Mass and energy balances of sewage sludge pyrolysis in a lab rotary kiln

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Abstract
The aim of this work is to study the influence of the main parameters of sewage pyrolysis in a rotary kiln on the product distriburion and energy balances. An indirectly heated rotary kiln at a laboratory scale was used (4 kg/h). An increase in the final temperature causes the reduction of the total condensable products and the non-condensable gas fraction increases. The residence time of the volatile phase has an important influence on the secondary reactions to increase the non-condensable gas with low tars content. These results contribute also a valuable input to perform LCA.
Keywords: Sewage sludge, pyrolysis, rotary kiln, energy and mass balance

1. Introduction

Sewage sludge is an organic solid residue generated during wastewater treatment with high recovery potential. Estimated global production of sewage sludge in 2015 is about 18,5 million dry tons/year used mainly as agricultural fertilizer, energetic uses and landfill disposal (E.U.D.O 2015). Agricultural use is the most traditional disposal option for sewage sludge; however, this application is limited due the pathogenic organisms and trace elements contents in sludge (Grobelak et al. 2017). Pyrolysis of sewage sludge produced from industrial and municipal wastewater treatments represents an alternative way to valorize this residue through energy and materials recovery. Sewage sludge pyrolysis produces a solid and a volatile phase (condensable and non-condensable gases). The volatile may be used as fuel in combustion processes. During sewage sludge pyrolysis the trace elements in samples are concentrated in the residual char which represents environmental benefits (Hossain et al. 2010). This work is focused in the evaluation of the influence of final temperature and the residence time of volatile phase on the product and energy balances. The reactor used in this work is a rotary kiln which has the capability of to handle raw materials with heterogeneous physical and chemical properties and carry out processes under different reactions conditions.

2. Materials and Methods

2.1. Sewage sludge characterization

Samples of sewage sludge were collected from the wastewater treatment plant El Salitre, located in Bogotá - Colombia. Moisture, ash and volatile matter contents were determined according to DIN 51718, DIN 51719 and DIN 51720, respectively. The carbon, hydrogen and nitrogen fractions were determined in an elemental analyzer (Exeter Analytical CE-440). The sulfur content is determined by atomic absorption and the oxygen content is determined by difference. The gross calorific value of solid samples was determined using a bomb calorimeter (C 2000 basic IKA) according to DIN 51900. The results of the sewage sludge characterization are presented in Table 1.

Table 1. Physicochemical properties of sewage sludge

Text	Text
H (wt.%). d.a.f[a]	7,4
C (wt.%). d.a.f.	55,8
N (wt.%). d.a.f.	6,5
S (wt.%). d.a.f.	6,4
O (wt.%)[c]. d.a.f.	23,9
Moisture (wt.%)	63,7
Volatile matter (wt.%). d.a.f.	85,7
Ash content (wt.%). d.b.[b]	51,3
Heating value (MJ.kg^{-1}). d.a.f.	11,3

[a] d.a.f., dry ash free base; [b] d.b., dry base; [c] Calculated by difference.

2.2. Experimental facility

Experiments were performed in a rotary kiln at laboratory scale with a processing material capacity up to 4 kg/h (Fig. 1). The reactor is externally heated by electrical resistances. The carrier gas used is nitrogen. The liquid fraction sampling is carried out according to the procedure and the setup described in the pre-standard DIN CEN/TS 15439. Water fraction in liquid product is determined through a Karl Fischer analysis. Liquid and gas composition are determined through gas chromatography; solid products are weighed.

