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1ST INTERNATIONAL WORKSHOP ON REAL-LIFE EMISSIONS

8 – 10 Nov. 2022
University of Eastern Finland, Kuopio campus

Results from PM sampling methods used during the Ineris measurement campaigns on the residential wood combustion:

- Dilution Tunnel, Porous Tube, SPC-IPA method and Dilution Chamber -

Benjamin Céa: benjamin.cea@ineris.fr

Life

Real-LIFE Emissions

Ineris - [CGR] - 206311

Introduction

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- Organic gaseous compounds in stack that condense on contact with the atmosphere due to dilution and cooling of the flue gases
- Represent a large part of air ambiant particulates from residential wood combustion *(Nussbaumer et al. 2008)*
- Most emission inventories are based on particle measurements that do not include condensables, leading to an underestimation of European emissions from wood burning by a factor of 2 to 3 *(Danier Van Der Gon et al. 2015)*
- Using EMEP and PMCAMx air quality models, inclusion of condensable emissions from wood burning in the emission inventories could lead to an increase of more than 50% in the in simulated particulate matter concentrations *(Danier Van Der Gon et al. 2015)*

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- By incorporating cycles of nominal and low combustion conditions during the measurements

- The reduced combustion output is a cycle widely used in France (>25% of users) to heat longer by increasing the duration of the fuel *(Ademe report 2018 - Survey on the use of domestic wood-burning equipment* - www.ademe.fr/mediatheque)

- Because the reduced combustion output, produces more condensables *(Nussbaumer et al. 2008)*

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1. Wood combustion test protocol used on the Ineris experimental platform

1. a. Ineris experimental platform

1. b. Protocol of combustion tests: *from Afac 2015* (Ademe/Ineris project)*

« Cold Start » : *Without measurement*

1. Ignition (first Batch)

~1,5kg Wood < 16% humidity + kindling

2. Initial phase (Preheating)

No flame, CO_2 < 4%, Ember bed ~ 3 cm

***Afac 2015, french report:** *Determination of pollutants emission factors of domestic wood stoves.*

1. c. Protocol of combustion tests: *from Afac 2015 (Ademe/Ineris project)*

« Warm Start »: *With measurement*

1. Initial phase (Preheating)
No flame, CO_2 < 4%
Ember bed ~ 3 cm

2. Load
(~1,5kg Wood)

3. Combustion tests
Start: straight after wood load (door closure)
End: No flame, CO_2<4%

1. d. Protocol of combustion tests: *from Afac 2015 (Ademe/Ineris project)*

Combustion Condition:

Combustion mode:
Nominal, Low or Intermediate conditions

Nominal and Low Output:
Only changing the air supply with same wood load.

- Nominal condition: draught from **11 to 13 Pa**
- Low condition: draught from **9 to 11 Pa**

Determination of combustion condition (%):

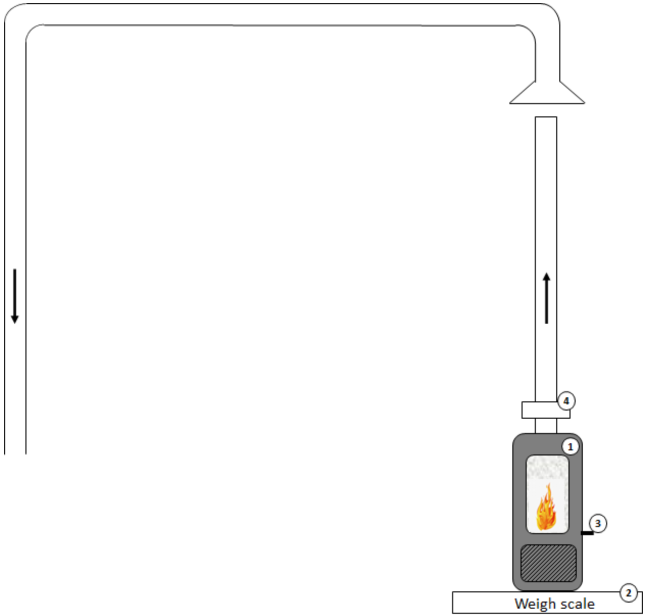
= Power Output / Nominal Power of stove

Power Output (kWh) depends on:

- Input power (kWh);
- Efficiency (%) of stove estimated during the test;
- Caracteristics of fuel used (% dry matter of C and H, Lower Calorific Value in kJ/kg of raw fuel)

2. Wood combustion tests used for Actions A1 to A2 of Real-Life project

2. a. Set up of the wood combustion tests:



1. Wood log Stove (7 kW). **2.** Weighing scale for wood mass consumption. **3.** Control of air supply (to change the combustion mode: Nominal, Low, Intermediate conditions). **4.** Gasket. 5. Condensator. **6.** Heated dilutor. **7.** Cold bath (< 4°C). **8.** Washing bottles filled with isopropanol (IPA). **9.** Filters holders. **10**. Silica gel. **11.** Pumps. **12.** Filter holder for SPE filters. **13**. Filter holder for EC/OC filters. **14.** AE33 analyser for Black Carbon.

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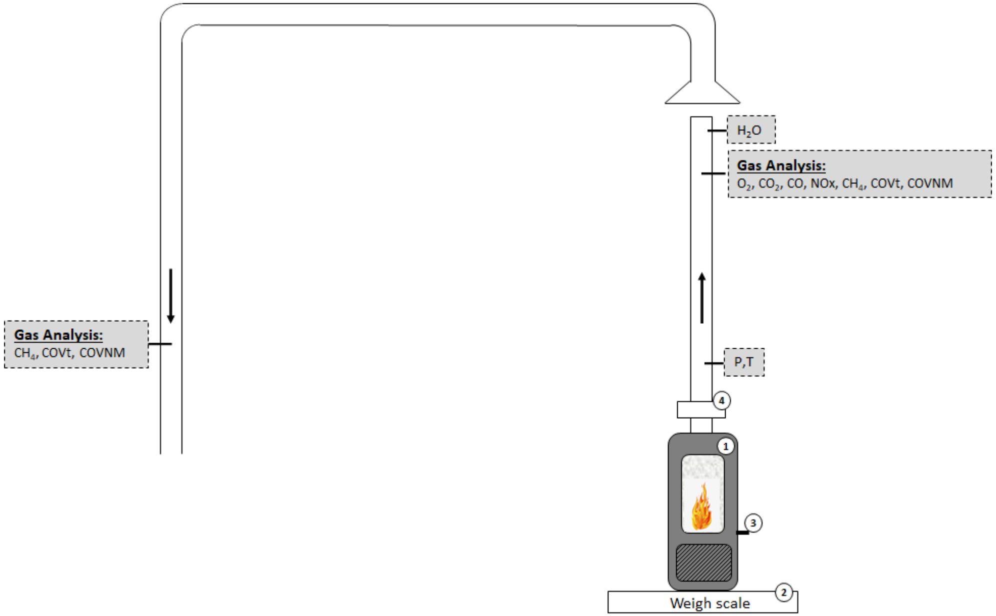

