

SET-UP OF A NEW SAMPLING METHOD TO MEASURE CONDENSABLE PM FROM RESIDENTIAL SOLID BIOMASS HEATING GENERATORS

F. Hugony*, C. Morreale**, G. Migliavacca**, S. Tamburrino*, M. Gualtieri*

*ENEA, National Agency for New Technologies, Energy and Sustainable Development, Viale Piceno 60, 20138 Milan, Italy;

** Innovhub Stazioni Sperimentali per l'Industria, Fuels Area, Via Galilei 1, 20097 San Donato Milanese (MI), Italy

ABSTRACT: The paper aims to describe the setting up of a new sampling method for the collection of condensable PM from small heating appliances fed with wood fuels. The method is based on dilution mechanism, which takes part in a reaction chamber. The paper describes the evolution of the dilution chamber design to join the final aim to collect condensed PM. The modification of the component was decided according to three experimental tests campaigns, which make possible to verify the good operating conditions of the built sampling train prototype and to compare the PM measured with the new method with PM collected by a reference sampling method for primary PM collection. Innovhub and ENEA are working to the new dilution system to measure condensable PM in the framework of IMPRESS II, a project funded by EMPIR initiative.

Keywords: measurement, emissions, solid biofuel

1 INTRODUCTION

Despite improvements, air pollution in Europe is still responsible for more than 400 000 premature deaths each year [1]; additional measures are therefore needed if European Countries want to reach air pollution levels that do not lead to undesired effects on human health and the environment. The EU environmental strategy identifies the control of emissions at source as a mean achieve these aims. Accurate measurement of emissions of pollutants is vital in enabling action to control and reduce air pollution in order to protect European citizens and the environment.

Biomass burning (BB), mainly when associated to small scale domestic appliances, is recognized to be responsible for huge outdoor pollution. In addition to a high level of particulate matter (PM), this kind of combustion processes produce Total Organic Compounds (TOC), with a high content of various toxic and carcinogenic compounds such as Polycyclic Aromatic Hydrocarbons, PAH and dioxins [2; 3].

TOC are divided in very volatile organic compounds (VVOC), volatile (VOC) and semi volatile organic compounds (SVOC), depending on their boiling points. These molecules can be found in the vapour phase at flue gas temperature in the stack but can subsequently form additional particles or droplets by nucleation and condensation [4]. This process forms what is normally defined as condensable PM.

In April 2015, as part of the EU Ecodesign Directive 2009/125/EC, two new regulations were published for local space heaters and heating boilers fed with solid biomass fuels. These regulations require thresholds of emissions for PM, CO, organic gaseous carbon (OGC) and NO_x and energy efficiency. Currently, no harmonized standard measurement methods exist for the determination of PM emissions produced by heating systems fed with biomass solid fuels. Thus, in order to achieve implementation of these regulations, which revision process will begin in the summer of 2019, it is important to develop validated and representative methods for the measurement of air pollutant emissions from BB.

Emissions from wood burning are an important source of directly emitted PM (primary PM), but also of secondary organic aerosols (SOA) and carcinogenic substances such as polycyclic aromatic hydrocarbons (PAHs).

These emissions come from households, and

commercial and institutional facilities. However, there are currently no harmonized standards for the measurement of in-stack PM, OGC and NO_x that can be applied to solid biomass local space heaters and to heating boilers.

The existing EU national standards are divided into two different strands. One, aiming at collecting primary PM directly from the chimney, by means of a probe connected to a filter holder heated around 70°C; the second one collecting primary and condensable PM from diluted exhaust gases with ambient air by means of a dilution tunnel. In this case, the filter holder is not heated and the organic gaseous compounds may condensate onto primary solid PM or, through coagulation and nucleation mechanisms form condensed PM.

Measuring also condensed PM allows obtaining a characterization of the tested heating generator, based on the potential impact of the appliance on ambient air. Adopting such sampling method allow the development of technological solutions for the heating generators in the direction of low organic matter emissions.

