Selection and integration of high temperature catalysts into a stove

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Project ERA-NET Bioenergy "Stove 2020"

Workshop: "Wood Stoves 2020 - Towards high efficiency and low emissions"

Stockholm (Sweden), 13th of June 2017

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Background and objectives (I)

- In the recent 15 years biomass based room heating systems became more and more popular and the development towards low emission appliances is progressing.
- In particular, a further development and optimisation of stoves is necessary in order to achieve low emissions of atmospheric pollutants and particularly to meet stricter emission limits.
- Secondary measures like oxidation catalysts are already applied for emission reduction of wood stoves.
- As these catalysts are usually installed in the flue gas duct down-stream the stove the emission reduction potential is limited due to:
  - **The comparably low temperatures at stove outlet**
  - **The expected slow heat-up of the catalyst at this position.**

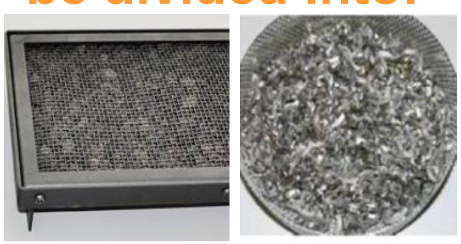
→ Almost no emission reduction during start-up where typically the highest emissions occur

Background and objectives (II)

- Therefore, a catalyst implementation into a stove may have several advantages:
  - Light-off temperature of catalyst can be reached in short time
  - High operation temperatures of the catalysts may support tar and soot reduction
  - At high operation temperatures a better VOC reduction is expected
  - Reduced risk of tar and soot deposits
- However, suitable materials for a high temperature application are needed as well as a higher pressure drop has to be considered.
- As usually primary measures are primarily applied as a tool to reduce emissions, a combination of primary and secondary measures may be a suitable approach for low emission wood stoves.
- Based on this approach different high temperature catalysts have been integrated into a new low emission stove concept at different positions and their basic suitability has been evaluated.

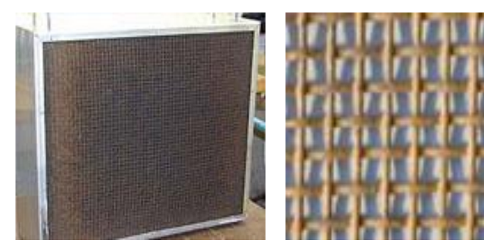
Catalysts for wood stoves (I)

- The most common catalytic procedure to reduce emissions from stoves is the heterogeneous catalysis. At this type of catalysis the phase of the catalyst differs from that of the reactants:
  - catalyst → solid
  - reactants → gaseous
- The basic structure of solid catalysts consists of metals (most common is iron alloy) or ceramics (e.g. aluminium oxide, zirconium oxide)
- Regarding the structure solid catalysts for emission reduction can be divided into:



Packed beds

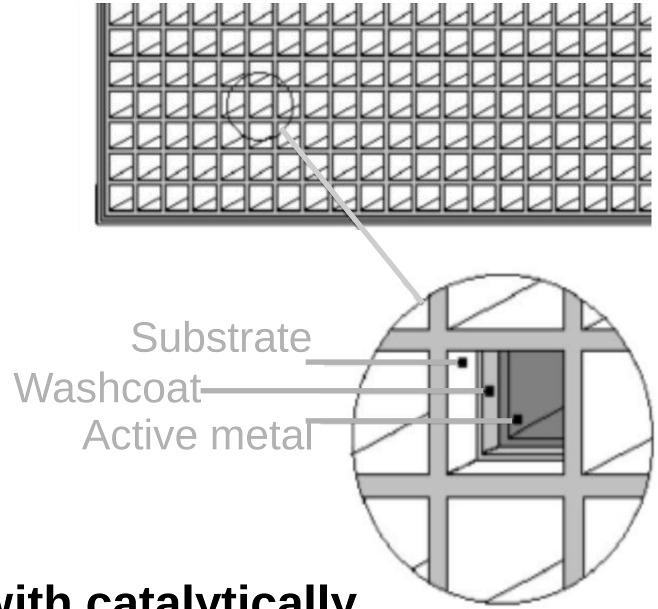
Monoliths (honeycomb or foam structure)



Networks/ wire meshes

Catalysts for wood stoves (II)

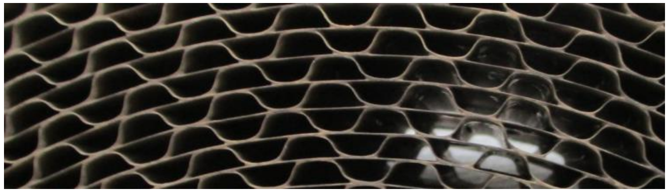
Components of solid catalysts:



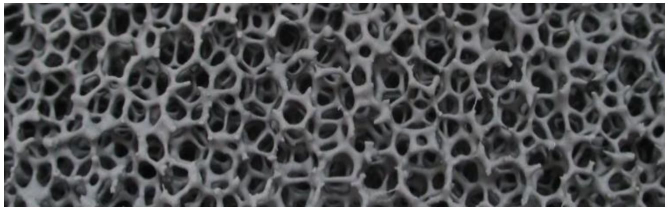
- **Substrate: Carrier material for the washcoat and the active metal. The structure of the catalyst is defined by the material and production process of the substrate.**
- **Washcoat: To increase the surface of the catalyst a washcoat (powder suspension of metal oxides) is spread and dried on the substrate.**
- **Active metal: The surface is impregnated/coated with catalytically active components. Thereby the following main activities of the metals occur:**
  - **Rh > Pd > Pt → oxidation of CO**
  - **Pt > Rh > Pd → oxidation of VOC**
  - **Rh > Pd > Pt → reduction of NO**
- **At high operation temperatures also metals like Ni, Cu and Mg can achieve considerable conversion rates.**