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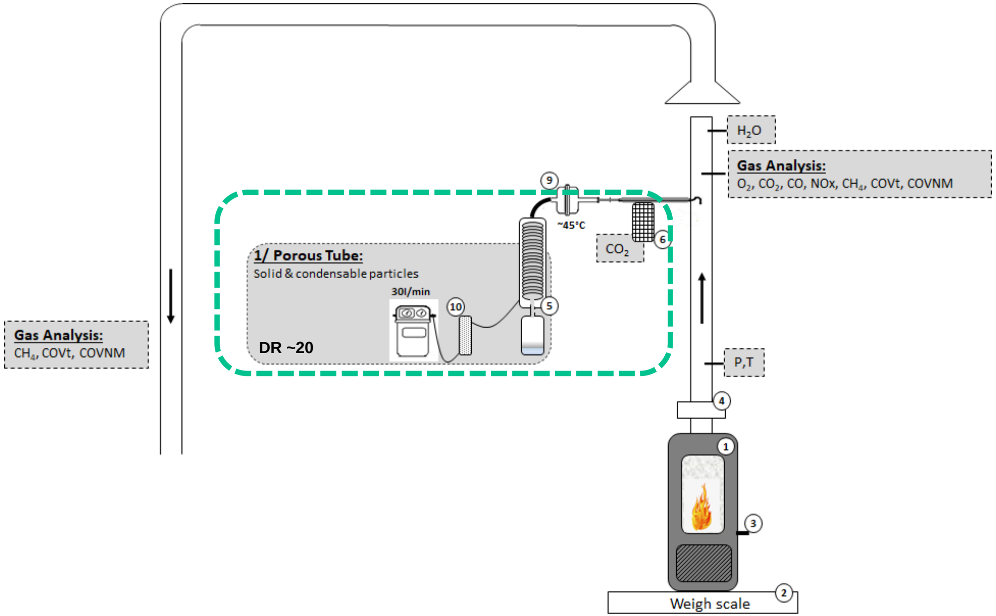

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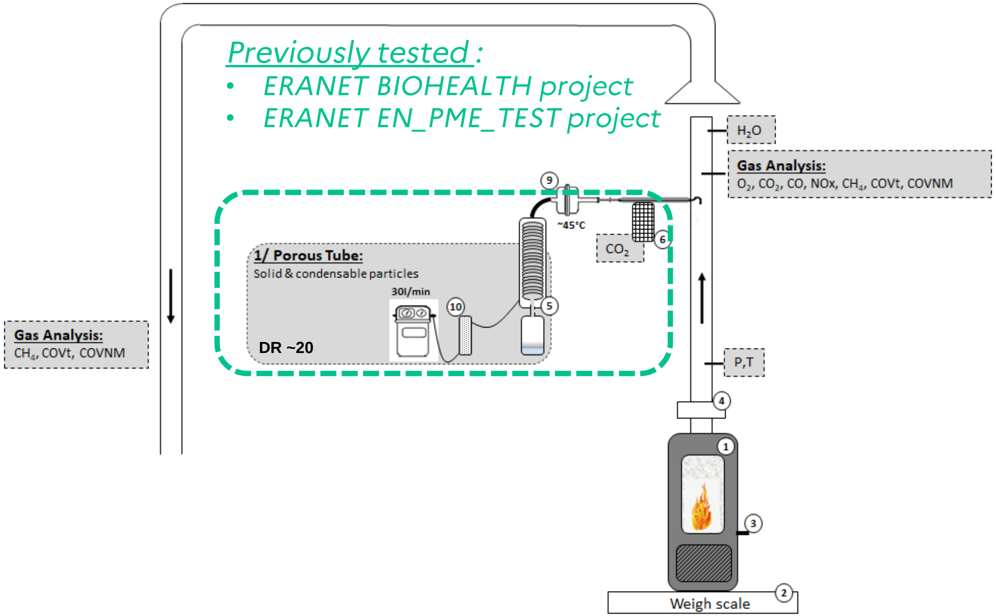

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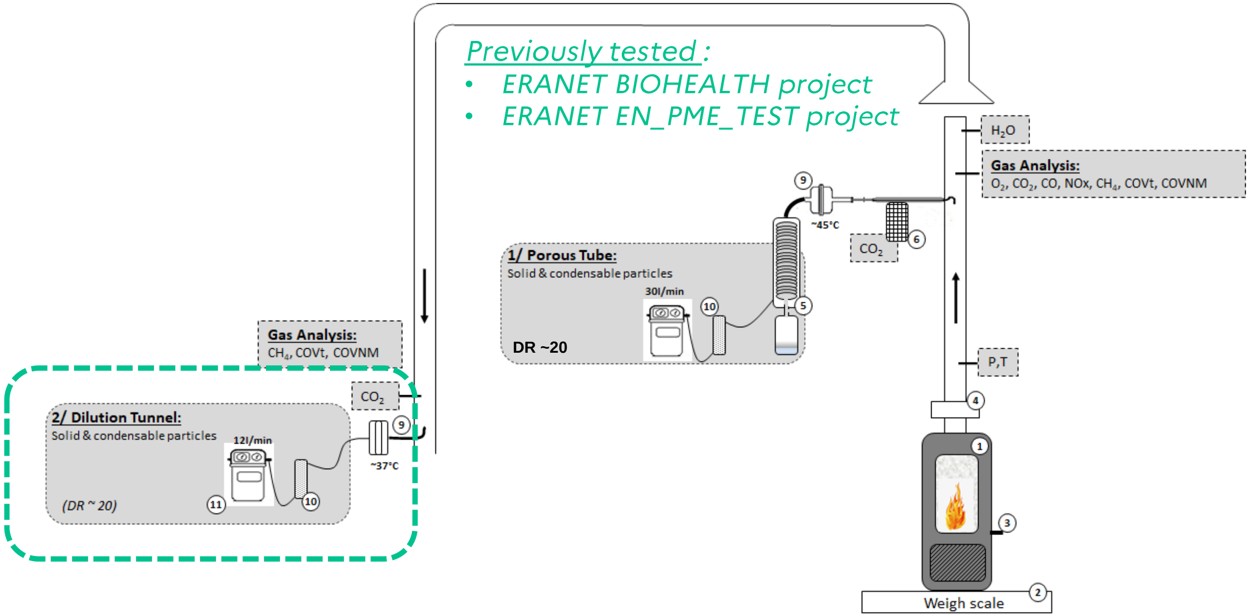

