OPTIMIZATION OF MICROWAVE PROCESS TO IMPROVE THE BIODEGRADABILITY OF MEAT PROCESSING SLUDGE

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ABSTRACT

Microwave (MW) technique is a promising process for sludge conditioning, numerous papers has verified the beneficial effects on the microbial degradation and anaerobic digestion of municipal sewage sludge, but cannot be found study specialized on the investigation of MW process with different intensities for sewage sludge generated in food industry wastewater purification technologies. Our research was focused on obtaining optimum parameters of MW pre-treatment for meat processing sewage sludge (MPSS) using solubility index (SLI) and the 5 days biodegradability index (BDI_5) as control parameters. For the modeling and optimization response surface methodology (RSM) and multiple linear regressions (MLR) were applied, respectively. The investigated factors were the irradiated MW energy (IMWE) and the specific MW power level (MWPL). The results shown, that since the large-scale biodegradability enhancement, the MW pre-treatment is suitable for MPSS conditioning. The MW pre-treatments could be advantageous in numerous process based on biological transformation, such as activated sludge recycling processes, composting and anaerobic digestion.

1. INTRODUCTION

Compared to the other industrial sectors, the food processing technologies output a great amount of wastewater because of the high water content of the raw materials processed, the commonly used dehydration operations, and in addition, the high water demand of flushing and cleaning procedures. The methods of chemical precipitation, biological treatment and their combination with mechanical processes have been widely used to purify municipal wastewater but because of the lack of biological stage in food industry wastewater management systems a large amount of sludge with high organic matter content has been also generated. Several novel technologies have been investigated to develop flexible adaptable wastewater purification and sludge management technology for food industry effluents. The dosage of added chemicals can be mitigated by membrane separation, according to the minimal processing principle (Hodúr et al., 2004). Nanofiltration (NF) in combination with advanced oxidation processes (AOP) is suitable for achieving higher capacity of membrane purification due to the reduced membrane fouling (László et al., 2009). The concentrate remained in these hybrid processes has a lower environmental load, compared to the sludge produced in a commercial precipitation wastewater purification technology. Additionally, the NF process alone can be suitable for producing recyclable process water from high surfactant contented dairy wastewater, for instance (Kertész et al., 2008).

Conventional treatment and disposal of sewage sludge involves several steps, such as anaerobic digestion, chemical conditioning, thermal conditioning, and mechanical dewatering followed by disposal as landfill, application to cropland or incineration (Tang et al., 2010). The commonly used treatment with polyelectrolyte is mentioned as an expensive method, and furthermore the added chemicals contribute to form extracellular polymeric substance (EPS) (Higgins and Novak, 1997). Different species of microorganisms, biomass produced by the degradation of grease, nitrogen, and phosphorus; heavy metals and synthetic organic compounds agglomerated together with EPS into the polymeric network of sludge. It causes hydrophilic characteristic of sludge, and increases the difficulty to achieve effective bioconversion during anaerobic condition (AD) or aerobic processes (composting, for instance). Various alternative methods such as sonication, AOP's, freezing, electrolysis, and thermal pre-treatments have been investigated to improve dehydrate capability and the disintegration of sludge (Na et al., 2007; Yuan et al., 2010).

Many researches were focused on examining the efficiency of microwave (MW) treatment on sludge characteristic. Effects of high frequency electromagnetic field can be manifested in the change of the dipole orientation of the molecules, and it can lead to polarized side-chains of macromolecules, and the breakage of hydrogen bounds, which has an effect on biodegradability, anaerobic digestion efficiency, and disinfection ability (Hong et al., 2004; Szép et al., 2007; Toreci et al., 2009). However, several results show that the MW irradiation affected the enzyme activity as well (Neményi et al, 2008). The MW irradiation in combination with alkaline pre-treatment has a synergetic effects on the biogas generation from municipal sewage sludge (Dogan and Sanin, 2009), and the MW irradiation of sludge contented oxidizer (H_2O_2) could accelerate the decomposition of H_2O_2 into hydroxyl radicals what is manifested in enhanced organic matter solubilization and increased disintegration rate of sludge flock (Eskicioglu et al., 2008). Investigating the dewatering characteristic of MW irradiated sludge, Wojciechowska (2005) concluded that increase the exposure time beyond the optimal value the pre-treatment effects has been worsened and the specific energy consumption was notably increased.

