Evaluation of metal based mesh catalysts for stoves

Project ERA-NET Bioenergy "Wood Stoves 2020"

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Introduction

Background

- **Emissions of unburned components from stove operation cannot be totally avoided by primary measures**
- **Further particle reduction at low levels hard too achieve by primary measures**
- **Aim for fast & affordable solution for improving existing stoves and stove models without possibility for design change**

→ secondary measures, such as filters & catalysts

Literature studies & pretests

- **Literature study and experimental evaluation of non-catalytic ceramic filters indicated no significant improvement**
- **Literature study on catalyst impact on stove emissions and pretests with integrated catalyst showed some promising results**
- **Mesh catalyst provide wide design choice opportunities**

Evaluation procedure

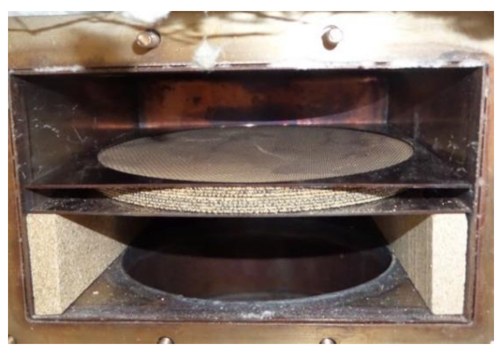
- **Choice of catalyst**
  - **Platinum based mesh catalyst**
- **Evaluation in catalyst test rig**
  - **Heated test rig with sampling locations up- and downstream catalyst**
  - **Catalyst testing (temperature variation, activation conditions, "long-term" use, cleaning impact)**
  - **Comparison with non catalytic inserts & other catalyst models/types**
- **Evaluation of stove integrated catalyst**
  - **Modified traditional stove with catalyst integrated into stove socket**
  - **Evaluation according to project's "close to real life" testing cycle**
    - 8 batches (5 nominal & 3 partial loads + cool down), starting at cold conditions
    - PM sampling at 180°C (Batch 1,3,5,7 and complete test),
    - Bark free birch wood (16% moisture content)
    - Recharge criterion: CO_2 between 3-4% when CO_2 < 25% of $CO_{2,max}$

Evaluation procedure
Catalyst

- **Manufacturer**
  - Catator AB
- **Type & Size**
  - Platinum based mesh catalyst
  - 8 pieces, ø 180mm
- **Mesh properties**
  - Base material: High temperature steel (AISI 330)
  - Wire diameter: 0.5mm
  - Wire opening: about 1.24mm
- **Coating**
  - Stabilized Ce-Oxide / stabilized Platinum

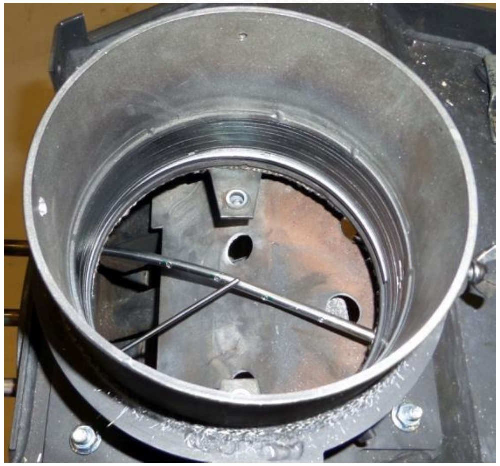
Evaluation procedure
Catalyst test rig

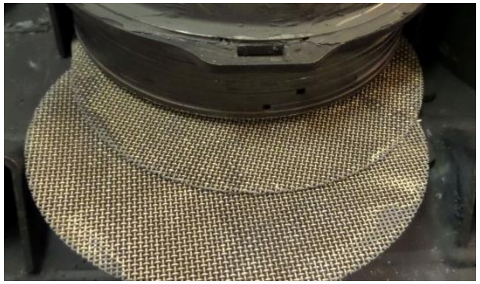
- **Setup**
  - **Stove, heated flue & two identical measuring sections up- and downstream catalyst box**
- **Equipment**
  - **2 sampling trains for gaseous components (IR, paramagnetic, FID)**
  - **2 sampling trains for particles (gravimetric)**
  - **Thermocouples**
  - **Pressure transmitter for catalyst pressure drop & chimney draft**



