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Anaerobic digestion of wastewater screenings for resource recovery and waste reduction

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Abstract. Wastewater screenings are produced during the first stage of the wastewater treatment process and at present are disposed of to landfill. This material may not only cause operational failure to the treatment system, but also lead to environmental problems. In view of the high organic content of screenings, anaerobic digestion method may not only offer the potential for energy recovery, but also nutrient. In this study the, anaerobic batch digestion was performed at different dry solids concentrations of screenings to study the potential of biogas and phosphorus recovery. The tests demonstrated wastewater screenings were amenable to anaerobic digestion with methane yield was 355 m^3/kg VS, which are comparable to the previous results. The digestate was high in P content and can be recovered up to 41%. This study also shows that anaerobic digestion was not only to turn this waste into useful resources, but also has a potential in reducing the organic content up to 31% for safe disposal. In this way the amount of wastewater screenings going to landfill is not only can be reduced, but also valuable products such as methane and phosphorus can also be recovered.

1. Introduction

The recovery of resources from organic waste has received a lot of attention over the past decade and the theoretical basis for resource recovery is well understood. However one such waste that has largely been ignored is the wastewater screenings (WS) produced during the first stage of the sewage treatment process, including rags, paper, plastic, wood and other untreatable solid material. With a growing stress on global resources, wastewater is no longer viewed as a waste stream, but as a resource from which to generate many resources. Currently, WS are disposed of to landfill which results in greenhouse gases (GHGs) emissions, with lost energy, nutrients, with other recoverable resources and also other problems such as odour problems as well as limited space remaining for landfilling.

There are different methods are employed for the treatment of solid wastes, which one of them is anaerobic digestion (AD). AD is a complex biological process in degrading organic matter in the absence of oxygen, with the major stages including hydrolysis, acidogenesis, acetogenesis and methanogenesis. It is a sustainable approach that combines wastewater treatment with the recovery of valuable by-products, including renewable energy and nutrient [1]. Therefore, AD treatment is not only alleviate environmental problems, by stabilising sludge and reducing the mass of waste sludge for final disposal, but also eases the stress on depleted resources and growing energy insecurity, by converting waste to biogas. The digestate liquor has a high phosphorus concentration that can be recovered [2–5], with the potential to be used in agricultural activities.

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The long term oil crisis and consequent price rises have spawned considerable interest in the exploration of renewable energy sources. Bioenergy will be the most significant renewable energy source in the next few decades until solar or wind power production offers an economically attractive large-scale alternative. In AD study, special attention has been paid to the final stage of the process i.e. methanogenesis to produce methane. Besides producing a significant amount of versatile energy in the form of methane, anaerobic digestion also solubilises the nutrients phosphorus and nitrogen, making them easy to recover. Meanwhile, phosphorus (P) is a limited resource which is anticipated will be exhausted in the 21st century [6–8]. While natural sources like oil can be substituted with other sources when its reserves peak (such as wind, solar, or thermal energy), P has no substitute and cannot be manufactured or synthesized. The main source of P is extracted from the phosphate rock in the earth's crust. Due to the depleting P resource and higher extraction cost, there are increasingly studies have been undertaken to recover phosphorus from waste streams [5,9–13]. The best way to recover phosphorus from solid waste is to solubilise it in the form of liquid. The use of AD technique to extract and solubilise phosphorus from solid waste has been extensively reported for the past 20 years. There are a number of studies have been reported in using anaerobic digestate liquor from various type of solid wastes to recover phosphorus [14–17], but as yet non from screenings has been reported. As this material has received little attention, research on treatment of screenings by AD is rare. Therefore, this study aims to examine the potential of wastewater screenings for methane production and phosphorus recovery following its mesophilic AD. Prior to AD, WS will be characterised to allow for proper examination of the feasibility of the WS for conversion into recoverable resources. The biodegradability of the material will also be investigated to evaluate its potential in reducing the volume of the waste for final disposal.