Methodology (I) – Description of high temperature catalysts applied

- **Based on an evaluation of catalysts available on the market and the experiences of test runs already performed two different types of high temperature catalysts have been investigated:**
  - **Metal based honeycomb catalysts**
    - Active metals: Pt, Pd



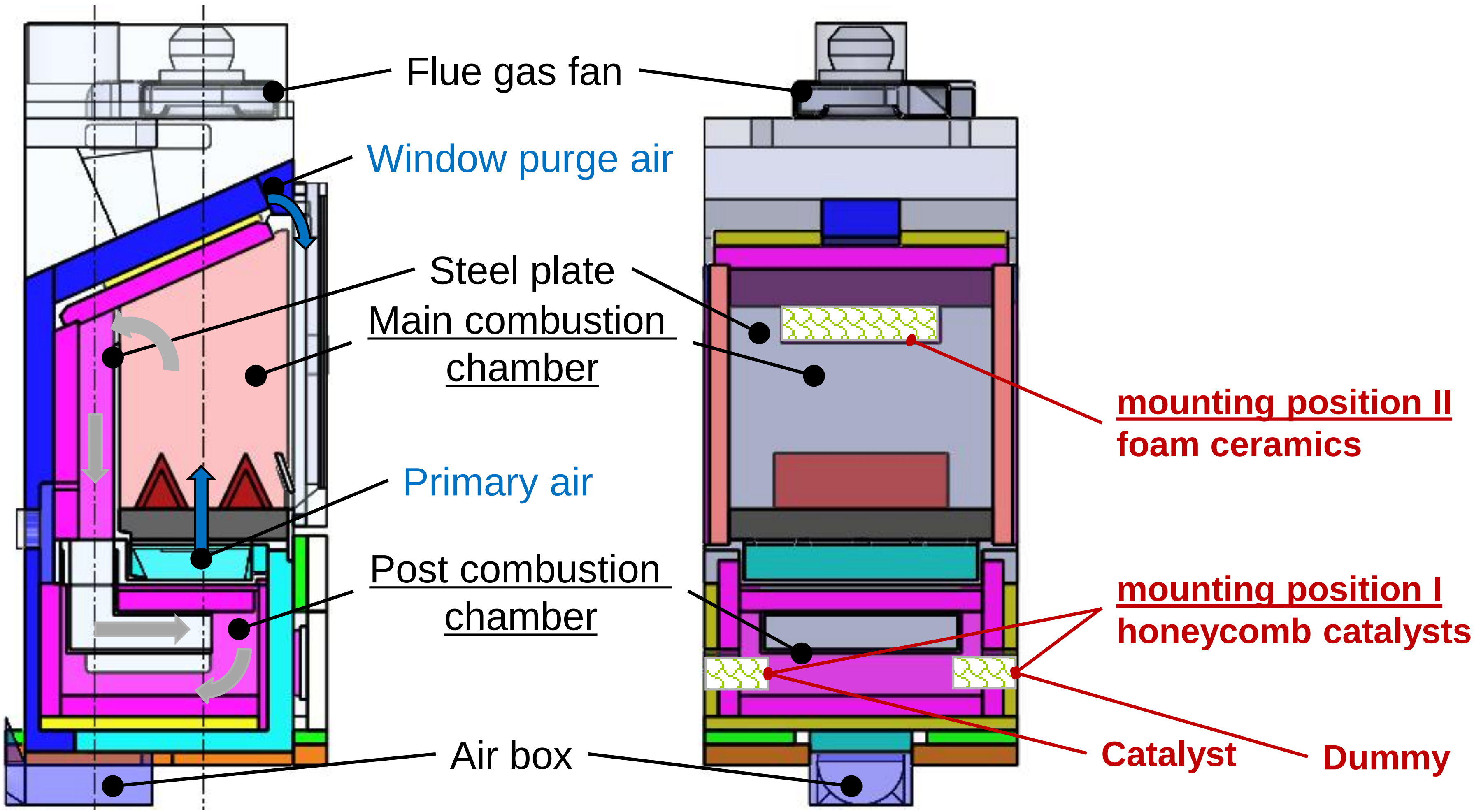
  - **Catalytically coated foam ceramics**
    - Active metal: Pt



