Biomass and Bioenergy 89 (2016) 201–209

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Co-gasification of wastewater sludge and different feedstock: Feasibility study

Salah Akkache [a], Ana-Belén Hernández [b], Gabriel Teixeira [c], Franck Gelix [c], Nicolas Roche [a, *], Jean Henry Ferrasse [a]

[a] Aix-Marseille University, CNRS, M2P2 UMR7340, Europôle de l'Arbois Bâtiment Laënnec, Hall C, 13454 Aix en Provence, France
[b] University of Johannesburg, Department of Civil Engineering Science, Kingsway Campus, PO Box 524, Auckland Park, 2006 Johannesburg, South Africa
[c] Veolia Recherche et Innovation, 78520 Limay France

ARTICLE INFO

Article history:
Received 2 March 2016
Accepted 3 March 2016
Available online 24 March 2016

Keywords:
Co-gasification
Wastewater sludge
Waste-to energy
Pollutants release
Ash slagging and fouling

ABSTRACT

Gasification experiments were performed for several feedstocks alone (wastewater sludge, waste wood, reeds, olive pomace, solid recovered fuel, paper labels and plastic labels) using a fixed bed reactor operating in semi-batch conditions. In order to combine them in an optimal gasifying blend, the gasification behavior of each feedstock was compared with that of wastewater sludge through the following criteria: the raw feedstock proximate and ultimate composition, the solid conversion, the gas heating value, the pollutants release and the ashes melting. Operated alone, the conversion rate of the feedstocks after 58 min of solid residence time was over 77% of initial mass. The Syngas low heating value produced at 1123 K was in the range of 9.0 to 11.9 MJ m^{-3}. The major concerns regarding the wastewater sludge were the pollutants precursors' release (NH_3, COS…) and the ash slagging and fouling. The calculated slagging and fouling indexes were high also for olive pomace and for waste wood. Finally, among the possible blends studied the paper labels and plastic labels can be co-gasified with secondary and digested wastewater sludge without any restriction, reeds and solid recovered fuel can be blinded with secondary wastewater sludge without any restriction, a specific attention have to be taken to fouling when they are blended with digested wastewater sludge. The blend based on waste wood and olives pomace should be avoided for instance due to their ash slagging and fouling tendency.

1. Introduction

The WasteWater Sludge (WWS) is a renewable energy source with a significant energy content, of about 24 MJ kg^{-1} on dry ash free basis (daf) [1]. However, WWS may contain considerable amount of nitrogen, sulfur, as well as heavy metal, bacteria, virus, pharmaceutical and hormones. This particular composition leads to pollution release with the current disposal ways [2–6] (land farming, landfilling and incineration). Gasification is an alternative thermal process that allows for a solid mass reduction (approximately 70% of the solids initial dry mass (dm)) [7], the energy recovery and the removal of organic pollutants and pathogenic organisms. Unlike incineration, gasification may limit the presence of SO_x and NO_x precursors in the syngas [8] and reduce the leachability (or potential toxicity) of ash [5]. Co-gasification based on multi materials can improve the quality of the raw fuel gasification [9–11]. The weakness of WWS are related to pollutants release and the presence of high moisture content. Coal – sludge co-gasification was investigated in literature [12–15]. The consensus is that adding WWS to coal increases the reactivity of coal with catalytic effect. This is probably due to the high mineral mater present in the WWS. However, the pollutants release (H_2S, NH_3, HCl) increases by adding WWS to coal.

There is a limited knowledge concerning WWS – biomass co-gasification in the literature. Van der drift et al. [16] carried out demolition wood – WWS co-gasification (at 20% mass fraction of WWS in the blend) in circling fluidized bed, they found that the NH_3 level in the syngas was the same level with the demolition wood alone, the H_2 and the syngas heating value were the same for both the blend and the demolition wood alone, the results suggest that blending WWS with biomass does not generate any operational problem at this concentration. Ong et al. [17] studied WWS – woody biomass air gasification in downdraft fixed bed reactor, they

* Corresponding author.
E-mail address: nicolas.roche@univ-amu.fr (N. Roche).

http://dx.doi.org/10.1016/j.biombioe.2016.03.003
0961-9534/

Abbreviation (Volumes are given in m^3 at standard conditions (273 K and 1.013×10^5 N m^{-2}))

