# SUGGESTION FOR NEAR-TERM AND LONG-TERM MEASUREMENT METHOD, TESTING PROTOCOLS, AND RESTRICTED EMISSION POLLUTANTS FOR RESIDENTIAL SOLID FUEL COMBUSTION

12/2024

PROJECT: HARMONIZING RELIABLE TEST PROCEDURES REPRESENTING REAL-LIFE AIR POLLUTION FROM SOLID FUEL HEATING APPLIANCES

**Real-LIFE emissions, Life preparatory project 2020**

**Project Number: LIFE20 PRE/FI/000006**

**Authors: Juho Louhisalmi (UEF), Paula Inkeroinen (UEF), Claudia Schön (TFZ), Hans Hartmann (TFZ), Isaline Fraboulet (INERIS), Sergio Harb (INERIS), Kamil Krpec (VSB), Jarkko Tissari (UEF)**

# Contents

# 1. Introduction

A new particulate matter (PM) measurement method for small-scale solid fuel heating appliances has been implemented in the EN 16510-1:2022 standard. However, this method is not capable of measuring particles that condense at temperatures below 180°C. Consequently, PM results are underestimated, providing an unrealistic picture of PM emission levels.

In this report, we present two options for more realistic PM emission measurements: the extended ENPME method as a near-term solution and the PTD+ED method as a long-term solution. The extended ENPME method, developed during the Real-LIFE emissions project, is an enhanced version of the method described in the EN 16510-1:2022 standard. The PTD+ED method, which has been used in research for decades, is a two-stage partial flow dilution method.

General requirements for emission measurements of small-scale solid fuel heating appliances in type testing include the capability to measure relevant parameters concerning human health and the environment. This also includes condensable particles, which are not accounted for in current type testing measurements. Additionally, it is important to differentiate the performance of tested appliances. This can be achieved through a comprehensive Real-LIFE testing protocol that includes different phases of combustion.

# 2. Near-term method

## 2.1 Restricted emissions

In the near-term, the restricted emission pollutants can largely remain consistent with those specified in the Ecodesign regulation and in the EN 16510:2022 standard. These pollutants include organic gaseous carbon (OGC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM). In addition, the near-term method would also include condensable particles into the PM measurements through the novel extended ENPME method.

## 2.2 Extended ENPME method description

The extended ENPME method is a two-stage PM measurement technique that includes an ENPME measurement probe, a porous tube diluter (PTD), and two separate filter collections (Figure 1). The first stage involves ENPME sampling as described in the EN 16510:2022 standard, with a flow rate of 10 l/min (0°C, 1013 hPa) and a filter collection temperature of 180 ± 10°C. The second stage involves diluting the remaining sample in the PTD and collecting particles on a second filter. In the PTD, the sample cools down and is diluted which leads to the formation of new particles. The temperature of the second filter depends on the dilution air and ambient temperature, but it should be around 40°C.

Particles deposited on the filters cause a pressure drop, which can lead to decreased flows due to pump deficiency. Therefore, a larger filter, such as a 90 mm filter, is recommended for the second filter. The total PM concentration is the sum of the concentrations from the first and second filters. Teflon filters are recommended for the second filter because they do not absorb gaseous compounds as quartz filters do (Turpin et al., 2000).

A dilution ratio (DR) of 1:8 was used successfully during the project, but the effects of higher or lower DRs should be studied. A higher dilution ratio decreases the sample temperature more but leads to lower concentrations of condensing gases. Lower temperature enhances the gas to particle transition, but lower partial pressures may cause the gases to remain in the gas phase and less particles are formed. The dilution air must be purified and be at ambient temperature. Determining the dilution ratio using $CO_2$ concentration, as described in Equation 1, is recommended.

$$DR = \frac{CO_{2,FG} - CO_{2,BG}}{CO_{2,D} - CO_{2,BG}} \qquad \text{Equation (1)}$$

where $CO_{2,FG}$ is $CO_2$ concentration in flue gas, $CO_{2,BG}$ is dilution air $CO_2$ concentration and $CO_{2,D}$ is $CO_2$ concentration in diluted flue gas (Tissari et al., 2019).