Unfortunately, the dilution tunnel method has a number of disadvantages mainly due to the non-automatic system operating conditions, which makes difficult the replicability of the operating parameters among different tests. For example, the residence time between exhaust gases and dilution air is not controlled and it depends on different appliances and ambient conditions. The characteristics of dilution air (temperature, humidity, PM contents, etc...) as well, are strictly dependent on external uncontrolled variables, such as, the season and geographical lab location.

To overcome these obstacles and thanks to the experiences with CTM039 US-EPA method, Innovhub and ENEA in 2014 began to design a new condensable PM sampling method based on the dilution of exhaust gases. Once the system was designed and a prototype was built, thanks to the EMPIR initiative, the two research centers were able to test and make the implementation of the new method.

This paper will describe the main tasks of the new method and the tests performed at Innovhub lab, to improve the dilution chamber, which is the core of the sampling system.

2 MATERIAL AND METHOD

2.1 Description of the new sampling system

The dilution system has been designed to operate

with small biomass appliances, like stoves, fireplaces and domestic boilers, fed with wood fuel (wood logs, pellets, briquettes and wood chips).

The system is composed by five parts:

- a compressor of ambient air;
- a control unit, containing the pump and connecting the other 4 devices;
- a flow regulation unit, to collect the exhaust gases from the chimney with the desired dilution ratio;
- a dilution cabin, at a controlled temperature around 35-40°C, containing the dilution chamber, the thermocouple measuring the diluted gases temperature, the dilution air heater;
- a laptop connected via bluetooth, with the control software.

The control unit coupled with the flow regulation unit allows the regulation of the flows: the exhaust gases sampling rate and the dilution ratio. The dilution cabin contains the dilution chamber where the flue gas coming from the chimney is mixed with dried, filtered, pre-heated air, generated by the compressor.

The dilution air gets in the dilution chamber, through a mixing cone, tangentially the flue gas to increase turbulence and improve the mixing of the two flows. The temperature inside the dilution chamber is monitored by a thermocouple and it is adjustable by means of an air heater. The whole system is located in a heated cabin that maintains a constant temperature during the test around 35-40°C.

Two different dilution chambers were designed and tested.

The first one has been designed taking into account a residence time between 0,4-0,6 seconds, according to the residence time indicated in CTM039 US-EPA method to allow condensation. The reaction chamber is made by glass, the chamber diameter is 37 mm, and it directly leads diluted gases to a filter cartridge.

The second reaction chamber was designed bigger than the first one getting a residence time around 2-3 sec, around the residence time investigated by Bomann et al [5]. The mixing cone remained the same of the first chamber in order to guarantee homogenous mixture between exhaust gases and dilution air. A plane filter, with standard dimensions of 37 mm, was integrated in the new configuration assuring a simple handling during the filter positioning and removing.

Figure 1 and Figure 2 represent the schemes of the two combustion chambers.

All the components are controlled by means of a dedicated software and all the parameters are recorded.

The dilution ratio can be set from 1 up to 10, also the sampling flow can be modified and vary between 1 to 10 l/min.

2.2 Test rig description

The system was tested with a domestic pellet stove of nominal output around 8 kW, fed with pellet classified as A2 according to ISO 17225-2. The choice of the appliance was due to the necessity to have stable emissions allowing the comparison of several samplings performed to verify the reliability of the new device.

O₂, CO, VOCs and primary PM were measured in parallel with condensable PM. Primary PM (HF PM, Heated Filter PM) was sampled using a gravimetric method, with constant flow and where filter holder was

maintained at 120°C.

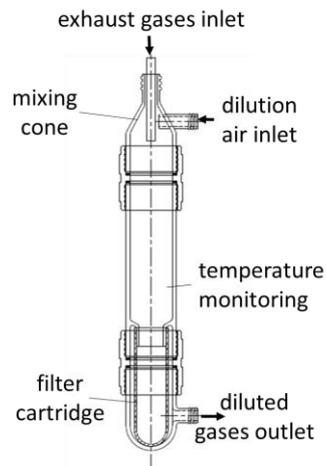


Figure 1: first dilution chamber configuration.

