Thermal treatment of wastes of anaerobic digestion of grape skins by drying-combustion in a conical spouted bed reactor

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Abstract

The purpose of this study is to prove the suitability of a conical spouted bed reactor for valorization of the digestate obtained in the anaerobic digestion of grape skins. The flow regimes of beds consisting of grape skins were determined in a conical spouted bed reactor under different operating conditions. The effect of moisture content on the minimum spouted velocity was evaluated. Thermal treatment by drying-combustion of digested grape skins was carried out in a conical spouted bed reactor at temperatures ranging from 425 to 550 ºC. Beds of digested grape skins were dried prior to the combustion process in order to improve combustion efficiency. The high experimental combustion efficiency calculated from the concentration of the exhaust gases assessed the proper suitability of the conical spouted bed combustor for the thermal combustion of digested grape skins.

Keywords

Anaerobic digestion; conical spouted beds; drying-combustion; digestate; grape skin wastes

Introduction

Fruits processing generates large amounts of wastes, which requires appropriate management to exploit these resources. One of the most important fruit crops of the world is grape, with a world extension of cultivated vineyard (*Vitis vinifera*) lands of 7.5 million Ha in 2016 with a global grape production of almost 76 million tons in 2016 and worldwide wine production of 241 million of hl (Wine Institute, 2017). The wine sector generates high amount of wastes suitable for valorization. The main organic wastes of the wine production are pomace produced during the pressing of the grape, constituted by skins and scrapes, obtained after the extraction of the grape juice (Barcia *et al.*, 2014); lees that are precipitates generated in the process of clarification of the fermentation and maturation of wine (Pérez-Serradilla *et al.*, 2008); and vinasse depleted of the wine obtained from the sludge washing waters and sewage sludge.

The anaerobic digestion allows to increase the added value of biomass wastes by producing a methane-rich biogas used to produce electricity and heat and an organic by-product, the digestate, that could be valorized in agriculture, due to its high proportion of mineral N, and a relatively stable organic matter (Tambone *et al.*, 2010). However, the digestate may not be often suitable, as it comes from the digester, for the direct application to agricultural soils so a series of treatments must be applied such as decanting/sedimentation, drying, for later use for fertilization of fields or as compost.

One alternative to application of digestate as soil amendment is thermal treatment for energy. Among the technologies sustainable for thermal valorization of wastes fluidized beds (Caneghema, et al, 2012) and conventional spouted beds (Konduri et al 1998; Rasul et al., 2001) technologies stands out. The Spouted Bed technology in a conical geometry has been successfully applied for exploitation of biomass wastes by drying (San José *et al.*, 2010a, 2010b, 2011, 2013a, 2017) and by combustion (San José *et al.*, 2013b, 2014a, 2014b). In this paper, a conical spouted bed has been applied for valorization by drying-combustion of digestate from processes of anaerobic digestion of grape skin waste. Digestate particles of grape skin have been dried at 105 ºC in the same experimental equipment before combustion. Likewise, the performance of a conical spouted bed for combustion of beds consisting of digestate particles and the combustion efficiency has been determined from the exhaust gases concentration.

Experimental

The drying-combustion process has been carried out in a plant designed at purpose, Figure 1, which consists of a blower, an electric resistance, thermocouples, two rotameters, two mass flow-meters, two high efficiency cyclones and the reactor. The combustor used is made of AISI-310 stainless steel, it has a cone angle of γ= 36º, and it is thermally insulated.

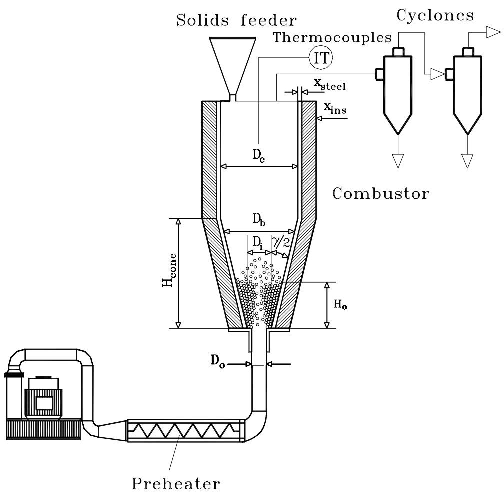

Figure 1. Schematic diagram of the experimental plant and of the conical spouted bed combustor

Biomass used has been beds consisting of digestate particles obtained in processes of anaerobic digestion of grape skin, wet digestate, Figure 2a and dry digestate, Figure 2b, of density ρ_s = 1050 kg/m^3 and 870 kg/m^3, respectively and mean Sauter diameter, d_S =3-7 mm.

(a) (b)

Figure 2. Digested particles of grape skin. (a) wet digestate; (b) dry digestate.

The operating conditions of beds consisting of grape skin wastes in a conical spouted bed combustor have been analyzed in the spouted bed regime. Drying-combustion process of digested grape skin wastes was conducted in a conical spouted bed combustor with inlet air temperature range 425-550 ºC. The combustor was preheated by passing air flow, measured by mass flowmeter, through an electrical resistance located at the inlet pipe of the combustor. The mass of digested grape skin was fed to the combustor, when the set bed temperature was attained. Aiming to raise the combustion efficiency, the moisture content of the grape vine wastes was removed by previous drying at 105 ºC. During this stage, samples of digestate particles were collected and their moisture content was measured with the drying time by Mettler Toledo HB43-S Halogen hygrometer (accuracy ± 0.01 %) and the drying time to achieve equilibrium moisture content was evaluated. The air flow used was high enough to avoid air saturation and to obtain a driving humidity gradient. The drying process was considered finished when the difference between two consecutive measurements of solids moisture content was lowerr than ±0.05 wt%.