The first filter is thermally post treated at 180 °C in accordance with EN 16510-1:2022 whereas the second filter after the dilution step is only stored at ambient temperature in a desiccator for maximum one hour before weight determination. The first filter is pretreated at 200 °C.

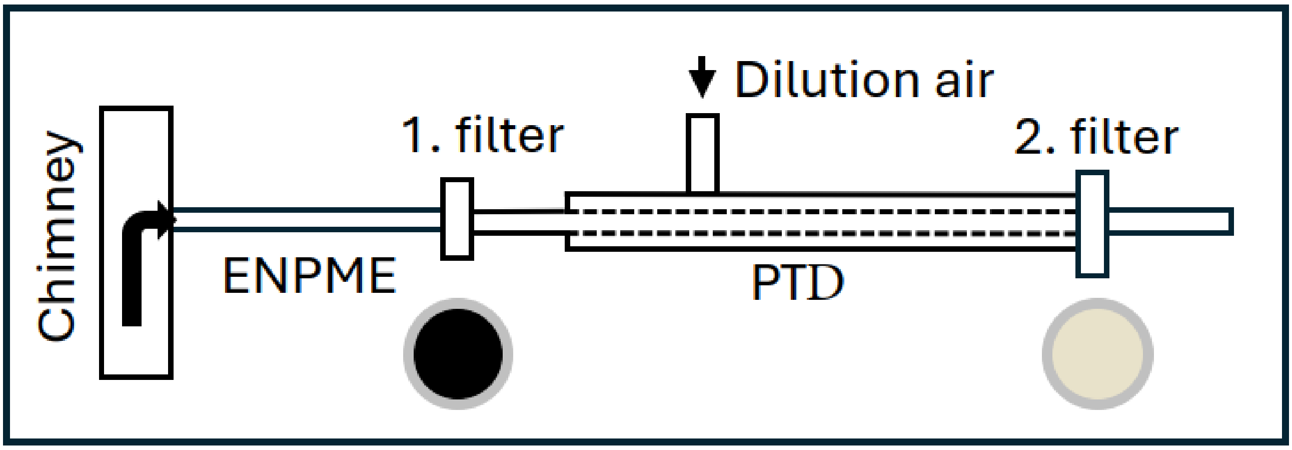


*Figure 1. Schematic figure of the extended ENPME method comprising of the ENPME sampling and the porous tube diluter (PTD).*

The extended ENPME method has several advantages. It is based on a standard method and is significantly smaller than methods such as the full flow dilution tunnel (FFDT). Additionally, it is capable of measuring condensable particles, and the preliminary data collected during Real-LIFE emissions project appears promising.

However, there are also some disadvantages. The method requires two filters for particulate matter (PM) determination, and the laboratory equipment needs upgrades, also concerning an additional and adequate $CO_2$ determination in the diluted flow. For the ENPME sampling probe, also no clear cut-off size of particles with a larger aerodynamic diameter can be specified, which means that random large particles may get to the first filter causing deviations and making it difficult to use the data for emission inventories. Therefore, a validation project is necessary for the impact on particle size separation effects.

Regarding the PTD specifications, the optimal dilution ratio (DR) for new particle formation still needs to be determined. This is also true for acceptable temperature range at the second filter. Several other questions concerning the kind and availability of the equipment (filter materials, filter diameters, definitions of porous tube diluter layout, etc.) are still open. Concerns that the removal of particles in the first hot filter stage could hinder the formation of condensate upstream of the second filter stage (due to lack of condensation nuclei) have not yet been fully dispelled in the current project.

In summary, it can be stated that the extended ENPME method is a promising method, which, however, cannot yet be transferred directly into practice without further testing and validation involving also other accredited testing laboratories and notified bodies.