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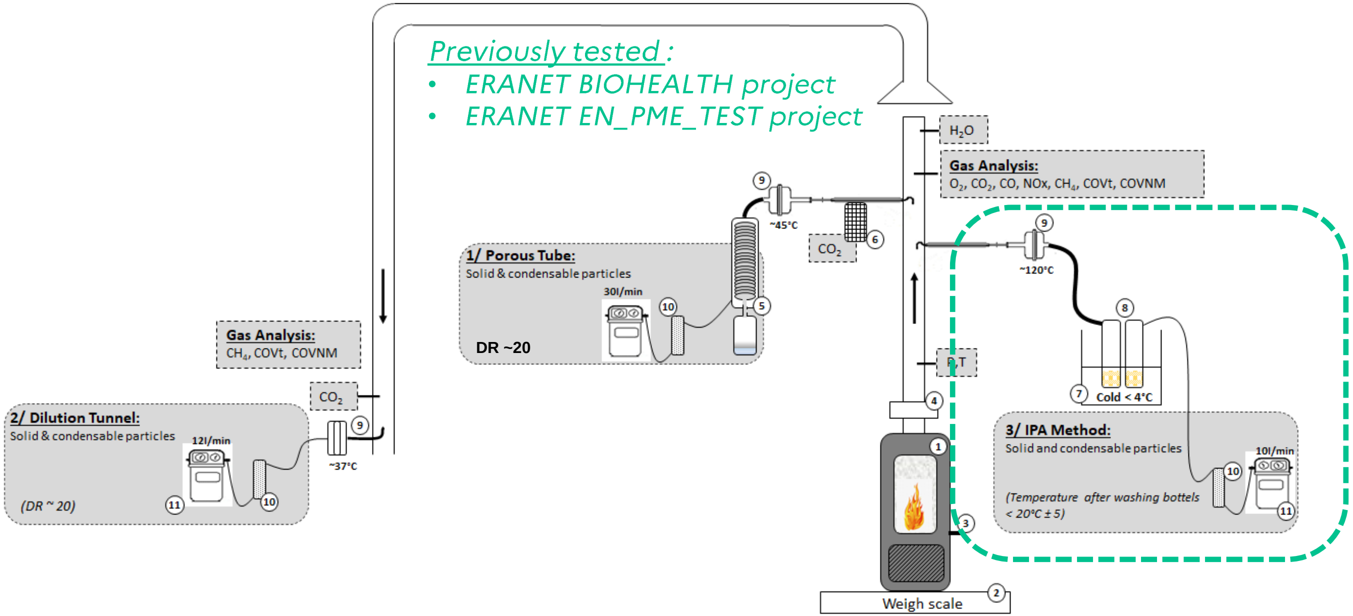

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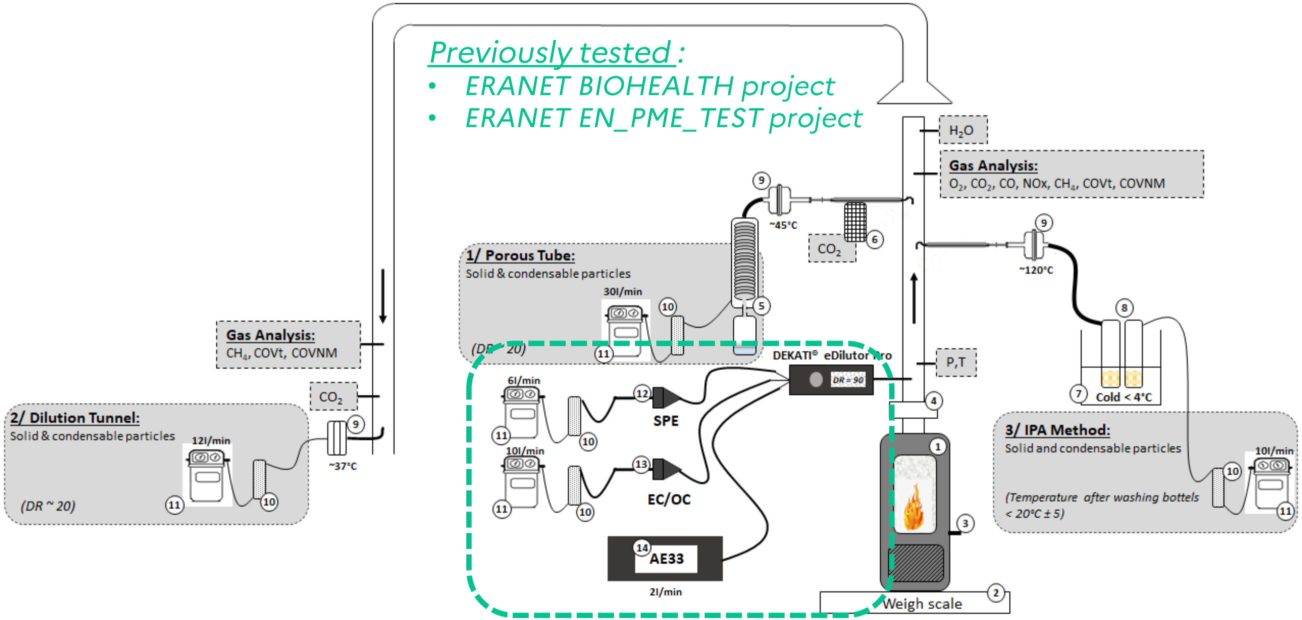

