CHEMICAL ENGINEERING TRANSACTIONS

VOL. 37, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Katharina Kohse- Höinghaus

ISBN 978-88-95608-28-0; **ISSN** 2283-9216

Reduction of PM Emissions from Biomass Combustion Appliances: Evaluation of Efficiency of Electrostatic Precipitators

Gabriele Migliavacca[a] *, Carmen Morreale[a], Francesca Hugony[a], Ivan Tombolato[b], Giordano Pession[b]

[a] INNOVHUB- Stazione Sperimentale per i combustibili, V.le de Gasperi 3, 20097 San Donato Milanese, Italy.
[b] Agenzia Regionale per la Protezione dell'Ambiente della Valle d'Aosta, Regione Grande Charrière 44, 11020, Saint Christophe (AO)
migliavacca@mi.camcom.it

Particulate Matter (PM) emissions from small scale appliances burning wood fuels used for domestic heating is one of the major environmental issues in many European areas. Biomass combustion leads to the presence of high concentrations of PM10 measured in ambient air, especially during the winter season and in those areas where wood stoves and fireplaces are the main heating systems. In this study the efficiency of PM abatement of small scale electrostatic precipitator (ESP) are measured and compared for different appliances. In particular two different commercial systems specifically developed for domestic stoves have been tested in connection with different kinds of appliances; the two devices differ from their electrode length. Particle emissions were measured upstream and downstream of the ESPs to evaluate the efficiency of the devices. Both the devices have been used in connection with an 8 kW pellet stove and a 25 kW pellet boiler; the ESP with shorter electrode has been tested also with an advanced wood stove.
Beech wood logs and a low quality pellet have been used in the tests. The gas composition of the fumes have been determined at the exit of the appliances in order to estimate the combustion performances of the stoves and boiler, in particular the amount of oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), nonmethanic gas phase hydrocarbon (VOC-NMet) have been measured.
ESPs are specifically devoted to reduce particulate matter concentration in gas streams and their efficiency is dependant on particle resistivity and then it may change with the composition of the particle emitted. Another factor that can affect the efficiency of ESP is the level of fouling of the active surfaces and hence the aging of the precipitator may strongly reduce the abatement. These effects have been studied in the present work by measuring the mass concentration of total particulate matter and the total number concentration (TNC) of nanoparticles (with an aerodynamic diameter between 5.6 and 560 nm) in the different appliances with different fuels and under different operating conditions; in particular aging tests have been carried out to simulate the typical usage in a domestic installation. The test results show a good rate of abatement both on PM and nanoparticles for both the ESPs and in all conditions when the filters are clean, while a progressive reduction in the efficiency is observed after a long term use mainly in the smaller device where the active surfaces are lower.

1. Introduction

The use of renewable energy sources is constantly increasing in most European countries because of the general policy of reduction of the emissions of greenhouse gases. Biomasses play a very important role in those applications where the energy output has to be strictly under control directly by the users, like in domestic heating. Wood fuels in particular are commonly used in conventional fireplaces and stoves, but also in modern appliances like pellet stoves and boilers which grant higher efficiency and lower emissions. The high level of pollution associated with biomass combustion (Boman et al., 2011) (Pettersson et al., 2011)

(Rodin et al. 2009) is one of the main factors limiting the diffusion of biomass heating in many European areas, as in some Italian Regions, where major environmental issues exist. It has been demonstrated (Caserini et al., 2007) that the local air quality may be negatively affected by an intense use of wood appliances, mainly on the PM concentrations.
The optimization of the combustion process is one of the means used to reduce the pollutant emission from any combustion appliance, but in the case of small scale biomass stoves and boilers it is generally not enough to get the desired values. Adoption of abatement technologies, conventionally used in combustion plants, is a possible way to obtain a further reduction of pollution. But the scale down of these technologies to small appliances is a complex and not straightforward task, which requires a proper adaption of the existing techniques and have to take into account the specific limitations related to the domestic environment. First of all abatement device dimensions should be small enough to be lodged in a chimney installed in a house, then it should be able to work without any particular facility not available in a domestic ambient, like compressed air or steam, or high voltage current. Also moving parts should be avoided to prevent a frequent maintenance. Another important constrain is represented by the cost of any possible abatement device, which must be proportionally lower than the price of the appliance itself.
Another important aspect in the development of an abatement device consists in its applicability to different types of appliances working in different ways (manual or automatic feed, different fuels, ...) producing fumes at different temperature and different oxygen content, which may change during the combustion cycle. Any efficient device should be able to work under each possible operating condition of the appliance.
The main types of abatement technologies adapted to small scale wood appliances include monolithic catalytic filters for the oxidation of unburnt species, wet scrubbers and electrostatic precipitators (ESP) for PM. The ESP seems to be the most efficient method for PM abatement reaching the 50-85% of dust precipitation (Mandl et al., 2012). The abatement efficiency strictly depends on fuel types and flue gas velocity (Bologa et al., 2010).

