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Effect of VS organic loads and buckwheat husk on methane production by anaerobic co-digestion of primary sludge and wheat straw

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ABSTRACT

An environmentally acceptable disposal of sewage sludge and agro-wastes presents an urgent problem facing many countries. Anaerobic digestion (AD) is a robust and suitable technique for producing renewable energy from wastes. This study aims to improve methane production from anaerobic co-digestion of primary sludge (PS) and wheat straw (WS) depending on their volatile solids (VS) organic load and by adding a proposed waste material of buckwheat husk (BH) based on their carbon to nitrogen (C/N) ratio. Mesophilic anaerobic batch tests were carried out in 500-mL digesters. Individual and six mixtures of PS and WS at different VS organic loads were anaerobically digested to optimize VS load for the greatest gas production. The highest cumulative methane yield (CMYs) occurred with combined substrates at a VS load of 7.50 gVS/L. In general, the optimized organic loads that gave the highest cumulative biogas yield (CBYs) and CMYs were in the range of 6–8 gVS/L. In addition, AD of individual substrates of PS, WS, and BH and of their mixture at different C/N ratios was investigated regarding to the methane yields. Multi-component substrates produced the greatest CMY at a C/N ratio of 10.07. The CMYs was increased by 39.26% when the proposed waste material of buckwheat husk (BH) was added to the different mixtures of PS and WS compared to the co-digestion of PS and WS. Experimental results were approved using statistical analysis by ANOVA test at *P*-value less than 0.05. Purification of methane and biodegradation of VS were evaluated. The results emphasized positive synergy of anaerobic co-digestion for improving CMY and best feedstock utilization.

1. Introduction

Currently, the management of sewage sludge produced from wastewater treatment plants is one of the most serious challenges in biological wastewater treatment. Its amount is increasing worldwide as the quantity of wastewater being treated rises [15]. Fresh and untreated sludge will have many pathogens, a high proportion of water, high biochemical oxygen demand (BOD), and is normally putrid and odorous. Treatment and disposal of sewage sludge accounts for about half, even up to 60%, of the total cost of wastewater treatment [38]. It is an expensive and environmentally sensitive problem. With some traditional disposal routes (landfill, land application, and incineration) coming under pressure and others such as sea disposal having been phased out, the challenge facing sludge managers is to find cost-effective and innovative solutions whilst responding to environmental, regulatory, and public pressures.

Simultaneously, a huge quantity of wastes is generated from agricultural crops all over the world. Amount of agriculture residues is proportional to the production volume and they are generally disposed of by incineration or land filling leading to damaging effects on the environment. Agro-wastes contain valuable resources which can be recovered for many and very diverse economic, social, and environmental purposes. Among agricultural products commonly found worldwide, wheat is considered one of the most important. It is grown in large amounts all over the world and represents the second major edible commodity after rice [4]. As well, buckwheat is an important crop, which is widely grown

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in Europe and Asia. It can be used in human nutrition, as feed for livestock, and as a honey crop. The increasing amount of agro-wastes from wheat and buckwheat crops encourages researchers to pay more attention to particular aspects of its management, especially to recycling and waste-to-energy issues.

A cost-effective disposal of sewage sludge and agricultural residues in a way that is environmentally acceptable is one of the most urgent problems facing many countries [28]. Both aerobic and anaerobic processes can be used for waste stabilization. Anaerobic digestion (AD) has several advantages such that it consumes a little or even no energy, stabilizes the feedstock, and the residual cake can still be used as a soil ameliorant. In addition, it is considered one of the most suitable techniques for producing renewable energy from wastes. This technique converts organic matters in sewage sludge [45] and crop residues [44] into biogas (rich with methane) by a consortium of microorganisms, which can be used for heating and producing electricity [39].

Sewage sludge is a valuable feedstock for anaerobic digestion (AD) as it contains a high percentage of nitrogen, which can provide a buffering capacity and an improved balance of nutrients [31]. Although convenient and feasible, it has been recognized that the individual digestion of sewage sludge did not achieve the most efficient production of biogas due to its inherent deficiency of carbon; i.e., low carbon/nitrogen (C/N) ratio [21]. In contrast, agro-wastes contain a high percentage of carbon and a low percentage of nitrogen (high C/N ratio). Co-digestion of sewage sludge and agro-wastes is considered the best solution for enhancing methane yields [10], improving the C/N ratio [20], and decreasing the risk of ammonia inhibition [9]. Different types of agro-wastes can be used in admixture with sewage sludge, such as wheat straw [36] and rice straw [13]. A high biogas yield was obtained from the co-digestion of food wastes and rice husk based on C/N ratio of the mix [6].