Evaluation procedure
Stove integrated catalyst test stand

- **Setup**
  - **Traditional stove with new socket for integration of catalyst (ø 150mm)**
  - **Upstream sampling for gaseous emissions**
  - **Downstream sampling according standard**
- **Equipment**
  - **2 sampling trains for gaseous components (IR, paramagnetic, FID)**
  - **Sampling trains for particles (gravimetric)**
  - **Thermocouples & pressure transmitter**

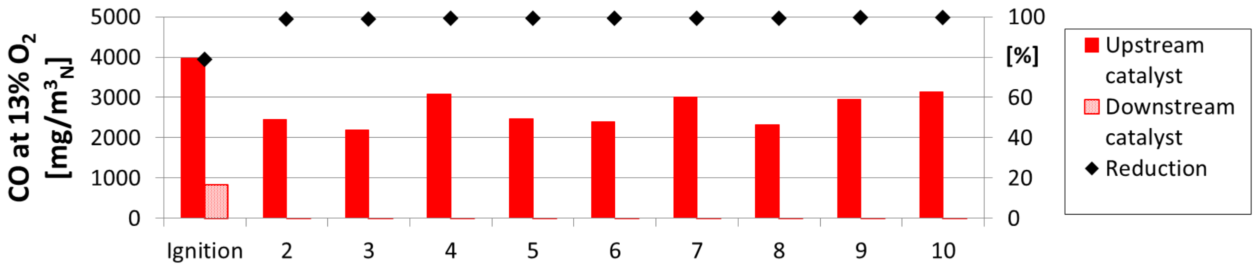




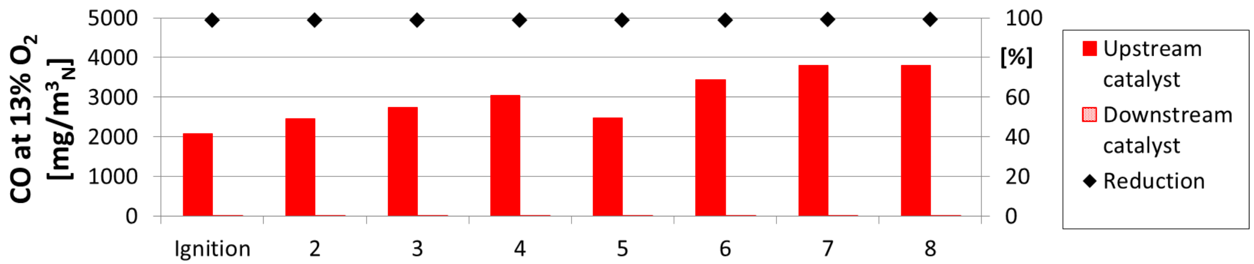
Results catalyst test rig
Summary

- **Significant reduction of gaseous emissions**
  - **Nearly complete CO conversion at temperatures > 300°C**
  - **HC reduction in range between 25-75% (depending on composition)**
  - **Activation temperature for CO reduction around 250°C**
  - **No clear change in conversion rates during evaluation period observed**
- **Significant reduction for particle emissions**
  - **Range 20-50%, (in main part due to reduction of particle forming HC's)**
- **Noticeable flow resistance (catalyst pressure drop)**
  - **Further increasing when running at low temperatures (temporarily & permanently, reversible at higher temperatures & through cleaning)**
- **Impact of area reduction (4/2/1 pcs. equals 50/25/12.5 %)**
  - **Decrease in pressure drop, but also in reduction rates (more visible for particle & HC conversion and at tests with lesser area)**

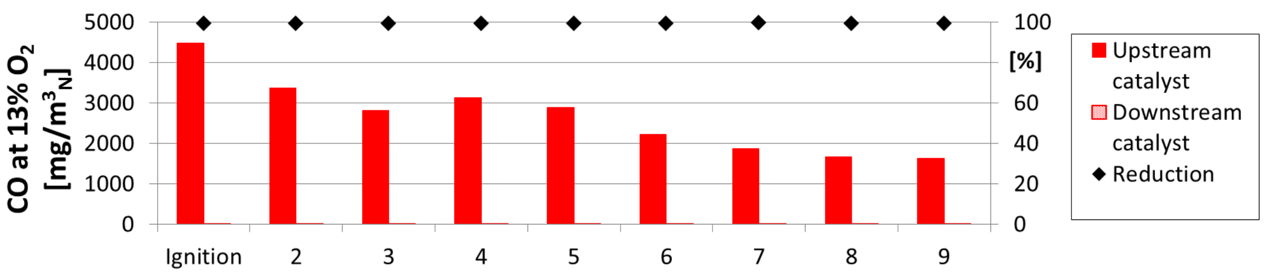
Results catalyst test rig
Carbon monoxide