# 3. Long-term method

## 3.1 Restricted emissions

In the long-term method, the restricted emissions should focus on fine particle mass concentration ($PM_{2.5}$), black carbon or elemental carbon concentration (BC or EC), polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and secondary organic aerosol (SOA) potential. These parameters are crucial for assessing health and environmental impacts of residential solid fuel combustion.

In addition to these, there are supportive and indicative parameters that would provide further insights. These include lung deposition surface area (LDSA), particulate size distribution (PSD), particulate number concentration (PN), ultrafine particle number concentration (UFP), carbon monoxide (CO), and nitrogen oxides (NOx). These parameters help to understand the broader implications of emissions and their behaviour in the environment.

## 3.2 PTD+ED method description

The sampling method consists of a two-stage partial flow dilution system using a porous tube diluter (PTD) and an ejector diluter (ED) (Figure 2). Initially, the sample passes through a cyclone, which removes particles larger than 10µm in diameter. The sample then travels through a heated line to the PTD and ED. The PTD minimizes particle losses, while the ED ensures good mixing and stable sample flow. Before filter collection, the stable sample flow is introduced to a $PM_{2.5}$ impactor, which removes particles larger than 2.5 µm in diameter.

Moderate dilution ratios and a large nozzle in the ED contribute to the method's effective functioning. During dilution, the sample is cooled, and filter collection occurs at ambient temperature. This process includes condensable particles in the $PM_{2.5}$ concentration, allowing for accurate measurement of $PM_{2.5}$ with a single filter. Additional online aerosol instruments can be easily integrated into the system. The dilution ratio (DR) is accurately determined by changes in $CO_2$ concentrations and is automatically controlled with a computer and mass flow controllers (MFC).

$$DR = \frac{CO_{2(FG)} - CO_{2(BG)}}{CO_{2(D)} - CO_{2(BG)}}$$

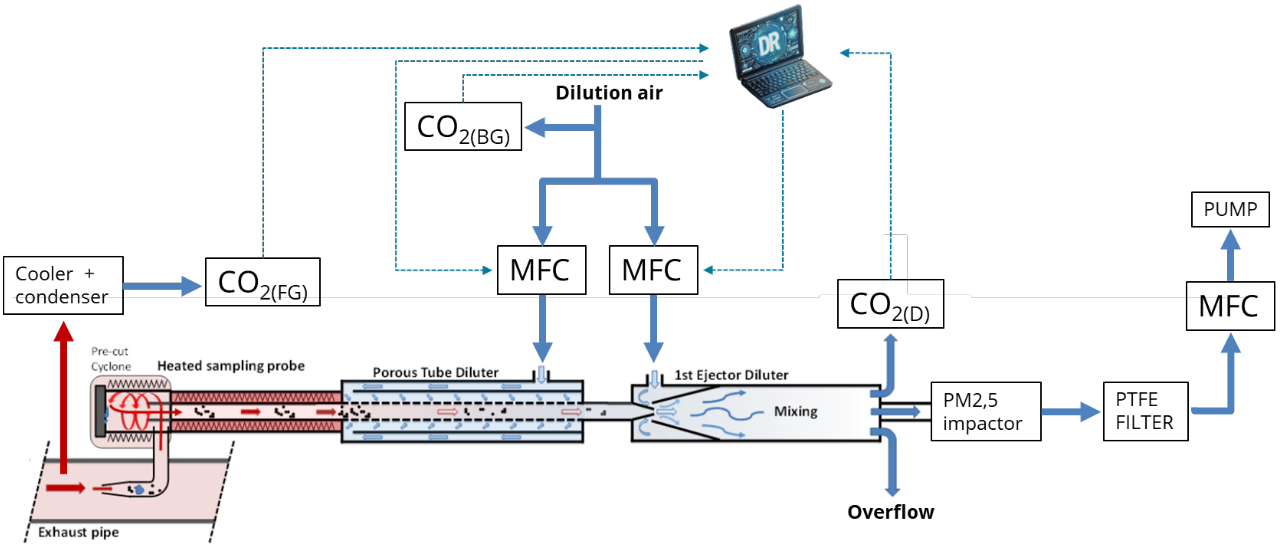


*Figure 2. Schematic figure of porous tube diluter and ejector diluter combination method (PTD+ED ) with dilution ratio control system.*