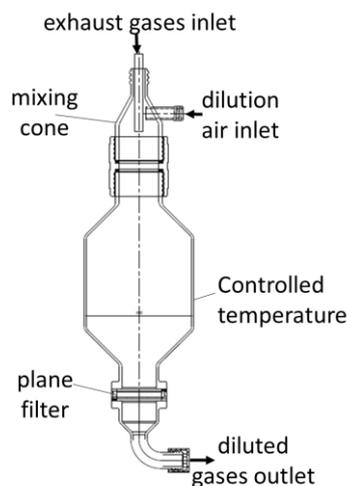


Figure 2: new dilution chamber with a maximum diameter of 100 mm.

To measure VOCs an FID analyzer was used, while for the other gases a portable analyzer based on electrochemical cells was adopted.

The sample period of the data presented in this paper corresponds to 15 minutes. During IMPRESS II work package 2 many experimental tests were performed to verify that the automatic setting of the sampling flows made by the control unit, corresponded to the real ones. In this paper only data used to optimize the dilution chamber are presented.

In Table 1 are described the combustion conditions of the three experimental campaigns. During the second campaign the pellet stove was set to lower heat output to increase the incomplete combustion components in order to generate higher amount of condensable PM.

Table I: Combustion conditions of the three experimental campaigns.

	Tests characteristics		
	Tgases	O2	CO
	°C	%	mg/Nm3 13% O2
1st campaign	124,6	13,1	989,0
2nd campaign	76,2	17,2	2583,5
3rd campaign	113,7	14,5	1258,6

3 RESULTS AND DISCUSSIONS

The aim of the first task in charge of ENEA and Innovhub was to study the configuration of the existing dilution chamber and, if necessary, design and test a new one.

Three set up of reaction chamber were realized before having the final configuration.

3.1 First configuration

The first configuration is the first designed reaction chamber where the residence time was in the range of 0.4-0.6sec, depending on the dilution ration and sampling flow set.

The nozzle used during these first tests was not heated.

In Figure 3 a comparison of the condensable PM and primary PM concentration, normalized at 13% of O₂, is shown.

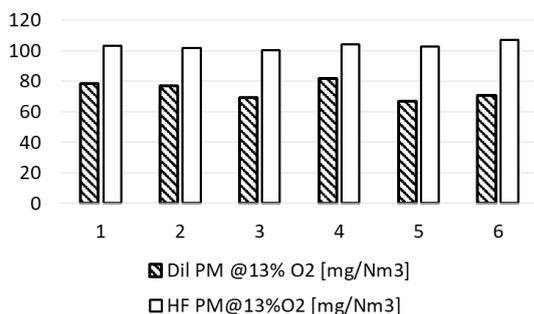


Figure 3: comparison of the condensed PM (Dil PM), measured with the first set up of dilution chamber, and primary PM (HF PM) concentration, normalized at 13% of O₂.

In the diagram condensed PM are lower than primary PM. After few tests it was observed that the problem was in the filter holder design as the positioning and removing of the filter cartridge caused a release of filter material leading to important weight losses. Moreover it was observed that a lot of organic gases components were condensed on the inner walls of the nozzle.

3.2 Second configuration (intermediate)

To avoid the criticisms registered during the first campaign, some modifications were applied to the reaction chamber.

At first the nozzle was heated and thermal insulated by means of a heating band wrapped with a fiberglass material. Further, a plane filter of 37 mm replaced the filter cartridge and the dilution chamber was connected to a plane filter holder after a 90° glass curve.

In Figure 4 a comparison of the condensable PM and HF PM concentration, normalized at 13% of O₂ is shown.

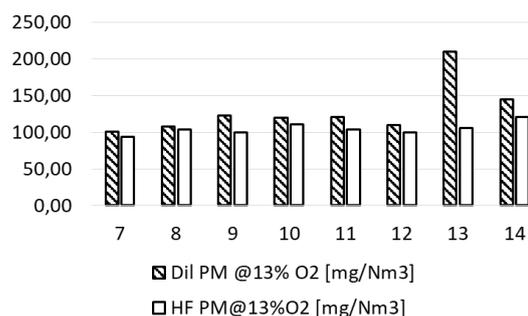


Figure 4: comparison of the condensed PM (Dil PM), measured with the second set up of dilution chamber, and primary PM (HF PM) concentration, normalized at 13% of O₂.