The concentrations of the gases CO_2 and CO (% volume) were measured with the time in the outflow during the process by Testo 350 gas analyzer. The experimental values of combustion efficiency were determined from the concentration of CO_2, CO (% volume) gases.

Results

Operating conditions for beds consisting of digested grape skins have been determined for thermal exploitation in the spouted bed regime. The minimum air flow rate necessary to attain the spouted bed regime was determined when the standard deviation pressure drop fluctuations was less than 10 Pa (San José et al., 2015). The experimental values of minimum air velocity corresponding to the beginning of the spouted bed regime are plotted in Figure 3 for beds consisting of wet digested grape skins wastes, Figure 3a, and of dry digested grape skins wastes, Figure 3b, with stagnant bed height (H_o) in the range of 0.02-0.20 m along with an outline of solid particles in the fixed bed and in the spouted bed regime for a system taken as example. As observed, at each stagnant bed height, as air velocity increased from zero, the bed passes from the fixed bed to the spouted bed regime and the minimum velocity requires to reach the spouted bed regime is the minimum spouting velocity. It is noticeable that all studied systems are stable and spouted bed regime is attained in all of them and that the minimum spouting velocity increases with the stagnant bed height. An increase in inlet air temperature results in higher minimum spouting velocities and this effect is more noticeable at high stagnant bed heights. Besides, the higher the solids moisture content, the higher the minimum spouting velocity.

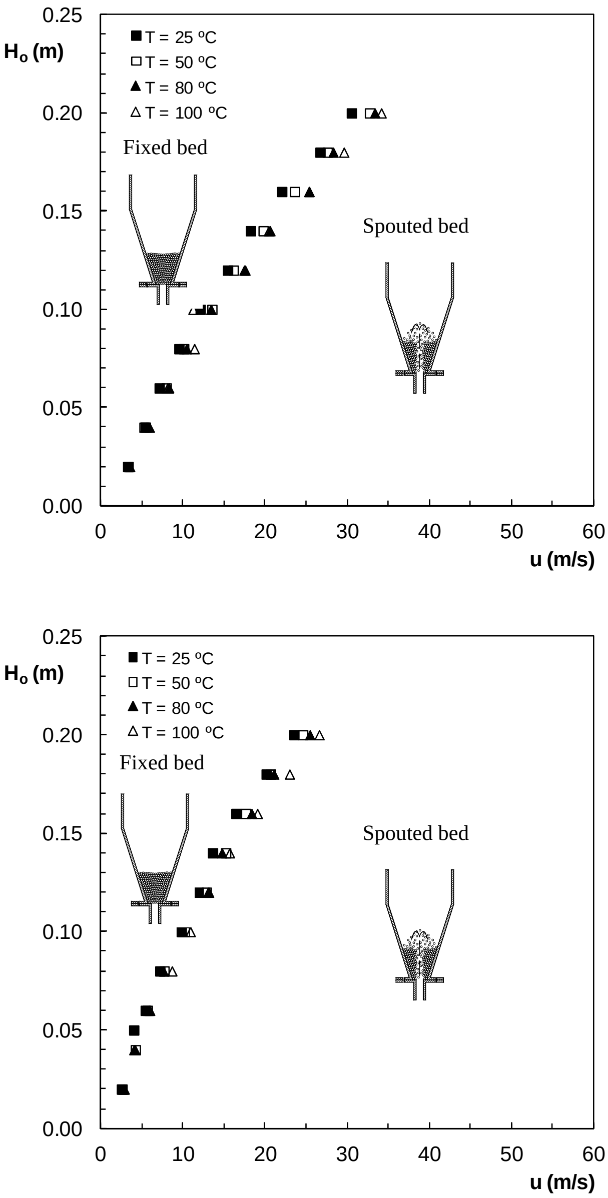

Figure 3. Operating map of stagnant bed height versus the gas velocity. Experimental system: γ= 36º D_o= 0.03 m. (a) wet grape skins wastes of d_S= 4.47 mm. (b) dry grape skins wastes of d_S= 4.20 mm.

During the drying process, the moisture content of a bed consisting of 100 g of grape skin wastes decreases with the time from the initial moisture (150 wt %, d.b.) to the equilibrium moisture content. This decrease is more pronounced at the beginning of the drying process, which is controlled by evaporation of the free moisture, while at the end of the process, solids moisture content variation with the time is asymptotic until the equilibrium moisture content is attained.

Batch combustion process of digested grape skin particles was performed in the conical spouted bed combustor at temperatures ranging from 425 to 550 ºC. During the combustion process of grape skin wastes, the concentration of CO_2 and CO gases in the flue gases was monitored with the time by Testo 350 gas analyzer. The experimental values of combustion yield obtained in grape skin wastes combustion in a conical spouted bed combustor were calculated from the mean concentration of CO_2 and CO (% volume) in the flue gas (San José *et al.*, 2013b, 2014a, 2014b). The experimental data of combustion efficiency obtained are higher than 75 %, and these values increase as the inlet air temperature is increased at temperatures range between 425 and 550 ºC.

Conclusions

The suitability of a conical spouted bed plant for thermal valorization by drying-combustion of the waste of anaerobic digestion of grape skins in the spouted bed regime has been demonstrated. The range of operating regimes beds consisting of digested grape skins has been established under different experimental conditions.

The moisture content of digested grape skins waste reduces with the time from the initial moisture content to equilibrium moisture content, and this decrease is more appreciable at high moisture content at the starting of the drying process.

Spouted bed technology in conical geometry is suitable for valorization of digested grape skins wastes from wine production by drying-combustion at temperatures range of 425-550 ºC with high combustion efficiency.

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