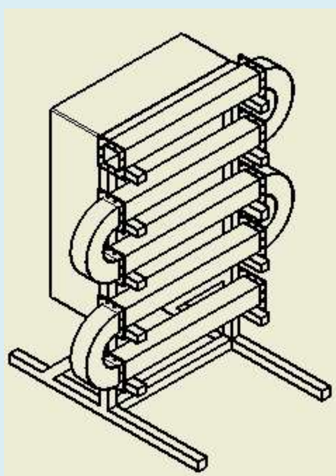
The facility for organic substrate disintegration with ultrasound consists of 5 tubular segments with square cross-sections. The size of a single segment is 96 x 96 x 850 mm. The active volume of one segment is 8 liters. Segments are made of acid-proof steel. It cycles automatically, using a circulating pump for feeding and emptying.





Ultrasound disintegrator characteristics:

• Power:	10 kW
• Converters:	n = 60
• Frequency:	24 kHz
• Active volume of disintegrator:	40 l
• Number of working cycles per day (feeding/disintegration/discharge):	12
• Time for a single disintegration cycle (feeding/disintegration/discharge):	30/900/30 s
• Total time of disintegration:	3.0 h/d
• Volume of disintegrated substrate:	500 l/d
• Required daily quantity of energy:	30 kWh/d



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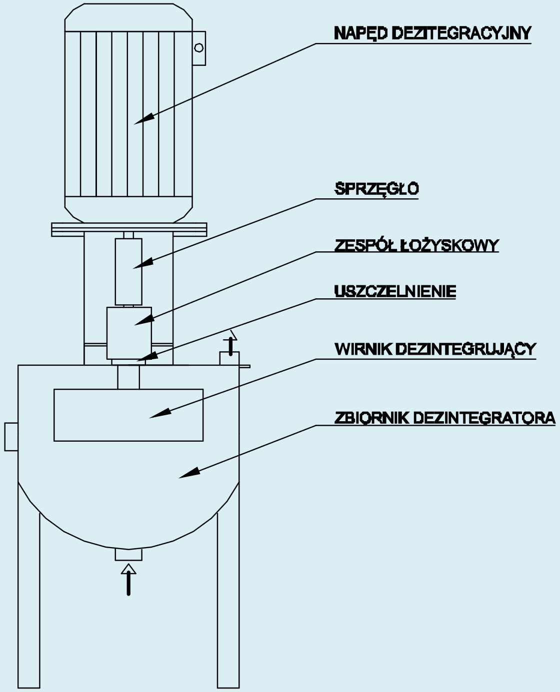
hydrodynamical cavitation

hydrodynamical cavitator, used in the study consists of a rotor multifunctional made by patent PL 214 335 B1

Hydrodynamical desintegrator:
- Power: 4 kW
- rotational speed : n = 2800/min
- capacity : 25 l
- Number of working cycles per day (feeding/disintegration/discharge): 16 x d
- Time for a single disintegration cycle (feeding/disintegration/discharge): 60 / 600 / 60 s