Test run with fresh catalyst at 300°C

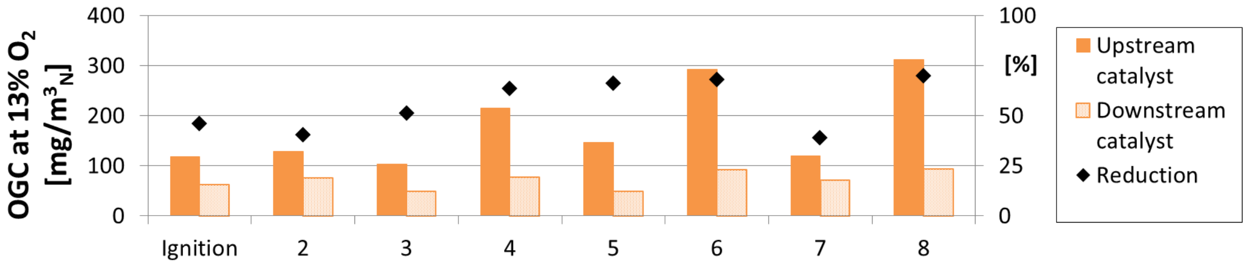


Test run with fresh catalyst at 400°C

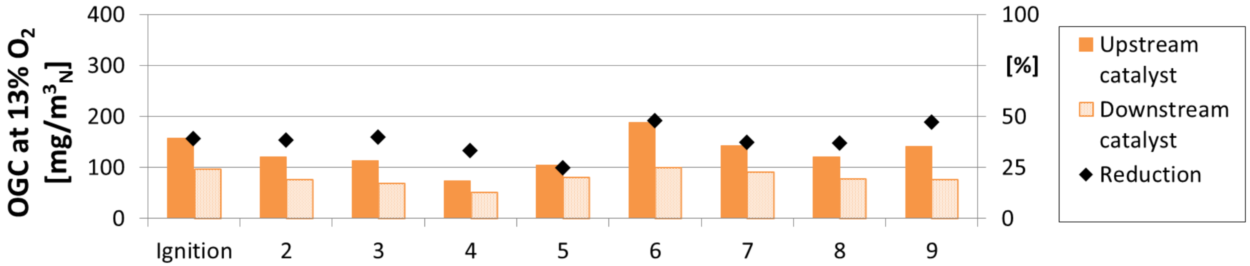


Test run with used catalyst at 300-500°C

Results catalyst test rig
Hydrocarbons



Test run with fresh catalyst at 400°C