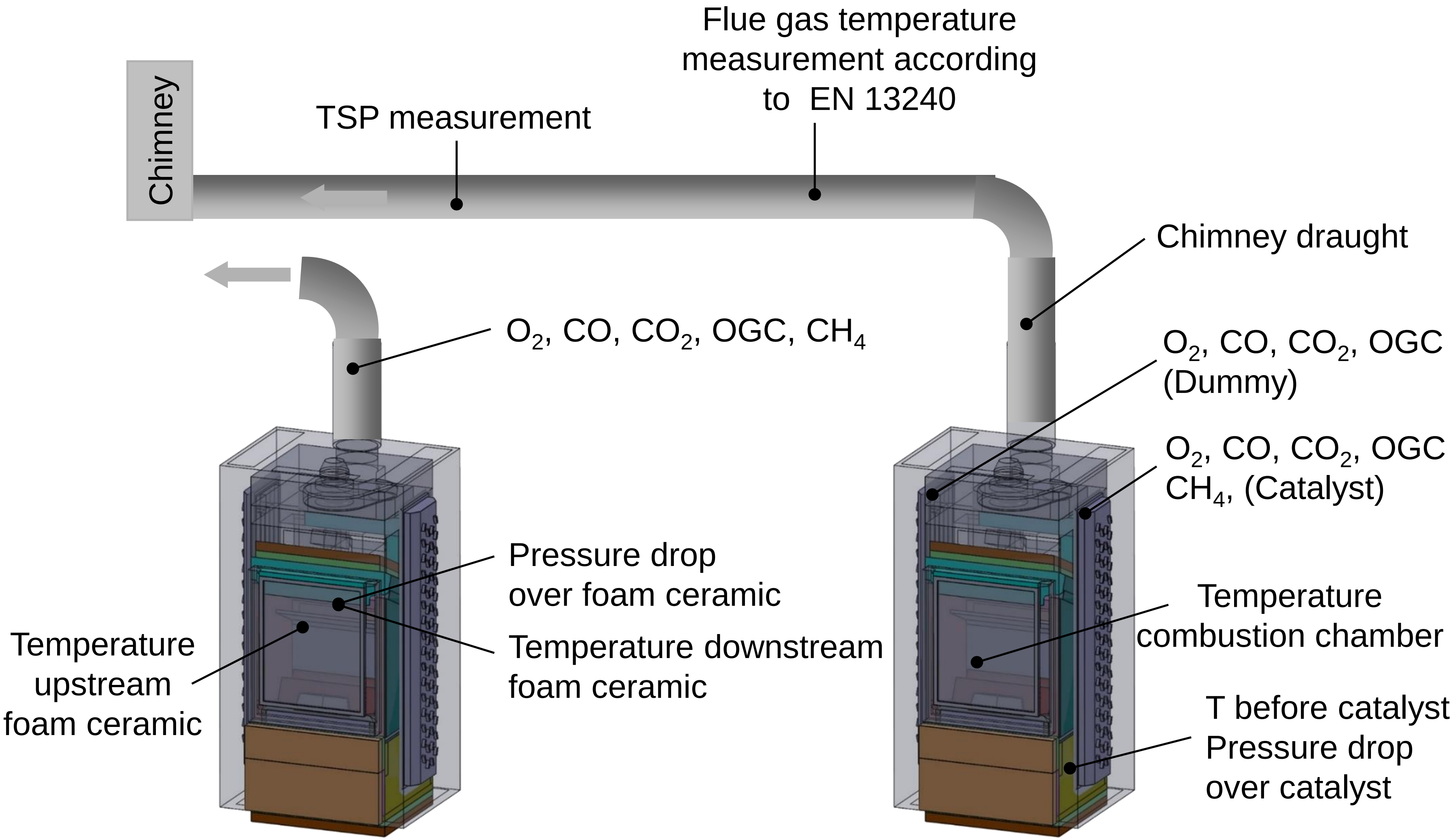
- **The catalysts applied have been tested at different positions of the low emission stove:**
  - **Metal based honeycomb catalysts installed at the outlet of the post combustion chamber – mounting position I**
  - **Foam ceramics with and without catalyst installed at the outlet of the main combustion chamber – mounting position II**

Methodology (II) – Description of the chimney stove applied

- Specially adapted low emission logwood chimney stove with 2 flue gas pathways downstream the post combustion chamber



Methodology (III) – Description of the test stand



mounting position II - foam ceramic

mounting position I - honeycomb catalyst

Methodology (IV) – Test run procedure

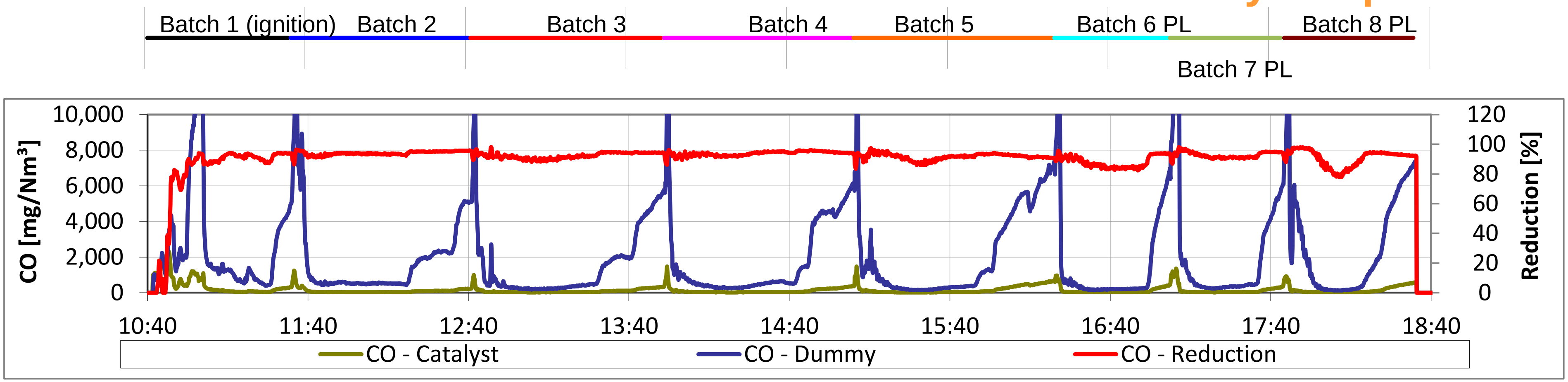
- **Performance of test runs with different high temperature catalysts at a low-emission logwood stove**
  - **Long-term (2 or 3 weeks) operation of the stove with each catalyst**
  - **Performance of dedicated testing campaigns with emission measurements**
  - **One operation day consists of 8 successive batches (5 full load + 3 partial load)**

- **General operation conditions**
  - **Constant draught of 12 Pa over the stove**
  - **Test fuel: hardwood (beech) without bark, moisture content: 12 - 16 wt% w.b.**

