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Combustion of lignin-rich residues with coal in a pilot-scale bubbling fluidized bed reactor

Roberto Solimene [a,*], Antonio Cammarota [a], Riccardo Chirone [a], Paolo Leoni [b], Nicola Rossi [b], Piero Salatino [c]

[a] Istituto di Ricerche sulla Combustione, Consiglio Nazionale delle Ricerche, Piazzale Vincenzo Tecchio 80, 80125 Napoli, Italy
[b] Enel Ingegneria e Ricerca S.p.A, Via Andrea Pisano 120, 56122 Pisa, Italy
[c] Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale, Università degli Studi di Napoli Federico II, Piazzale Vincenzo Tecchio 80, 80125 Napoli, Italy

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ABSTRACT

The production of second-generation bioethanol generates a waste stream consisting of lignin-rich residues whose valorization has to be found. Fluidized bed combustion technology can be considered as a promising and viable option to recover thermal power from lignin-rich residues of a second-generation bioethanol production plant. This work aims at investigating the combustion of lignin-rich residues with coal in a pilot-scale bubbling fluidized bed combustor (FBC). An experimental campaign was carried out to study gaseous and particulate emissions and thermal regimes during the combustion of mixtures of coal with 30%$_w$ of lignin-rich residues varying bed temperature, excess air and fluidization velocity. A few experimental tests were carried out for comparison using only coal, a mixture of coal with 40%$_w$ of lignin-rich residues and a mixture of coal with 20%$_w$ of wood chips. The analysis of the experimental results mainly highlights that: 1) the gaseous emissions did not significantly change with respect to coal or to reference biomass-coal mixture at least until the content of lignin-rich residues in the mixture was 30–40%$_w$; 2) the particulate emissions increased with the percentage of residues content, but, at the same, the particulate carbon concentration was significantly reduced. Bottom bed particles were analyzed at the end of each experiments, highlighting the absence of agglomerates. However, a significant enrichment of metals like Fe, Mg, Na, Ca and K, most of them probably coming from the ash of lignin-rich residues, was observed when the FBC was operated under conditions which emphasize ash accumulation inside the bed.

1. Introduction

The deployment and the exploitation of bioethanol as automotive fuel became more and more relevant to reduce the emissions of greenhouse gases and to limit the dependence on countries supplying fossil fuels. In this perspective, the European Community legislation regulated, with the 209/28 EC Directive, the minimum amount of biofuel at 10% for automotive fuels by 2020. OECD estimates predict that the production of second-generation bioethanol, i.e. ethanol produced from lignocellulosic biomass and scraps of agricultural crops, will be of 155 billion litres by 2020. The composition of lignocellulosic biomass is typically: cellulose (35–45%$_w$), hemicellulose (25–30%$_w$) and lignin (25–30%$_w$). The cellulose and hemicellulose are made of fermentable sugars, while the lignin is a polymer consisting of several units of not fermentable phenylpropanoids. As a consequence, the residues of second generation bioethanol production, typically the solid residues after ethanol distillation and separation, are characterized by high lignin content. These residues can be used only in part to energetically support the process of bioethanol production (about 40%), whereas the valorization of the remaining 60% has to be found.

The lignin-rich residues coming from a second-generation bioethanol production plant can be exploited for the production of some chemicals [1–4], as well as in thermochemical processes like combustion [5], co-combustion [6], gasification [7] or pyrolysis [8].

Lignin pyrolysis [9–13] was typically proposed in order to obtain bio-oil as intermediate reactant for production of bio-fuels or chemicals and, at the same time, biochar to use as amendment or agricultural fertilizer. Combustion [14–15] and gasification of lignin, as it is or pelletized, was investigated for combined heat and power (CHP) generation [16]. Lignin was also proposed as co-fuel in pulverized coal-fired power plants. Reactivity tests carried out in a thermogravimetric analyzer [6] and in lab-scale experimental apparatus [17–18] highlighted that the addition of lignin to coal favours the combustion process. On the other hand, the analysis of ash generated by the combustion of mixtures coal-lignin shows that addition of lignin determines negligible differences in terms of ash fusibility and tendency to fouling and slagging [17–18].

Fluidized bed combustion [19–22] and gasification [7] technology as well as dual interconnected fluidized bed configurations for the

* Corresponding author.
E-mail address: solimene@irc.cnr.it (R. Solimene).

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pyrolysis process [23] were also applied to this type of fuel, even if some difficulties mainly related to fuel feeding [7] and to the occurrence of bed agglomeration phenomena [21] were observed.

Fluidized bed combustion technology can be considered as a promising and viable option to recover thermal power from lignin-rich residues of a second-generation bioethanol production plant. The co-combustion with coal in fluidized beds could be extremely attractive for the energetic and environmental valorization of these lignin-rich residues. However, the performances of fluidized bed combustors continuously fuelled with mixtures of coal with lignin-rich residues at bench- and pilot-scale are still not reported in literature. As a consequence, this work aimed at investigating the combustion of these lignin-rich residues with coal in a pilot-scale bubbling fluidized bed combustor (FBC). An experimental campaign was carried out to study gaseous and particulate emissions and stable thermal regimes during the combustion of mixtures of coal with 30%$_w$ of lignin-rich residues varying bed temperature, excess air and fluidization velocity. A few experimental tests were carried out for comparison using only coal, a mixture of coal with 40%$_w$ of lignin-rich residues and a mixture of coal with 20%$_w$ of wood chips.