The effect of total solids (TS) concentration on biogas and methane yields from anaerobic digestion of a single type of wastes has been investigated in several previous studies. Beevi et al. [3] investigated the effect of TS concentration on anaerobic digestion of organic fraction of municipal solid wastes using varying substrate concentrations. Yavini et al. [42] studied the effect of TS concentration on biogas yields of agricultural wastes. Tanimu et al. [32] studied the effect of volatile solids (VS) feeding load on both biogas and methane production in batch mesophilic anaerobic digesters treating food wastes. Although, the anaerobic digestion (AD) is considered an economic and environmentally friendly technology, it confronts certain limitations regarding high retention times, restricted methanogenic production, and low overall organic dry solids degradation efficiency [1]. A reliable overcoming of these restrictions in a wide range would be of a great value.

Most of the previous studies were concerned with the effect of the total solids concentration on biogas production from anaerobic digestions. There are fewer studies about the effect of volatile solids (VS) organic load in biochemical methane potential (BMP) tests for the optimal methane production and the best utilization of feedstock components. On the other hand, the optimization of methane production from co-digestion of different feedstock materials can significantly improve methane yields, anaerobic digestion performance, and biodegradability of the feedstock. The main objective of this research is to investigate the possibility of improving the methane yields from anaerobic co-digestion of nitrogen-rich primary sludge in combination with carbon-rich wheat straw based on their VS organic loads and by adding a proposed waste material of buckwheat husk depending on the carbon to nitrogen ratio that achieve a better balance of nutrients and positive synergisms in the digestion medium.

2. Methodology

2.1. Preparation of the substrates

A primary sludge (PS) substrate was collected from a full-scale municipal wastewater treatment plant located in Nantes, France. The plant system follows the activated sludge treatment method. Primary sewage sludge samples were dried for stabilization and stored for the later determination of their characteristics and the following anaerobic digestion processes. A wheat straw (WS) substrate was obtained from a farm located in Nantes and dried at the room temperature. Yong et al. [43] recommended that the size of the straw is better to be ranged from 0.30 to 1.0 mm for economic and energy-saving reasons. The size of WS substrate was reduced to be less than 1.0 mm using a hammer mill followed by a coffee grinder. The grinded WS feedstock was kept for determining its characteristics and feeding anaerobic digesters. A buckwheat husk (BH) substrate, a waste material that was suggested for improving methane production, was supplied by the Voltière mills in Garnache, France. It was dried, grinded, and kept for use as the other feedstock components.

2.2. Inoculum

Samples of fresh cow manure were collected from a small farm located in Nantes, France to be used as an inoculum in the anaerobic digestion processes. To remove the dissolved methane and residual organic matter contained in the fresh manure, it was stored in an anaerobic headspace for more than one month. To readapt microorganisms for mesophilic conditions, the inoculum was kept at a constant temperature of 37 °C using a water bath for 15 days before starting the batch tests [7]. The measured value of TS of the inoculum was found to be 5.59% relative to its dry weight while its VS amounted to 73.18% of its TS. The inoculum had a pH value of 7.21.

2.3. Analytical techniques

Volatile solids (VS), total solids (TS), and pH values for the substrates of anaerobic digestion and residues of the digestion processes were determined according to APHA Standard Methods [2]. In addition, total carbon (TC), total nitrogen (TN), total oxygen (TO), and total hydrogen (TH) were estimated with a thermal conductivity detector using a FLASH EA 1112 Series CHN Analyzer. The composition of the produced biogas from anaerobic digestion was determined by a Clarus 500 Gas Chromatograph (Perkin Elmer). After absorbing carbon dioxide from the produced biogas, the volume of the produced methane was measured daily by the water displacement method. Characterization results of the feedstock

Table 1
Characteristics of the feedstock components used in the biochemical methane potential (BMP) tests.

Characteristics	Primary sludge (PS)	Wheat straw (WS)	Buckwheat husk (BH)
VS (TS %)	82.50 ± 0.10	95.64 ± 0.05	97.60 ± 0.08
TS (dry wt.%)	81.70 ± 0.15	90.82 ± 0.20	85.00 ± 0.36
TC (dry wt.%)	39.90 ± 0.44	47.62 ± 0.58	47.50 ± 0.51
TN (dry wt.%)	6.70 ± 0.25	0.30 ± 0.04	2.30 ± 0.12
TO (dry wt.%)	28.30 ± 0.19	44.10 ± 0.42	43.37 ± 0.30
TH (dry wt.%)	5.40 ± 0.09	5.54 ± 0.17	6.10 ± 0.12
C/N ratio	5.96	158.73	20.65

Notes: VS = volatile solids, TS = total solids, TC = total carbon, TN = total nitrogen, TO = total oxygen, TH = total hydrogen, and C/N = nitrogen to carbon. The data represent the means ± SD, $n = 4$.