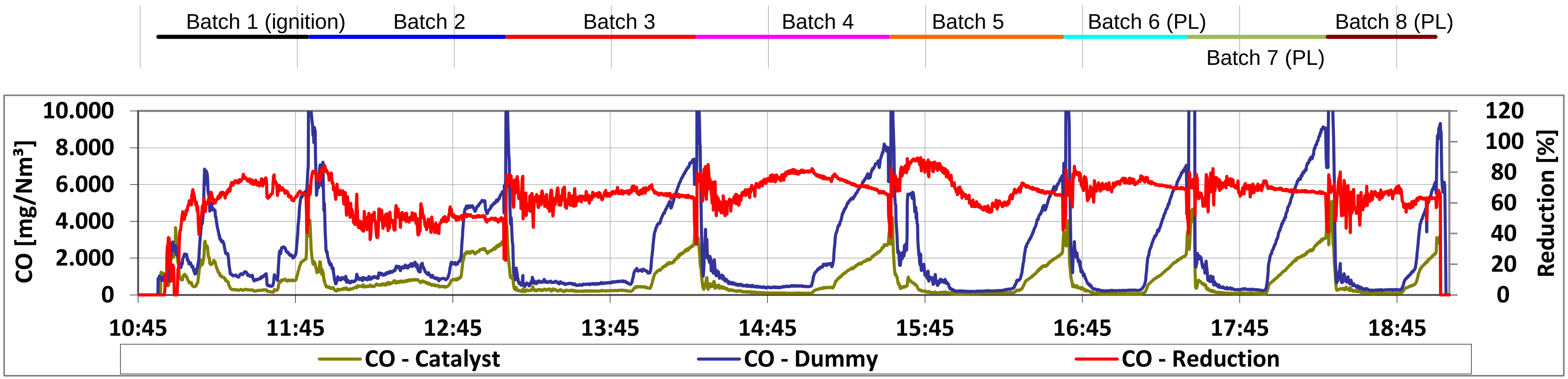
- **Performance of gaseous and TSP emission measurements**
  - **Gaseous emissions (CO, OGC, CH_4, O_2): continuous measurement from before ignition of batch 1 until the end of test run**
  - **TSP emissions (according to VDI 2066): over the whole batch (from closing the door until opening it again)**

Results of test runs performed (I) – Honeycomb catalyst – mounting position 1

■ Trends of CO emissions and CO reduction at the 1st day of operation



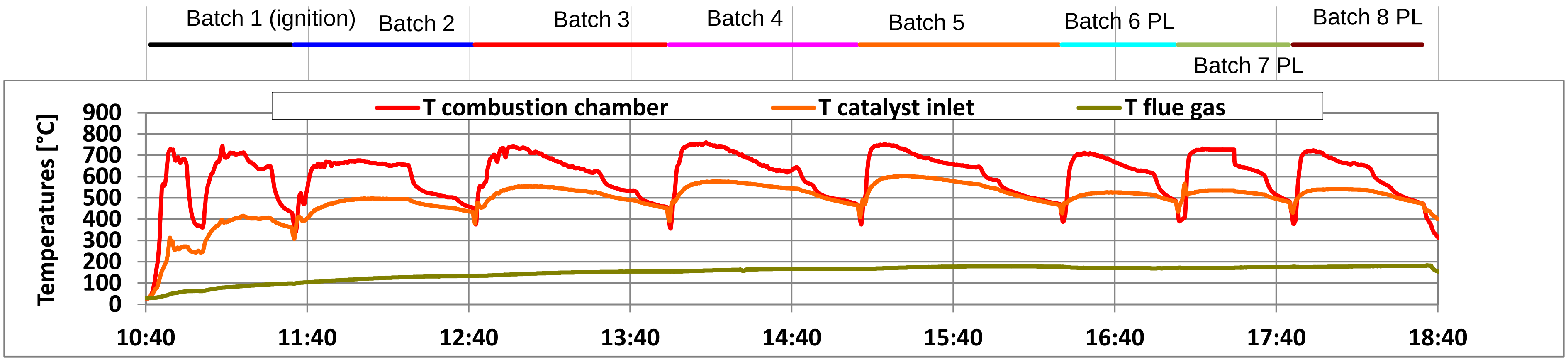
■ Trends of CO emissions and CO reduction at the 11th day of operation



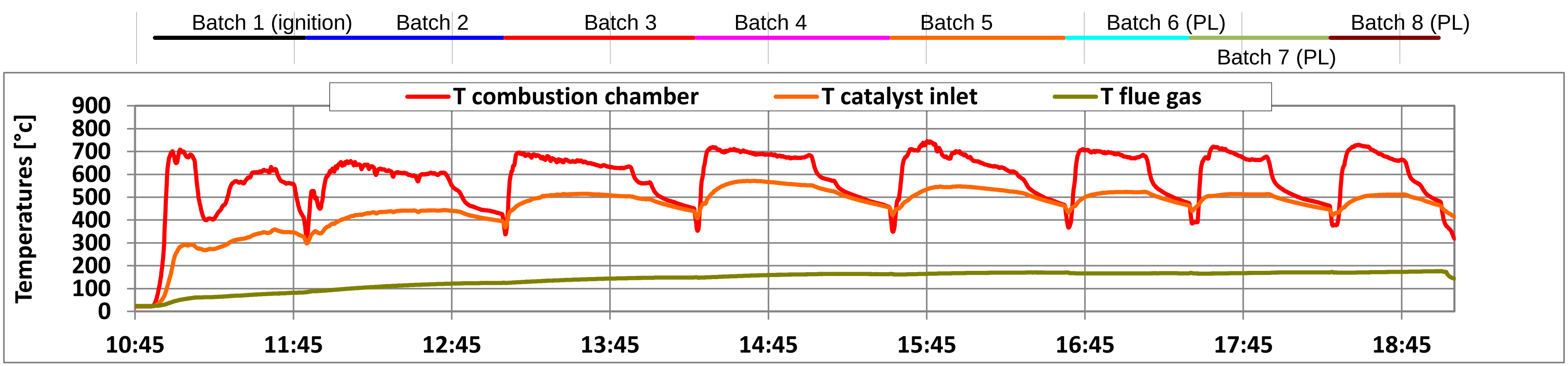
Explanations: Emissions related to dry flue gas and 13 vol% O_2

