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Soot abatement from biomass boilers by means of open-cell foams filters

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ABSTRACT

Currently, fossil fuels such as oil, coal and natural gas represent the main energy sources in the world, but it is well known that these sources of energy will deplete within the next years. So, due to increasing environmental concerns especially related with the use of these fossil fuels, new solutions to limit the greenhouse gas effect are continuously sought. Among the available alternative energy sources, including hydro, solar, wind etc. to mitigate greenhouse emissions, biomass is the only carbon-based sustainable option. However despite an environmentally friendly use of renewable energies, incomplete combustion of biomass can lead to the emission of environmental pollutants as well as substances which are hazardous to health. In comparison to gaseous and liquid fossil fuels, the emissions of particulate matter (PM, or soot) are higher, leading to concerns about the availability of cost-effective techniques to reduce emissions in biomass combustion plants: so filtration devices are mandatory. Actually different filtration systems are available; some have reached a technological maturity and a consequent wide diffusion while others, though promising, have not yet demonstrated adequate features to be considered competitive. In the first class there are electrostatic precipitators, sleeve filters and wet scrubbers, which are standard solutions in medium to large plants. In the second class there are ceramic filters which in principle can be applied both in new equipment and in retrofit of existing boilers, and may be easily scaled according to the size of the boiler. In our previous works we studied the use of catalytic ceramic wall flow filters as soot emission control devices of biomass-fired boilers and stoves. Starting from those results, in this work we investigated the use of a different kind of filters, the open-cell ceramic foams, characterized by a different porosity if compared to wall flow filters. The prepared filters were tested in a customised sampling line at the exhaust of a 30 kW pellets boiler, and regeneration was specifically obtained by a high-temperature electrical heater. PM concentration in the flue gas was monitored by means of a real-time continuous detector and a cascade impactor. The tests evidenced that the higher average pores diameter of the foams, compared to ceramic wall-flow filters, resulted in two main consequences, (i) lower pressure drop, and (ii) a filtration efficiency higher than 50%. These results are very important, in particular because the pressure drop never reached a critical value for the normal biomass boiler functioning: in this way this solution could be a feasible device for soot emissions control. Further studies are still running to investigate the deposition of a catalyst on the foams.

1. Introduction

Currently, fossil fuels such as oil, coal and natural gas represent the main energy sources in the world (approximately 80% of the total use of more than 400 EJ per year). However, it is well known that these sources of energy will be depleted within the next years [1]. Today biomass is seen as the most promising energy source to mitigate greenhouse gas emissions [2]. Despite an environmentally friendly use of renewable energies, incomplete combustion in biomass combustion systems can lead to the emission of environmental pollutants as well as substances which are hazardous to health. Besides particulate matter (PM, or soot), a wide variety of gaseous substances can also be emitted. Among those, polycyclic aromatic hydrocarbons (PAH) and several organic volatile and semi-volatile compounds (VOC) are present [3]. The optimisation of

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the combustion and the electronic control devices of the combustion process are primary measures that must be taken into account to reduce emission but, above all for small scale appliances, different factors limit the results which may be obtained and secondary measures may become necessary in order to respect stricter limits [4].

In particular among the different technologies for soot abatement, monolithic wall flow catalytic filters may represent an efficient solution, as they combine physical filtration processes for particles removal with catalytic oxidative reactions for their burning [5]. Moreover, such solution may be applied both in new equipment and for the retrofit of existing boilers and stoves, and may be easily scaled to their size. Other PM abatement techniques currently available are electrostatic precipitators (ESPs), fabric filters and wet scrubbers [6], [7]. ESPs are effective in reducing PM concentrations in gas streams and their efficiency depends on particle resistivity, thus it may change with the composition of the emitted particles, and on the fouling of the electrically charged surfaces. ESPs and fabric filters are standard solutions for big combustion plants, and their scale down to small appliances is not straightforward, because specific limitations, both technical and economical, related to the domestic users and environment must be taken into account. Nevertheless some ESPs are available also for small scale boilers, and their performance has been evaluated in some studies [8,9].

In our previous works, we investigated the use of catalytic wall-flow filters as soot control devices for soot emissions from biomass boilers [10,11]. The results evidenced that the silicon carbide filters in "Wall-Flow" configuration, although characterized by a filtration efficiency higher than 90%, typical for these devices used at the exhaust of Diesel engines [12], showed excessively high pressure drop for the specific application. So our researches focused on the study of different filters, the open-cell ceramic foams, characterized by a filtration mechanism named "deep bed filtration". Fig. 1 illustrates the open-cell structures, evidencing that they have solid edges and open faces, allowing fluid flow from one cell to another, and highlighted three components: (i) struts, which are composed of solid ceramic material; (ii) cells, which are approximately spherical voids enclosed by struts; and (iii) windows, which are openings connecting the cells.

