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Action A4: Intercomparison campaign

Technical report on intercomparison campaign of the new extended ENPME method and OGC measurement

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Summary

This action was led by Ineris with the involvement of all project partners. The main objective was to evaluate the implementation of the extended ENPME method (ENPME method with PM sampling at 180 C followed by porous tube dilution at a dilution ratio of about 1:8 and PM sampling below 40 C). One of the largest uncertainties in combustion emission tests arises from the lack of comparable data on method performance, which compromises the scientific reliability of these methods. To address this, a measurement campaign was conducted at Ineris using a horizontal flue gas simulator composed of a pellet boiler (40 kW) connected to a titanium that can accommodate up to 12 beneficiaries (12 sampling ports), allowing for the collection of large amounts of emission data simultaneously around the same chimney.

Feasibility tests performed prior to the measurement campaign showed that the concentration levels of OGCs was homogeneous across the entire simulator, whereas solid PM concentrations were homogeneous from sampling ports 7 to 12 only.

Following the feasibility study, a measurement campaign took place in September 2023 and included three consecutive days of measurements, one fuel type was tested per day. A minimum of four parallel measurements were conducted per day. A total of 16 trials were conducted at varying concentrations of OGCs and PM (solid and condensable fractions): 5 trials at 0-50 mgC/Nm³ for OGCs and 0-50 mg/Nm³ for PM emission, and 11 trials at 50-650 mgC/Nm³ for OGCs and 50-300 mg/Nm³ for PM emission.

Results showed that solid particle measurements were consistent overall (with an average daily coefficient of variation of 18%). Condensable levels varied depending on the method configuration, with the two laboratories using the full flow configuration reporting concentrations of the same order of magnitude (with an average daily coefficient of variation of 19%) being higher compared to the partial flow configuration. The evaluation of rinsing with acetone after blowing revealed residual particle deposition, indicating that regular cleaning is necessary, as required by the EN 16510-1:2022 standard. Furthermore, OGC measurements showed good agreement between the three laboratories using the FID technique (with average daily coefficient of variation of 22%).

Future work should focus on enhancing the capability to generate higher concentrations of condensables with the simulator. Additionally, further investigations are needed on the full flow configuration of the extended ENPME method to evaluate its performance at different concentrations, including tests on stoves. Finally, a more comprehensive comparison with other methods should be performed to validate these findings.

1. Context and Objective

Action A4 was led by INERIS with the involvement of all project partners. The main objective was to evaluate the implementation of the extended ENPME method, proposed as the short-term method to be tested by the partners of the Real-LIFE Emissions project.

One of the largest uncertainties in combustion emission tests arises from the lack of comparable tests and data on method performance, which compromises the scientific reliability of these methods. To address this, a measurement campaign was conducted at INERIS using a horizontal flue gas simulator (Figure 1). This setup consists of a titanium loop where gaseous effluents of similar composition can be generated from various combustion sources such as biomass, gas, or fuel oil using boilers. This simulator can accommodate up to 12 beneficiaries (with 12 available sampling ports), allowing for the collection of large amounts of emission

data simultaneously around the same chimney. It is important to mention that the temperature inside the simulator is controllable and can be maintained constant over the testing duration.

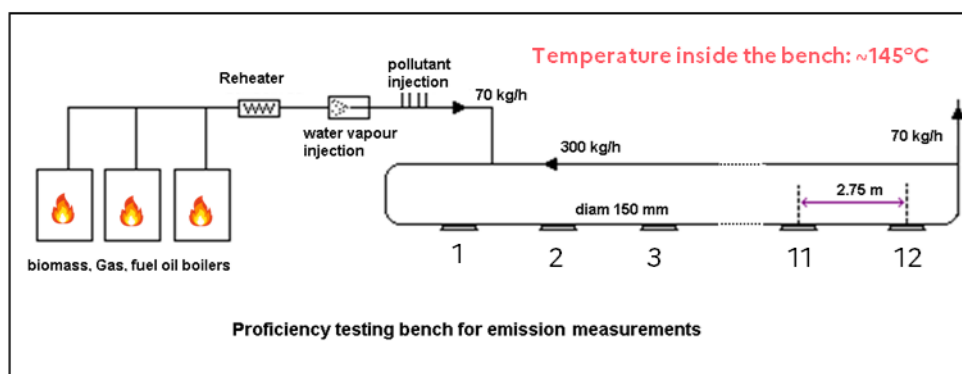


Figure 1. The horizontal flue gas simulator at INERIS.

