

Enhancing Biogas Production of Meat Industrial Wastewater by Microwave Pretreatment

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Abstract. The effects of microwave pre-treatment of meat industrial wastewater were investigated in this study. The focus of this investigation was to determine the optimum conditions in a continuous flow microwave treating system under which the microwave pre-treatment of meat industrial wastewater would facilitate the maximum biogas yield. Response surface analysis was applied to screen the effects of volumetric flow rate (FR), number of treating (NT) and power of the magnetron (PM).

Keywords: pre-treatment, biogas, microwave, anaerobic digestion

Introduction

Every area of the economy produces liquid, solid or gaseous pollutions. Applying sewage without any pre-treatment is harmful for the receiving environment in many ways. It can exacerbate such effects as exhaustion of oxygen in the receiving waters, reduction of natural regenerating capacity, the formation of bad odours and eventually the death of aquatic life. Besides, wastewater frequently contains pathogenic bacteria, nutrients and toxic compounds such as heavy metals. For these reasons, it is inevitable to use sewage treatment, to develop applied technologies, and to introduce new methods. A very important portion of sewage treatment is the removal of organic matter present in soluble and particulate form in wastewater. Anaerobic digestion (AD) is an efficient process both for the treatment of wastewater and the energy recovery.

This process is biological degradation by a complex microbial consortium of organic substrates in the absence of oxygen. AD reduces the

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pathogen content, stabilizes the wastewater and reduces the volume to be disposed of without any addition of chemicals with only the action of other type of bacteria. During the process, organic matter is converted, mainly, to methane, carbon dioxide and more biomass. This process is very attractive because besides not needing any added chemical reagents, no oxygen is required, it can produce a usable form of energy, as methane gas such that in certain cases, an energy surplus can be obtained.

AD is a series of parallel and sequential metabolic processes, performed by a variety of microbiological consortia. This process contains four main steps (Batstone, 1999): hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis is considered as the limiting step in the anaerobic degradation. In this step, larger particles and/or insoluble particles are degraded into smaller and more degradable forms.

Wastewater is mainly comprised of microbial cells and extracellular polymeric substances (EPS) produced by the cells as part of their metabolic activity. These contents form a matrix that is the substrate for the anaerobic digestion. Most of the EPS (proteins and carbohydrates) are negatively charged. Binding of EPS with positively charged cations increases the strength of the structure. In respect of their physical state, microbial cells represent a relatively unfavourable substrate for subsequent microbial degradation. A large part of the organic matter is compartmentalized within the microbial cell membranes. The cell envelope of microorganisms is a semi-rigid structure providing sufficient intrinsic strength to protect the cell from osmotic lysis. This microbial cell wall contains glycan strands cross-linked by peptide chains that give the walls resistance to biodegradation. Therefore for achieving acceptable biodegradation rate conventional biological digestion techniques require long hydraulic retention times. The efficiency of digestion can be increased by disrupting the microbial cells and making organic matter inside the cell walls available. (Pavlostathis and Giraldo-Gomez, 1991).

Disintegration may be performed by chemical, thermal, mechanical, biological techniques or by a combination of these. (Adel et al., 2010; Fernandes et al., 2009; Mosier et al., 2005; Sun and Cheng, 2002)

The pre-treatment also has the goal of decreasing the particle size, allowing a greater surface area per unit volume available for degradation (Muller et al., 2004).

This paper deals with one of the thermal pre-treatment: microwaves. In microwave processing, energy is supplied by an electromagnetic field directly to the material. Volumetric heating can be accomplished in shorter processing time and more economically compared with conventional

heating. In addition, heating occurs instantly and throughout the whole sample, heating can be controlled instantly, heat concentrates in the materials that have a high dielectric factor (selectivity). (Hong, 2002)

The microwave field and the dielectric response of a material govern its ability to heat with microwave energy (Thostenson and Chou, 1999). The behaviour of a sample subject to microwave heating is depending on its chemical and physical properties. The most important properties are the dielectric loss factor, the dielectric constant and the dissipation factor.

Several studies were carried out on matter solubilisation by microwave previous to anaerobic digestion. After the microwave pre-treatment, the total biogas production improved, and the microwave irradiation additionally decreased the initial lag-phase of anaerobic digestion (Beszédes et al., 2011; Jackowiak et al., 2011).