Test run with used catalyst at 400°C

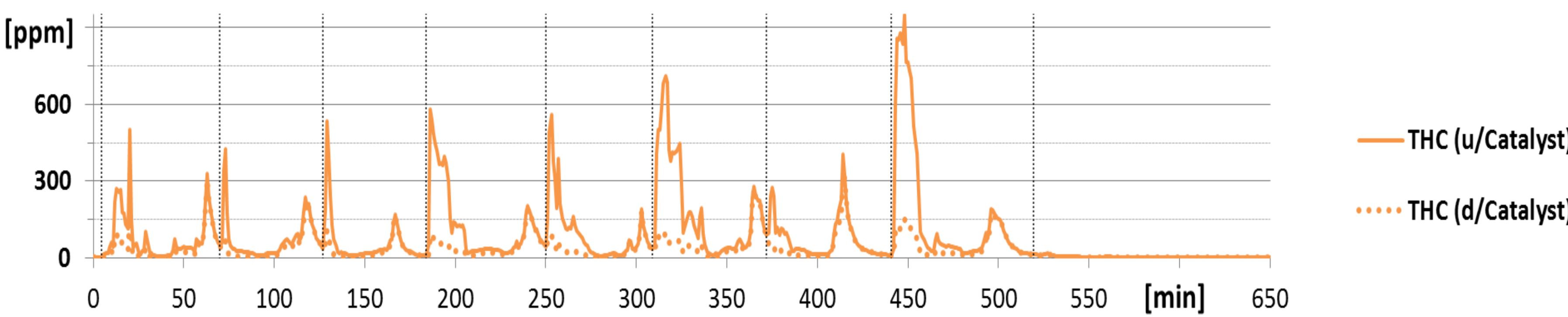


Chart from test run with fresh catalyst at 400°C

Results catalyst test rig
Catalyst activation temperature

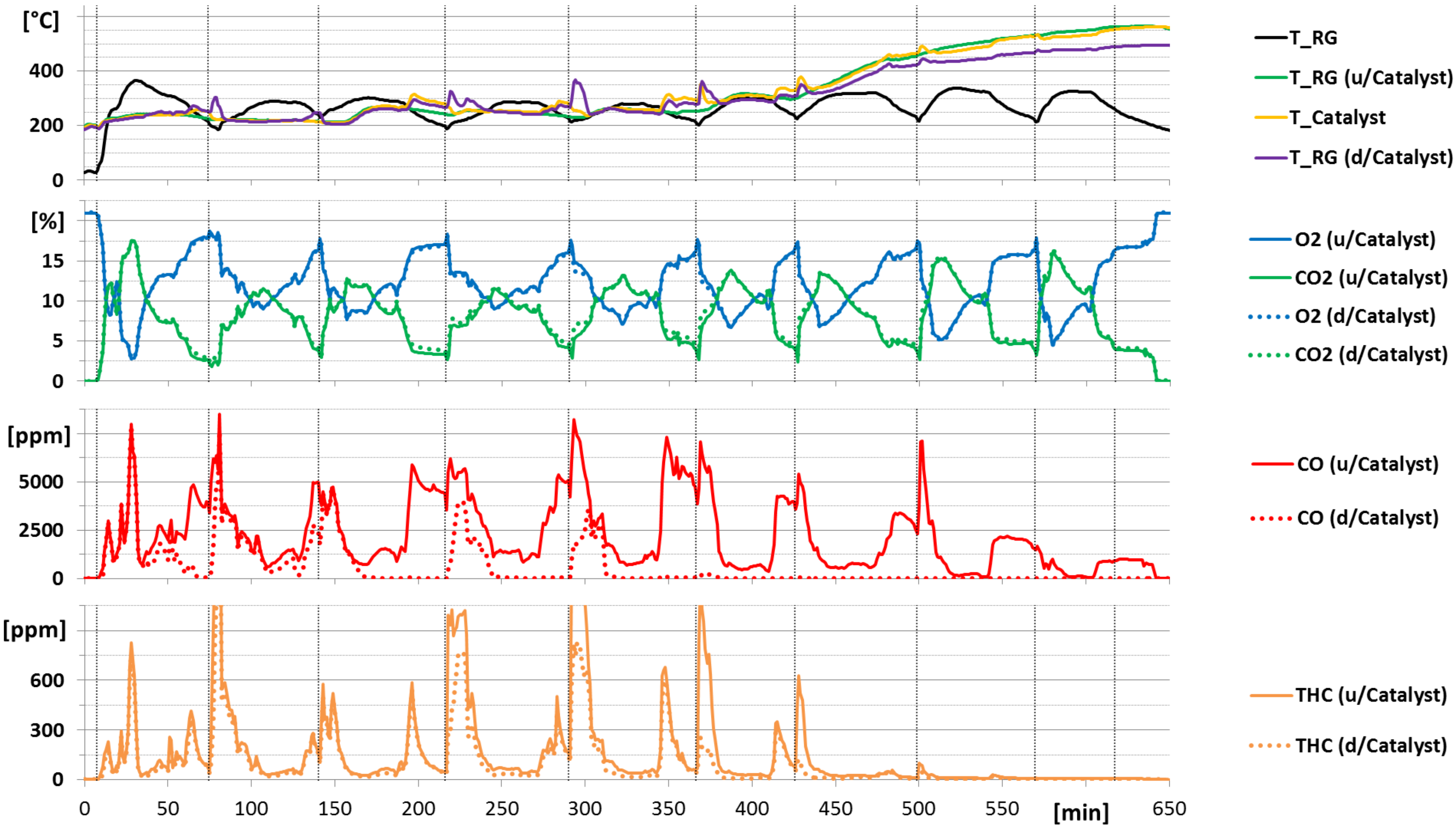
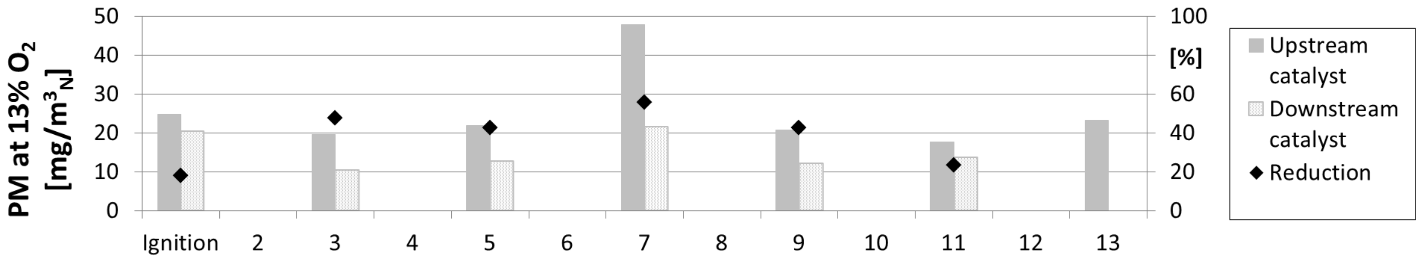
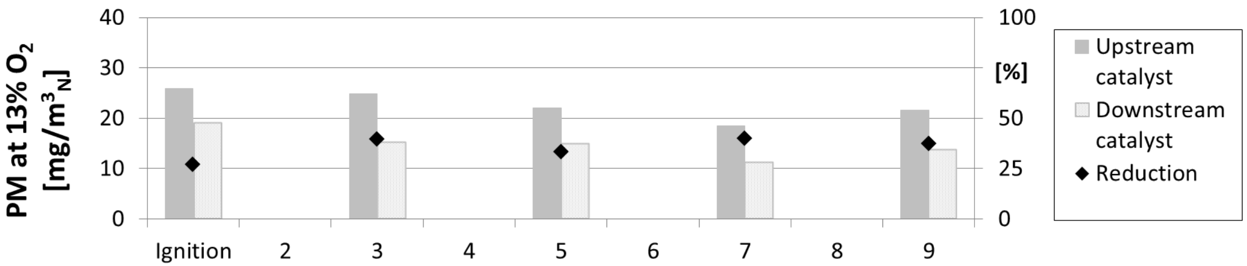