2. Feasibility Tests and Results

Prior to the measurement campaign, feasibility tests were performed with the aim of: i) checking the concentration levels of OGCs and PM generated by the wood boiler operating at different combustion outputs to ensure typical combustion conditions and emission levels, and ii) assessing the homogeneity of the gases over the whole horizontal gas simulator. To do so, INERIS selected a pellet boiler (40 kW) as the biomass combustion source, and three types of fuel were tested: dry wood chips, fresh wood chips, and pellets. Different levels of OGCs and solid PM were generated according to the fuel type, with the lowest levels observed for pellets (Table 1).

Table 1. Average levels of OGCs and solid particles generated using different types of fuel during the feasibility tests conducted on the horizontal flue gas simulator.

Fuel type	OGCs (ppm, wet)	Solid particles (mg/m ³)
Pellets	30	20
Dry wood chips	213	180
Fresh wood chips	360	95

Results for the homogeneity test are presented in Figure 2. It can be observed that concentrations of OGCs are constant and can be considered homogeneous across the entire simulator, whereas concentrations of solid PM decreased from sampling ports 1 to 7 and remain

constant afterward and thus are considered homogeneous from sampling ports 7 to 12. Therefore, for PM, it is important to set the sampling lines on ports 7 to 12.

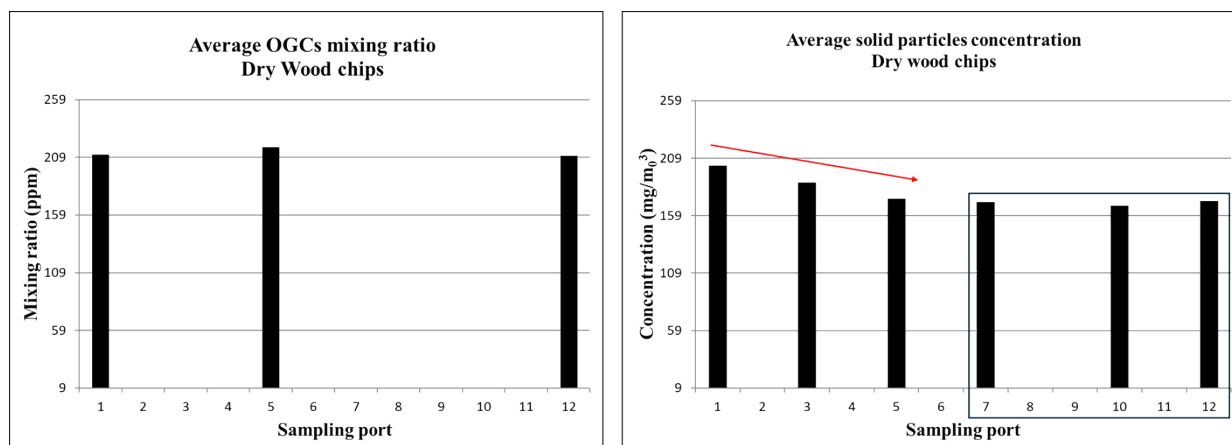


Figure 2. Results from the feasibility tests conducted on the horizontal flue gas simulator using dry wood chips: Left, average OGCs mixing ratios; Right, average solid particles concentration.

3. Measurement campaign

3.1. Overview and Methodology

The extended ENPME method was evaluated through a comprehensive measurement campaign involving all partners (TFZ, UEF, VSB, and INERIS). The campaign spanned five days, from September 18th till September 22nd, 2022. The schedule was as follows:

- Day 1: Partners' arrival, introduction to the horizontal flue gas simulator, briefing session, and equipment installation.
- Days 2-4: Three consecutive days of measurements with three types of fuel tested: pellets, dry wood chips, and fresh wood chips. One experimental day was dedicated to each type of fuel. A minimum of four parallel measurements per day were conducted between sampling ports 7 to 12. OGCs were continuously measured, while total PM was sampled for 30-45 minutes. In addition, other combustion gases (O₂, CO₂, CO, and NO_x) were monitored by INERIS.
- Day 5: Debriefing session, equipment storage, and partners' departure.