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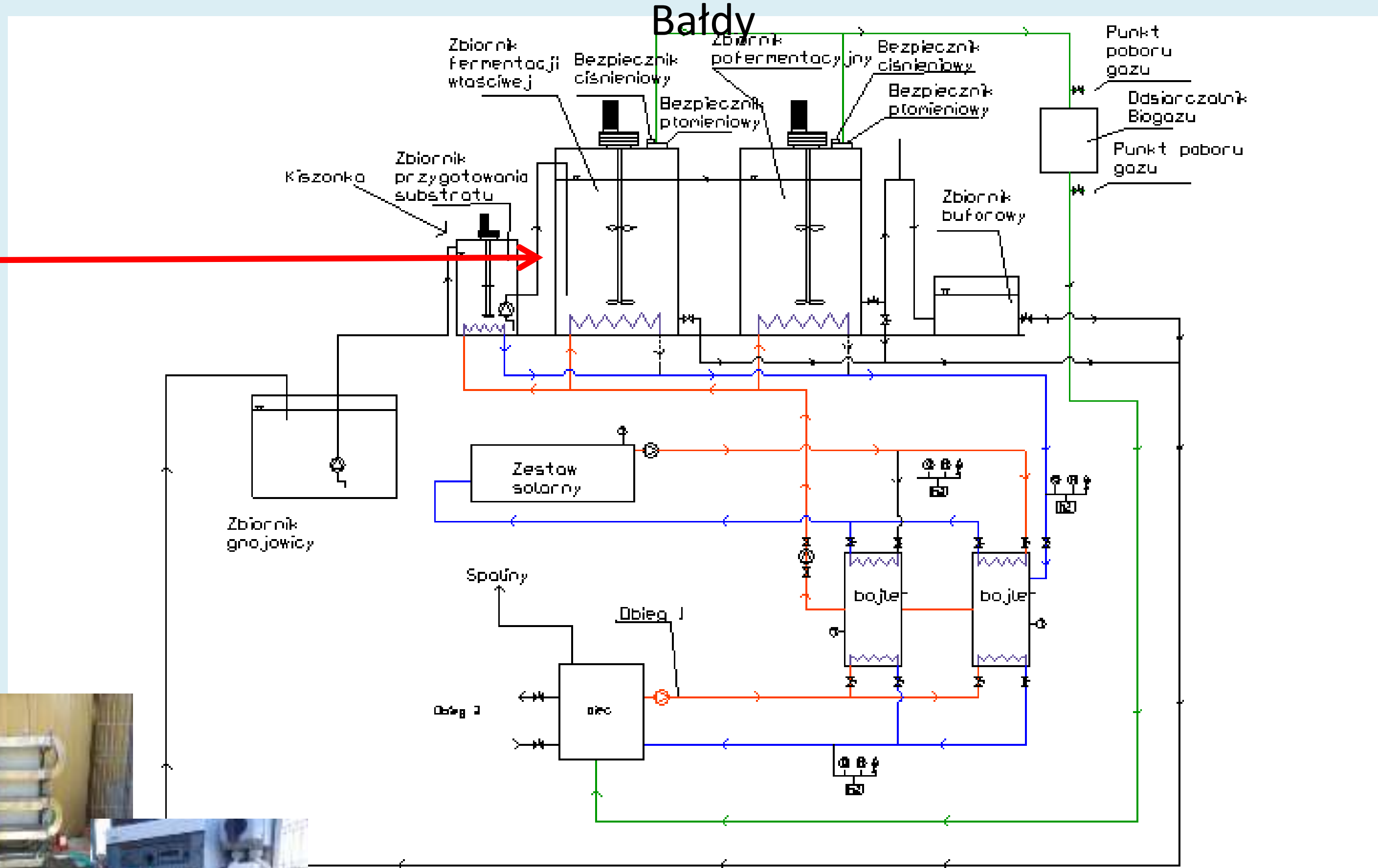
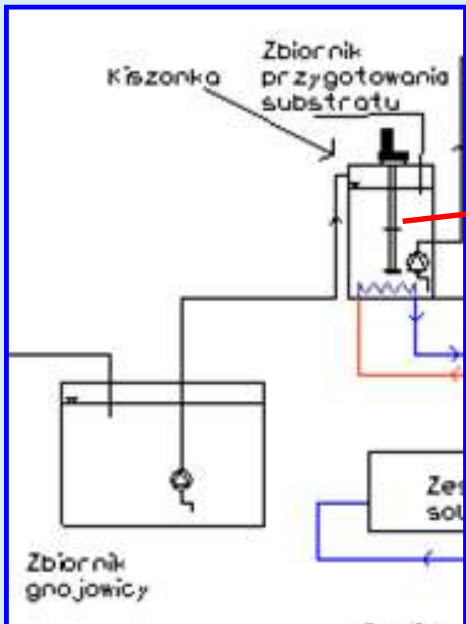
Ultrasound disintegrator and hydrodynamical cavitator location in technological system of Small Biogas Plant in Bałdy

DISINTEGRATOR BEFORE INLET OF ORGANIC SUBSTRATE TO MAIN FERMENTER



Substrate Preparation Tank



The internal diameter	$D_w = 2.55$ m
The outer diameter	$D_z = 2.75$ m
The total height	$H_c = 1.08$ m
The active height	$H_{cz} = 1.00$ m
The active volume	$V_{cz} = 2.5\ m^3$