Chart from test run with check for activation temperatures

Results catalyst test rig
Particles



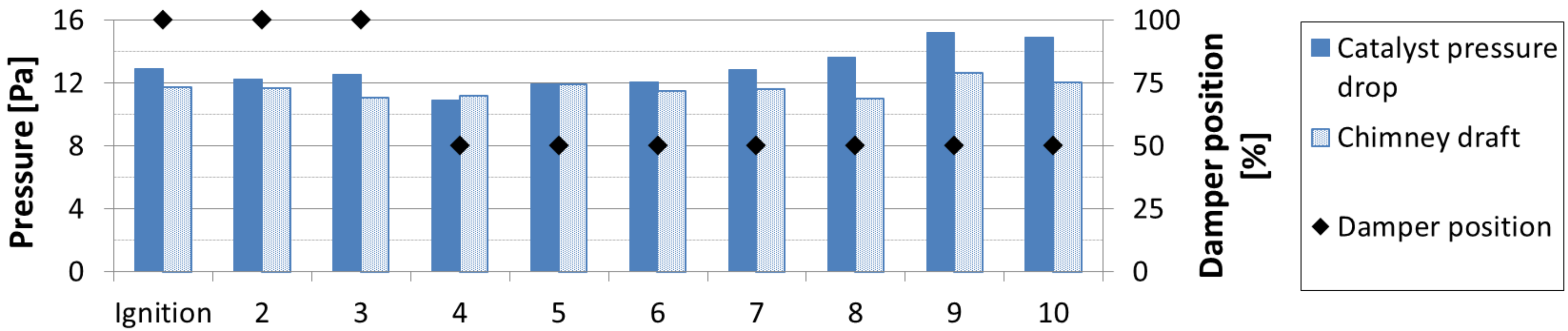
Test run with fresh catalyst at 400°C

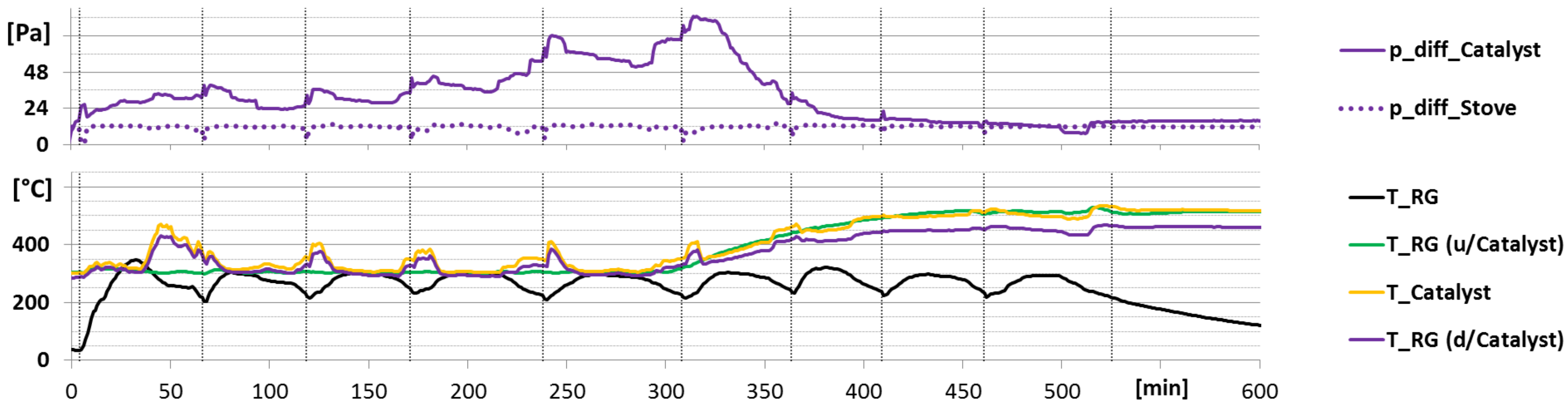


Test run with used catalyst at 400°C

Catalyst after 120h of operation

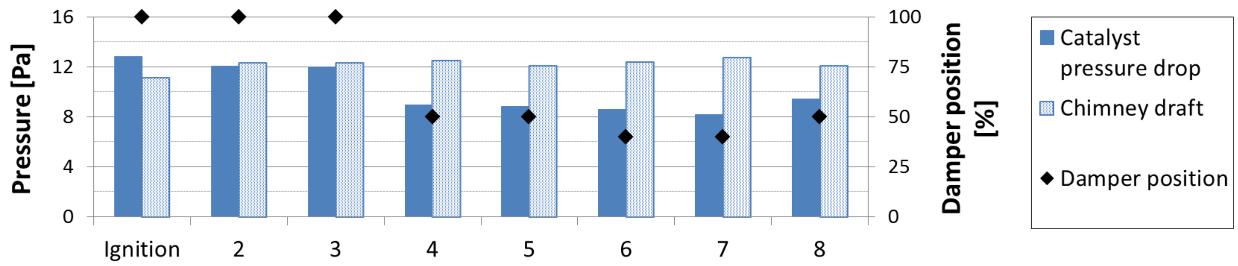
Results catalyst test rig
Flow resistance