2. Materials and Methods

Three kind of heating systems have been selected to study the efficiency of PM abatement for ESP devices:

- a pellet stove (PS) with a thermal power between 2.6-9 kW and efficiency of 91% provided of a feeding container with capacity of 18 kg, the combustion chamber feeding is automatic by means of a cochlea which operates periodically. The stove is equipped with a smoke extraction fan that allows the simultaneous intake of air for the combustion. The stove, during the tests, has been set at a power of 8 kW;
- a pellet boiler (B25) (thermal power of 7.3-25 kW and efficiency of 93%) equipped with an inertial accumulator with a heat exchanger serpentine. This boiler is provided of an internal fuel stock container of 60 kg and an automatic refuelling system. By means of a lambda probe the boiler controls constantly the oxygen in the flue gas and sets the amount of pellet and air for combustion optimization. The boiler has been set at a power of 18 kW;
- a manual wood stove (WS) with a nominal power of 8 kW, efficiency of 75% and primary and secondary air manually controlled.

The manual wood stove has been fed with beech wood logs, the automatic stove and boiler have been tested with a low-quality pellet. The characteristics of the fuels are reported in table 1.

Table 1: fuels composition

Fuel		pellet	beech wood
LHV	kJ/kg	18568	17606
C	% m/m	47	43.5
H	% m/m	6.42	6.41
S	% m/m	1.00E-02	1.20E-04
N	% m/m	0.19	0.33
Cl	% m/m	6.00E-03	1.50E-02
H_2O	% m/m	7.4	9.65
ashes	% m/m	0.9	0.58

Two kinds of electrostatic precipitators (ESP) have been selected: one provided with a long electrode and the other with a short one as described below . Both ESPs can be installed on small scale household appliances burning wood fuels and are suitable for laboratory test rig; they are commercially quite popular or their purchase is encouraged by regional or national government's contributions.
A test rig consisting of a pipeline 10 m long from the outlet of the appliances to the final sampling port (see Figure 1) and having 4 right angle elbows, has been used in this work; a sucking fun at the top of the pipe, provided with a power control device, allows to get the desired draught, independently from the design of the pipeline.
ESP devices have been installed in the vertical descending branch of the pipeline, with sampling points upstream and downstream of this section; the short ESP occupies only a short portion of this duct (because it has very short electrode only 30 cm long), while the long one spans for nearly all its length, with its 1.60m electrode length. A particularly important difference between the two installations consists in their sealing: the short ESP is perfectly sealed, while the long one, designed to be installed at the top of the chimney, allows the ambient air to enter the tube and mix the flue gases. No automatic cleaning systems are designed for the two ESP tested.