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2. b. Experimental parameters:

Wood log stove: FV 7*, 7 kW
Wood type: Beech and Hornbeam (~1,5 kg)
#combustion tests: 15 combustion tests

Combustion conditions: From **40 % to 60%** of the nominal power as « **Low** », from **75% to 100%** of the nominal power as « **Nominal** » and between **60% and 75%** of the nominal power as « **Intermediate** »

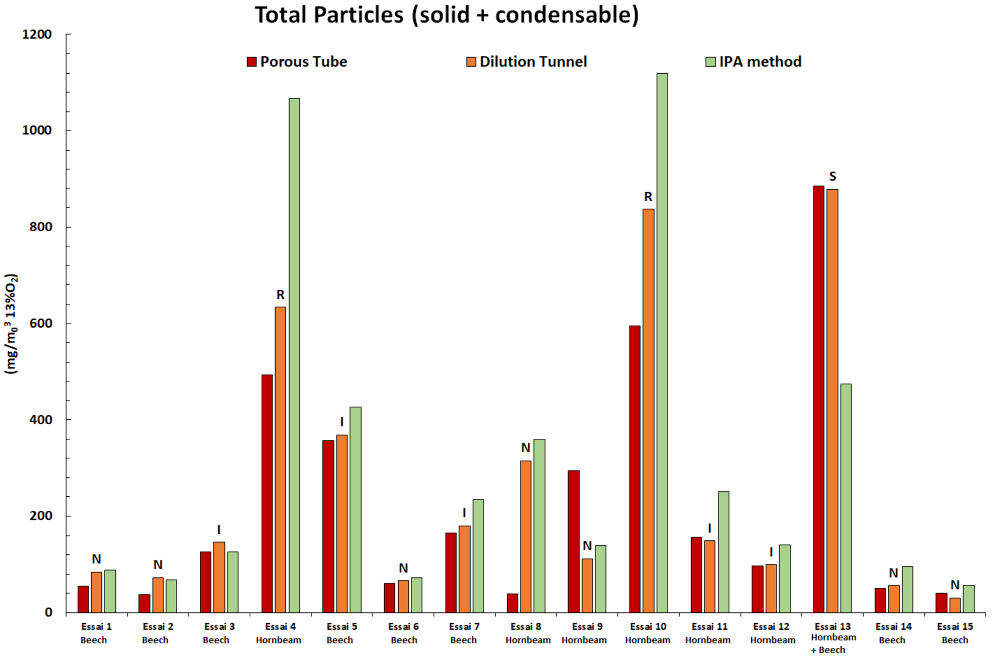
Time by test: between 35min. and 1h20

Dilution Ratios (DR): Between **15 and 25** (calculated with CO_2 ratio for the Dilution Tunnel and the Porous Tube methods)

3. Results of Real-Life combustion tests

3. a. PM sampling (solid and condensable):

Dilution Tunnel, Porous Tube and SPC-IPA methods

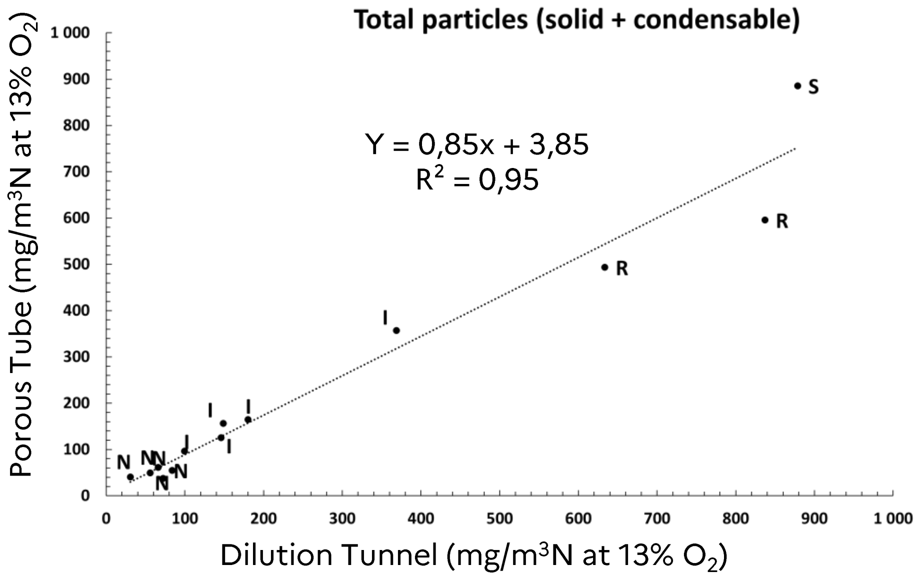


Combustion Conditions:

- N: Nominal (75 – 100%)
- I: Intermediate (60 – 75%)
- R: for Low (40 – 60%)
- S: « Cold Start »

3. b. PM sampling (solid and condensable):

Comparison between *Porous Tube and Dilution Tunnel methods*



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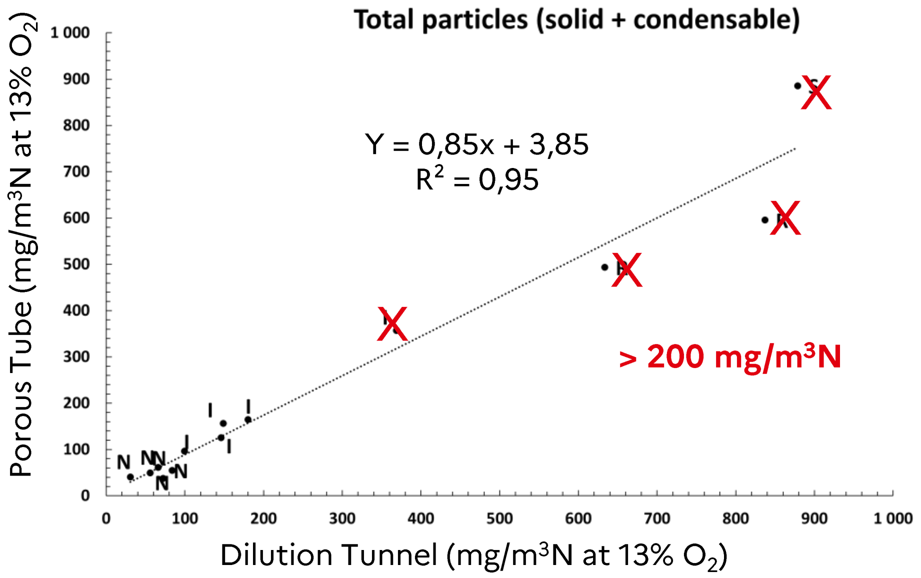