Results of test runs performed (II) – Honeycomb catalyst – mounting position 1

Trends of flue gas temperatures at the 1st day of operation

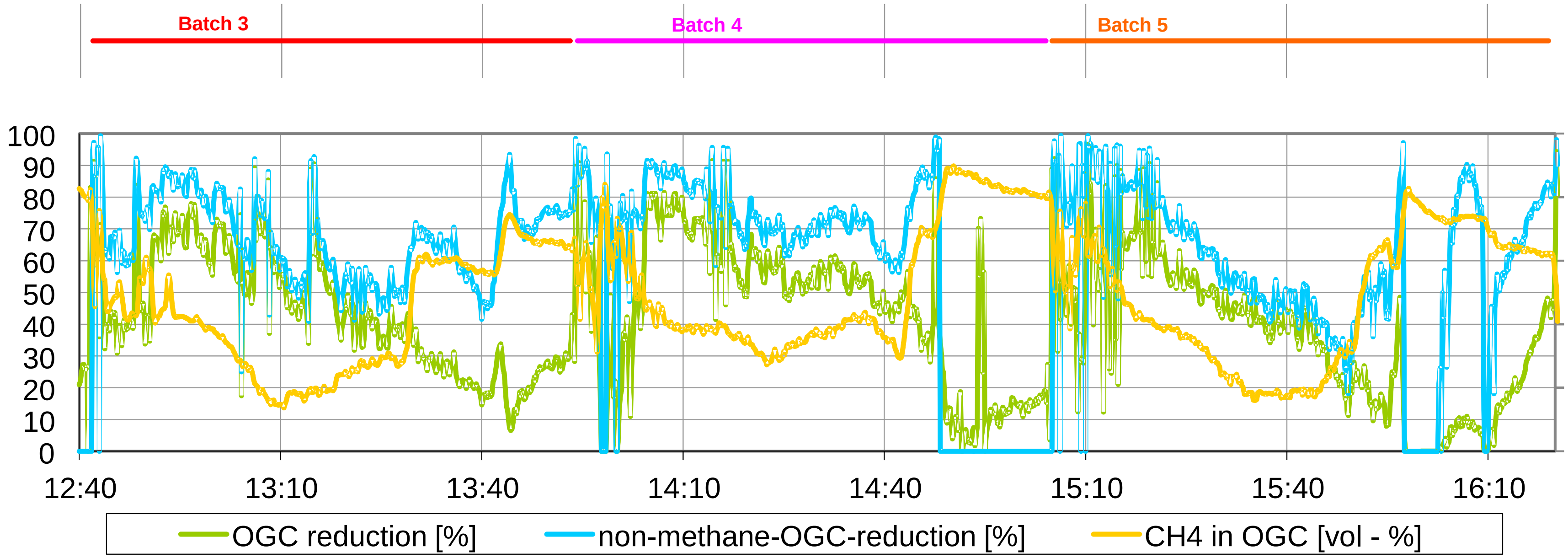


Trends of flue gas temperatures at the 11th day of operation



Results of test runs performed (III) – Honeycomb catalyst – mounting position 1

- **Influence of CH_4 on OGC reduction**



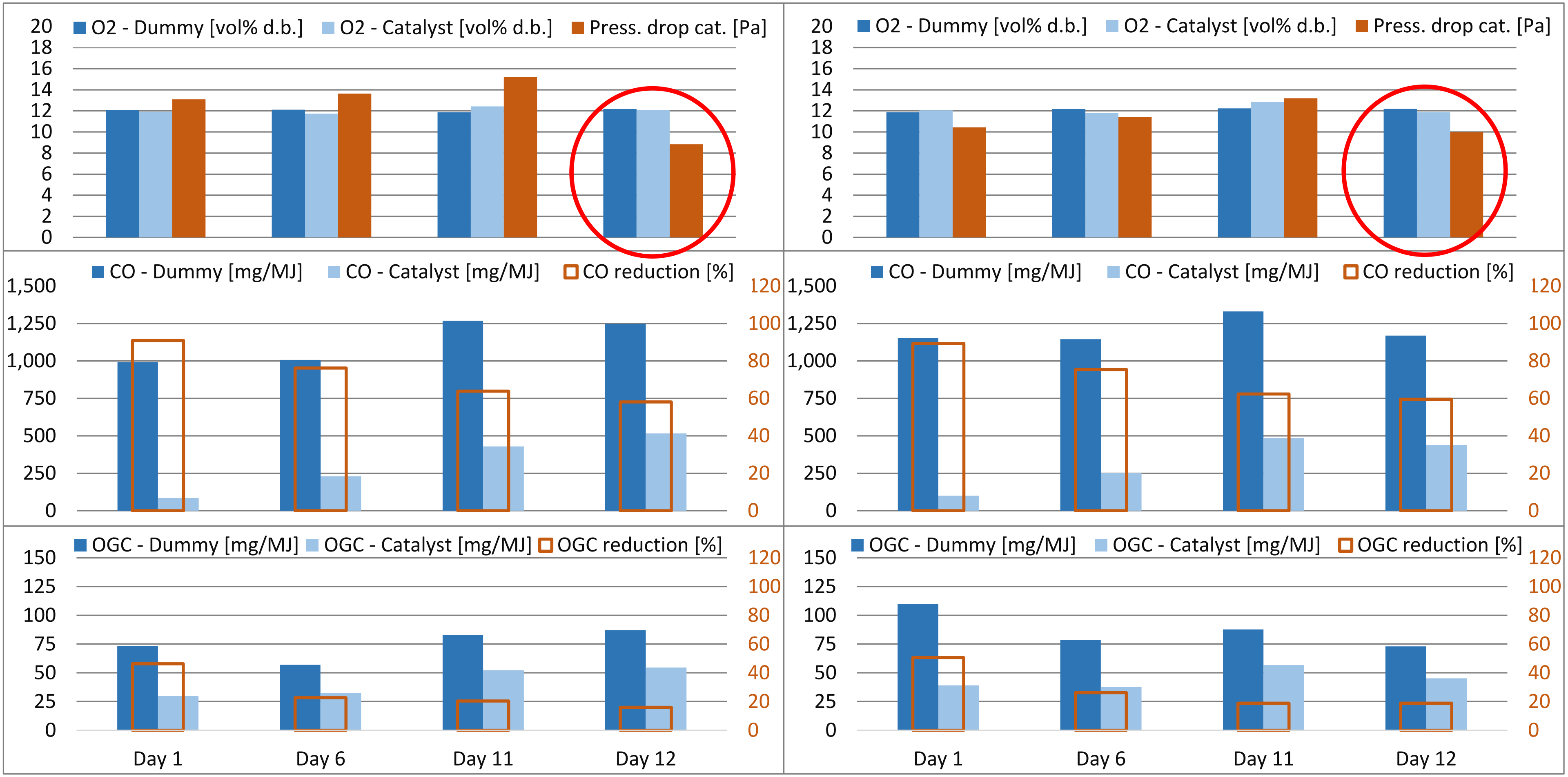
→ CH_4 is hardly converted by the catalyst

