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Anaerobic digestion of waste wafer material from the confectionery production

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ABSTRACT

This paper presents results of semi-continuous mesophilic anaerobic digestion of waste wafer materials at high loadings. The digestion was carried out in a partially mixed horizontal fermenter. A model digestion was conducted in a way that the volume of the fermenter reached a high intensity of methane production at a low production of digestate without the addition of trace elements. For this reason, the waste was fed in a concentrated form. The intensity of dry biogas production was 6.44 $mN^3\ m^{-3}\ d^{-1}$ with the average methane content of 55.1 vol% at the average load of 8.23 $kg_{VS}\ m^{-3}\ d^{-1}$ during 203 days and the average hydraulic retention time of 148 days. The process was running stably at C:N ratio 5.3:1, at pH between 7.5 and 8.2, at the average temperature 39.7 °C and the ratio of total inorganic carbonate to the sum of lower fatty acids about 1:1. The specific biogas yield from waste wafer material was 0.703 $mN^3\ kg^{-1}$. The digestate contained 13.4 wt% of total dry matter in average with the loss on ignition of 75.4 wt% for the whole process. The dry matter of digestate contained 10 wt% of lipids and to 3.5 wt% of lower fatty acids.

1. Introduction

In the past few decades especially in advanced countries, the benefits of anaerobic digestion were observed in agriculture and also in the area of inactivating and using of industrial, municipal and food biowaste [1,7,13,15]. Through a gradual development, the most appropriate conditions for anaerobic digestion of biomass/biowaste with content of low to very high moisture were identified [4,6,9]. The comparison of the high-solids digestion with the traditional low-solids suspension anaerobic digestion can achieve the comparable measurement yields of biogas and methane, and even in high-solids process only a small amount of wastewater is formed and the technology has other benefits [5,11,12].

Bio-waste from the manufacture of confectionery (raw materials unsuitable for consumption by humans) is possible, in most cases, to classify as highly concentrated and valuable raw material for the production of biogas. One of the most common types of bio-waste is waste wafer material and defective confectionery. A weekly production of bio-waste in a typical confectionery manufactory is about in units of tons. Other bio-wastes being produced in similar quantities are dough, chocolate mass, fatty flavor fillings, starch from jelly production, etc. Also defective wafer products imperfectly shaped, pasted, broken or only packed defectively or labeled incorrectly are produced in large quantities which may reach up to 10% of total confectionery production.

Currently, processes such as composting and anaerobic digestion are applied as procedures for handling with bio-waste from the food industry [2,10]. It is due to the Waste Act of Czech Republic (Act No. 264/2011 Coll., as amended, chapter 92) from which implies that the use of materials has a priority over other ones. A huge part of bio-waste from the food industry is still landfilled which is in contrary to EU Directive (Council Directive 1999/31/EC). Anaerobic digestion as a method of treating bio-waste is effective and reduces impact on the environment [3,8].

The authors [16] showed that during high solids anaerobic digestion of dewatered sludge, the addition of food waste not only increased the system stability but also greatly increased the volume production of biogas. Maximum volatile solids removal from food waste was estimated to be 90.3%. The stable anaerobic digestion of food waste for the period of 368 days in the continuous replenishment of trace elements was achieved in contrast to the failure of digestion of food waste itself [17]. The aim of this paper is to present the results of laboratory tests of semi-continuous low-to-high solid mesophilic anaerobic digestion of waste wafer materials and

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defective wafer products without the addition of trace elements. The anaerobic process was conducted in order to achieve the highest possible intensity of production of biogas or methane at a minimum production of digestate according to the active volume of fermenter. Therefore the batch of fermenter was viscous pumpable slurry.

2. Materials and methods

2.1. Laboratory model

Anaerobic digestion was carried out in the partially mixed horizontal fermenter made from the three-layered bag from the material Sioen B6070 of a specific weight 1150 g.m^{-2}. The bag with the diameter 0.5 m, length 3.6 m and the total volume 0.7 m^3 provided an effective reaction volume 0.5 m^3. The laboratory model of fermenter consisted of a circular steel front equipped with a short cylindrical nozzle of diameter 0.5 m to fasten the bag, and further from the bag of fermentation, a heater unit for recirculation of hot air around the bag and a box made from plates for thermal insulation (polystyrene, 100 mm). The heating unit located at the rear end of model consisted of two electric heaters (2 × 400 W), air duct fan (type Vents VKMz 100 with a controller of rotations), aluminum pipes for air recirculation (2 × 4 m) and a thermostat with a meter of electricity consumption. Vaulted ends of fermentation bag were blown by warm air (75 °C) from the fan. Further, warm air flew in the box of thermal insulation along the bag toward the front of fermenter. The cooled air (40 °C) was sucked from the front to an aluminum pipeline back to the fan and the heating coils. Air heating was chosen with regard to the limitation of piping in contact with the bag, which might eventually physically interfere. Typical power consumption of the heater was 333 W. The model fermenter was placed horizontally on the laboratory desk.