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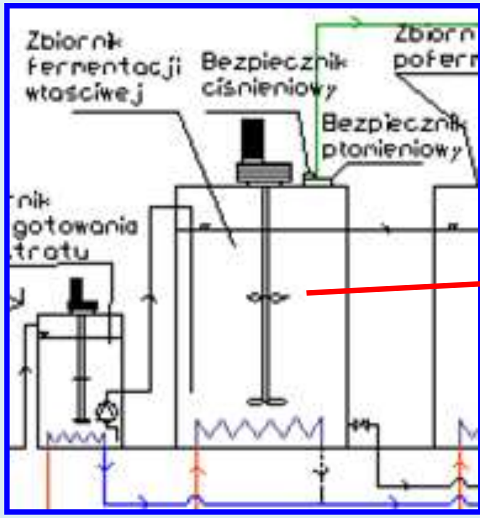
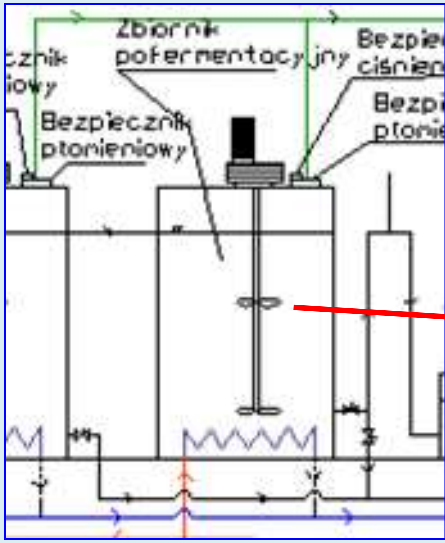
Main Fermentation Tank



The internal diameter	D_w = 3.40 m
The outer diameter	D_z = 3.60 m
The total height	H_c = 2.60 m
The active height	H_{cz} = 2.40 m
The active volume	V_{cz} = 20.9 m^3
The total volume	V_c = 23.6 m^3
The volume of gas	V_g = 2.70 m^3

Post-fermentation Tank



The internal diameter	D_w = 3.40 m
The outer diameter	D_z = 3.60 m
The total height	H_c = 2.60 m
The active height	H_{cz} = 2.40 m
The active volume	V_{cz} = 20.9 m^3
The total high	V_c = 23.6 m^3
The volume of gas	V_g = 2.70 m^3

Substrates:

Fresh mass of substrates		
Cattle manure with straw	M_m	≈ 250 kg/d
Cattle slurry	M_s	≈ 250 kg/d
Total	$\mathbf{M_t}$	**≈ 500 kg/d**

Dry mass of substrates		
Cattle manure (≈ 25 ± 2.6 %)	$M_{m\ d.m.}$	≈ 63 $kg_{d.m.}$/d
Cattle slurry (≈ 3 ± 1.2 %)	$M_{s\ d.m.}$	≈ 7 $kg_{d.m.}$/d
Total	$\mathbf{M_{t\ d.m.}}$	**≈ 70 $\mathbf{kg_{d.m.}}$/d**

Organic dry mass of substrates:		
Cattle manure (≈ 76 ± 3.9 %)	$M_{m\ o.d.m.}$	≈ 48 $kg_{o.d.m.}$/d
Cattle slurry (≈ 73 ± 3.1 %)	$M_{s\ o.d.m.}$	≈ 5 $kg_{o.d.m.}$/d
Total	$\mathbf{M_{t\ o.d.m.}}$	**≈ 53 $\mathbf{kg_{o.d.m.}}$/d**

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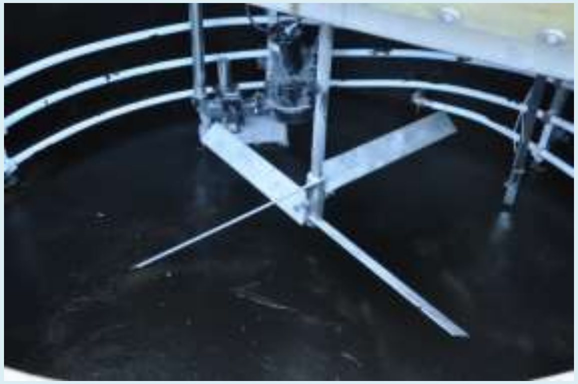
Technological parameters