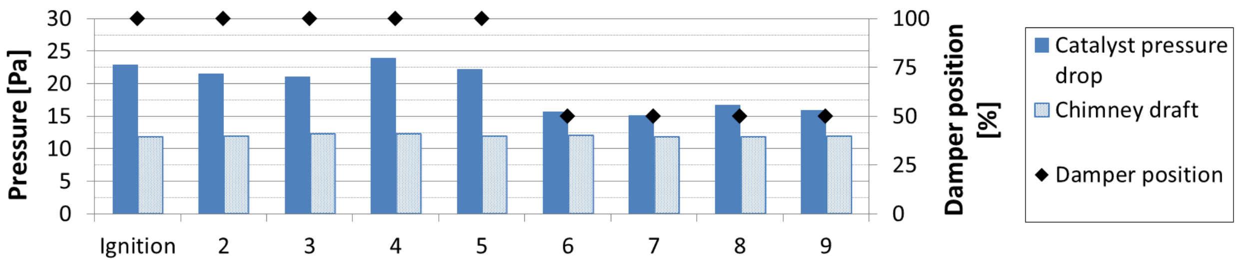


Examples for pressure drop increase when operating at low temperatures

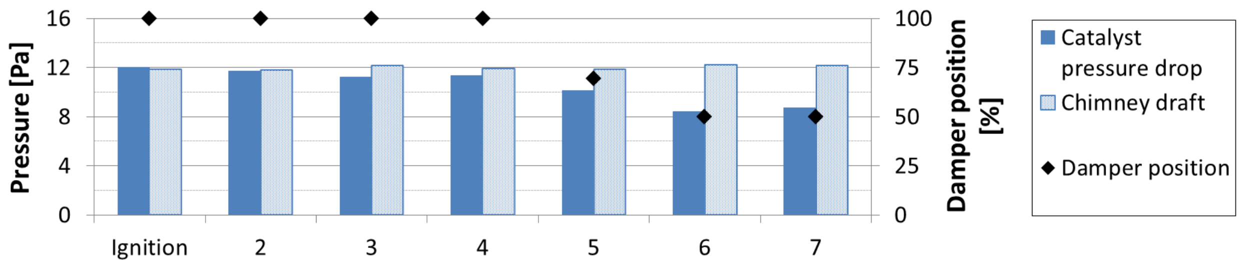
Results catalyst test rig
Flow resistance



