Gasification of Municipal Wastewater Primary Sieved Solids in a Rotary Drum Reactor

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Municipal sludge contains significant amounts of energy, which can be exploited by the use of anaerobic digestion, combustion or gasification. However, the relatively high moisture content of dewatered biosolids (usually over 80%) and long field experience makes anaerobic digestion the most favourable process for energy production from biosolids. Micro-sieves are novel apparatuses for the removal of solids form raw wastewater through a sieving process, using a rotating fabric belt assembly with continuous solids scraping (Koliopoulos and Gikas, 2013). The removed primary sieved solids (PSS) are distinctively different from conventional biosolids, as they do not contain cellular mass. They also differ from primary sludge, as they are collected almost "intact" on the fabric belt, which allows for efficient dewatering through an auger device, producing biosolids with solids content above 40%. Biosolids with relatively high solids content are more suitable to undergo thermal processing (combustion or gasification) for treatment and exploitation of its energy content.

Gasification is a thermal process for the reformation of organic substances, with carbon monoxide and hydrogen, as main products. Carbon dioxide and methane may also be formed in considerable quantities, while trace amounts of hydrocarbons may also be produced. The inorganic fraction of the feed is collected as ash (solid restitute). The gaseous product of gasification process is known as synthesis gas (syngas). Gasification is a process known since the 17th century (Miller, 2004), however, biosolids gasification has been exploited only recently (Fytili and Zabaniotou). Recent studies have shown that the electric energy produced by the gasification of conventional biosolids (at 80% moisture content) can be up to about two times the electric energy produced by anaerobic digestion (Gikas, 2014).

The present study investigates the potential for the production of syngas from gasification of primary sieved solids from municipal wastewater, in an Ultra High Temperature (UHT) rotary drum gasifier.

PSS (Table 1) had been collected from the wastewater treatment plant of Adelanto, Ca, USA, using an MS-54, M2Renewables, Inc., Ca, USA, microscreen (Fig. 1-left), and where shipped in two batches to the Pyromex AG facility in Munich, Germany, where gasification process took place. The microsieve was equipped with a cloth filter with openings of 350μm, however, the effective pore size was significantly lower, as the solids accumulated on the cloth filter act as a fine filter. The elemental analysis of PSS (ash free, dry product) is expressed by the following empirical formula: $C_{5.0}H_{8.1}O_{3.3}N_{0.10}S_{0.01}$, while its high heating value (HHV) was measured as 19 MJ/kg (dry basis). The initial moisture content of the PSS was about 59%, while they were further air-dried to reach moisture content of about 17%.

Table 1. Chemical and physicochemical characteristics of primary sieved solids (dry basis).

Parameter	Volatile solids	Ash	Fixed C	Total C	H	N	O	S	Cl
% (dry basis)	86.31	5.79	7.9	45.8	6.54	1.57	40.1	0.22	0.036

Gasification took place in an Pyromex (Switzerland), UHT rotary drum gasifier, with maximum loading capacity of 1 ton/day (Fig. 1-right). The gasifier can be heated using electric power, up to a maximum temperature of 1300 ºC. Temperature is controlled to the desired set point ±2 ºC, using a thermocouple at the middle of the drum. The biosolids were shredded to form particles with diameter smaller than 2 cm and were stored in a nitrogen purged vessel, from where they were fed on a continuous mode into the gasification chamber using an auger screw conveyer. The produced syngas was purified in a water scrubber and then was flared. The flowrate and concentration of H_2, CO, CH_4 and CO_2 in the syngas were measured every 3 min, at the exit of the gasifier, using a gas flowmeter and an on-line gas analyzer. The produced ash was continuously removed and stored in a container.

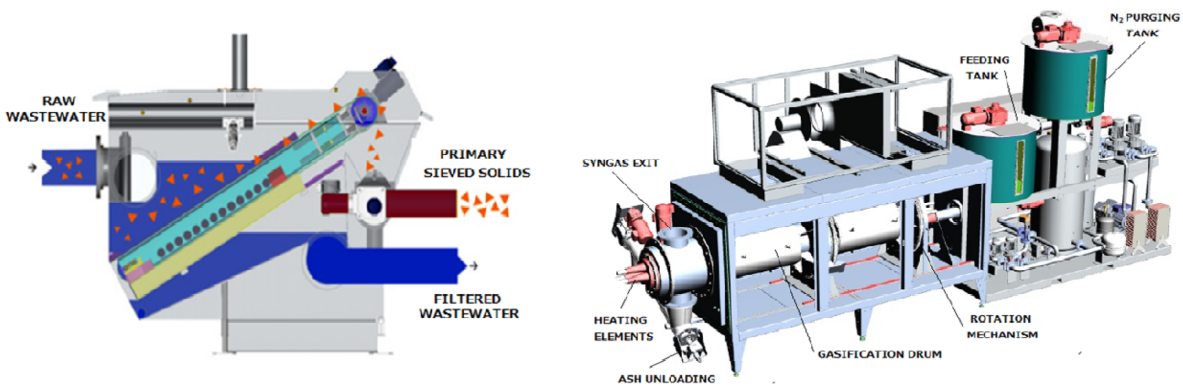

Fig.1. Drawing of M2 Renewables Inc., microscreen (left) and Pyromex AG, UHT rotating drum gasifier (right).