The comparison involved comprehensive assessments among partners:

- Measurement of total PM (solid + condensable fractions) using four prototype sampling lines of the extended ENPME method.
- Evaluation of sampling probe cleaning techniques: blowing and rinsing.
- Comparison between the SPC-IPA method previously developed by INERIS and the extended ENPME method.
- Comparison of OGCs measurements using three FID and one FTIR.

During the three days of measurement, a total of 16 trials were conducted at varying concentrations of OGCs and total PM:

- OGC Concentration Trials:
 - 5 trials ranged between 0 and 50 mgC/Nm³
 - 11 trials ranged between 50 and 650 mgC/Nm³
- Total PM Concentration Trials:
 - 5 trials ranged between 0 and 50 mg/Nm³
 - 11 trials ranged between 50 and 300 mg/Nm³

The extended ENPME method. This method consists of sampling the combustion flue gas through a heated probe. The solid fraction is collected on a heated filter, and then the condensable fraction is collected on a second filter after dilution. It is important to mention that implementing the extended ENPME method incurs additional costs compared to the standard ENPME method. These include additional investments in equipment (porous tube, filter holder, CO₂ analyzer to monitor and adjust the dilution rate), consumables (additional quartz filters), and extra labor hours (For more details concerning the costs, please refer to action C3 described in a separate report).

During the comparison campaign, two sampling configurations for the condensable fraction were tested: (i) the full flow configuration (Figure 3-A), where all the sampling flow enters the porous tube and is diluted before passing through the second filter; and (ii) the partial flow configuration (Figure 3-B), where only a part of the sample flow is directed to the porous tube for dilution.

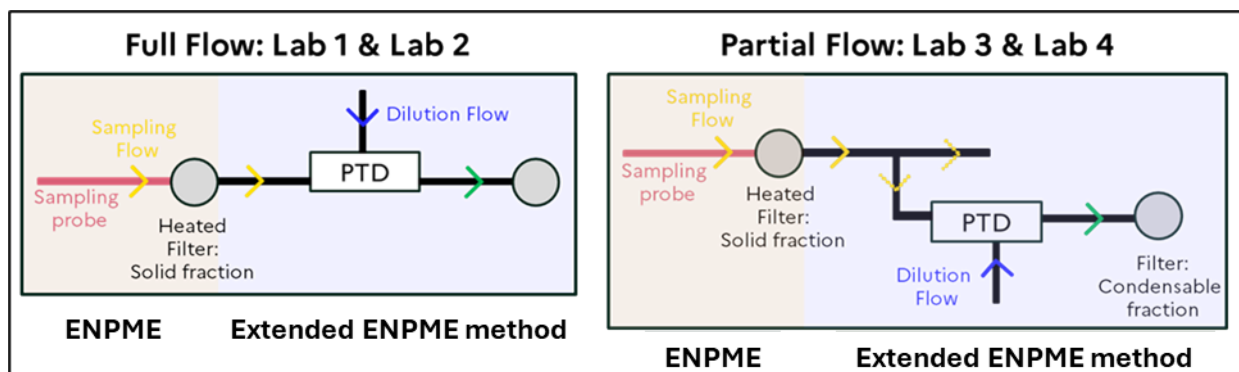


Figure 3. The two sampling configurations for the condensable fraction tested during the comparison campaign.

Sampling Conditions. Table 2 outlines the sampling conditions for all participating laboratories. The measured sampling flow rate for Labs 1 and 4 ranged between 7 and 10 NL/min whereas Labs 2 and 3 operated with an unmeasured flow rate of 10 NL/min. All participants heated the sampling probe and the first quartz filter, which collects solid particles, to 180°C. However, the heating of the connector between the first filter and the porous tube was not consistent across all laboratories. The pre- and post-conditioning of filters were standardized among all participants. The dilution ratio varied between 8 and 12. The temperature of the second filter, which collects the condensable fraction, differed among the participants: it was lower for Labs 1 and 2 and higher for Labs 3 and 4. Finally, Labs 1 and 2 used a full flow configuration, while Labs 3 and 4 worked with a partial flow configuration.