Materials and Methods

Meat industrial wastewater was collected in a Hungarian medium-sized meat processing company; the sampling point was after the grease tap. Sewage originates from meat processing technology, mainly from the flushing and rinsing process of equipment (slicing and packaging machines, smoking chambers). To remove grit, particles and other large-sized solids a cloth filter was used.

Table 1. Characteristics of wastewater

Parameter	Value
Total solid (TS) (mgL ⁻¹)	3210 ± 296
Total organic carbon (TOC) (mgL ⁻¹)	834.1 ± 35.3
Lipid (mgL ⁻¹)	115.1 ± 21.7
Protein (mgL ⁻¹)	379.4 ± 21.2

Microwave pre-treating system

Microwave pre-treating system (Fig. 1) contains a water-cooled, variable-power magnetron (M) operating at 2450 MHz. High-voltage power supply (NF power supply) feeding the magnetron consists of two transformers, one of them produces cathode heating voltage and heating current, the other produces the anode voltage which can be controlled by the primary circuit

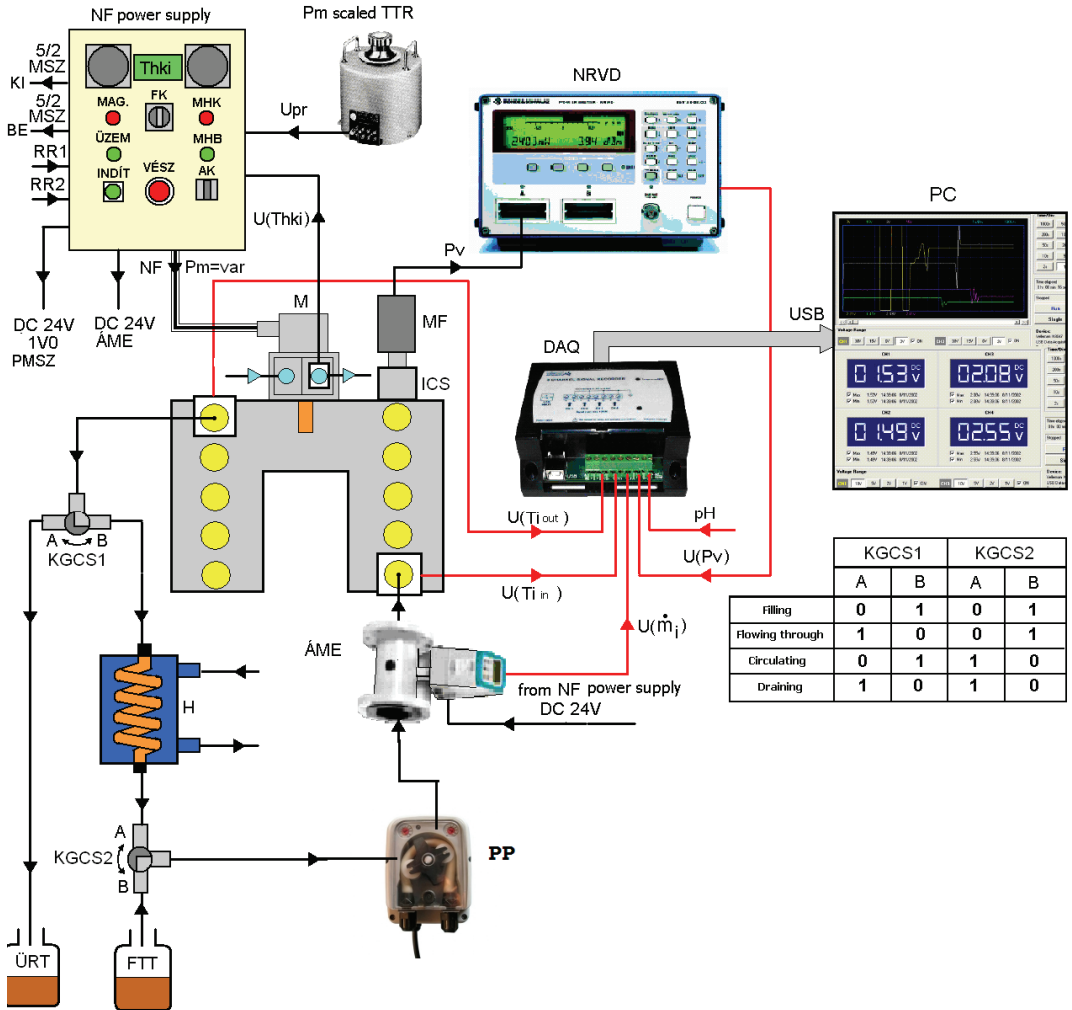


Fig. 1. Microwave pre-treating system

of an external auto-transformer. With this device (PM scaled TTR) the power of the magnetron can be set as well. Electromagnetic energy of the magnetron spread over a resonant slot. Getting through this slot the energy gets in the toroidal resonator. (Kovács et al, 2012). During the operation of toroid resonator energy is given to the treated material. As a result of energy transmission the temperature of the material rises and the dielectric properties change continuously. The effect of the microwave energy intake,

variable power, impedance and dielectric relationships are formed in the microwave resonator. Some of these can be measured (eg. power dissipation, reflected power), some of them can only be determined by calculation, knowledge of the other parameters (J. Zhu et al, 2007). Material is transferred in the continuous-flow microwave treating system by a peristaltic pump (PP) with variable flow.

Fermentation process, biogas measurement

Anaerobic digestion (AD) tests were carried out under controlled mesophilic temperature range ($35\pm0.2\text{ }^{\circ}\text{C}$). in 12 mini continuously stirred laboratory scale reactors with 250 mL total volume, equipped with Oxitop C.

Experimental design