As expected condensable PM concentration is higher than primary PM, and it was also observed that the nozzle deposits were reduced. For these tests the pellet stove operated at reduced power output in order to guarantee the formation of condensed PM (Table 1).

3.3 Third configuration (new dilution chamber)

Due to the positive results of the modified reaction chamber configuration, a new one was designed taking into account the necessity to integrate the plane filter holder in the new component.

To take advantages to the realization of the new chamber it was decided to increase the exhaust residence time to study the influence of this parameter in the process of coagulation, in order to increase the condensed PM concentration collected with the new system.

In Figure 5 a comparison of the condensable PM and HF PM concentration, normalized at 13% of O₂ is shown.

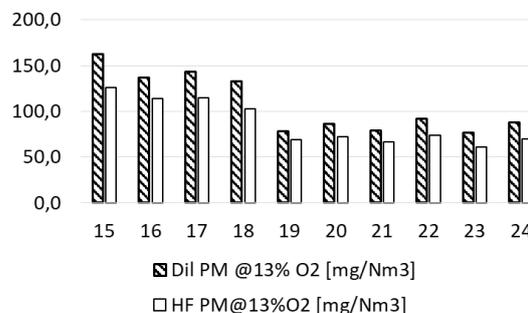


Figure 5: comparison of the condensed PM, measured with the third set up of dilution chamber, and primary PM concentration, normalized at 13% of O₂.

In this case the differences between “Dil PM” and “HF PM” are higher than the second set-up, further tests are necessary to verify that this behavior is due to longer residence time in dilution chamber.

4 FURTHER STEPS

Once obtained the new dilution chamber further tests are necessary to better investigate the efficiency of the new system in capturing condensed PM.

At Innovhub lab the new sampling system will be tested with wood stove, where the amount of VOCs (SVOCs in particular) is high and the PM comparison will be performed between primary PM and condensable

PM measured with dilution tunnel method.

The sampling time period will hopefully be all stove combustion cycle long, to represent the environmental impact of the appliance without losing information due to PM sampling period shorter than the normal burning cycle of the tested heat generator.

Further tests will be focus on verifying that the new method is able to collect in the plane filter the major part of SVOCs emissions, by means of condensation and coagulation. So it will be necessary to perform PAH analysis on the filter and compare it with the results coming from a PAH standard sampling method performed in parallel with new system.

So far the new dilution sampling method has been testing by the other labs participating at IMPRESS II project: SE in Sweden, DTI in Denmark and INERIS in France. The aim is to verify the capacity handling of the system and to make comparisons between the new method and PM sampling methods used in other EU Member States.

6 REFERENCES

- [1] Air quality in Europe 2015 report, European Environment Agency Report No 5/2015
- [2] J. Mc Donald, B. Zielinska, E. Fujita, J. Sagebiel, J. Chow, J. Watson, Energy Fuels, 2011, 25 (1), pp 315–323.
- [3] E. Pettersson, C. Boman, R. Westerholm, D. Bostrom, A. Nordin, Environ. Sci. Technol., 2000, 34 (11), pp 2080–2091;
- [4] Thomas Nussbaumer, Biomass Combustion in Europe, overview on technologies and regulations, Final Report, 2008
<https://www.nyserda.ny.gov/-/.../Biomass-Combustion-in-Europ...>
- [5] Boman, C., Nordin, A., Westerholm, R., Petterson, E. 2005. Evaluation of a constant volume sampling setup for residential biomass fired appliances – influence of dilution conditions on particulate and PAH emissions. Biomass and Bioenergy, 29:258-268.

9 ACKNOWLEDGEMENTS

The described experimental tests and results are part of Work Package 2 of the project 16ENV08 IMPRESS 2: Metrology for air pollutant emissions, coordinated by NPL Management Limited, the UK metrology institute, and funded by EURAMET (European Associations of National Metrology Institutes),
<http://empir.npl.co.uk/impress/>.