Table 2. Sampling conditions for all participating laboratories

	Sampling Flow rate NL/min	ENPME probe	Filter 1	Connection Filter1-PTD	Filter 1 Pre-conditioning	Filter 1 Post-conditioning	Dilution ratio	Filter 2	Partial Flow rate NL/min
Lab 1	7-10	180°C	Quartz 180°C	Not heated	200°C, >1h, desiccator overnight, Weighed	180°C, >1h, desiccator overnight, weighed	8-11	Quartz 25-32°C	-
Lab 2	10		Stuff cartridges (days 2 and 3) +Quartz 180°C	Not heated			8	Quartz 25-34°C	-
Lab 3	10		Glass fiber 180°C	180°C insulated			8	1,2,3,6: quartz Rest: Teflon 42°C	5
Lab 4	8-10		Quartz 180°C	180°C			8-12	Teflon 32-40°C	5

3.2 Results and Discussion

Solid and condensable fractions. Results for the solid and condensable fractions from the comparison campaign are presented in Figure 4. For the solid fraction (upper panel), it is evident that results are of similar orders of magnitude (with an average daily coefficient of variation of 18%). At higher concentrations, Lab 4 exhibited a higher value compared to the other participants.

Regarding the condensable fraction (lower panel), it is notable that the generated levels are generally low, typically < 25 mg/Nm³. Additionally, there is a difference between partial flow and full flow sampling conditions. Under partial flow configuration, concentrations are low, while for full flow configuration, there is relatively good agreement between Lab 1 and Lab 2 (with an average daily coefficient of variation of 19%).

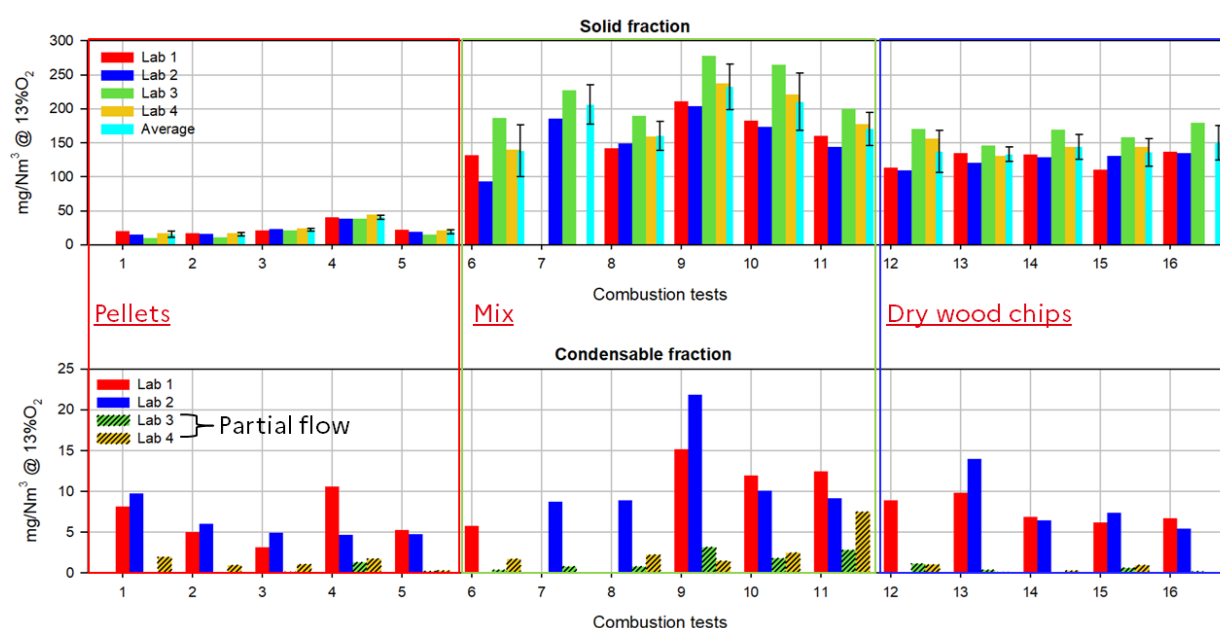


Figure 4. Results for the solid (upper panel) and condensable (lower panel) fractions from the comparison campaign using the extended ENPME method.