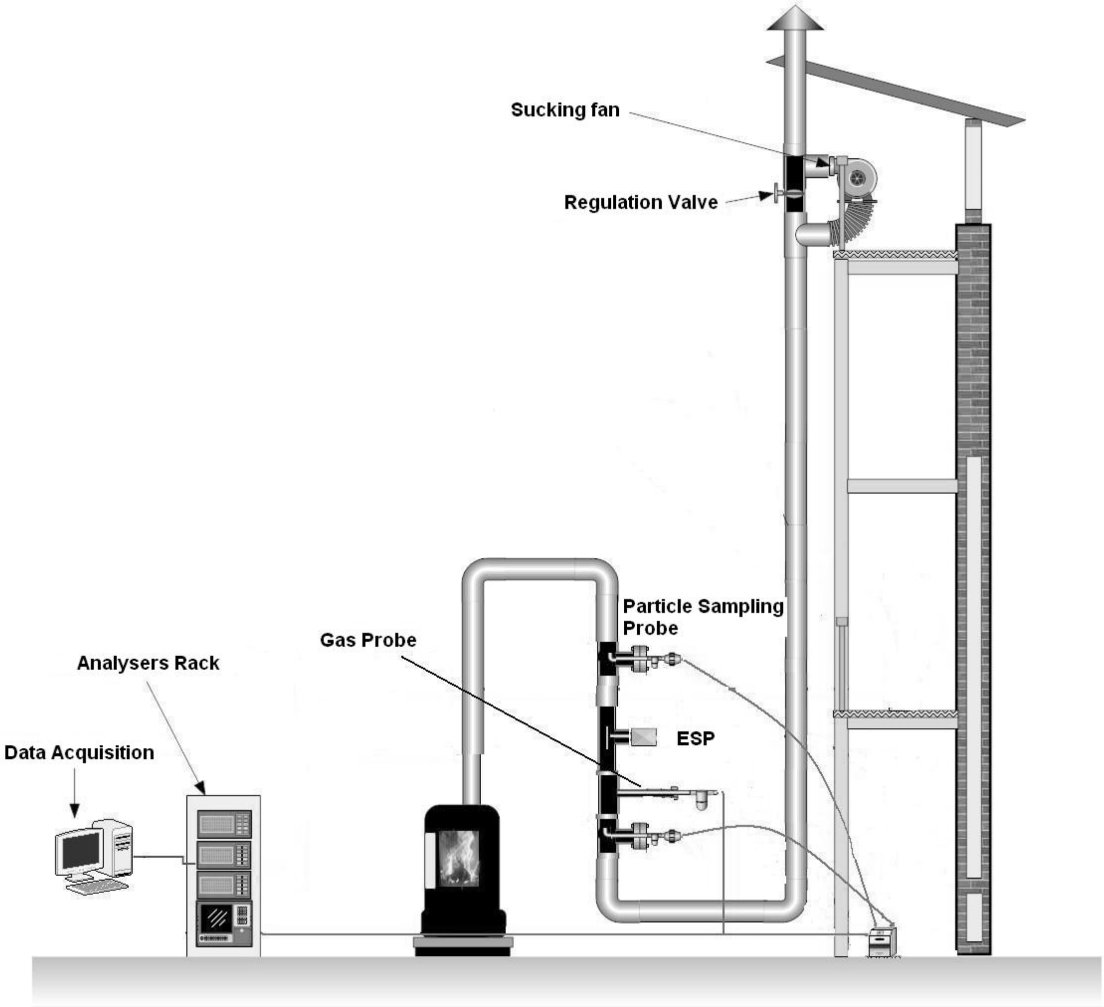

Figure 1 Experimental test rig

Particulate matter has been determined gravimetrically, while a TSI Fast Mobility Particle Sizer (FMPS) has been used to measure the number of nanoparticles in the range 5.6-560 nm, downstream of the ESP, after a controlled dilution of the fumes (about 1/30) (Migliavacca et al., 2010). Combustion characteristics are monitored through continuous analysers measuring O_2, CO, CO_2 and Non methane organic volatile compounds (VOC-NMet).

To investigate the different ESP's characteristics, aging tests have been performed for both devices. The aging tests consist in measuring PM concentration and nanoparticles TNC after 5 days and after 10 days of ESP working.

3. Results and discussion

Representative parameters for the three appliances are reported in Table 2, where the average emissions, in absence of any abatement device, are summarized. Emission concentrations are reported at 13% of oxygen.
Unfortunately the scheduled established for the aging tests could not have been respected for all the appliances due to the difficulties met in tests conduction. Table 3 shows the tests carried out in this work, including the aging tests. The short ESP has been tested on all the appliances, but only with the pellet stove and the boiler it has been possible to carry out the aging tests, due to the extreme fouling occurring with the wood stove, and only with the pellet boiler it has been possible to perform a 10 days aging test. The long ESP has been tested only with the automatic appliances and the boiler only was used in the aging tests. The following table shows the average values of the exhausts properties which were registered during preliminary tests on biomass boiler.

Table 2: Combustion characteristics of the tested appliances.