A factorial design was used in order to test all the conditions and possible interactions between PM, FR and NT. Treatments were carried out at different PM, at different FR, and different NT. Three levels from these parameters were used and combined (*Table 3*). The method of least squares was used to estimate the coefficients. The values used in the experimental design are given in *Table 2*.

Table 2. Factorial design of the experiment

	Factors		
Level	Power of the magnetron (PM) [W]	Flow rate (FR) [Lh ⁻¹]	Number of treatings (NT) [-]
-	300	6	1
0	500	15.5	3
+	700	25	5

Table 3. Assignment of operational parameters in the 2^p factorial design

Run	Factors		
	Power of the magnetron [W]	Flow rate [Lh ⁻¹]	Number of treatings [db]
1	+	+	+
2	+	+	-
3	+	-	-
4	-	+	+
5	-	-	+
6	-	+	-
7	+	-	+
8	-	-	-
9	0	0	0
10	0	0	0
11	0	0	0

To evaluate energetically pre-treatment process specific energy demand (SED) was determined.

$$SED = \frac{E}{BP} \quad (1)$$

where BP is biogas production, E is the energy demand of pre-treatments calculated from the power of the magnetron (P_M) and the time of irradiation (t).

$$E = P_M \cdot t \quad (2)$$

The aim of this study was to screen the effects of PM, the FR and NT by the use of a composite design. Response surface analysis was used to represent the linkage between the response SED (Y) and experimental variables (PM (X_1), FR (X_2), NT (X_3)). Relationship can be written as function of variables,

$$Y = a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + a_3 \cdot X_3 + a_{12} \cdot X_1 \cdot X_2 + a_{13} \cdot X_1 \cdot X_3 + a_{23} \cdot X_2 \cdot X_3 + a_{123} \cdot X_1 \cdot X_2 \cdot X_3 \quad (3)$$

where $a_0, a_1, a_2, a_3, a_{12}, a_{13}, a_{23}$ are coefficients.

Effect of FR, NT and PM on biogas yield

The aim of this study was to define the effects of microwave treatment on wastewater for enhancing biogas yield.

The effects of microwave pre-treatment on biodegradation were investigated with a composite experimental design. FR, NT, PM profiles are shown in *Table 4* with the associated response which is SED. Results were correlated as function of FR, NT, PM (Eq. (3), *Table 5*) and represented with response surfaces (*Fig. 2*). The 30-day trial version of Design-Expert® software was used for data processing.