Test run with fresh catalyst at 400°C



Test run with used catalyst at 400°C

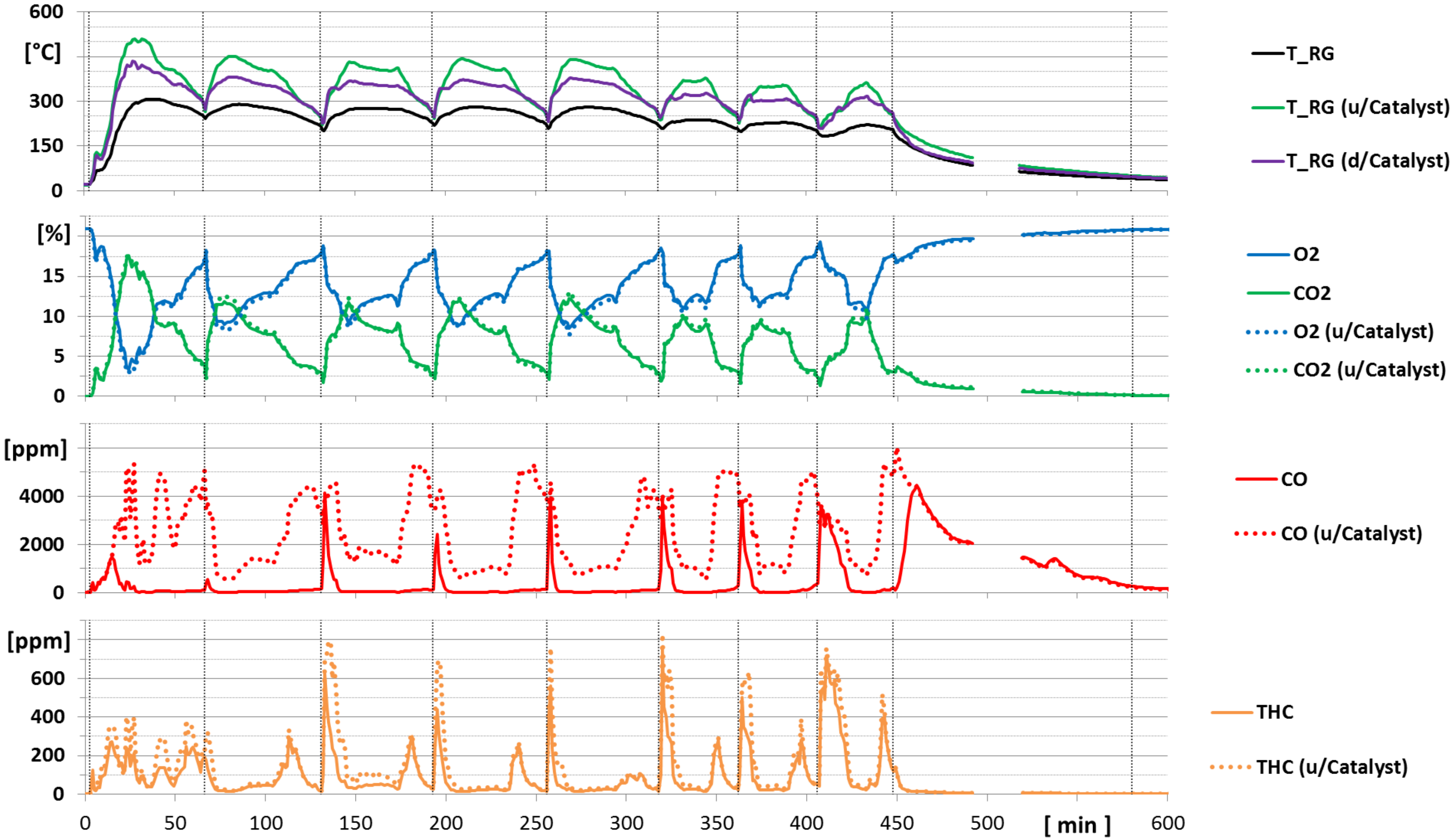


Test run with cleaned catalyst at 400°C

Results stove integrated catalyst
Summary

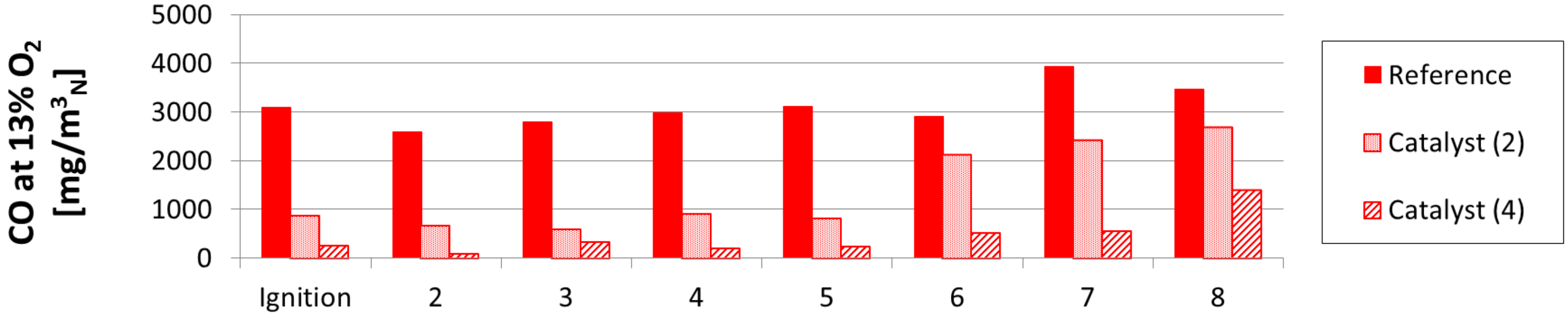
- **Significant catalyst impact on combustion conditions**
  - **Increased flow resistance results in air flow decrease at same damper position (impact on combustion conditions)**
  - **CO reduction changes time of reaching recharge criterion (impact on temperature/start conditions at recharge)**
- **Placement of catalyst not optimal**