2. Materials and methods

2.1. Collection and preparation of wastewater screenings (WS) and primary sludge (PS)

The WS used in this study were collected from the Knostrop Wastewater Treatment Plant (KWWTP), located in West Yorkshire, Leeds. The sample was simply collected when needed. Four major sampling regimes were undertaken, labelled as 1, 2, 3 and 4. Primary sludge (PS) was also collected from the same treatment plant to be used as seed inoculum (SI). The PS supplied the seed bacteria that needed to boost the AD process. After removing plastics, the fresh WS were ground, to achieve homogenized sample as representative specimens. The sample was then kept in a fridge at 4^oC prior to use.

2.2. Characterisation of WS

Characterisation involved analysis of component composition and physical character. This was done using the fresh WS. The composition was determined by manually segregating different type of materials in the sample such as paper, rags, plastic and kitchen waste. The percentage was determined by taking the wet weight of each material over the wet weight of the total sample. The physical analysis, i.e. pH, total solids (TS) and volatile solids (VS) were carried out according to Standard Methods [18]. For TS determination, the sample waste dried in an oven for 24h at 105^oC, subsequently ignited in a furnace for 4h at 550^oC for VS determination.

2.3. Anaerobic digestion (AD)

Anaerobic batch experiments were performed at a laboratory scale based on the method described by [19] and revised by others [20,21]. The reactors were developed using serum bottles with effective volume of 400mL. The reactors were sealed and tightened with neoprene bungs. There were four reactors were used with different dry solids concentrations, i.e. 3, 6, 9 and 12%, represented by R1, R2, R3 and R4, respectively. While the control represented by R5. Each reactor was filled with WS and seed inoculum at 1.5:1 ratio. Nutrient was also added at 1mL/L containing all the micro and micro nutrients and vitamins essential to the growth of the anaerobic microorganisms. While, R5 contained only seed inoculum and nutrient, as a control, to correct the biogas production of the inoculum. To perform the batch experiments, pH was measured and nitrogen gas was sparged to create anaerobic conditions in the reactors before starting the experiments. The experiment was operated in a shaker incubator at 37^{o}C and 100 rpm for 30 days. The pH was maintained in the range of 6.8-7.2 using 0.1M HCl and 0.1M NaOH.

2.4. Biogas measurement
Biogas produced from the reactors was measured by a liquid displacement method using 5% NaOH to scrub CO_2. The measured biogas volume was corrected to standard temperature and pressure. The biogas production was determined by subtracting the background values for the incubation period of 30 days which ensures that complete biodegradation of all the organics.

2.5. Phosphorus (P) determination in the digested liquor
To study the potential of P recovery, the digested effluent produced on the final day was centrifuged, filtered and the resultant supernatant analysed for its P concentration according to the procedures outlined in [18]. The concentration of P was determined using Agilent Cary 60 UV-Vis Spectrophotometer at wavelength 880 nm. The calibration curve was plotted using standard solutions with different concentrations prepared from 100 ppm of P stock solution.

3. Result and discussion
2.6. Wastewater screenings characterization
Ideal operation of the AD process requires that the organic and inorganic composition of the WS is known prior to feeding into the digester, to permit modifications to the key parameters. The physical characteristics of WS sampled at different collection times are presented in Table 1. Despite the wide gaps between collection periods, the composition of each sample was very consistent. The average dry solids content was 29.56%, which is considered to be quite high. According to [22], treatment involving compaction of the screenings increases the dry solids content by dewatering the waste. This explains the high dry solids as the WS collected were dried by compaction, during preliminary treatment at the plant. Dry solid content of dewatered screenings was also reported as 24 – 30% [23], and 30% [24]. Clay et al. [25] suggested the dryness of screenings should be at least 25% solids to avoid spillage during transportation and for reducing the costs of disposal. Despite the dryness, WS were still high in moisture and unsuitable for the modern landfill. The VS were always higher than 90%, suggesting a high organic matter content. This agrees with the observations of [22], who reported the VS of WS was about 90%. High volatile solids illustrate the potential of methane production as well as nutrient recovery. The average pH was 6.2 suggesting that the material will digest well without the need for external pH correction.

Table 1. Physical characteristics of wastewater screenings.

