

Effects of the Quality of the Biomass on Combustion Emissions of Stoves and Small Boilers

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Abstract

Particulate matter is one of the most important indicators of air quality and has also a significant impact on human health. The negative contribution of small biomass stoves on air quality is so evident that some Italian regional administrations had to adopt urgent regulations. In this work, the relationship between emission quality and biomass characteristics related to the combustion of biomasses with different properties was assessed in a 13 kW pellet stove and a 150 kW wood chip boiler. Test combustion using biomass with high moisture and ash content produced higher particulate concentrations. The values relevant to the pellet stove ranged from 110 to 360 mg/MJ utilizing different types of biofuel. Also the biomass stove fed with low quality wood chip increased the dust emissions. These data highlight the current limitations of biomass burning in small plants and should encourage manufactures to improve the technology level of their heating devices. Anyway, considering the possibility to supply biomasses from agriculture and agro-industry, the development of technical standards appears one of the most interesting ways of approaching these problems, allowing a comparison between biomass producers, manufacturers devices and monitoring bodies.

Keywords: air quality, particulate matter, biomass quality

Introduction

The increase of fuels prices has encouraged the development of alternative energy sources especially at household and rural level. However, biofuels are generally more difficult to burn respect the standard fossil fuels, due to incorrect and/or inconstant combustion occurring in stoves and small boilers. As a consequence, the exhausts could contain significant amount of hazardous substances, like particulate matter (PM) and partially oxidized organic compounds (Nikolaou, 1984; Swartz, 1995; Mccrillis, 1992).

Physical dimension and size distribution of fine parts of the biofuel and the technical features of stoves and boilers are the most important parameters that influence the quantity and the characteristics of the pollutants. PM could originate from inadequate mixing between combustion air and biofuel, from high biomass' ash content, low combustion temperatures and short residence times of the combustion gases at higher temperatures. These are some of the most important conditions causing the increase of PM concentration in the exhausts (Van Loo, 2008).

According to a world global estimate, 50% of households use biofuels for heating and cooking (WHO, 1992). In Italy about 20% of households burns wood more than 4 times a year in more than 5 million domestic wood stoves (APAT, 2008) and the wood consumption in small devices is estimated in 3-6 millions of t/year. In some Italian regions the PM from biomass combustion is considered a serious problem and the Authorities are introducing some drastic restrictions like the ban of biofuels in some locations.

Considering these problems and also the need to increase the production of renewable heat, it is urgent to find new solutions for the control of the quality of the biofuel and of the emissions of stoves and small boilers. The most critical parameter is the PM and in this work, developed by the Biomass Laboratory of the Polytechnic University of Marche, are given the results of some combustion tests carried out with a stove, a boiler and different grades of solid biofuels.

Materials and methods

Combustion tests were conducted in two different heating systems: a 13 kWt pellet stove and a 150 kWt woodchip boiler. Each heating system has been fed with different types of biomass. In the case of the stove were used two types of pellets with different ash content. In the case of the boiler, combustion tests were carried out with two types of wood chips (A and B) and blends of wood chips with grape residues.

Table 1 shows more in detail the combustion test planning and relative information.

Table 1. Type of heating systems, biomass and power used during tests.

DEVICES	BIOMASS	OPERATING CONDITIONS
Domestic stove	Pellet A	P2 and P4
Domestic stove	Pellet B	P2 and P4
Boiler	Wood chip A	90 kWt
Boiler	Wood chip B	90 kWt
Boiler	Wood chip + Grape residues	90 kWt

In the case of the stove, samples were collected at two different loads: 5.4 (P2) and 9.4 kWt (P4). In the case of boiler a setting of 90-105 kWt was chosen.

Analytical laboratory methods specifically developed for solid biomass were applied on each biofuel. In particular, it was considered to the purpose of this study to measure the moisture content, the ash content and the calorific value according to the technical standards defined by CEN/TC 335 on solid biomass (table 2).

Table 2. Technical normative used for biomass characterization.

TECHNICAL NORMATIVE	DESCRIPTION
CEN/TS 14774:2004	Solid biofuels - Methods for the determination of moisture content - Oven dry method
CEN/TS 14775:2004	Solid biofuels - Method for the determination of ash content
CEN/TS 14778-1:2005	Solid biofuels - Sampling - Part 1: Methods for sampling
CEN/TS 14780:2005	Solid biofuels - Methods for sample preparation
CEN/TS 14918:2005	Solid Biofuels - Method for the determination of calorific value

For the determination of the PM was adopted the method described in the standard UNI EN 13284-1. The gas sampling system was based on an isokinetic probe (MiniStack Tecora) that has an internal filter to capture the PM from warm exhausts using an AISI 316 probe.