Probe cleaning. As previously mentioned, an evaluation of sampling probe cleaning using blowing and rinsing was performed. Results are presented in Table 3. It can be seen that blowing represents less than 3% of the collected fraction on the first filter, whereas rinsing can account for up to 13% of the collected fraction on the first filter. These findings suggest that residual deposits remain after blowing, emphasizing the necessity of cleaning the probe between testing days as required by the EN 16510-1:2022 standard.

Table 3. Sampling probe cleaning: blowing and rinsing.

	% Blowing (Avg)	% Rinsing (Avg)
Lab 1	3	13
Lab 2	2	7
Lab 3	2	No data
Lab 4	2	4

OGCs concentrations. Finally, results for OGCs from FID measurements are presented in Figure 5. Good agreement is observed across the different tests (with average daily coefficient of variation of 22%).

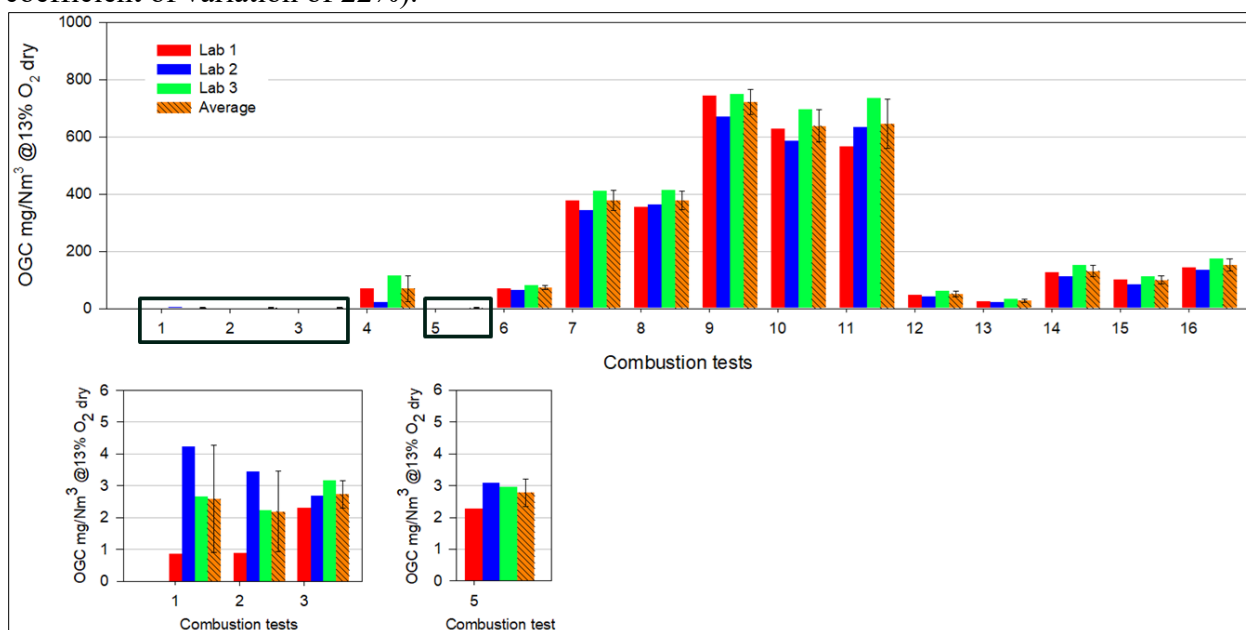


Figure 5. OGCs concentrations from FID measurements.

4. Conclusion and Perspectives

We successfully conducted comparisons on the INERIS horizontal gas flue simulator with varying concentrations of PM (solid and condensable). Two configurations were tested for the extended ENPME method. It was observed that levels of condensables were different and depended on the method configuration. Additionally, the two laboratories using the full flow configuration reported concentrations of the same order of magnitude. The evaluation of rinsing after blowing revealed residual particle deposition, indicating that regular cleaning is necessary,

as required by the EN 16510-1:2022 standard. Furthermore, OGCs measurements showed good agreement between the three laboratories using the FID technique.

Future work should focus on enhancing the capability to generate higher concentrations of condensables. Additionally, further investigations are needed on the full flow configuration of the extended ENPME method to evaluate its performance at different concentrations, including tests on stoves. Finally, a more comprehensive comparison with other methods should be performed to validate our findings.