Table 4. PM, FR, NT used in the composite design and response associated

No.	PM [W] X_1	FR [Lh ⁻¹] X_2	NT [-] X_3	t [s]	E [J]	SED [J/ml]
1	700	25	5	360	252,000	845
2	700	25	1	72	50,400	183
3	700	6	1	300	210,000	646
4	300	25	5	360	108,000	420
5	300	6	5	1500	450,000	1510
6	300	25	1	72	21,600	87
7	700	6	5	1500	1,050,000	3,125
8	300	6	1	300	90,000	310
9	500	15.5	3	348	174,000	642
10	500	15.5	3	348	174,000	651
11	500	15.5	3	348	174,000	644

Table 5. Coefficients values of equations representing the response surfaces of SED as function of FR, NT, PM

Variables		Values of coefficients
Coefficients	Name	
a_0	Constant	-833.26
a_1	PM (X_1)	1.5
a_2	FR (X_2)	46.64
a_3	NT (X_3)	314.57
a_{12}	PM x FR	-0.094
a_{13}	PM x NT	0.5
a_{23}	FR x NT	-17.66

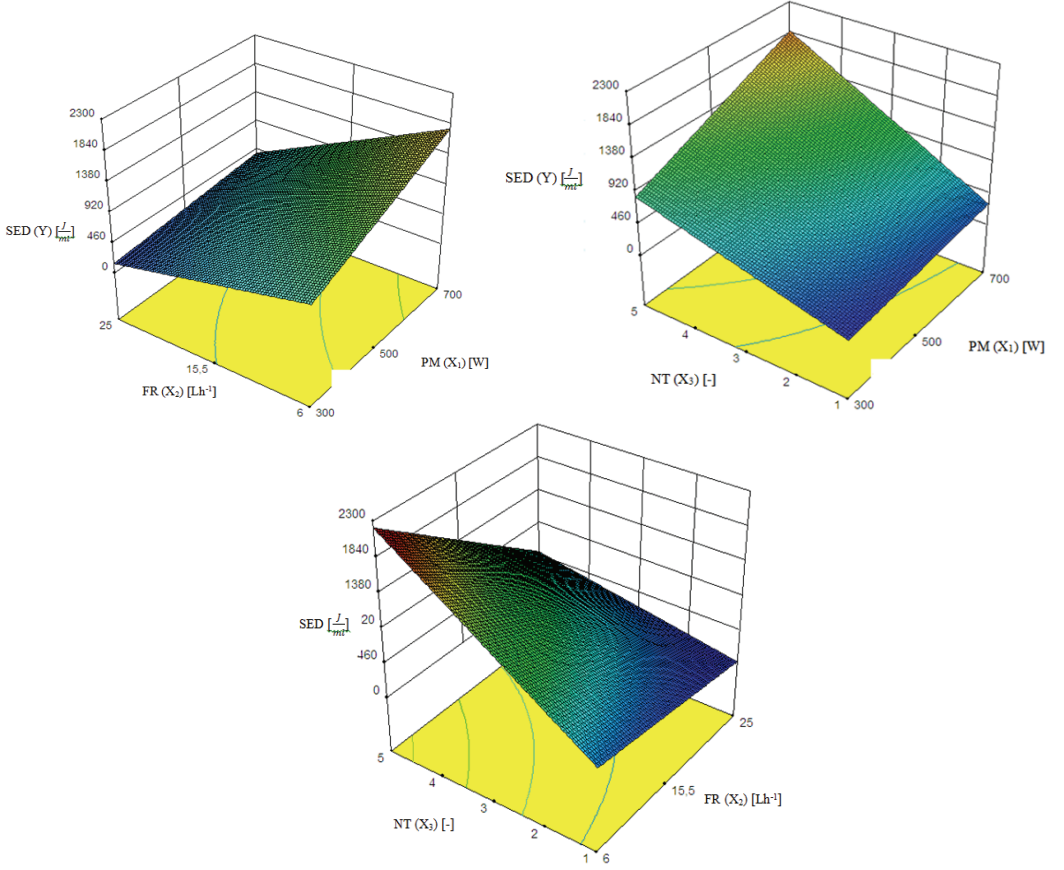


Fig. 2. The response surfaces of SED as function of PM, FR, NT

The approximate mathematical model of SED is as follows

$$SED = -833.26 + 1.5 \cdot PM + 46.64 \cdot FR + 314.57 \cdot NT - 0.094 \cdot PM \cdot FR + 0.5 \cdot PM \cdot NT - 17.66 \cdot FR \cdot NT \quad (4)$$

In case of energy demand such as SED, the aim of optimization is to minimize its value. Accordingly from Table 4, the optimal setting is No.6. As shown, this model for SED is a function of three input variables individually and the interaction between them. Figure 3 shows the predictive capability of the model. The predictive figure shows the correlation between the actual and predicted data and the accuracy of fitting.