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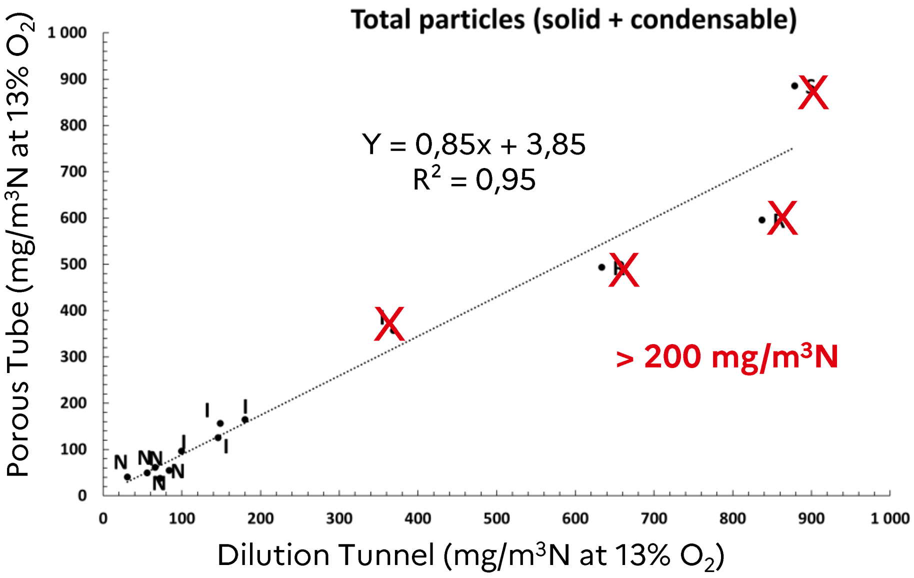
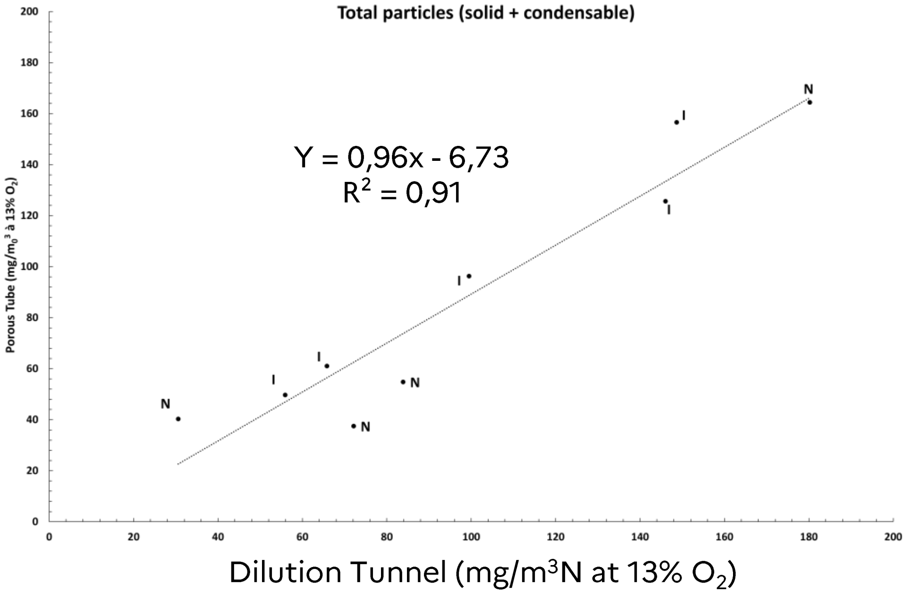
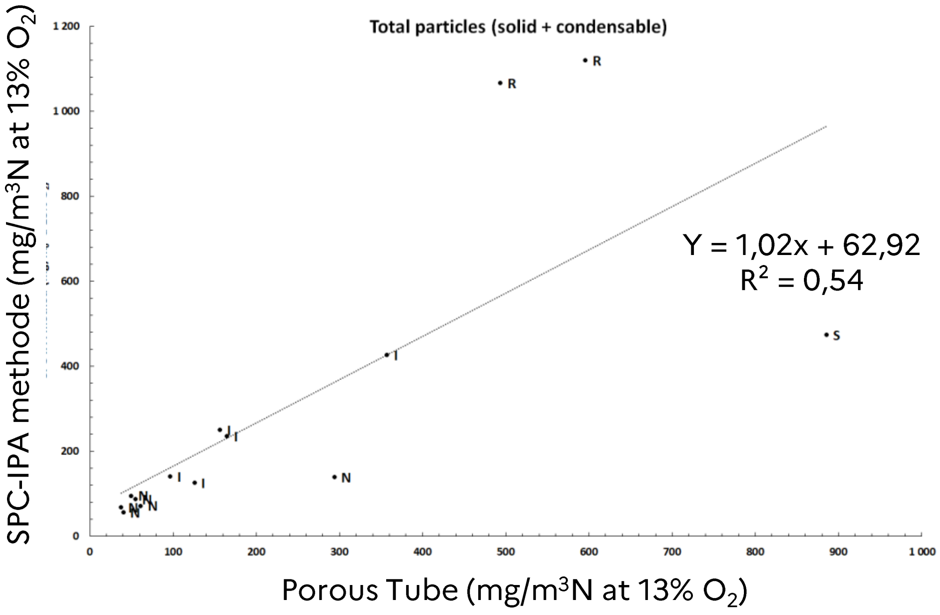