A container with volume 0.03 m^3 was used for dosing the feed mixture. The container was connected to the self-priming pump with a rubber impeller (with power 1500 W). The stirring of the fermenter content was provided in two ways. The recirculation was switched-on manually several times a day using the self-priming pump. The dose was sucked-off by a hose with a diameter DN50 (located at the bottom to the rear of the bag) and returned to the opposite end of the bag (to the front) or vice versa. This stirring by the pump was performed daily at 9.00 for 15 min before dosing and after each dose of substrate for 5 min. Further stirring of the dose was performed by a continuously running twin blade stirrer (power 180 W, rotation speed 23 min^{-1}) located horizontally just above the axis of the front bag, which also contained the penetration of foam into the trap for biogas.

A constant volume of dose was ensured by overflow of digestate over the hose DN50 bended at a constant height (slightly above the axis of stirrer). The overpressure of biogas (10–100 Pa) was checked by a manometer (type U) and belayed by a liquid lid. Biogas flew to a cube-shaped sink for biogas (volume 0.02 m^3) placed above the steel front of fermenter. Biogas production was measured by a drum-type gasometer. Biogas composition was measured by a portable IR/electrochemical analyzer.

The schematic section of model fermenter is shown in Fig. 1 and the view on the model at laboratory digestion is shown in Fig. 2.

The laboratory model fermenter was developed in a research project (TA01020959) supported by the Technology Agency of the Czech Republic in the cooperation with the Centre for Environmental Technology, VSB – Technical University of Ostrava and the company CERNIN Ltd. The aim of the project is to develop and launch a biogas station, non-demanding for design, low-cost and potentially mobile, suitable for small farms, food production, etc. The company CERNIN Ltd. is now ready for producing the mobile container biogas plants working in accordance with the model described above. The cost of the typical 10 kWe unit will be around 185 000 EUR.

2.2. Feedstock

The liquid digestate (reaction mixture) was used as the inoculum from the first stage of agricultural biogas station Klokočov (Vítkovská zemědělská Ltd.), treating cattle slurry, silage, haylage and bio-waste from the manufacture of confectionery from the company Mondelez CR Biscuit Production Ltd., OPAVIA in Opava, Czech Republic including waste wafer materials. The temperature of inoculum during the transfer decreased from 40 °C to 30 °C.

The substrate as the mixture of waste wafer materials and defective wafers was obtained from the company Mondelez CR Biscuit Production Ltd., OPAVIA in Opava, Czech Republic. It contained trimming pieces of wafer materials, fragments or crushed wafer materials of all kinds and broken, dirty, defectively pasted or wafer products defective in other ways, unsuitable for the consumption by humans. Bio-waste also contained a certain amount of scraps from plastic and paper packaging. The proportion of these anaerobically non-degradable additives was negligible, <0.1 wt % by estimation. The waste wafer stream was about 90–100 tons per month in Opava in 2012. In 2014 this stream increased to 300–350 tons per month and in few years the firm expects it to be about 1000 ton per month (about 2000 ton per month in the whole Czech Republic). Bio-waste was imported in two-week intervals and stored at room temperature (20 ± 3 °C) in open boxes.

Bio-waste was crushed to particles <20 mm. The dosing from 1.0 to 3.5 kg of substrate was carried out once a day, higher daily doses of substrate were divided into 2–3 sub-doses pumped into the fermenter with the time interval of about 4 h.

The parameters of one the typical sample of substrate and one inoculum sample are shown in Table 1 (the elementary analysis). The methods and standards are shown in Table 2.

2.3. Anaerobic digestion test

The anaerobic digestion of waste wafer material was held in semi-continuous mode at the average reaction temperature 40 ± 2 °C for 203 days. The process began as the classic wet anaerobic digestion. The fermenter was filled with 450 kg of liquid inoculum. The reaction temperature 40 °C was reached during the first 10 h. Since the first day of test, the substrate was dosed after dilution by the recirculated digestate in the weight ratio about 6:1. The dosage of substrate was carried out almost regularly seven days a week till the first one hundred days of test.

After 100 day of test, it was about to verify the system's ability to cope with the sudden overload with a subsequent discontinuation during the first weekend without dosing. After that, the dosage was omitted during some weekends (it was not possible to assure operators). Therefore, there was the decrease in activity of anaerobic biomass. On the other hand, the resistance of system to fluctuations of loading was verified. The loading of fermenter by organic compounds and shortening of hydraulic retention time was increased by the progressive increase of daily weight of substrate. The process was performed in a way that the content of dry matter should increase from 6.5 wt % to 10 wt % in the shortest possible reaction time and then gradually to the limit still safe for the reliable pump operation (about 15–17 wt %). The doses of substrate were reduced when the overload was recognized due to the value of specific biogas production from the substrate dosed during the previous day dropped below the value about 0.7 mN^3 kg^{-1} d^{-1} or the value of FOS/TAC (the ratio of inorganic carbonates to fatty acids)