Appliance	Fuel consumption	O_2	CO	COV NMet	TSP	TNC
	Kg/h	%	mg/Nm^3	mg/Nm^3	mg/Nm^3	$\#/Nm^3$
WS	3.4	11.5	5848.8	341.5	99.4	8.7E+13
PS	2.1	11.8	175,9	5.9	67.2	3.1E+13
B25	3.5	12.6	512.4	3.6	24.2	1.2E+14

Table 3: Scheme of successful tests with ESPs also during the aging tests

Usage	1st day		5th day		10th day
ESP	TSP	TNC	TSP	TNC	TSP
Short ESP	WS, PS, B25	WS, PS, B25	PS, B25	B25	B25
Long ESP	PS, B25	PS, B25	B25	B25	

In Figure 2 the abatement efficiencies of PM, measured in this work, are reported and compared. It is possible to observe the progressive reduction of the ESP efficiency with ESP continuous usage.

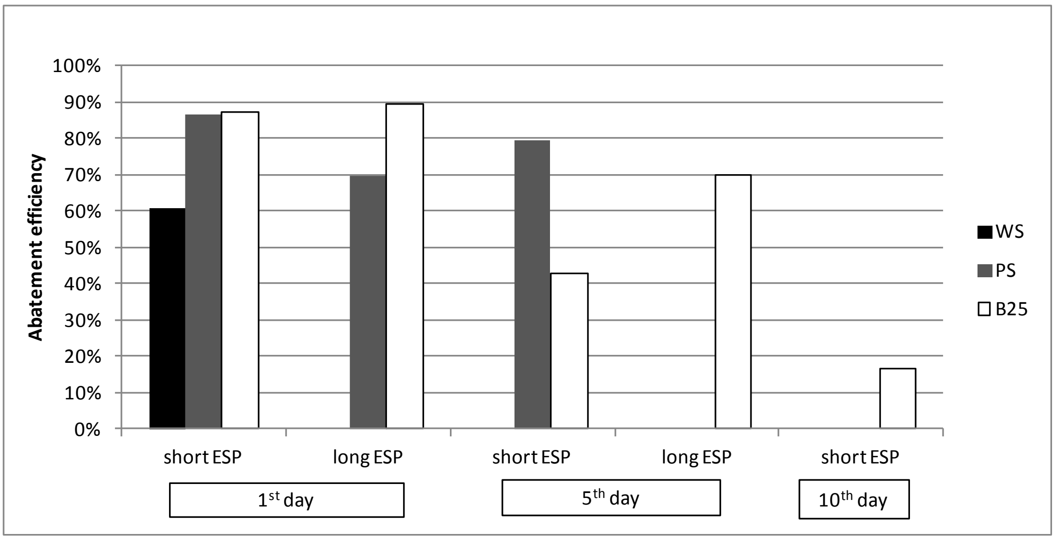

Figure 2 PM abatement systems efficiencies for the three appliances also during aging tests.

In Figure 3 the Total Number Concentration (TNC) of nanoparticles is reported; no estimation of the abatement efficiency is possible in this case, because simultaneous measurements of TNC upstream and downstream of the ESPs haven't been performed, but a comparison with the emissions without any ESP (tq data) can be useful to understand the behaviour of each device.

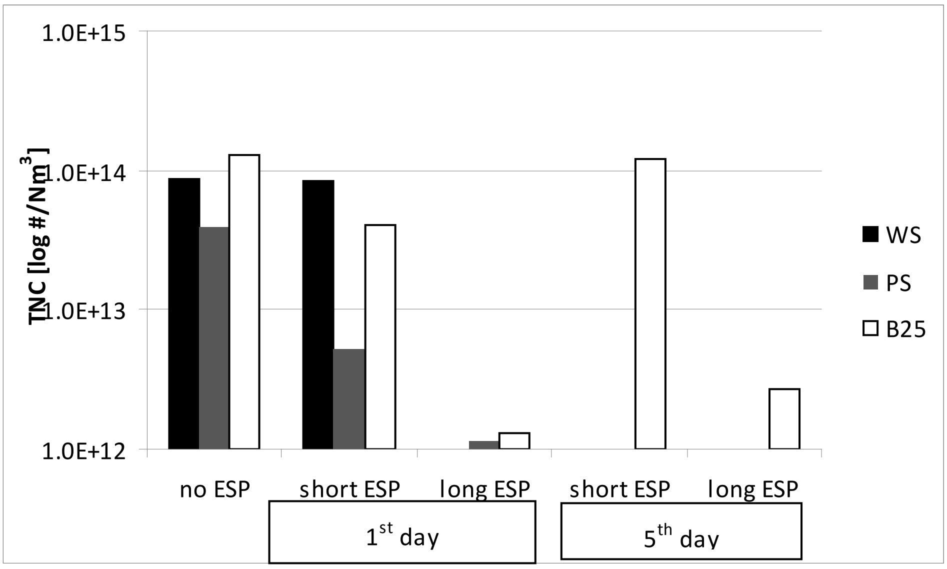

Figure 3 TNC Emissions expressed in number per Nm^3 at 13% of O_2 (#/Nm3) for the different appliances with the two ESPs

Similarly to PM abatement, long ESP shows good efficiency in nanoparticle abatement, also at the end of the aging period, while for short ESP aging, in particular in WS, reduces significantly its efficiency.