Explanations: Results of test run at day 1; OGC reduction (green), non-methane OGC reduction (blue); % CH_4 in OGC = (ppm CH_4 / ppm OGC) * 100

Results of test runs performed (IV) – Honeycomb catalyst – mounting position 1

Nominal load

Partial load



Manual cleaning of the catalyst with compressed air after 11th day of operation

Results of test runs performed (V) – Honeycomb catalyst – mounting position 1

- **Catalyst before the test runs (view at outlet)**

- **Catalyst after 11 days of operation (view at inlet)**

- **Catalyst after manual cleaning after 11 days of operation (view at inlet)**

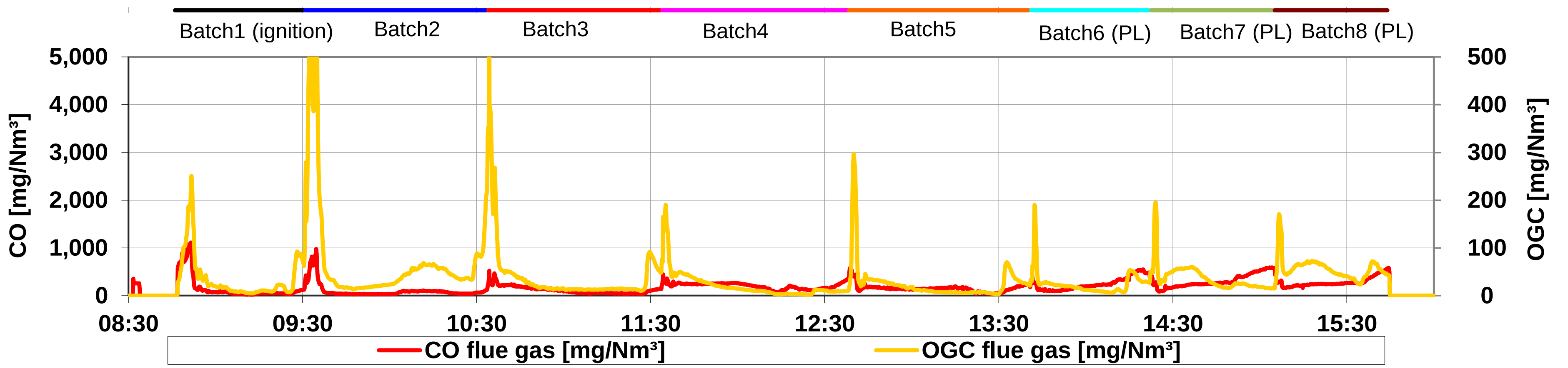
- **Significant and partly very hard to remove fly ash deposits**
  → pressure drop increased

- **Manual cleaning showed no effect on the emission reduction efficiencies**

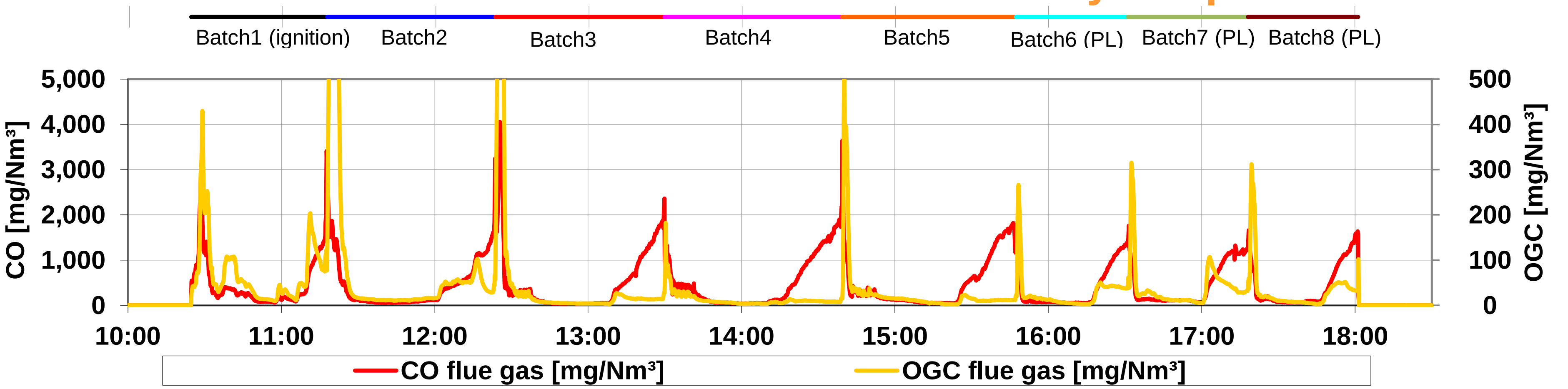
- **Chemical analyses as well as SEM/EDX analyses clearly indicated that the catalyst has been de-activated by aerosol deposits (condensation of mainly K_2SO_4 and KCl), which have blocked the active centre of the catalysts**