The advantages of this method are that it is compact, user-friendly, and adjustable. Its effectiveness is well-documented in numerous publications (e.g. Tissari et al., 2007, 2019; Suhonen et al., 2021). A particulate size-cutting impactor can be used, and the data is compatible with emission inventories. Additionally, an SOA reactor can be directly added after dilution.

However, there are some disadvantages. The system is not yet a commercial product, and there are no producers. It is more complex than the ENPME or FFDT methods, but it can be automated to be user-friendly. Although it is more expensive, it saves working hours and resources. The system requires extensive upgrades for laboratory instrumentation and more education due to its extensive instrumentation. There is also a need for an external laboratory for PAH analysis if this is of interest.

In summary, the method is designed for quantifying health and environment-relevant emissions released from combustion. It is also suitable for product development and type testing. It can differentiate the performance of tested appliances, ensuring accurate assessments. Additionally, it produces data that can be easily used in emission inventories and climate modeling. The method is reliable and simple to use, making it accessible for various applications. Furthermore, it is expandable for secondary organic aerosol (SOA) measurements, enhancing its versatility.

# 4. Testing Protocol

To effectively and realistically measure emissions from small-scale solid fuel heating appliances the comprehensive testing protocol is crucial. Testing protocols should reflect real-life use of each appliance type, including different operational variants. This project focused on wood stoves, but a similar approach should be applied to other appliance types, such as slow heat release appliances, cookers, and sauna stoves. The Real-LIFE test protocol includes all combustion phases at different load and different draught conditions (Figure 3). Emission measurements are conducted from each batch including the ignition (cold start). The protocol is described in more detail in the A5 summary report published in projects website (https://sites.uef.fi/real-life-emissions/materials/)**.** This protocol should be applied with both near-term and long-term methods described in this report.