In last decade, numerous papers have dealt with the examination of dewaterability and AD characteristic of MW irradiated sludge, but study cannot be found that specialize on the effects of MW irradiation with various power levels on the biodegradability of food industry sludge. In our work we focused on the examination, and optimization of MW pre-treatment for meat processing sewage sludge (MPSS).

2. MATERIALS AND METHODS

Dewatered (27.24 ± 1.8% TS) MPSS came from tertiary wastewater purification stage of a meat processing company located in Szeged (Hungary). Before the measurements the samples were frozen at –20 °C. The initial BOD_5 and TCOD of sludge was 112.48 ± 9.2, and 478.36 ± 6.6 [kg m^{-3}], respectively.

The MW pre-treatments were performed in a microwave cavity resonator equipped with a 700 W magnetron operating at a frequency of 2.45 GHz. The magnetron power ($P_{magnetron}$) is changeable continuously from 50 to 700 W through varying the heating voltage with a toroidal-core transformer.

For modelling and to optimize the process parameters response surface methodology (RSM) with central composite face centered (CCF) experimental design was performed using MODDE 8.0 statistical experimental design software (Umetrics, Sweden). The studied factors were the microwave power level (MWPL), and the irradiated MW energy (IMWE). MWPL (Wg^{-1}) was defined as the ratio of magnetron power to the quantity of treated sludge. IMWE was calculated as the product of magnetron power ($P_{magentron}$) and the exposure time (τ_{irr})

$$IMWE = P_{magnetron} \times \tau_{irr} [kJ] \qquad \text{Eq. (1)}$$

The selected responses were the solubilisation index (SLI) and the aerobic biodegradability for 5 days (BDI_5). The solubilization index for organic matters was determined by indirect COD measurement method

$$SLI = \frac{(SCOD/TCOD)_t - (SCOD/TCOD)_0}{(SCOD/TCOD)_0} \quad \text{Eq. (2)}$$

where $(SCOD/TCOD)_0$ and $(SCOD/TCOD)_t$ is the solubility ratio of the untreated and MW pre-treated MPSS, respectively. The total COD (tCOD) was measured by the standard dichromate method (APHA 5250D, 1995) sampled from the total sludge. The soluble COD (sCOD) was determined after centrifugation (6000 rpm, 20 min). For the separation of the water soluble phase a 0.45 μm pore-sized disc filter (Millipore) was used.

The biodegradability index (BDI_5) was calculated by the following expression

$$BDI_5 = \frac{(BOD_t / tCOD_0) - (BOD_0 / tCOD_t)}{(BOD_0 / tCOD_0)} \quad \text{Eq. (3)}$$

The biochemical oxygen demand (BOD_5) measurements were carried out in a respirometric BOD system at 20 °C for 5 days. To ensure the consistency of the experiments acclimatized standard microbes (BOD SEED, Cole-Parmer, U.S.) were used as inoculums for the measurements.

3. RESULTS AND DISCUSSION

The range and the levels of the experimental variables investigated, and the responses are shown in Table 1. To evaluate the reproducibility of the fitted model the experiments were conducted duplicated with six center points. In order to reduce the systematic error the run of the experiments were randomized.

Solubilization index indicates the change of water soluble fraction of sludge organic matters. Preliminary researches had reported that MW pre-treatments may disintegrate the flock structure of municipal sludge and, therefore, the solubilisation of the organic matters was enhanced (Bougrier et al., 2008; Eskicioglu et al., 2006). Because of the destruction of sludge flock, the specific surface of the sludge particles and the efficiency of biological degradation increased. In our research the effect of IMWE (from 100 kJ to 1050 kJ) and MWPE (from 0.5 to 5 Wg^{-1}) on COD solubilization efficiency were investigated. The experimental data are shown as the contour plot of fitted models.

Our results show, that increased IMWE from 100 to 500 kJ at a MWPL range of 1.5 to 4 Wg^{-1} could increase the solubility index to 0.9 (Fig. 1.). The increment of COD solubility can be explained by the hydrolysis of the large molecular weight organic compounds, the lysis of the cell walls, and the disintegration of the sludge flock, which was intensified by the applied MW irradiation. It was found, that beside the energy carried by MW irradiation, the applied MWPL had effect on the change of soluble fraction of the organic compounds of sludge as well. The lower than 2.5 Wg^{-1} MWPL was not enough to achieve the maximum organic matter solubilization.