	Characterisations at different collection times				Average (std. dev.)
	1	2	3	4	
TS (% dry)	31.75	29.91	32.02	24.55	29.56 (3.00)
VS (% TS)	93.74	91.42	93.05	95.03	93.31 (1.30)
pH	6.08	5.83	6.40	6.55	6.22 (0.28)

The composition of fresh screenings in terms of their gross composition was also similar and the predominant fractions were papers and rags, followed by vegetable and organic wastes, plastics and grits (Table 2). Both collected WS showed similar composition, albeit differing slightly in percentage. The high proportion of paper suggests common practice in using paper products, such as cardboards and paper bags as packaging materials in the local area. The predominant fraction of paper may results in higher VS, biodegradability and thus produce high methane yield from digestion of WS. This finding also opens the possibility for the material to be recycled from waste stream, especially paper recycling. It has been noted that paper and paperboard are always the largest component of the

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municipal solid waste (MSW) stream, compromising more than one-third of total generation [26]. According to [27], a high paper composition results in higher VS, i.e. above 82%, consequently higher biodegradability and resource recovery.

The high proportion of rags, underlined the increasing use of disposable wipes [22], which are mainly made of cotton comprise a large fraction of the rags in WS. This large fraction of sanitary material is another reason why WS are categorised as a difficult waste, which may lead to difficulties in storing and disposal [25]. While the low proportion of plastics, vegetable and organic wastes as well as grits, indicates low composition of these materials arrived at the treatment plant.

Table 2. Composition of WS collected from the KWwTP, Leeds.

	Composition (% of wet screenings)		
Sampling time	1	3	Average (%)
Papers	67.02	61.65	64.34
Rags	22.83	31.57	27.20
Plastics	2.25	2.16	2.21
Vegetable and organic wastes	6.01	4.59	5.30
Grits	1.89	0.02	0.96

3.2 Biogas production and P recovery

The profile of cumulative gas production (GP) at standard temperature and pressure (STP) was measured and over the first 20 days there was negligible difference in gas production between feed solids of 3 and 6%. (Figure 1). However the higher dry solids (also represented by total solids, TS) continued to produce gas after this period whereas there was a plateau for the 3% solids. By contrast gas production for both 9 and 12% dry solids was poor. Thus the cumulative GP for 6% and 3% reached 4,466 mL and 3,097 mL of biogas, respectively, whereas gas production from 9% and 12% was low with a cumulative GP of 835 and 756 mL, respectively. This suggests that 6% is the optimum feed concentration of TS for anaerobic digestion, and 3% is the second place. By contrast 9% and 12% suggested that high concentrations of dry solids were inhibitory to methanogenesis possibly as a result of overloaded with high ammonia or volatile fatty acids (VFA) concentrations.

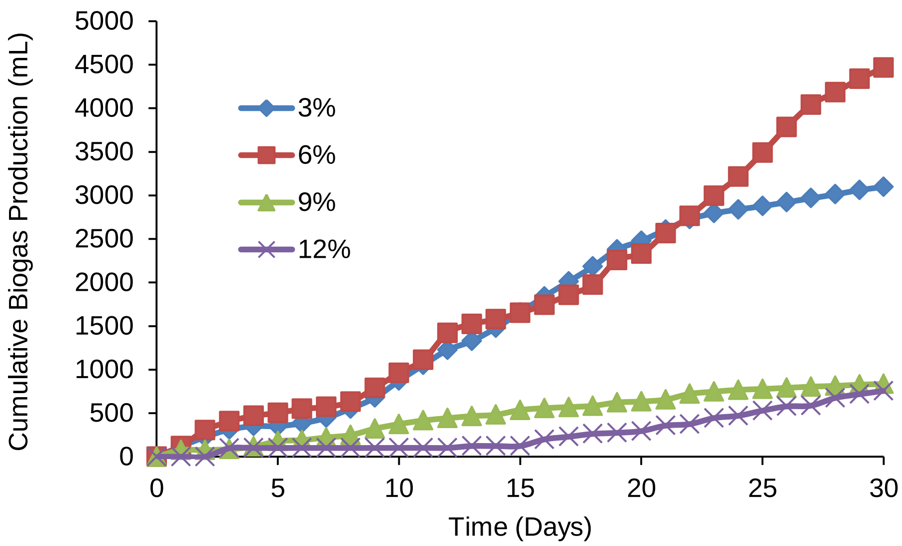

Figure 1. Cumulative GP at different dry solids concentrations

During the AD process, the first stage is the hydrolysis of large organic material (generally measured as volatile solids) to smaller, more readily biodegradable monomers. For complex wastes, this process is slow and indeed it is generally the rate-limiting step in the anaerobic digestion process.