Two consequent gasification tests (Test 1 and Test 2), at different gasification temperatures (1050 and 950 ºC, respectively) were carried out, using 8.15 kg PSS it total (with 17% moisture content). The duration of Test 1 and Test 2 was 32 and 37 min, respectively. Fig. 2 shows the composition (H_2, CO, CH_4 and CO_2) of the syngas produced and the cumulative syngas production, during the tests. N_2 was continuously purged into the feeding container, thus N_2 (and possible trace amounts of other gases produced) are also summed in the volume of produced gas. The composition of the syngas, at the end of the feeding stage, for each Test, is shown in Table 2. The total ash produced was measured as 0.52 kg. It seams that the system reaches steady state at the end of the feeding period, as the summation of the monitored gases which are produced during gasification accounts for more than 97% of total gases.

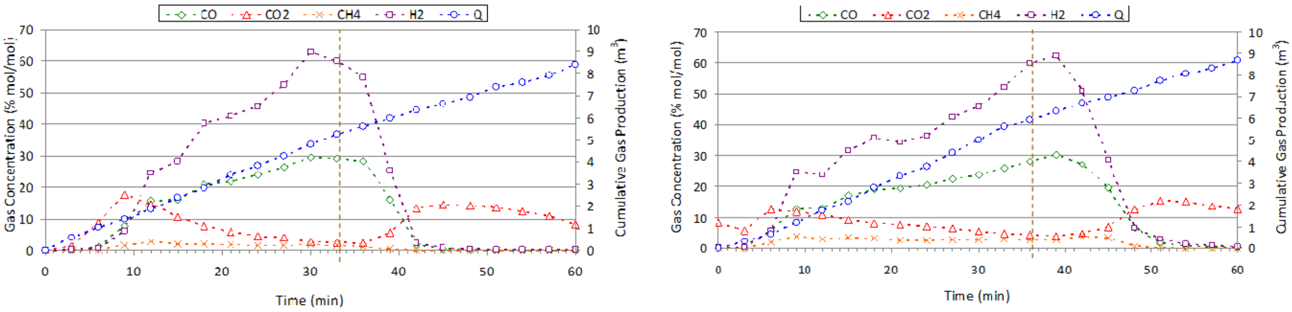

Fig. 2. Concentration of H_2, CO, CH_4 and CO_2 and cumulative gas production during Test 1 (left) and Test 2 (right).

Table 2. Operational conditions and syngas composition at stade state for Test 1 and Test 2.

Test No	PFS solids (kg)	Moisture (%)	Temp. (˚C)	CO (%)	CO_2 (%)	CH_4 (%)	H_2 (%)	Other gases (%)	Ash (kg)
Test 1	8.15[a]	17	1050	29.87	2.63	1.79	62.96	2.75	0.52[b]
Test 2	8.15[a]	17	950	29.86	4.14	2.92	62.18	0.90	0.52[b]

a: Combined weight of infeed charge for Test 1 and Test 2
b: Total amount of ash from both Test 1 and Test 2

From Fig. 2, it seams that the system behaved similarly during both Tests. Towards the end of the feeding periods, when it seams that steady state was established, the summation of H_2 and CO accounted for about 92% of total volume, and at a ratio of approximately 2:1; while (the non-combustible) CO_2 was below 4 %. From Fig. 2, it is obvious that gas continues to exit from the system after the completion of the feeding period, as material is still present in the drum, and also because of the N_2 purged towards the and of the trials, to ensure a safe equipment shut down.

From the present experiments is not possible to completely close mass and energy balances, as the purged N_2 to the system was not monitored, thus, it is not possible to account for the volume of other gaseous substances produced. Also, the exact mass of PSS used in each Trial is not known, but the total PSS utilized in both Trials is known. Thus, assuming that by the end of each Trial the system had reached steady state, and taking into account that the flowrate of the exit gases (including N_2) is relatively constant throughout the experiments (see Fig. 2), the expected yield (at steady state conditions) may be estimated. Thus 12.75 m^3 of syngas is produced from 8.15 kg PSS (17% moisture), with average composition 62% H_2, 30% CO, 2.4% CH_4 and calculated HHV of 12,626 kJ/m^3, thus the total syngas energy for 12.75 m^3 is calculated as 160.9 MJ. The HHV of the input PSS is 15.8 MJ/kg (wet basis at 17% moisture). The electric energy for the duration of both Trails (excluding heating up period) was measured as 18.4 kWh (equal to 66.2 MJ). Thus, considering the energy consumption of the gasifier alone, the ratio of energy (stored in the syngas) over the eclectic energy utilized is calculated as 2.43:1.00.

All thinks considered, UHT gasification appears as a promising technology for the conversion of biosolids, and specifically PSS into syngas. Two gasification temperatures (950 and 1050 ºC) had been tested, with minimal differences, with respect to syngas yield. The system appears to reach steady state after about 30-40 min from start up. The composition of the syngas at steady state was measured approximately as 62% H_2, 30% CO, 2.4% CH_4 and 3.4% CO_2, while the ratio of the energy content of the produced syngas over the electric energy utilization for the operation of the gasifier has been calculated as 2.43:1.00.

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