3. c. PM sampling (solid and condensable):

Comparison between *SPC-IPA and Porous Tube methods*



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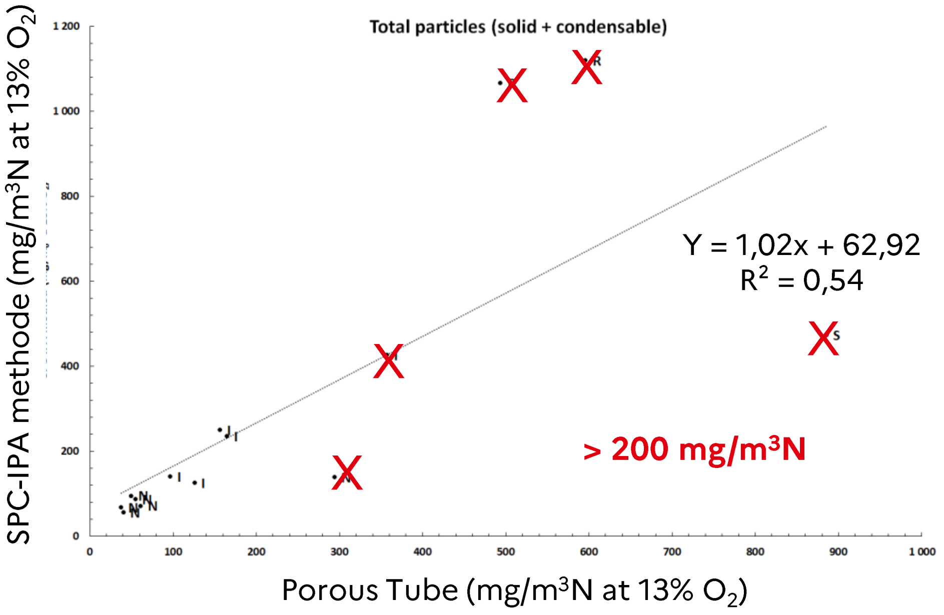

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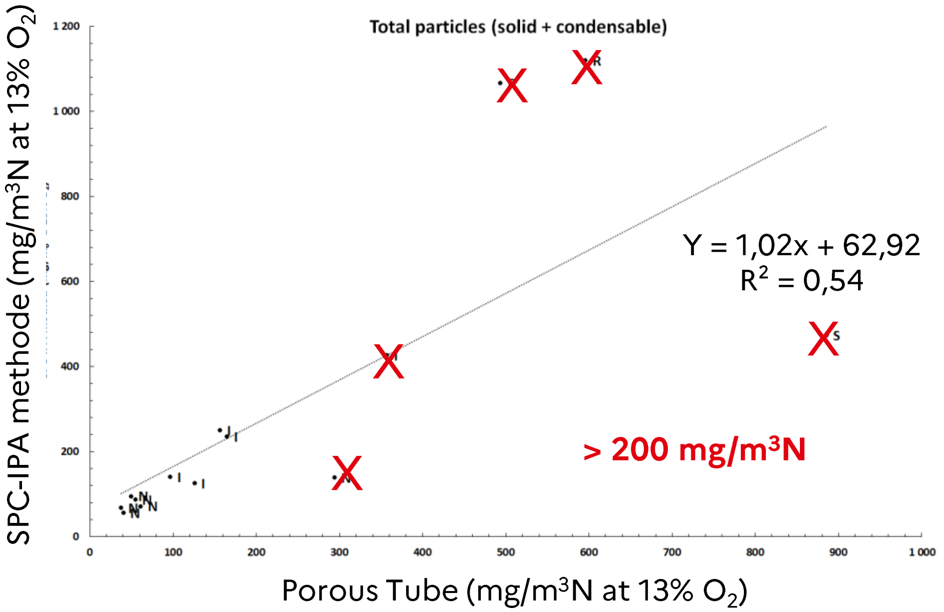
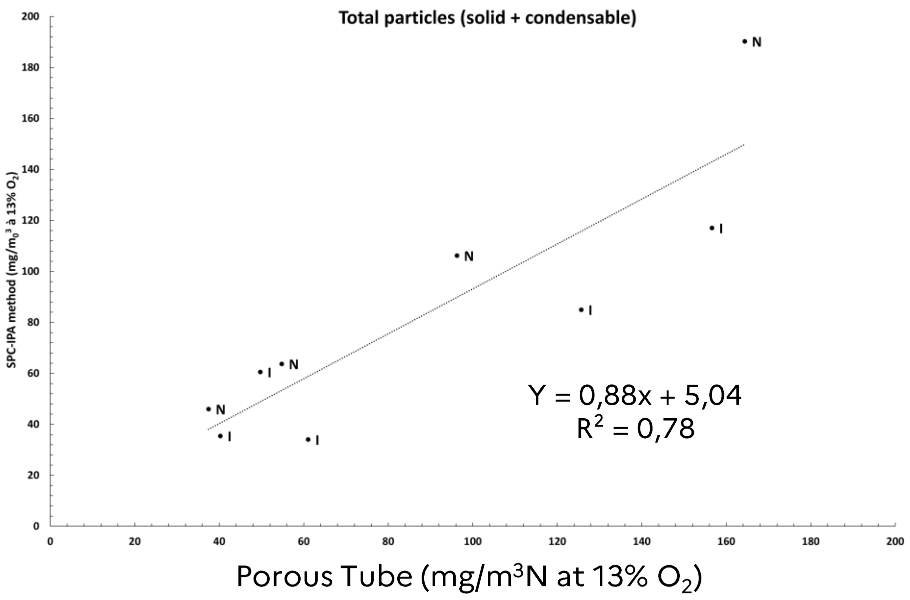




3. d. PM sampling (solid and condensable):

Wood log stove: Comparison between Dilution Tunnel, Porous Tube and SPC-IPA methods

Combustion conditions	n	DT method	PT method	SPC-IPA method
		Mean PM (mg/m^{3}N)		
Nominal	7	104	87	126
Intermediate	5	189	180	236
Low	2	735	545	1093
*Limit of quantification**	LOQ	*36,7*	*15,4*	*7,1*

**Limit of quantification = LOQ = Analytical limit / sampled volume*

4. Wood combustion tests performed within the Impress 2 project

EMPIR Grant Agreement 16ENV08 IMPRESS 2 v1.0

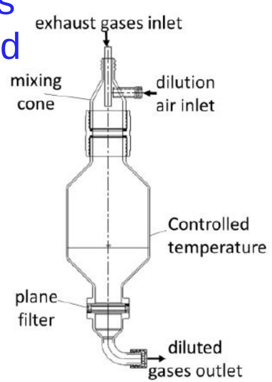
EMPIR
EURAMET
The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Horizon 2020
European Union Funding
for Research & Innovation

4. b. PM sampling (solid and condensable):

Dilution Chamber method:

- 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) and tested to sample both the solid and condensable fractions of PM.
- Technology developed by Innovhub, ENEA and Dado Lab
- Complete design features are described in the study of *Hugony et al. 2019*.