Hydration of substrates



Hydration of cattle manure $W_m = 75 \pm 2.6$ %
Hydration of cattle slurry $W_s = 97 \pm 1.2$ %

$$W_t = (W_s \text{ x } M_s) + (W_m + M_m)/(M_s + M_m)$$
$$W_t = (80 \text{ x } 250) + (97 \text{ x } 250) / (250 + 250)$$

$W_t \approx 88 - 90$ %

Because the required hydration of substrate fed to the biogas plant is ca. 90%, additional hydration of substrates is unnecessary.

Technological parameters

Daily volume of substrates

The total volume of substrate was calculated using average weight and density.

Density of cattle manure $\rho_m = 0.8\ kg/dm^3$

Density of cattle slurry $\rho_s = 1.05\ kg/dm^3$

$\rho_t = (\rho_m \times M_m) + (\rho_s + M_s)/(M_m + M_s)$

$\rho_t = (0.8 \times 250) + (1.05 \times 250) / (250 + 250)$

ρ_t **= 0.93 kg/dm³**

$\rho_t = M_t/\rho_t$

$\mathbf{Q_t \approx 0.50 - 0.55\ m^3/d}$

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Technological parameters

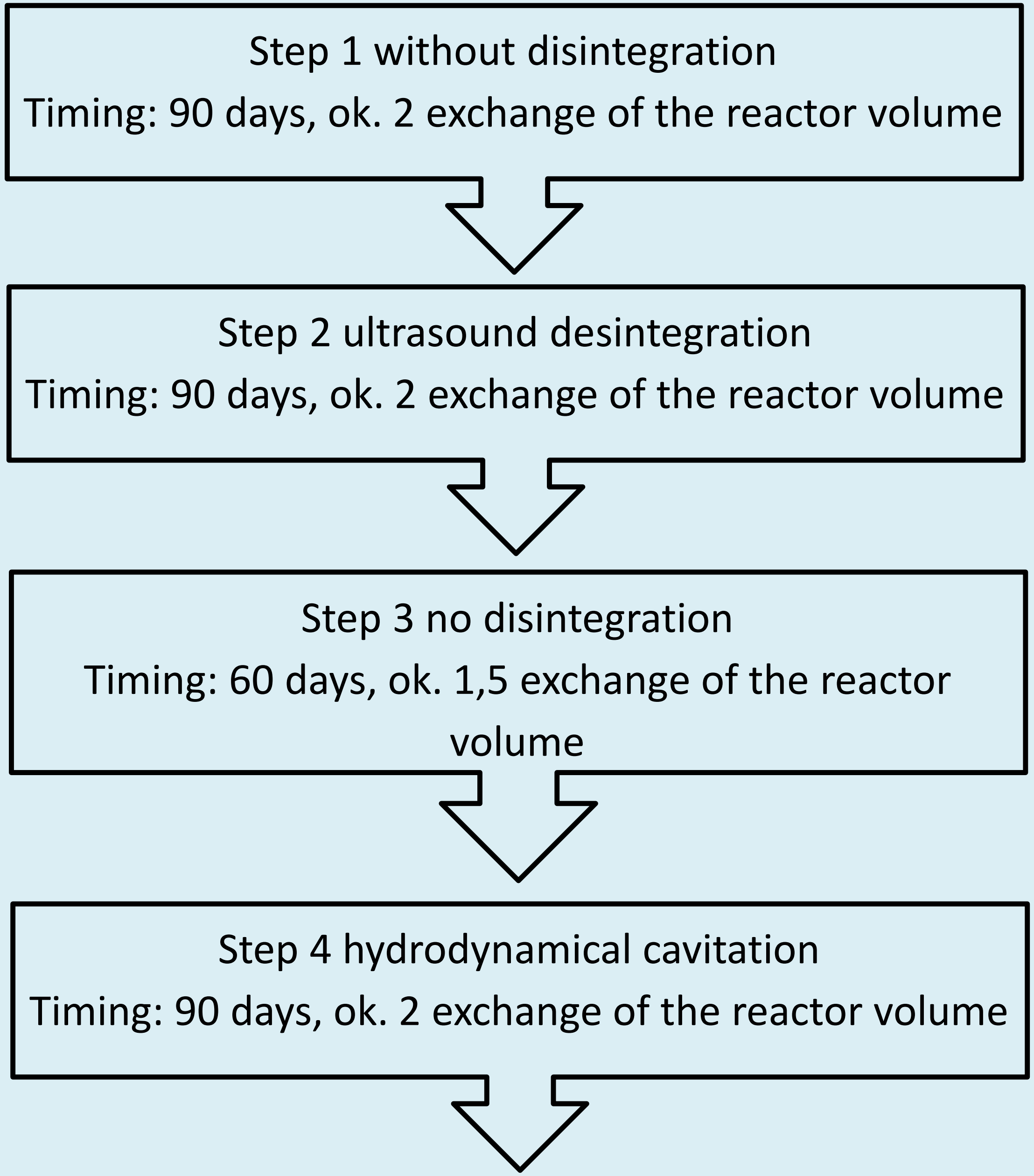
Hydraulic Retention Time:

Substrate Preparation Tank (Hydrolyzer):	**≈ 5 days**
Main Fermentation Tank:	**≈ 42 days**
Post Fermented Tank:	**≈ 42 days**
Total HRT:	**≈ 89 days**

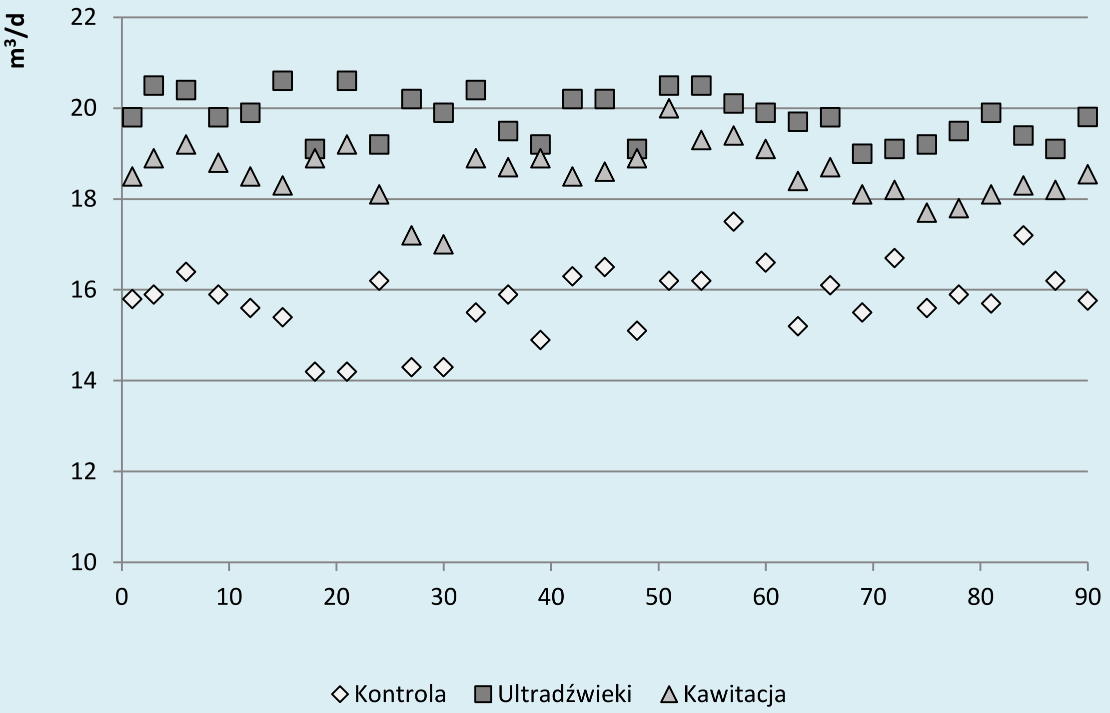
Organic Load Rate:

Organic dry mass of substrates:	**$M_{t\ o.d.m.}$**	**≈ 53 $kg_{o.d.m.}/d$**
Total volume of fermentation tank:	**V**	**≈ 21 m^3**
OLR:	**A**	**≈ 2.5 $kg_{\ o.d.m.}/m^3$ x d**

Temperature: **35°C**


Step 1 without disintegration
Timing: 90 days, ok. 2 exchange of the reactor volume
Step 2 ultrasound desintegration
Timing: 90 days, ok. 2 exchange of the reactor volume
Step 3 no disintegration
Timing: 60 days, ok. 1,5 exchange of the reactor volume
Step 4 hydrodynamical cavitation
Timing: 90 days, ok. 2 exchange of the reactor volume

Daily biogass production depending the the used method of disintegration

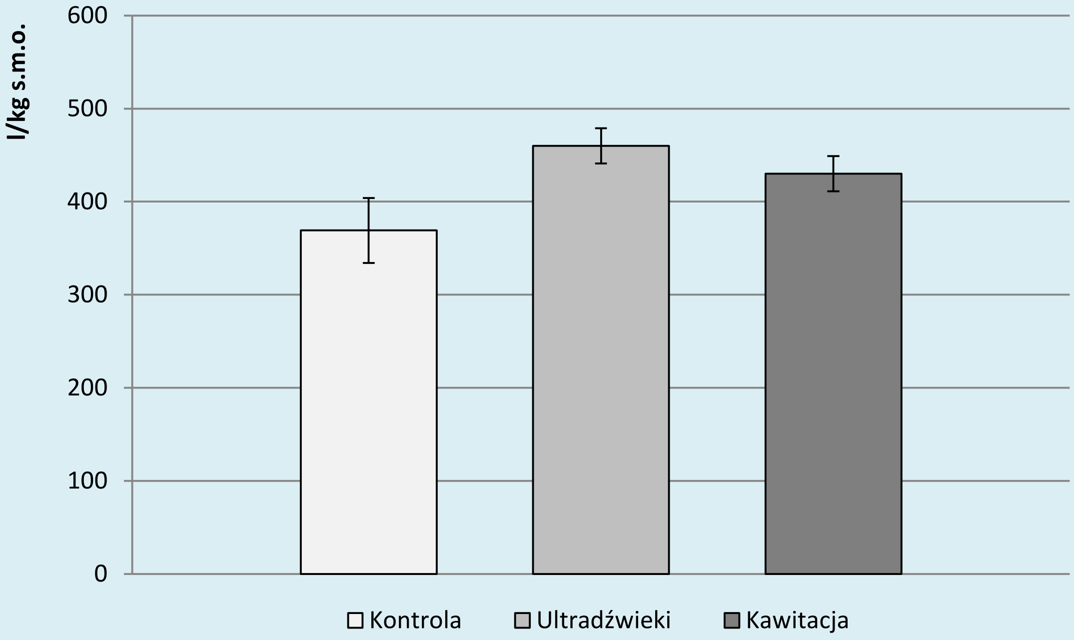


Substrate:
Cattle manure with straw
Cattle slurry

Average biogas production

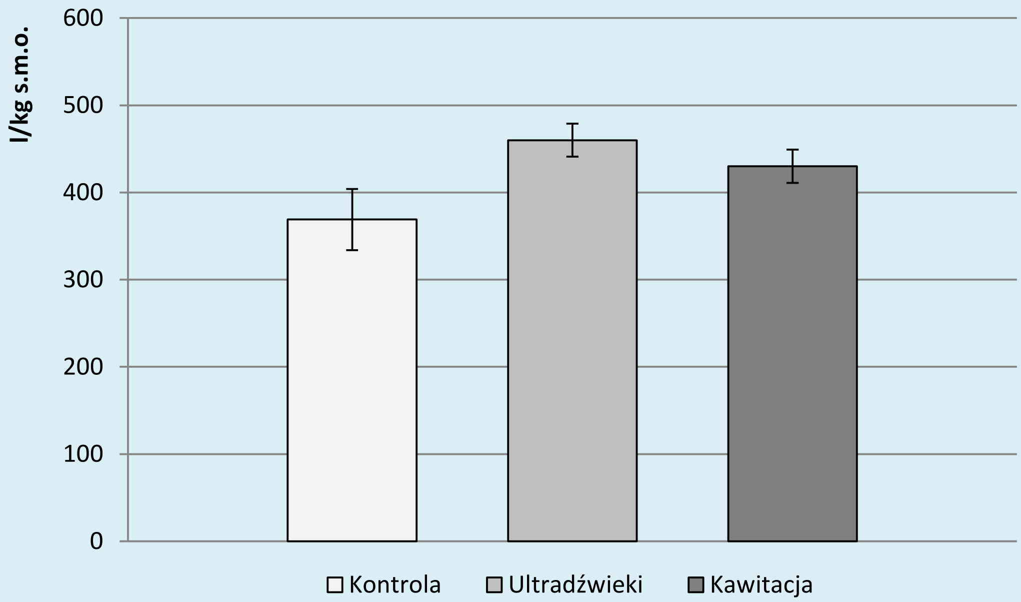
1. Without disintegration 15,9 m^3/d
2. Ultrasound treatment 19,8 m^3/d
3. Hydrodynamical cavitation 18,5 m^3/d

Yeld of biogass production depending the the used method of disintegration



1. Without disintegration $y = 369\ l/kg_{d.o.m.}$.
2. Ultrasound treatment $y = 460\ l/kg_{d.o.m.}$
3. Hydrodynamical cavitation $y = 430\ l/kg_{d.o.m}$

Methane content in produced biogass depending the the used method of disintegration



Substrate:
Cattle manure with straw
Cattle slurry

Average biogas production

1. Without disintegration 52,3 %,
2. Ultrasound treatment 53,0 %
3. Hydrodynamical cavitation 54,1%

Biogas and energy production

Results:

Variant	Pretreatment	Biogas production [dm^3/kg o.d.m.]	Organic dry mass [kg o.d.m../day]	Biogas production [m^3/d]	Methane content [%]	Daily production of total energy [kWh/d]
