学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Proper Treatment and Energy Recovery through Codigestion of Two Phase Olive Mill Waste
(オリーブオイル残渣の混合メタン発酵による 適正処理とエネルギー回収に関する研究)

Many agro-food industries produce a huge amount of waste in a form of biomass as a byproduct. Improper disposal of this waste can cause serious environmental problems. Olive milling is one of the main agro-food industries in the Mediterranean region. The short period of olive production leads to the uncontrolled discharge of the olive milling waste to the environment, causing serious environmental problems.

The two phase olive mill waste (2POMW) is the semisolid wet residue produced from the extraction of olive oil using two phase centrifugation. The doughy structure of this waste makes its storage and disposal difficult and can cause serious environmental problems because of its phytotoxicity and high organic content. Anaerobic digestion (AD) is an attractive process for the treatment of liquid and semisolid residues such as the 2POMW. In addition to the stabilization of the waste, energy can be recovered. In this study the main objective is to develop a process of anaerobic digestion in order to achieve both proper treatment and energy recovery for the 2POMW. Anaerobic digestion of the 2POMW is limited by the presence of lignocellulosic compounds; therefore, the first objective of this study is to enhance the hydrolysis of the 2POMW by a pretreatment step before AD. In addition, anaerobic digestion of the 2POMW as a sole source is limited by the presence of inhibitors, mainly long chain fatty acids (LCFA). This limitation can be overcome by digestion with another source of waste (food waste); codigestion dilutes the high concentration of inhibitors. Therefore the second objective of this study is to investigate the codigestion conditions, e.g., the mixing ratio which is required for the design of AD plants.

For the first objective, a series of batch experiments were performed to evaluate the effect of pretreatment. The pretreatment conditions performed were (1) mechanical pretreatment by size reduction, (2) alkaline pretreatment with different concentrations of NaOH (2.4, 6, 10, 20 and 30%) and (3) alkaline pretreatment with different concentrations of CaO (2.4, 6, 10, 20 and 30%). Following the pretreatment, anaerobic digestion was conducted in batch mode (using 200 mL vial with effective volume of 100 mL, 37 ^{o}C) for 26 days. The effect of pretreatment on the amount of soluble organic compounds (represented as soluble chemical oxygen demand (sCOD)) and on methane production was determined. Since mechanical pretreatment had no effect on the sCOD, no improvement in methane production was observed. On the other hand, NaOH was able to solubilize part of the organic material. NaOH increased the concentration of sCOD, while the highest increase in the sCOD was for the 20% NaOH. Regarding methane production, when a loading rate of 0.88 ($gVS_{substrate}/gVS_{inoculum}$) of the NaOH pretreated 2POMW was applied without any pH control, the 6% NaOH pretreatment showed better performance than other treatments. The 20% NaOH pretreatment caused inhibition because of the high pH level inside the reactor (pH > 8.4). If pH is controlled, it is expected that methane production would increase. Degradation of the 2POMW by CaO was not sufficient to increase the

sCOD, therefore, methane production from the CaO pretreated 2POMW was less compared with the NaOH pretreatments. Considering a full scale reactor system receiving food waste as a main substrate and the NaOH-treated 2POMW as a co-substrate, the NaOH concentration of 20% might be sufficient regarding the sCOD concentration. It was also expected that too large amount of sCOD in the loading rate might inhibit the AD process because of the production of volatile fatty acid (VFA)

Continuous reactor experiment (reactor with effective volume of 6 L, 37 ^{o}C, hydraulic retention time of 30 days) for codigesting 2POMW with food waste was conducted. This study focused on investigating the mixing ratio of 2POMW to food waste in order to control the concentration of LCFA inside the reactor for a stable digestion process without inhibition. Mixing ratios of 3%, 4.3%, 5.7% and 8.3% were tested, considering the general total loading rate in COD. With increasing the mixing ratio, the organic loading rate as sCOD is also increasing, causing inhibition as expected before. To reduce the effect of sCOD on the AD process, the 2POMW used was with lower NaOH pretreatment for high mixing ratios, thus the organic loading rate as sCOD that was daily introduced into all reactors will be in the same level. There was no inhibition of methane gas production up to a mixing ratio of 4.3%; however, increasing the mixing ratio lead to higher oleic acid (the main LCFA in 2POMW) concentration and reduced methane gas production. Treatments of 10% NaOH-2POMW with 4.3% mixing ratio and 20% NaOH-2POMW with 3% mixing ratio were shown to be adequate concerning oleic acid concentration and methane gas production. Those treatments caused an increase in methane gas production by 548.5 mL/g-VS and 445.3 mL/g-VS respectively compared with the case of applying only food waste.

Our proposal of codigestion process of the 2POMW and food waste was applied to the existing biogas plant in Jordan which receives 60 t/d of food waste from different sources as a case study. This plant has the potential to produce 309 MWh of electricity per month. Applying 10% NaOH pretreated 2POMW in a mixing ratio of 4.3% (which showed the highest methane production in our study) during the five months of olive oil production can produce an additional 72.5 MWh per month, increasing the plant electrical production by 23.5%. This study showed that 2POMW, which has been illegally dumped, can be properly treated and that 2POMW can be a new renewable energy source for the existing biogas plant to recover additional energy significantly.

In conclusion, this study showed that NaOH pretreatment is an effective method to solubilize the lignocellulosic fraction of the 2POMW and to enhance methane production. Since the mono-digestion of 2POMW is limited by the high concentration of LCFA, this study proposed a codigestion system of 2POMW with Food waste. This study investigated the mixing ratio of 2POMW with food waste which is the main factor that controls the anaerobic digestion process. This study proposed a practical method for 2POMW to be successfully treated and converted to energy source by a combination of pretreatment and codigestion with food waste.