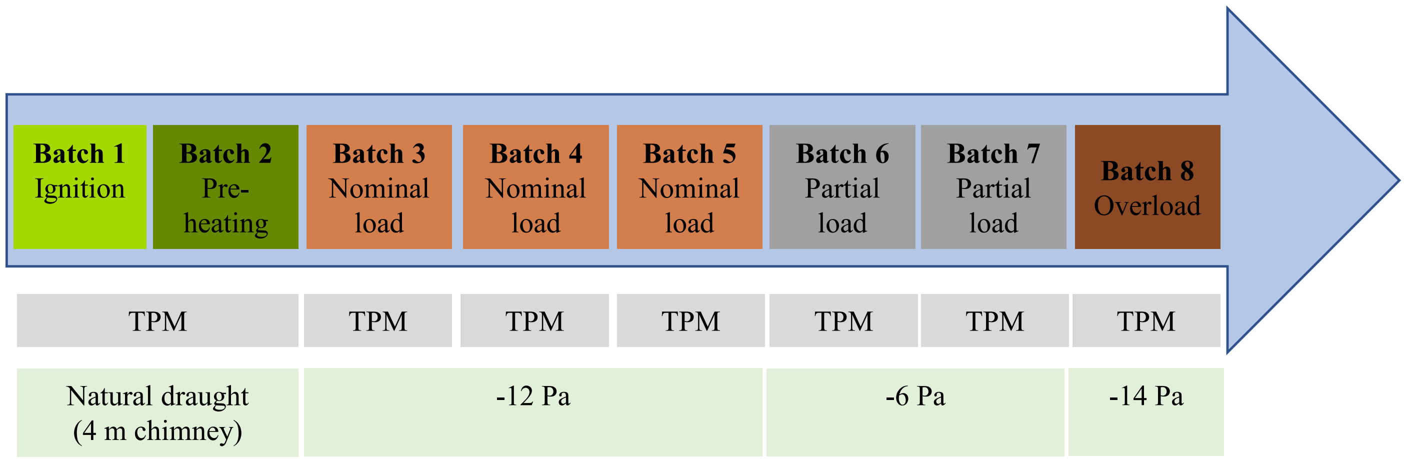


*Figure 3. Procedure of a log wood stove test following the Real-LIFE test protocol.*

# 5. Summary and conclusions

The extended ENPME method is a two-stage PM measurement technique that includes standard ENPME sampling probe and a porous tube diluter (PTD) with a 1 to 8 dilution ratio. It effectively measures condensable particles and has provided promising preliminary data. The method requires two filters for PM determination and laboratory equipment upgrades, and it lacks a clear cut-off size for collected particles. Before being transferred directly into practice, further testing and validation is required which also involves other accredited testing laboratories and notified bodies.

In the long-term, emission measurements should focus on $PM_{2.5}$, black carbon, PAHs, VOCs, and SOA potential. Supportive parameters include LDSA, PSD, PN, UFP, CO, and NOx. The PTD and ED system is compact, user-friendly, and adjustable, with documented effectiveness. However, it is not yet commercially available and requires extensive laboratory upgrades and education.

A comprehensive testing protocol is essential for determination of more realistic emission measurements, reflecting real-life use of the combustion appliances. The Real-LIFE test protocol, focusing on wood stoves, includes all combustion phases at different loads and different draught conditions. This protocol should be applied to both near-term and long-term methods, and it can be adapted for other appliance types.

# 6. References

EN 16510-1:2022, Residential solid fuel burning appliances. Part 1: General requirements and test methods.

Suhonen, H., Laitinen, A., Kortelainen, M., Koponen, H., Kinnunen, N., Suvanto, M., Tissari, J., Sippula, O., 2021. Novel fine particle reduction method for wood stoves based on high-temperature electric collection of naturally charged soot particles. J. Clean. Prod. 312, 127831. https://doi.org/10.1016/j.jclepro.2021.127831

Tissari, J., Hytönen, K., Lyyränen, J., Jokiniemi, J., 2007. A novel field measurement method for determining fine particle and gas emissions from residential wood combustion. Atmos. Environ. 41, 8330–8344. https://doi.org/10.1016/j.atmosenv.2007.06.018

Tissari, J., Väätäinen, S., Leskinen, J., Savolahti, M., Lamberg, H., Kortelainen, M., Karvosenoja, N., Sippula, O., 2019. Fine Particle Emissions from Sauna Stoves: Effects of Combustion Appliance and Fuel, and Implications for the Finnish Emission Inventory. Atmosphere 10, 775. https://doi.org/10.3390/atmos10120775

Turpin, B.J., Saxena, P., Andrews, E., 2000. Measuring and simulating particulate organics in the atmosphere: problems and prospects. Atmos. Environ. 34, 2983–3013. https://doi.org/10.1016/S1352-2310(99)00501-4

UNIVERSITY OF
EASTERN FINLAND

Harmonizing reliable test procedures representing real-LIFE air pollution from solid fuel heating appliances - **Real-LIFE Emissions** project.

**Project Partners**

- University of Eastern Finland (UEF)
- Technical University in Ostrava (VSB)
- The French National Institute for Industrial Environment and Risks (INERIS)
- Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ)

VSB TECHNICAL UNIVERSITY OF OSTRAVA | ENERGY AND ENVIRONMENTAL TECHNOLOGY CENTRE | ENERGY RESEARCH CENTRE

TFZ

RÉPUBLIQUE FRANÇAISE
*Liberté*
*Égalité*
*Fraternité*

INERIS
maîtriser le risque
pour un développement durable