Results of test runs performed (I) – Foam ceramic – mounting position 2

Trends of CO and OGC emissions at the 3rd day of operation



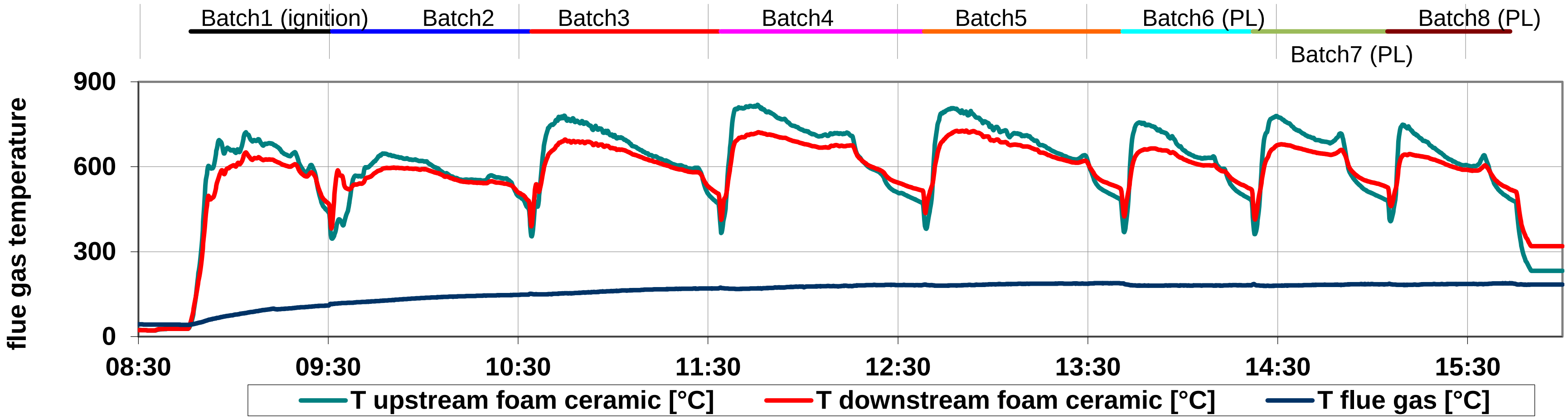
Trends of CO and OGC emissions at the 18th day of operation



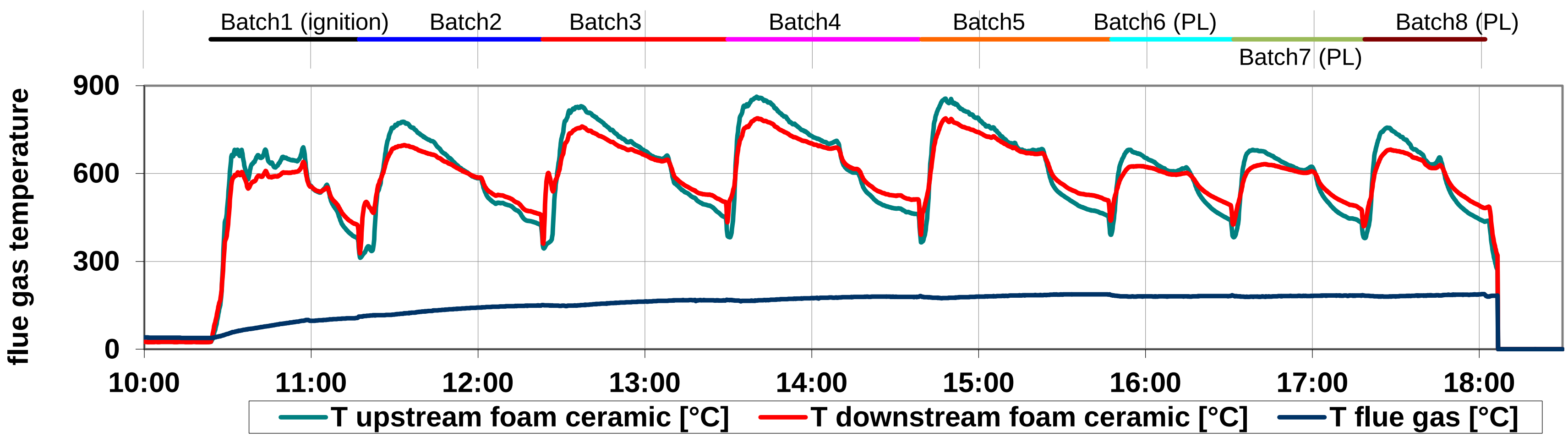
Explanations: Emissions related to dry flue gas and 13 vol% O_2