4. Conclusions

The use of renewable energy source and in particular wood biomass, is increasing in most European countries, as in some Italian Regions. The high level of pollution associated with biomass combustion, in particular PM concentration, is an aspect that has the attention of national and regional environmental policies. Objective of this study was the experimentation of two filtration devices installed on biomass small scale domestic equipments in order to assess their efficiency of PM abatement. In particular two different

electrostatic precipitators (ESP), specifically developed for domestic stoves, have been tested in connection with different kinds of appliances.
The two ESPs selected for this study are not provided with an automatic cleaning system and they don't have any particular control system, just an on-off switching command. This is very suitable for end-users which are usually not dealt with sophisticate controlling devices. The abatement systems tested are easily found in the market.
The two ESPs have been studied by measuring the concentration of total particulate matter and nanoparticles in the different appliances with different fuels and under different operating conditions; in particular aging tests have been carried out to simulate the typical usage in a domestic installation.

Many problems occurred during the installation of the devices in the laboratory test rig. In particular with the long electrode system which is very long and in its usual installation is located at the end of the chimney, while in the laboratory, to allow PM measurement upstream and downstream, has been positioned in the middle of the gas duct. However the obtained results allow to make some considerations:

- Both ESPs have good abatement efficiency, in particular in those appliances where PM emissions are lower (pellet boiler and pellet stove);
- The abatement systems good performances are shown for PM and nanoparticles emissions;
- During aging tests, abatement efficiency rapidly decrease after a not so long operation, mainly in the appliances with higher PM emissions values (logwood stove) probably due to the reduction of active surfaces, in particular in the case of the smaller ESP where active surfaces are lower and reduced by fouling.

For all the reasons stated above a comparison of the two tested devices is difficult, the long ESP would seem to provide better performance and a high reliability, probably due to the much greater length of the electrode, while short electrode ESP is more simple to manage.
However, other tests would be useful to study the behaviour of these devices on longer term periods and other operating conditions (e.g. transitory).

References

Bologa, A., Paur H.R., Ulbricht T.,Woletz K., 2010, Particle Emissions from Small Scale Wood Combustion Devices and their Control by Electrostatic Precipitation, Chemical Engineering Transactions, 22, 119-124, DOI: 10.3303/CET1022019

Boman, C., Pettersson, E., Westerholm, R., Boström, D., & Nordin, A.,2011, Stove performance and emission characteristics in residential wood log and pellet combustion, part 1: Pellet stoves. Energy and Fuels, 25(1),307-314

Caserini S., Fraccaroli A., Monguzzi A.M., Moretti M., Angelino E., Leonardi A., De Lauretis R., Zanella V. 2007) New insight into the role of wood combustion as key PM source in Italy and in Lombardy region. 16th Annual International Emissions Inventory Conference "Emission Inventories: Integration, Analysis, and Communications" Raleigh, North Carolina, May 14 – 17

Mandl C., Obernberger I., Biedermann F., 2012, State-of-the-art and assessment of filter technologies for residential biomass combustion systems, 20th European Biomass Conference and Exhibition, 18-22 June, Milan, Italy ,732-738.

Migliavacca G., Marengo S., Hugony F., Morreale C., Maggioni A., Bertagna S., 2010, Ultrafine particles from biomass combustion in small scale heating systems, 18th European Biomass Conference and Exhibition, 3-7 May, Lyon, France, 1321-1326Pettersson, E., Boman, C., Westerholm, R., Boström, D., & Nordin, A.,2011, Stove performance and emission characteristics in residential wood log and pellet combustion, part 2: Wood stove. Energy and Fuels, 25(1),315-323

Roden C., Bonda T., Conwayb S, Osorto Pinelc A., MacCartyd N., Stilld D., 2009, Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves, 43(6),1170-1181