Table 1. RSM for two variables and its experimental responses

Exp No.	Run ord.	IMWE [kJ]	MWPL [Wg^{-1}]	SLI	BDI_5
N1	5	90	0.50	0.303	0.886
N2	18	1050	0.50	0.734	1.186
N3	14	90	5.00	0.175	0.918
N4	17	1050	5.00	0.907	1.136
N5	8	90	2.75	0.253	1.005
N6	7	1050	2.75	0.903	1.246
N7	16	570	0.50	0.751	1.604
N8	20	570	5.00	0.793	1.619
N9	9	570	2.75	0.800	1.754
N10	11	570	2.75	0.798	1.749
N11	4	570	2.75	0.803	1.751
N12	15	90	0.50	0.297	0.891
N13	10	1050	0.50	0.745	1.213
N14	21	90	5.00	0.186	0.921
N15	6	1050	5.00	0.899	1.159
N16	22	90	2.75	0.267	0.991
N17	19	1050	2.75	0.902	1.259
N18	3	570	0.50	0.776	1.613
N19	13	570	5.00	0.809	1.594
N20	12	570	2.75	0.803	1.741
N21	2	570	2.75	0.801	1.76
N22	1	570	2.75	0.807	1.753

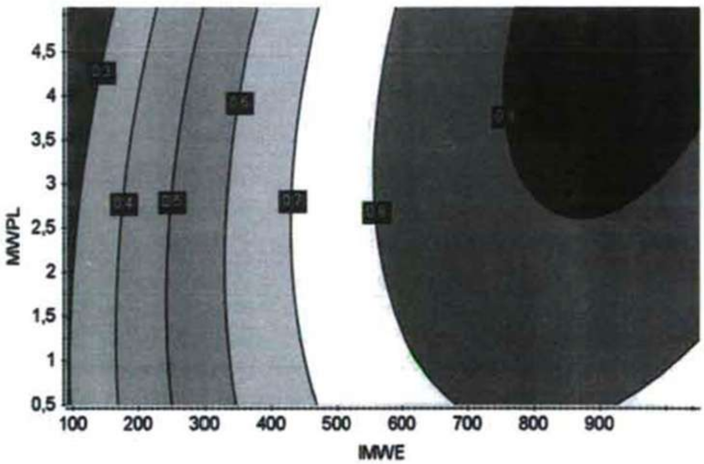

Figure 1. Contour plot of solubilization index (SLI) showing the effects of variables MWPL and IMWE

Since the biodegradability is linked to the solubility, the advantage of stronger MW irradiation predicts similar non-linear trends in the change of BDI_5, as well. But in the case of biodegradability limited increasing was found; applied MWPL over 4 Wg^{-1} and/or irradiated MW energy was more than 750 kJ the BDI_5 was worsened (Fig.2.).

The observed unfavourable effect of strong irradiation on biodegradability supposed to be due to the mineralization effects of MW heating. Furthermore, Eskicioglu et al. (2007) reported decreasing in the sugar and protein content of the soluble phase of sludge at an elevated temperature, explained by the Maillard reactions occurring between amino acids and reducing sugars. In our case the MPSS samples contained proteins with carbohydrate compounds; therefore the longer MW irradiation could manifest in Maillard reactions with a lower biodegradability.

The change of BDI_5 caused by the most efficient MW pre-treatment process parameters is corresponded to about 118% increment, relate to the biodegradability of untreated MPSS.

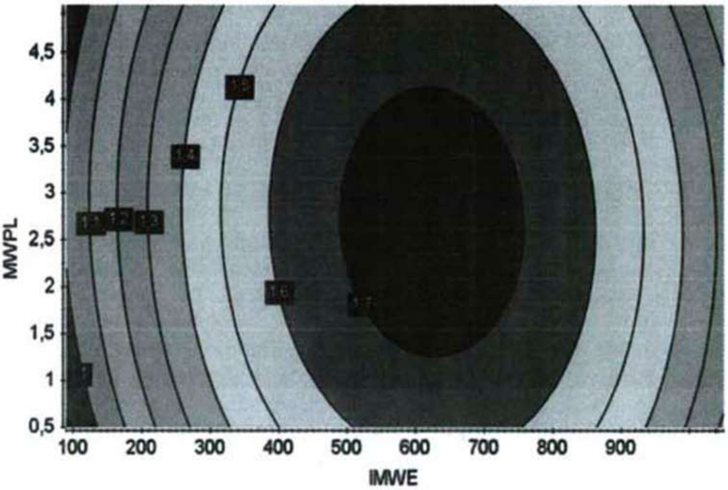

Figure 2. Contour plot of biodegradability index (BDI_5)

The applied empirical second order multiple linear regression model (MLR) for two factors was in general form according to Eq. 4. (Myers, Montgomery, 2002).