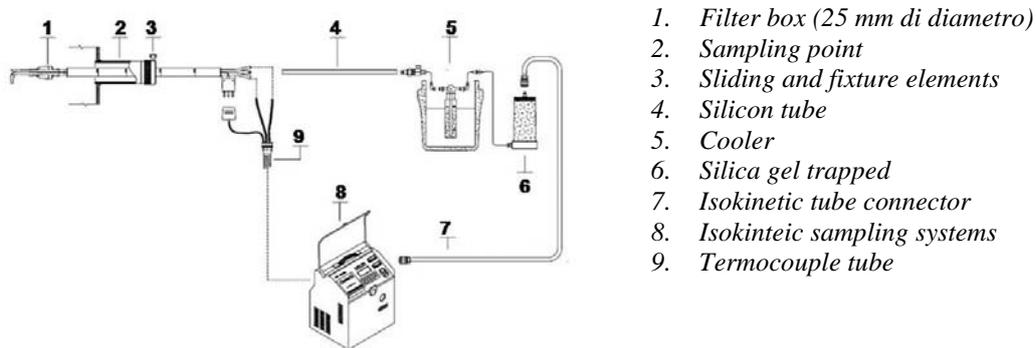


Figure 1. Apparatus for the determination of particulate matter.



Figure 2. Ministack probe on boiler chimney (left) and pellet stove (right).

The dust emissions values were calculated comparing the mass of dust filtered with the volume sampled. Data were normalized according the above mentioned standard and expressed also in relation to the energy produced.

Results

Table 2 summarizes the results of the biofuels characterization. It is possible to observe the strong difference in terms of ash content between the two types of pellets used in the domestic stove. More in particular, the first type is considered within the quality class “A” according to UNI TS 11263, while the pellet B would fall into class “C”. There are also strong differences between the characteristics of the biomass used in the tests on the boiler. Besides the difference in terms of ash content, there are strong differences in terms of moisture content.

Table 2. Characteristics of the biomasses used during the test combustions.

		Pellet A	Pellet B	Wood chip A	Wood chip B	Blend
Moisture content	(% _{ar})	8.2	8.3	25.5	47.2	38
Ash content	(% _{dm})	0.5	2.4	1.7	2.9	4.1
Net calorific value	(MJ/kg _{ar})	16.9	16.2	13.4	12	10.7

Note: ar = as received; dm = dry matter.

The results of combustion emission test in the case of pellet stove, are shown in table 3 and figure 4. It is interesting to observe that the values are related to the ash content of biofuel and also to load of the stove. Higher is the pellet quality, lower are the values of PM (mg/Nm³).

Table 3. Results of test combustion in pellet stove.

Pellet	Ash content (%)	Operative conditions	PM (mg/Nm³)	PM (mg/MJ)
A	0.5	P2	93.4	141.5
A	0.5	P4	142.0	108.4
B	2.4	P2	97.5	169.3
B	2.4	P4	243.0	356.4

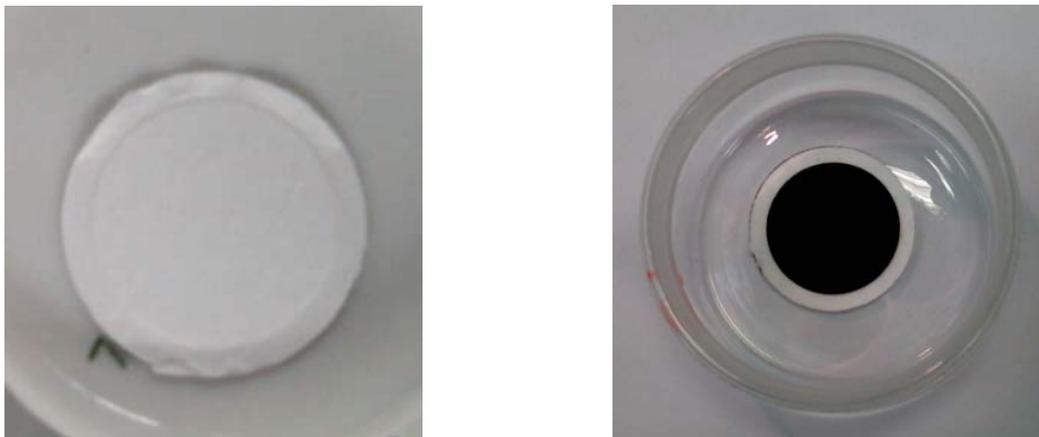


Figure 3. Particulate filter before (left) and after (right) test combustion.

Figure 3 shows the filter before and after the test. In this case, the black color of the filter indicates the carbonaceous organic nature of the particulate.