27th European Biomass Conference and Exhibition, 27-30 May 2019, Lisbon, Portugal

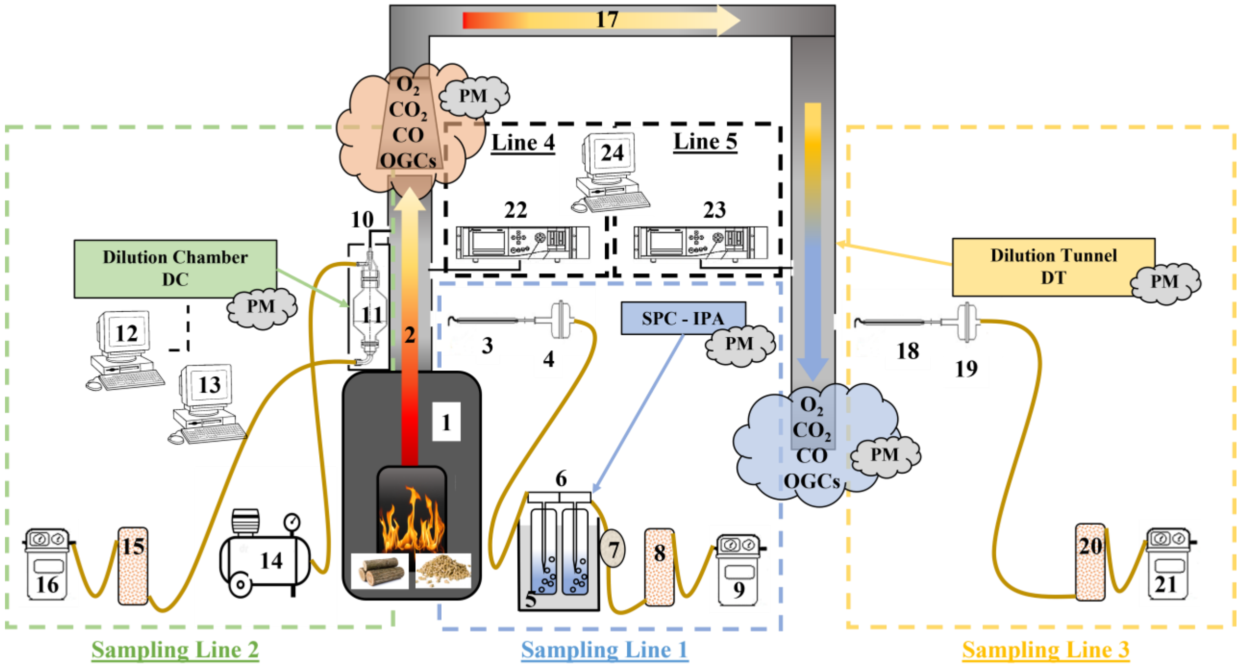
SET-UP OF A NEW SAMPLING METHOD TO MEASURE CONDENSABLE PM FROM RESIDENTIAL SOLID BIOMASS HEATING GENERATORS

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

4. c. Set up of the wood combustion tests: Impress 2

80 combustions tests carried out by 5 european institutes: ENEA, ISSI (Italy), Ineris (France), DTI (Denmark) and RISE (Sweden) – With wood log and pellet stoves

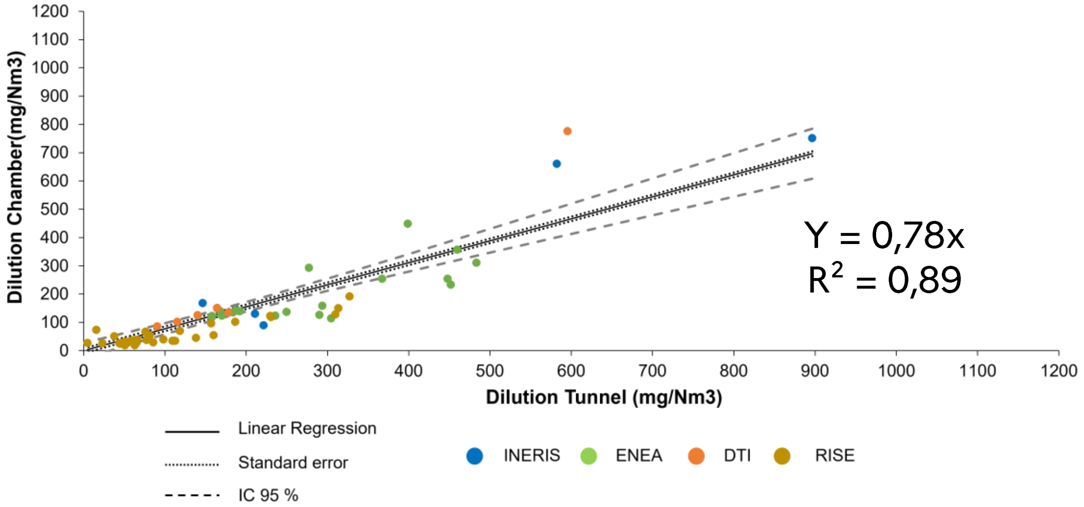


5. Results of Impress 2 combustion tests

5. a. PM sampling (solid and condensable):

Comparison between *Dilution Chamber and Dilution Tunnel methods*

All combustion tests
(Residential pellet and wood stoves)



5. b. PM sampling (solid and condensable):