The open structure is sponge-like, with typical pore densities of 10–100 PPI (pores per inch), creating an interconnecting porosity in the range of 75%–90% or even higher. Consequently, they have low resistance to fluid flow and considerable turbulence is generated by the tortuous flow paths: so the soot particles have high probability to adhere to the ceramic surface at each collision [13].

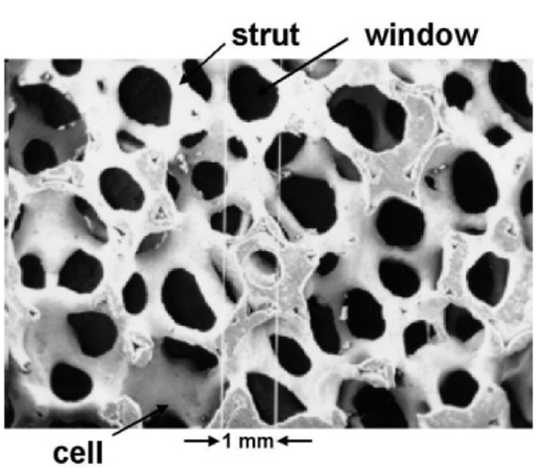

Fig. 1. Open-cell foam structure.

In this work we investigated the behaviour in terms of pressure drop, filtration efficiency and regeneability of filters prepared starting from two open-cell ceramic foams, characterized by 10 and 65 ppi, and tested at the exhaust of a 30 kW pellets boiler in ENEA laboratories. The tests highlighted that the ceramic foams, if compared with the wall flow filters, have lower pressure drop and a filtration efficiency of about 60%. In particular the foams were properly assembled in order to realize a radial flow of the exhaust gas, just in order to decrease the pressure drop while increasing the filtering surface. In this way the pressure drop never reached a critical value for the normal biomass boiler operation, so allowing the feasibility of this solution as a cheaper device for soot emissions control than traditional alternatives employed in biomass combustion systems.

2. Materials and methods

2.1. Open-cell foams

The filters were prepared starting from commercial SEDEX SiC Ceramic Foams, made in Silicon Carbide (SiC) and alumina, provided by Foseco International Limited with two different porosity, 10 and 65 ppi. The prepared filters, shown in Fig. 2, were assembled in order to realize a radial flow of the exhaust gas, which enters the lateral surface and leaves the filter from the central hole.

As evident from Fig. 2, the filters were properly shaped as cylinders, with nominal diameter 30 mm, length 125 mm and central hole diameter of 10 mm; the terminal part with the central hole was wrapped in a heat expanding intumescent ceramic-mat, i.e. Interam by 3M, in order to be enclosed in a filter housing placed in the sampling line at the exhaust of the biomass boiler in ENEA laboratories.

2.2. Materials characterization

The prepared filters were characterized by Scanning Electron Microscopy (SEM mod. LEO 420 V2.04, ASSING), and Energy Dispersive Spectroscopy (EDX mod. INCA Energy 350, Oxford Instruments), before and after the tests. Preliminary activities also included the characterization in terms of gaseous and solid compositions of the exhaust gases emitted by the biomass boiler used in the experimental tests. In particular a SDT Q600 thermogravimetric analyser (TGA), from TA Instruments, was used to characterize the soot composition. The sample was heated in the TGA, according to a heating program, in which the temperature, time, sample weight, and the other variables were continuously recorded throughout the whole program.

2.3. Test facility and operating conditions

The tests were performed at the TH.EX.A.S. (THermal EXperimental Area of Saluggia) facilities the ENEA. The exhaust gases were produced by a biomass boiler KWB Multifire USV with a rated power of 30 kW, fuelled with pellet stored in a tank with a capacity of about 1 m^3.

The filter was placed in a customised 1″ ¼ stainless steel housing located in the derivation column of the exhaust duct, from which the gases were aspirated by means of a Zambelli ZB1 volumetric pump. Upstream and downstream of the filter holder, two silicon heating bands with integrated temperature control were wrapped around the line in order to keep the temperature close to 160 °C, so avoiding any condensation of the flue gas.

Filters regeneration was achieved by a Watlow 900 W (Tmax = 750 °C) electric heater with 42.5 mm inner diameter and