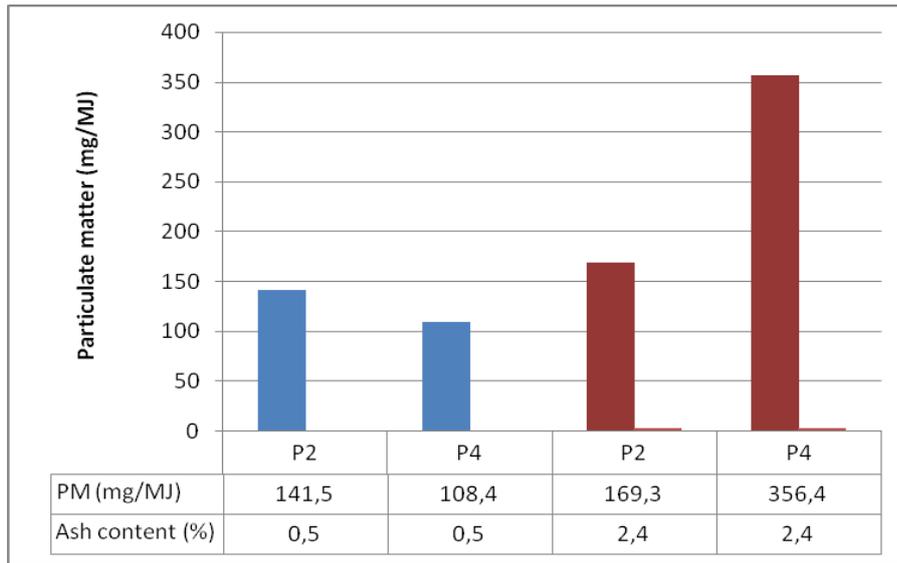


Figure 4. PM level for different biomasses and combustion conditions in the pellet stove.

The quality of biomass has a significant influence even in the case of combustion in the boiler. Test results with different types of biofuels are shown in figure 5, which highlights differences in PM (mg/Nm^3) that are very high even using the same type of biomass (wood chip), but with different characteristics (type A and B). In this case the moisture content is the most important parameter. The quality of the emissions significantly reduced in the case of blend that, besides higher moisture content, presents also an higher ash content of the wood chips.

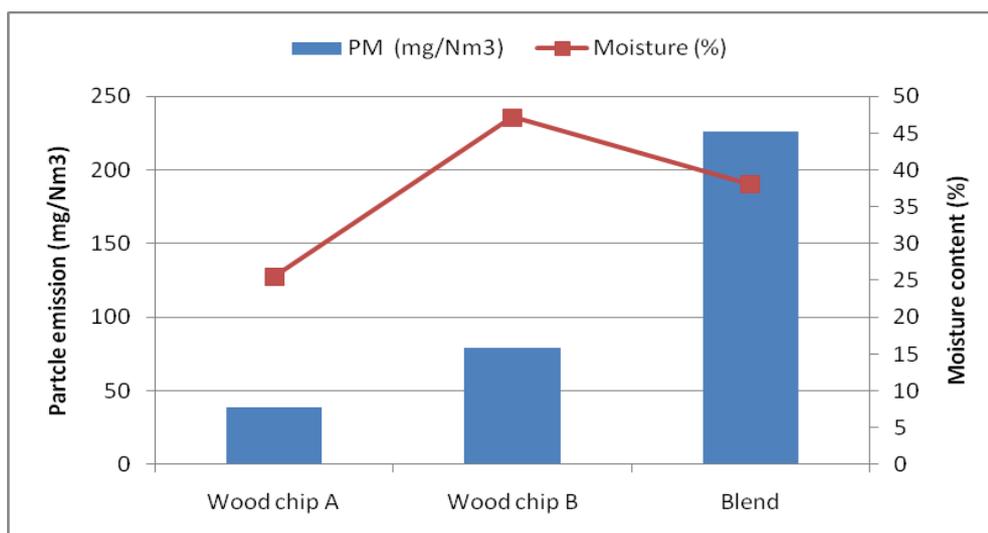


Figure 5. PM level for different biomasses in the heating boiler.

Conclusions

Small heating devices based on the combustion of solid biomass may originate wide variations in terms of quality of gaseous emissions. Indeed, the biofuels with high values of moisture and ash content increase the mass of pollutants.

In the case of wood pellets, that are considered as the best biofuel in the field of the solid biomasses, the variation of PM can range from just over 90 mg/Nm³ to 240 mg/Nm³ depending on the ash content. The difference between the best and worst measure increases if the values are referred to the energy produced. In this case, the values range from about 110 to 360 mg/MJ.

Similarly, referring to the boiler test, the combustion quality is affected by the moisture content of biomass. Increasing the moisture content from 25 to 45% the value of PM is doubled. The addition of a problematic fuel like grape residues (30% in mass) leads to over 200 mg/Nm³ of particulate (above the Italian law limit).

In conclusion, the control of the PM emissions require some actions:

- it is necessary to request the user to use quality biofuels especially in terms of ash content in the case of pellets and at least adequate moisture content for wood chips;
- verify that the compliance with the biomass manufacturer's specifications ensure a good quality level of emissions.

Taking into account that poor quality biomasses from agriculture and agro-industry are more abundant, the development of appropriate technical standards appears one of the most interesting ways to approach these problems allowing a comparison between biomass producers, manufacturers devices and monitoring bodies.

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