WWS	wastewater sludge
SWWS	secondary wastewater sludge
DWWS	digested wastewater sludge
WWTP	wastewater treatment plant
OP	olives pomace
RE	reeds
WW	waste wood
SRF	solid recovered fuel
PA	paper labels
PL	plastic labels
LHV	low heating value
Al	alkalin index
Rs	slagging index
Fu	fouling index
daf	dry ash free basis
dm	dry basis
m_{gas}	mass of the total gas collected along all experiment (calculated)
m_{tar}	mass of the total tar collected
m_{char}	mass of the total char collected at the end of experiment
m_0	initial sample mass
$\%_{daf}$	mass fraction of the dry ash free basis
y_i	volume fraction of the specie CO, H_2, CH_4 and C_2
η_{conv}	conversion rate

found that at 30% mass fraction of WWS in the blend caused the gasifier blockage due to the ash agglomeration. Seggiani et al. [18] studied the air co-gasification of WWS – wood pellets in updraft fixed bed. The authors found that adding wood pellets reduce the slagging behavior of sludge, increases the gas yield and the cold gas efficiency. André et al. [19] proved the technical feasibility of coal – olive bagasse co-gasification in fluidized bed reactor, however, the authors indicate that the bagasse should be taken below 40% mass fraction to maintain stable gasification. Pinto et al. [1,20] compared mixing coal and straw pellets to WWS in an air-steam fluidized bed gasifier. The authors showed that no significant changes are needed to carry out the gasification with the different blends and adding coal or straw pellets to WWS increases the conversion, CH_4, C_nH_m, the gas low heating value (LHV) and reduce the pollutants release compared to WWS alone.

The biomass ash is known to cause several operational problems [21]. This is due to partial melting of ashes, leading to formation of melt slug on the reactor or deposition in the downstream equipment, especially heat exchanger [21,22]. The deposit formation involves a decrease in the heat exchanges as well as corrosion problems. The fluidized beds are sensible to bed material agglomeration, sintering and defluidisation, these problems may lead to total device failure [23]. A special care have to be taken when mixing WWS and waste, since their ash content can reach 30% mass fraction of dm to 40% mass fraction of dm [24,25]. The alkaline compounds are the most problematic species. The K_2O can interact with SiO_2 generating low melting mineral phases and eutectic phases [26]. The ASTM Standard fusibility test can be used in order to predict the ash behavior. However, it has been reported as unrepresentative of real ash behavior [27–31]. Thereby, several empirical indexes based on the chemical ash composition were developed.

The Alkaline index "*Al*" (Eq. (1)) represents the alkaline content per heating value unit ratio

$$Al = \frac{(Na_2O + K_2O)}{HHV} \quad (1)$$

When the Al value is in range 170–340 g GJ^{-1} fouling or slagging is probable, when it is greater than 340 g GJ^{-1} slagging and fouling are virtually certain to occur [22].

The Slagging index "Rs" (Eq. (2)) represents the ratio of low melting temperature oxides per high melting temperature with taken into account sulfur effect. Sulfur may interact with alkaline and forming low melting temperature phases.

$$Rs = \frac{\%(K_2O + Na_2O + MgO + CaO + Fe_2O_3)}{\%(SiO_2 + TiO_2 + Al_2O_3)} \times \%S \quad (2)$$

When the Rs value is lesser than 0.6 there is a low slagging inclination, when it is in range 0.6–2.0 the slagging tendency is medium, high at 2.0–2.6 and sever at greater Rs values [32].

Fouling index "Fu" (Eq. (3)), represents the ratio of low melting temperature oxides per high melting temperature with alkaline effect emphasis.

$$Fu = \frac{\%(K_2O + Na_2O + MgO + CaO + Fe_2O_3)}{\%(SiO_2 + TiO_2 + Al_2O_3)} \times \%(K_2O + Na_2O) \quad (3)$$

When the Fu value is lesser than 0.6 there is a low fouling inclination, when it is in range 0.6–40 the fouling tendency is high, at greater Fu the fouling in severe [32].

The aims of this study are: 1 – to evaluate the behavior of the different feedstocks during their gasification in terms of gas quality, pollutant release and ash produced, and 2 – to analyze the co-gasification feasibility of WWS – biomass or synthetic feedstock blends by strengths and weaknesses identification for different feedstock. This comparison was carried out through pure steam gasification in semi-batch reactor. The criteria of comparison were conversion rate, gas composition, low heating value, ammonia release and ash composition and behavior.

2. Materials and method

2.1. Materials

Five different types of Feedstock illustrated in Fig. 1: B class waste wood (WW), reed (Re), olives pomace (OP), solid recovered fuel (SRF), paper labels (Pa) and Plastic labels (PL) were selected on technical-economic criteria such as cost, availability and seasonality. In addition, two different types of sludge were selected: 1 – a secondary wastewater sludge (SWWS) from wastewater treatment plant (WWTP) La Courtine (Avignon – France) which is only mechanically dewatered and 2 – a digested wastewater sludge (DWWS) from WWTP La Pioline (Aix en Provence – France) which is aerobically digested to reduce carbon continent and avoid its fermentation in end-use.

The raw materials were characterized in order to obtain their proximate and ultimate analysis (CHNS) composition and ash melting following standard methods. The results of characterization are given in Table 1.

2.2. Experimental setup

The experimental setup used in this study was developed by Hernandez et al. [8]. It has been established that this reactor is