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Blend design tools for Medium Combustion Plants (MCP) firing biomass wastes

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ABSTRACT

A feasible alternative for agricultural or forestry waste management is the operation of a distributed network of sustainable Medium Combustion Plants (MCPs). However, one of the main factors that hinder its development is the propensity to operational problems derived from corrosion, slagging and fouling characteristics of both bottom and fly ashes. Therefore, a cost-effective approach for these multi-product MCP could be based on predictive tools for an optimal formulation of a fuel blend. This work focuses on the assessment of the ability of these methods to provide guidance for preventing ash-related operational problems and to provide fuel-blending rules.

The more widespread tools pertain to two types: compositional classification based on chemical analysis of laboratory ashes, and thermodynamic prediction of the most likely species and phases. Both criterion numbers and compositional maps are ranking methods based on the chemical analysis at a given ashing temperature. Thermodynamic equilibrium modeling is not constrained by any difference in the physical conditions of the MCP compared to those in the laboratory.

Both kind of prediction tools have been validated in an MCP firing olive tree pruning residues as well as its typical blends in order to mimic a plausible pattern of fuels along a full year operating campaign. An intensive experimental campaign encompasses plant monitoring and off-line analysis of the ashes along the process line.

Interpretation of compositional plots has revealed to be potentially sensitive to ashing temperature. Here are presented examples showing how this variable could lead to either insignificant differences or to a substantial disparity in the a priori fuel diagnosis.

Some inconsistencies have been observed between the predictions based on criterion numbers, even for the same fuel and for ranking rules specifically formulated for biomasses. Moreover, it does not match consistently with the information obtained from phase diagrams. Therefore, their use should be limited to the case of a well-established selection of a fuel index for a well-defined fuel provided empirical evidence of an enough good description of the ash behavior, which is not the most frequent case.

Thermodynamic equilibrium calculations allow a more precise prediction of the main species in the condensed phase, without the constraint of the ashing temperature. Elemental closure of main ash-forming elements with the chemical analysis of the process ashes presents small differences, and their proximity localization on the phase diagrams denote similar prediction between predicted and process ashes.

1. Introduction

Mediterranean countries produce 95% of the total world olive oil with important environmental, social and economic implications. Olive tree pruning residue is an important resource in the Mediterranean Basin, where basically the 8.6 million hectares of olive trees grown worldwide are located (FAOSTAT, 2009). Spain ranks first in the olive global production with $7.2{\cdot}10^6$ t, which becomes 37% of this production (Red Española de compostaje, 2015). The estimated yield of pruning residue widely ranges from 0.3 t/ha, based on an average of 120 trees/ha and 25 kg dry pruning

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Nomenclature

Abbreviations

A	fuel component: composted fraction of sewage sludge
A′	triangular diagram compositional point for A process ashes
AC	blend of components A and C
AC′	triangular diagram point for blend AC process ashes
ACs	triangular diagram compositional point for AC simulation
B	fuel component: fraction of municipal solid waste
B′	triangular diagram compositional point for B process ashes
BC	blend of components B and C
BC′	triangular diagram point compositional for BC process ashes
BCs	triangular diagram point compositional for BC simulation
BF	bag Filter
C	case fuel: olive tree pruning waste
C′	triangular diagram point compositional for C process ashes
Cs	triangular diagram point compositional for C simulation
ESP	electrostatic precipitator
FB	fluidized bed
FC	fixed carbon
G	mole of gaseous species at T
HF	hybrid filter
HHV	high heating value
ICP/MS	inductively-coupled plasma/mass spectrometry
ICP/AES	inductively-coupled plasma/atomic emission spectroscopy
LHV	lower heating value
MCP	medium combustion plant
RH	relative humidity
S	total molar amount of solid species
STGE	scientific group thermodata Europe
T	temperature
VM	volatile matter
XRD	X-ray diffraction
XRF	X-ray fluorescence