I	Without disintegration of substrates	369	53	15.9±1.6	52.3±2.1	76.0
II	Ultrasound disintegration	460	53	19.8±0.8	53±3.4	97.0
III	Hydrodynamical cavitation pre-treatment	430	53	18.5±0.9	54.1±2.6	91.6

Energy demand depending on the used method of pre-treatment

unit	power [kW]	time [h/d]	Energy demand					
			No disintegration		ultrasound		Hydrodynamical cavitation	
			[kWh/d]	[kWh/m^3]	[kWh/d]	[kWh/m^3]	[kWh/d]	[kWh/m^3]
crusher	1,5	0,5	0,75	0,05	0,75	0,04	0,75	0,04
Rotating pomp	2,2	0.5	1,1	0,07	1,1	0,06	1,1	0,06
Mixer 1	0,5	12,0	6,0	0,38	6,0	0,30	6,0	0,32
Mixer 2	1,0	12,0	12,0	0,75	12,0	0,61	12,0	0,65
Ultrasound disintegrator	10,0	3,5	-	-	25,0	1,77	-	-
Hydrodynamical cavitation	2,0	2,7	-	-	-	-	10,7	0,68
		Sum	19,85	1,25	44,85	2,26	30,55	1,94

Energy production depending on the used disintegration method

	Energy production brutto [kWh/d]	Energy demant [kWh/d]	Net Energy production [kWh/d]
Control	76,0	19,85	56,15
ultrasound	97,0	44,85	52,15
cavitation	91,6	30,55	61,05

Conclusions:

- method of ultrasound disintegration increases biogas production from the analyzed substrates by 25% on average,
- with ultrasound disintegration, greater energy production is negated by greater energy demand,
- the system without ultrasound disintegration is significantly more energy-efficient.
- Method of hydrodynamical cavitation disintegration increase biogas production from the analyzed substrates by 16% on avaerage
- The system with hydrodynamical cavitation is more energy-efficient than the other used methods with and without ultrasound disintegration