Results of test runs performed (I) – Foam ceramic – mounting position 2

■ Trends of flue gas temperatures at the 3rd day of operation



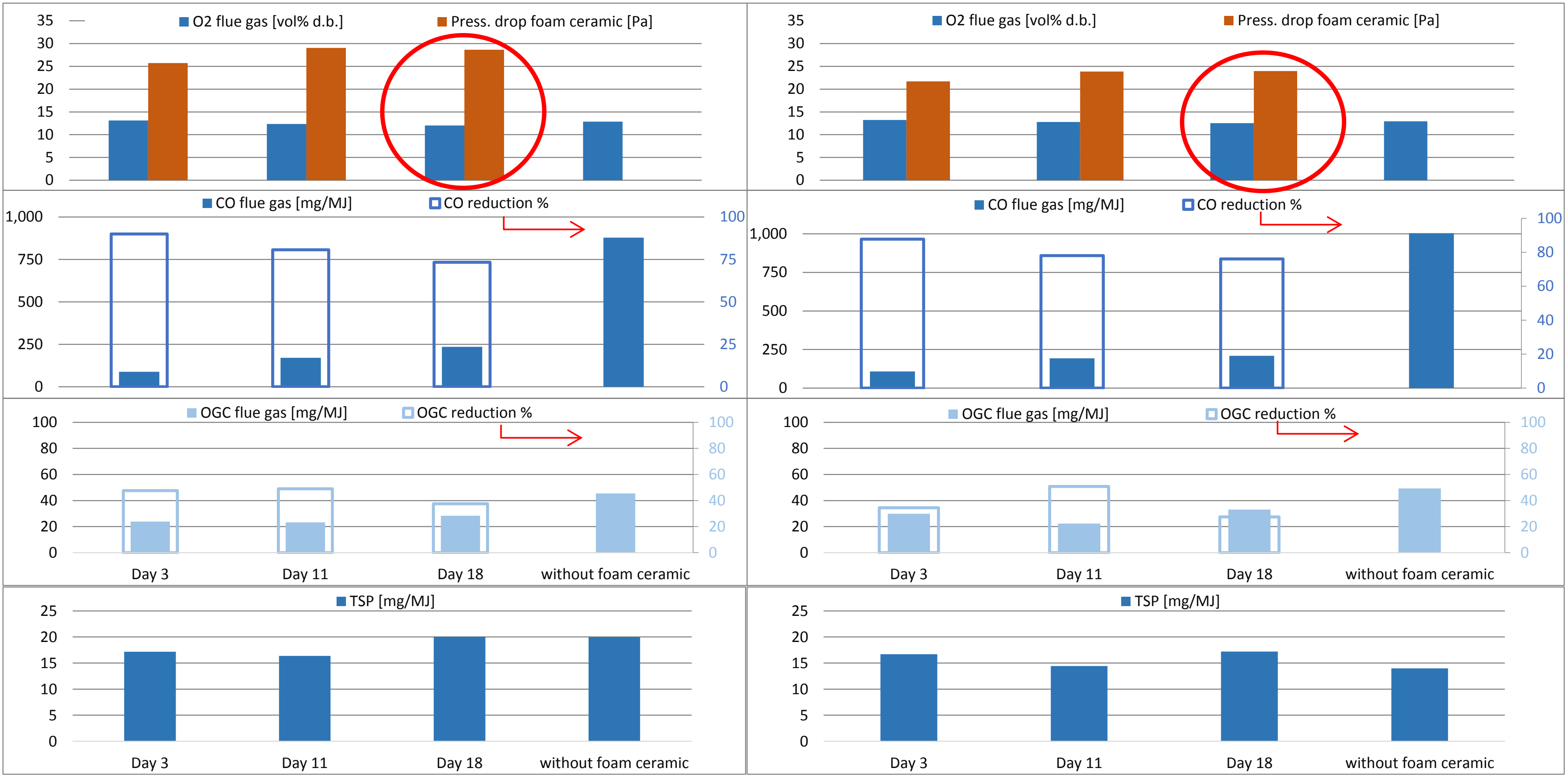
■ Trends of flue gas temperatures at the 18th day of operation



Results of test runs performed (II) – Foam ceramic – mounting position 2

Nominal load

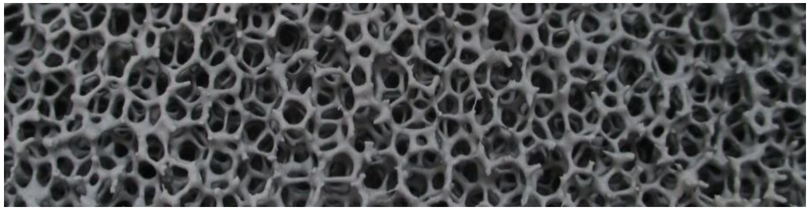
Partial load



Manual cleaning of the catalyst with compressed air after 11th day of operation

Results of test runs performed (III) – Foam ceramic – mounting position 2

- Foam ceramic before the test runs



- Foam ceramic after 11 days of operation

- Foam ceramic after 18 days of operation

- Some fly ash deposits on the surface of the foam ceramic
  → slight increase of pressure drop
- By manual cleaning most of the fly ash deposits could be removed and the pressure drop over the foam ceramic could be reduced again
- Manual cleaning showed no effect on the emission reduction efficiencies

Conclusions and recommendations (I)

- The implementation of a high temperature catalyst at the outlet of the post combustion chamber (temperature range of about 500 °C) is not recommended as tests showed unstable reduction efficiencies.

→ **Decreasing reduction efficiencies over time can most likely be attributed to catalyst de-activation as a consequence of blocking of active centers caused by aerosol condensation.**

- High temperature catalysts, which are mounted at the outlet of the main combustion chamber (temperature range 600 - 800 °C) showed sufficiently high emission reduction efficiencies regarding CO (69 – 73%) and OGC (27 – 38%) and seem basically to be suitable for logwood stoves.

→ **However, the emission reduction efficiency decreased for the catalysts over the testing period of about 100 hours of operation and manual cleaning showed no positive effect**

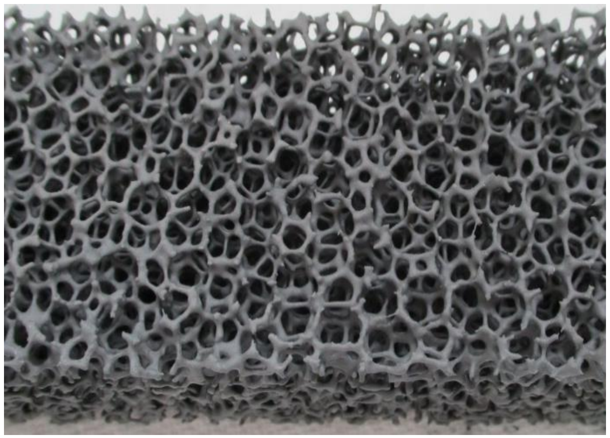
Conclusions and recommendations (II)

- **Tests over a whole heating period would be needed to be able to evaluate the long-term performance of catalysts in wood stoves as well as the possible need of cleaning.**

- **Furthermore, catalysts need enough surface to achieve a sufficient reduction efficiency. This is usually provided by narrow channels which cause a certain pressure drop. The pressure drops are usually too high for an operation of the stove with natural draught only.**

→ **Therefore, either a flue gas fan is needed if a catalyst should be integrated or the dimension of the catalyst needs to be increased.**

- **In general, the mounting position of integrated catalysts has to be carefully evaluated in terms of operating conditions (existing temperature), materials used and the availability to clean the catalyst.**



Thank you for your attention

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