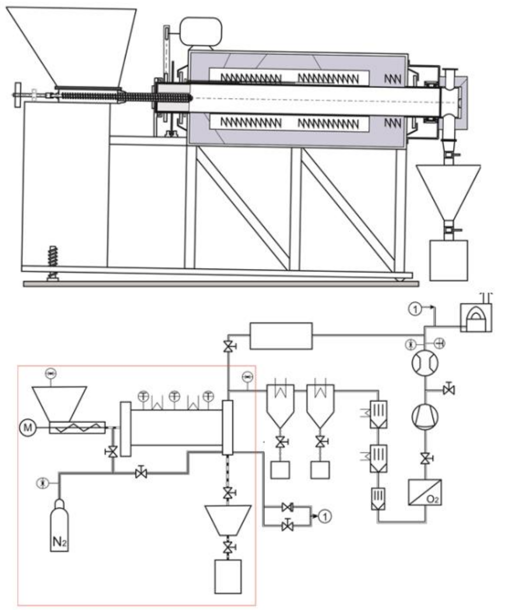

Figure 1. Rotary kiln lab scale system

2.3. Experimental plan

The influence of temperature was analyzed in the range of 550 to 850 °C. Residence times of the volatile phase in the reactor are varied by means of the volumetric filling degree, the mass flow rate and the flow of carrier gas. It´s influence on pyrolysis products was evaluated between 13 and 32 s.

3. Results and discussion

Temperature effect: The heating rate obtained in the reactor was approximately 100 K/min. Water fractions in condensate decreased slightly with an increase in temperature, mainly due to gasification reactions of char generated during the process (Fig. 2 (a)). Tar fraction decrease with the increasing of final temperature obtaining a reduction of 38,6 % in mass in the range of temperature evaluated. As consequence of tar conversion reactions with temperature an increment in the permanent gas fractions is presented. The energy distribution is shown in Fig. 3 (a). The energy in the gas fraction is increased maninly due to the increasing of CO and H_2 fractions with temperature which is consequence of the tar conversion and the the continuous decomposition of the sewage sludge samples at higher temperatures.

Residence time effect: Fig. 2 (b) show the mass distribution obtained at different residence time of the volatile phase. Char and water fractions remain constant. Tar fractions decrease with increasing residence time while gas fractions increase (Fig 2 (b)). Tar fractions in the volatile phase are reduced approximately 60 % in the range of residence time evaluated. In comparison with temperature, the residence time of volatile phase has more influence on the gas and liquid fraction during the process.

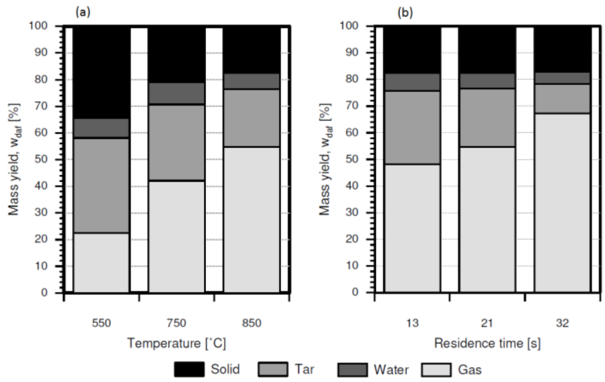

Figure 2. Mass balance obtained with variation of (a) final temperature and (b) residence time

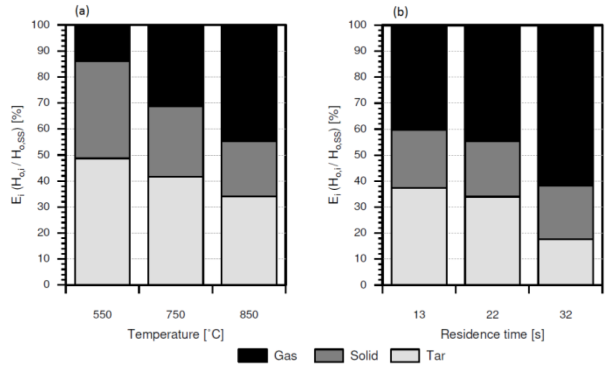

Figure 3. Energy balance obtained with variation of (a) final temperature and (b) residence time

4. Conclusions

Energetic valorization of sewage sludge through pyrolysis is a sustainable alternative for these solid wastes. Final temperature and residence time of volatile phase are parameters with high influence on the mass an energy distribution. An increase in final temperature causes the reduction of liquid fraction generated and consequently the increasing of mass and the energetic content in the gas fraction. The variation of the residence time of volatile phase has more influence on the mass and energy distribution than the final temperature.

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