2. Experimental

2.1. Experimental apparatus and materials

Fig. 1 shows the picture and the schematic representation of the pilot-scale FBC with its ancillary equipment used for the experimental campaign of combustion of coal with lignin-rich residues. The AISI 310 stainless steel fluidization column had a circular section (370 mm ID) for almost all its height (5.05 m) whereas the upper part of freeboard was characterized by ID of 700 mm and height of 1.85 m (total height of 6.9 m). The lower section of the column was equipped with a windbox split into two concentric sections: the core and the annulus section corresponding to 30% and 70% of the fluidized column cross-section, respectively [24]. The distributor plate was equipped with 55 bubble caps. The fluidization column was fitted with several access ports for temperature, pressure, and gas concentration probes. Two cyclones, having medium and high efficiency, respectively, were used for flue gas de-dusting. A probe was installed at the exit of the second cyclone for gas sampling. The entire vessel was thermally insulated by a ceramic wool blanket in order to minimize heat losses and to ensure a safe

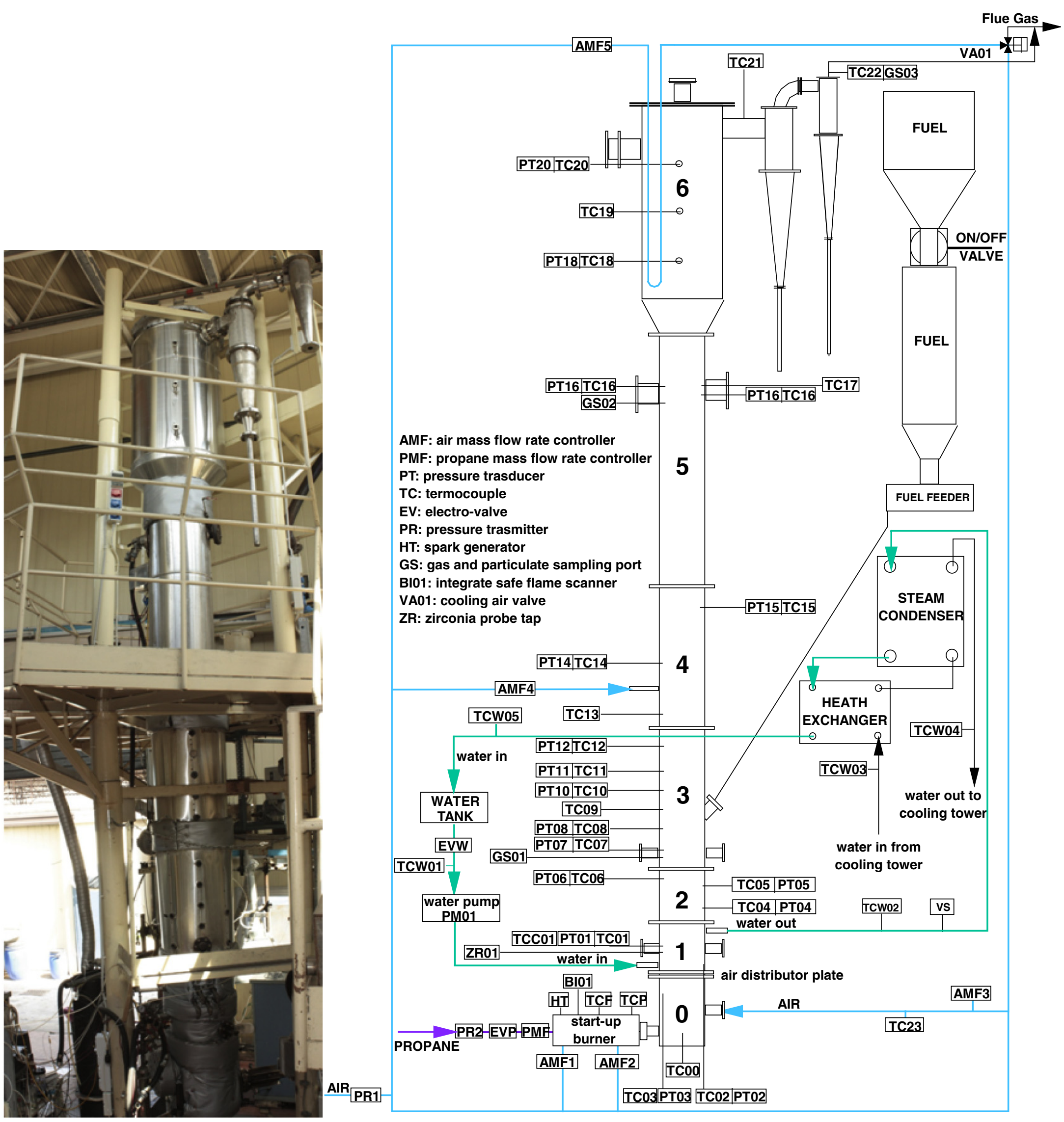

Fig. 1. The pilot-scale bubbling fluidized bed combustor.