per tree, to 1 dry ton/ha (Spinelli and Picchi, 2010) to 3 t/ha year (Red Española de compostaje, 2015). The use of olive tree pruning residue as an energy resource is growing and strongly depends on the local development of systems for collection, processing, and delivery as well as on the feasibility of blends to ensure the operation on a yearly basis (Aragon et al., 2015). Its use as domestic grade in the form of pellets is becoming popular, so the requirement of a low ash content for this use causes a further waste fraction of downgraded characteristics, although still able to be valorized in an industrial facility. The seasonal supply variability leads to this pruning waste to be blended with customary local components while keeping the nominal thermal output of the MCP. In addition to the characteristic seasonality in supply, which leads to a traditional practice of blending with other fuels, there is a growing interest on “fuel engineering” to minimize corrosion and fouling as well as “end-of-life”, and to prevent atmospheric emissions. The so-called “fuel engineering” (Boström et al., 2012, 2009b, Grimm et al., 2012, 2011; Lindström et al., 2007; Piotrowska et al., 2012, 2010; Steenari et al., 2009; Steenari and Lindqvist, 1998; Xiong et al., 2008), that is, the purposely-optimized inorganic content of the fuel, relies on user-friendly reliable tools for prediction and mitigation of critical ash and emission related issues.

Decentralized networks of MCP (1–50 MWth) are a promising choice in agricultural waste management, not only for logistic reasons but also for its ability to fulfill the requirements of a number of distributed energy applications, among them, electricity generation, domestic/residential heating and cooling, or heat/steam for industrial processes. However, some caveats related to ash behavior and fine particulate emission remain mostly unsolved.

Until now, there was a lack of emission limit values for 7operations with a rated thermal input less than 50 MW. However, the European MCP Directive (Directive (EU), 2015/2193, n.d.), establishing limit values for both existing and new installations will have to be transposed by Member States by December 2017. This is a strong driver for the implementation of new routine tools based on a knowledge transfer, which can guarantee both the sustainable operation of the MCP and the prevention of operational problems. FB combustion is a flexible technology that enables burning fuels of widely varying quality under easily controlled operation (Van Caneghem et al., 2012). Specifically, bubbling FB has turned into a popular technology for efficient combustion of heterogeneous fuels with high moisture and ash content.

Knowledge of the mixture influence on the properties of the final ash materials can make it possible to avoid fuel combinations with unwanted properties, or even to design an ash for a certain end-of-life application. Many kinds of biomass fly ashes (Cuenca et al., 2013) have similar pozzolanic properties to the coal fly ash, and can be added to concrete as mineral admixtures. However, this is not the case for ashes from olive wood combustion due to its characteristic low oxide content (Vassilev et al., 2010). The capacity to reduce ash-related problems is strongly influenced by the ratios between problematic reactive components in biomass ash, as well as reaction atmosphere and combustion technology. Depending on the fuel to be used, the blending criteria could be based on increasing the Al-silicates, sulfur, calcium and phosphorus content (Wang et al., 2012). Potential waste feedstocks rich in S and other elements such as Ca, P, Al and Mg, can capture released K and improve the sintering characteristics (Skoglund et al., 2013) and components with higher amounts of P, S and Si, can improve combustion properties of problematic fuels. This knowledge is still fragmentary because of the large heterogeneity of waste biomass feedstocks and its blends as well as the lack of user-friendly robust guidelines for feedstock blending.

Previous studies (Davidsson et al., 2008; Fernández Llorente et al., 2006; Kassman et al., 2013; Vamvuka et al., 2008; Wang et al., 2012) report the results of the use of additives, such as limestone and a variety of waste materials, to mitigate ash-related problems and atmospheric emissions. However, this can lead to undesired outcomes in the absence of specific knowledge of the consequences of whatever blending action on both emissions and ash characteristics. A frequent consequence of the Ca compounds is the undesired increase in KCl formation, due to the modification in the interplay between S and Cl. These Ca-silicates present higher melting temperatures than the K-silicates. Also, a higher K release is generated when the (Mg + Ca)/Si ratio is higher, demonstrating that Mg and Ca have an effect on K release (Thy et al., 2000). Knudsen et al. (2004) suggest that when the temperatures increase, Ca and Mg have stronger bonds with Si than with K, and therefore, K is available for its reaction with Cl. The high reac-

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