$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \sum \beta_{ij} X_i X_j \qquad \text{Eq. (4)}$$

where Y is the predicted response, X_i and X_j are the independent variables (IMWE and MWPL), and β_o, β_i, β_{ii} and β_{ij} are the regression coefficients of the fitted model. Since our main object was to examine and optimize the MW pre-treatments to enhance the biodegradability of MPSS, the modelling was performed using BDI_5 as response parameter.

Based on our experimental data the fitted model for biodegradability index (BDI_5) was the following equation

$$BDI_5 = 1.7393 + 0.1323X_1 - 0.0383X_2 - 0.5959X_1^2 - 0.1137X_2^2 - 0.0208X_1X_2 \qquad \text{Eq. (5)}$$

The response function was significant at confidence level of 0.95; the R^2 for BDI_5 was 0.9976, and in addition the goodness of fit (Q^2) was 0.995, which indicate good predictive power of the models (Fig.3.). The reproducibility was over 99.9% and the standard deviations of the fitted models were higher than the standard deviation of the residuals ($R^2_{adj} > 0.997$).

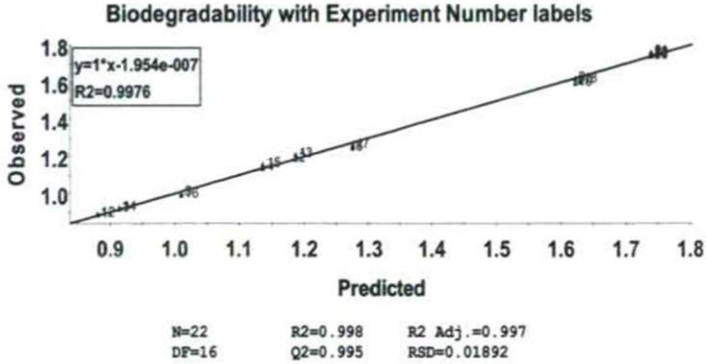

Figure 3. Observed versus predicted values for biodegradability index

Using the fitted model and based on the date obtained from the response surface analysis the optimal condition of MW process of MPSS for highest biodegradability with minimum irradiated energy and lowest MWPL were determined at IMWE of 621.9 kJ at MWPL of 2.684 Wg^{-1}. The MW pre-treatments with determined optimum process parameters caused a 114% increment of BDI_5. The final temperature of sludge irradiated with optimum parameters was about 95°C, therefore, for comparison purpose a commercial heat treatment was also carried out in laboratory heating equipment, at 95 °C for 120 min. The BDI_5 of commercial heated MPSS was obtained at 1.023 ± 0.23; also the MW pre-treatment has advantage over the conventional heating method.

4. CONCLUSION

In our work we focused on the examination of the effects of microwave (MW) pre-treatment on the solubility and biodegradability of meat processing sludge. For the experimental design and optimization MODDE 8.0 software was used, investigating the effects of the specific microwave power level (MWPL) and irradiated MW energy (IMWE) on the responses of solubility index of organic matters (SLI) and biodegradability index (BDI_5). Our results show that the MW irradiation could enhance the soluble and biodegradable fraction of MPSS and beside the IMWE the MWPL also affects the MW process. It was found, that in spite of the solubility increment, the MW pre-treatment with MWPL over 4 Wg^{-1} or IMWE over 750 kJ had an unfavorable effect on biodegradability. Using Response Surface Methodology (RSM) with Central Composite Face (CCF) centered design the optimal process parameters of MW pre-treatments were determined at IMWE of 621.9 kJ with MWPL of 2.684 Wg^{-1}. After MW pre-treatments with optimum conditions the solubility index (SLI) and biodegradability index (BDI_5) was enhanced by 194% and 117%, respectively.

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