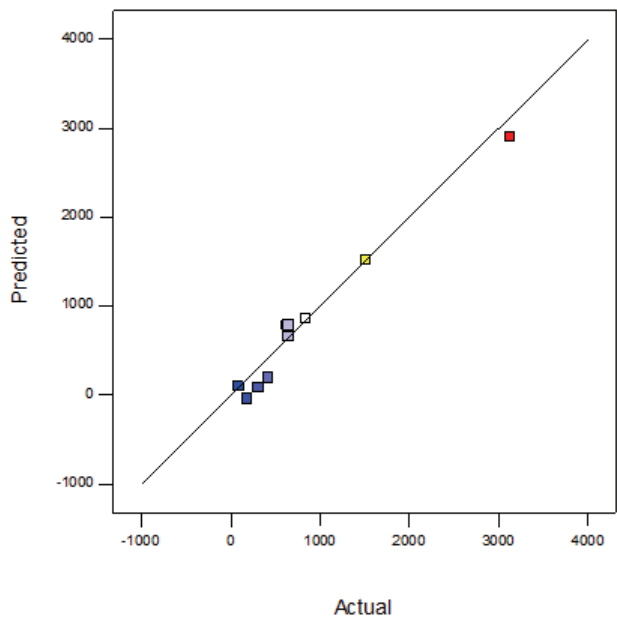


Fig. 3. Predicted vs. actual data

PM, FR, and NT and interactions have a statistically significant effect on SED as can be seen in the ANOVA Table 6. In case of PMxFRxNT p-value >>0.05, this interaction is not a significant term.

Table 6. ANOVA table for SED

Source	Sum of Squares	df	Mean Square	F	p-value
Model	7.030E+006	6	1.172E+006	25.44	0.0002
PM (X ₁)	7.638E+005	1	7.638E+005	16.59	0.0047
FR (X ₂)	2.056E+006	1	2.056E+006	44.65	0.0003
NT (X ₃)	2.731E+006	1	2.731E+006	59.30	0.0001
PM x FR	2.556E+005	1	2.556E+005	5.55	0.0506
PM x NT	3.232E+005	1	3.232E+005	7.02	0.0330
FR x NT	9.005E+005	1	9.005E+005	19.55	0.0031
Error	249.33	5	49.87		

Regression algorithms are more robust, precise and show fewer round off and multicollinearity errors when variables are coded and centered, so PM, FR and NT values were codified (PM', FR' and NT') according to expressions (5), (6) and (7), even though they could not be exactly centered:

$$X'_n = \frac{X_n - X_n^0}{\Delta X_n} \quad (5)$$

$$X_n^0 = \frac{X_n^{\max} - X_n^{\min}}{2} \quad (6)$$

$$\Delta X_n = \frac{X_n^{\max} - X_n^{\min}}{2} \quad (7)$$

Regression model initially considered as (3), becomes (8), using the coded variables

$$Y = a'_0 + a'_1 \cdot X'_1 + a'_2 \cdot X'_2 + a'_3 \cdot X'_3 + a'_{12} \cdot X'_1 \cdot X'_2 + a'_{13} \cdot X'_1 \cdot X'_3 + a'_{23} \cdot X'_2 \cdot X'_3 \quad (8)$$

Table 7. Estimated coefficients (along with 95% confidence intervals) for SED as a function of PM, FR and NT

Coefficient nt	Coefficient Value	df	Standard Error	95% CI	
				Low	High
a ₀ '	784.86	1	57.35	649.23	920.48
a ₁ '	309.00	1	75.87	129.59	488.41
a ₂ '	-507.00	1	75.87	-686.41	-327.59
a ₃ '	584.25	1	75.87	404.84	763.66
a ₁₂ '	-178.75	1	75.87	-358.16	0.66
a ₁₃ '	201.00	1	75.87	21.59	380.41
a ₂₃ '	-335.50	1	75.87	-514.91	-156.09

Conclusion

The results of Table 4 are used to create a response surface in order to obtain the output variables of the propulsion model as a mathematical function of

the three input variables and the interaction between them. Therefore, in every desired value of PM, FR and NT, output variables can be computed.

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