Pellet stove: Comparison between Dilution Chamber and Dilution Tunnel

Institutes	n	DC method	DT method	R^2
		Mean PM (mg/m^{3}N)		
Ineris	-	-	-	-
ENEA, ISSI	10	129	167	0,99
DTI	-	-	-	-
RISE	6 *(nominal)*	33	38	0,93
	7 *(low)*	118	220	0,93
LOQ		*18,3*	*58,9*	

Data from the study of Céa et al. 2021

5. c. PM sampling (solid and condensable):

Wood log stove: Comparison between Dilution Chamber and Dilution Tunnel

Institutes	n	DC method	DT method	R^2
		Mean PM (mg/m³N)		
Ineris	3 *(nominal)*	121	145	0,96
	3 *(low)*	501	567	
ENEA, ISSI	12	235	355	0,91
DTI	6	230	214	0,98
RISE	18	44	91	0,93
LOQ		*16,3*	*53,3*	

Data from the study of Céa et al. 2021

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5. a. PM sampling (solid and condensable):

Dilution Tunnel, SPC-IPA methods and Dilution Chamber

energy&fuels

pubs.acs.org/EF Article

Development and Evaluation of an Innovative Method Based on Dilution to Sample Solid and Condensable Fractions of Particles Emitted by Residential Wood Combustion

Benjamin Cea,* Isaline Fraboulet, Océane Feuger, Francesca Hugony, Carmen Morreale, Gabriele Migliavacca, Jes Sig Andersen, Morten Gottlieb Warming-Jespersen, Daniel Bäckström, and Sara Janhäll

Cite This: https://doi.org/10.1021/acs.energyfuels.1c02595 Read Online

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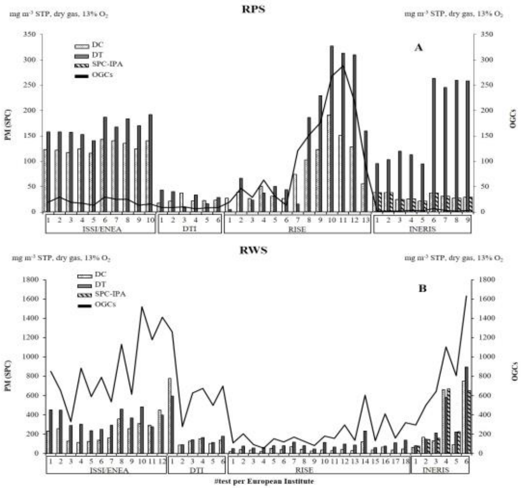

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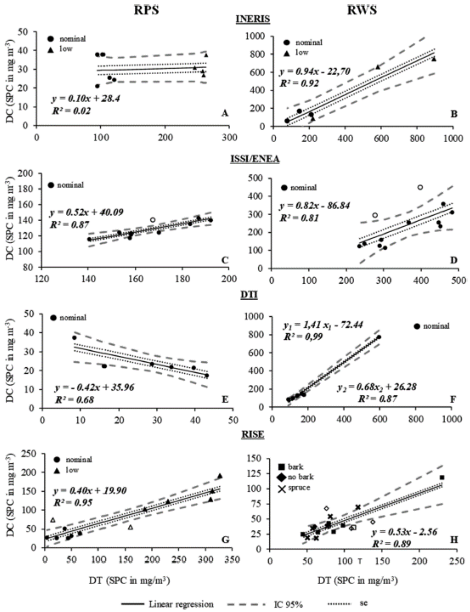

5. d. PM sampling (solid and condensable):

Other projects with the Dilution Chamber method:

- Profile Pizza an Italian project on emission from wood pizza ovens
- REMY LIFE project that investigates the impact of uncertainty in pollutants emission and air dispersion models that could negatively affect air quality plan

For these projects, the dilution system layout has been implemented with a refrigerating unit which allows to work with low temperature dilution air (0°C) in order to simulate winter conditions of dilution.

This new version of the system can cover a large range of dilution ratio and temperature.

Conclusions

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Real-LIFE Emissions

Real-Life project: Porous Tube methode (PT)

- Good correlations between the Porous Tube and the Dilution Tunnel (R^2>0,9) or SPC-IPA methode (R^2 = 0,78) at concentrations below 200 mg/m³N

  - ✓ Porous Tube advantages:
    - Sampling solid and condensable fractions of PM
    - Dilution method all terrain compared to the Dilution Tunnel = can be moved
    - Low investment required = low-cost method
    - LQ of Porous tube < LQ of Dilution Tunnel

  - ✓ Porous Tube disadvantage:
    - Need to control the dilution rate with a tracer gas (CO_2)

Perspectives:

- Replace the tracer gas method with a dilution rate control based on dilution air supply depending on the evolution of the flue gas temperature = same system as Dilution Chamber.
- PT need to be used with low PM concentrations (< 50 mg/Nm³)
- Decreased the LQ of PT (increase the sampling flow rate or increase the time sampling)
- PT to be used in the intercomparison of methods (Action A4 for Real Life project)

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Perspectives:

- Replace the tracer gas method by a dilution rate control based on dilution air supply depending on the evolution of the flue gas temperature = same system as Dilution Chamber.
- Decrease the LOQ of PT (increase the sampling flow rate or increase the time sampling) to be able to used it at low PM concentrations (< 50 mg/Nm³)
- PT to be used in the intercomparison of methods (Action A4 for Real Life project)

Impress 2 project:

- Good correlations between the Dilution Chamber and the Dilution Tunnel (R^2>0,9)

  ✓ Dilution Chamber advantages:
    - Sampling solid and condensable fractions of PM
    - Dilution method all terrain and more compact compared to the Dilution Tunnel
    - Automated adjustment of sampling temperature and DR in the chamber
    - LQ of Dilution Chamber < LQ Dilution Tunnel

  ✓ Dilution Chamber method disadvantages:
    - Investment cost = between 20 and 30 k€
    - Not easy to implementation = required qualified personnel
    - There is only one prototype developed by Innovhub and Dado Lab (Italy)

Perspectives:

- Continue to make further measurements with this device during combustion tests.
- Improve the dilution chamber system (decrease the LQ) – *projets des italiens ???*

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Not tested in Real-Life project

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Thank you for your attention