Although the methanogenesis stage is also slow, for such complex wastes the rate of methane production is able to keep pace with the hydrolysis of organic material. Consequently the gas yield is expressed in terms of volume of gas produced/ amount of volatile solids applied (Table 3). This is clearly seen for the digestion of WS at 6%, where hydrolysis proceeds rapidly over the first 8 days and a rapid increase after 12 days indicates more complex material is destroyed, thus produced 0.355 m^3CH_4/kg VS methane yield. Previous studies also found the yield obtained from WS is typical of the value of other readily biodegradable wastes, such as organic fraction municipal solid waste (OFMSW) with 0.349 m^3CH_4/kg VS [28], food waste with 0.385 m^3CH_4/kg VS [29] and complex organic substrate with 0.243 m^3CH_4/kg VS methane yields [30]. The potential of P recovery was evaluated based on the percentage of P produced in the digestate from 1g dry solids of WS during the AD tests. The results show not much variation on the percentage when studied at different dry solids concentrations. It ranged between 37%-41%, with 6% shows the highest. These indicate that WS provides an ideal feedstock for resource recovery.

Table 3. The effect of dry solids on the anaerobic digestion performance.

Dry Solids (%)	VS destruction (%)	Total GP (mL)	Yield (m^3 CH_4/kg VS)	P recovery (%)
3	31.28	3097.11	0.298	37
6	31.44	4465.74	0.355	41
9	26.68	835.21	0.45	39
12	30.03	756.57	0.28	38

Note: the gas is assumed to be in the form of methane

3.3 Volatile solids (VS) reduction

In this study, VS reduction defined as the amount of organic content degraded from initial concentrations of dry solids by digestion process. The results show a constant value at different concentrations of substrate feed which ranged between 26.68%-31.44% (Table 3), with the highest reduction was at 6% dry solids. These values were less than some of the previous studies, which achieved up to 88.5% VS reduction [31]. This may due to the digestion system used, where previous studies used two-stage system. The results however, are similar to those found for digestion of terrestrial weeds which resulted in 46% reduction [32], and dairy manure at the highest VS removal about 35% [33]. Nonetheless, this study shows the digestion of WS is not only beneficial for resource recovery, but also for safe disposal of the digestate with a much reduced in organic matter content up to 31%.

4. Conclusion

In this study, the potential of a material that has received little attention, namely wastewater screenings, was examined for recovering valuable products. This material is considered high in organic matter with dry solids and volatile solids contents were 29.6% and 93.3%, respectively. In view of the high organic content of screenings, AD method may not only offer the potential for energy recovery, but also nutrient. This indicated by the sufficient P released in the digested liquor with 41% P recovery. The digestion was well-buffered without the need for external pH control as the pH of the material was 6.2 close to the ideal pH for digestion between 6.8 and 7.2. WS also can be used as a source of paper recycling as the highest component was paper with 64%, followed by rags with 27.2%. The digestion tests demonstrated WS were amenable to AD with methane yield was 0.355 m^3/kg VS at initial 6% of dry solids. Dry solids concentrations higher than 6% were inhibitory to methanogenesis possibly as a result of high ammonia or VFA concentrations. The organic content (in the form of volatile solids content) can be reduced up to 31%, which is environmentally beneficial and can reduce sludge volume for final disposal. The low VS reduction compared to previous studies implying WS is a difficult solid waste to digest, which may due to the high proportion of rags. Therefore, for future work it is suggested to perform pre-treatment and use two-stage digestion in treating difficult waste like WS. Overall, it can be concluded that AD treatment is not only alleviate environmental problems, by stabilising sludge and reducing the mass of waste sludge for final disposal, but also eases the stress on depleted resources and growing energy insecurity by converting waste to methane and phosphorus.

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