  - **Placement more close to combustion chamber for avoiding falling below catalyst activation temperature at recharging**
- **Impact on emissions**
  - **Significant CO reduction (improvable with altered catalyst position)**
  - **Noticeable hydrocarbon reduction (improvable with altered position)**
  - **Noticeable particle reduction (partly due to changed air flow)**
- **Efficiency increase due to decrease in chemical & thermal losses**

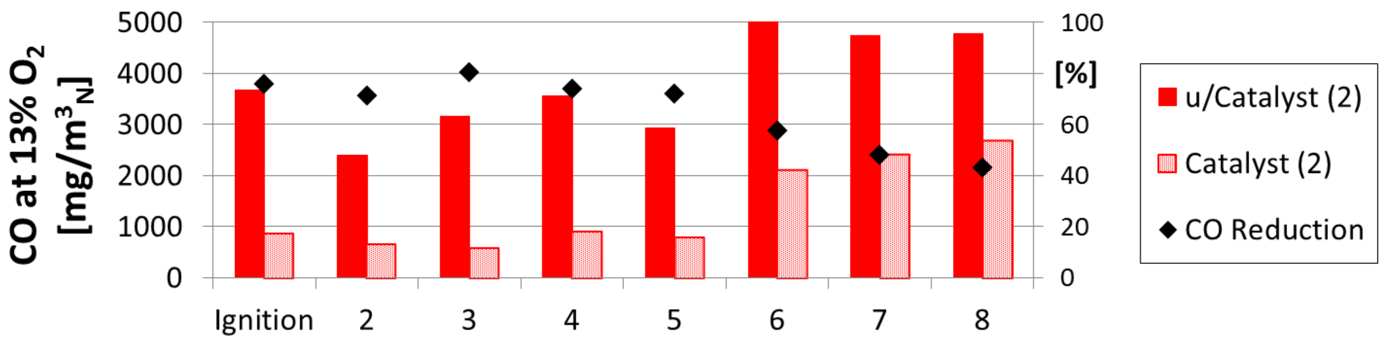
Results stove integrated catalyst
Test run with Catalyst (4)



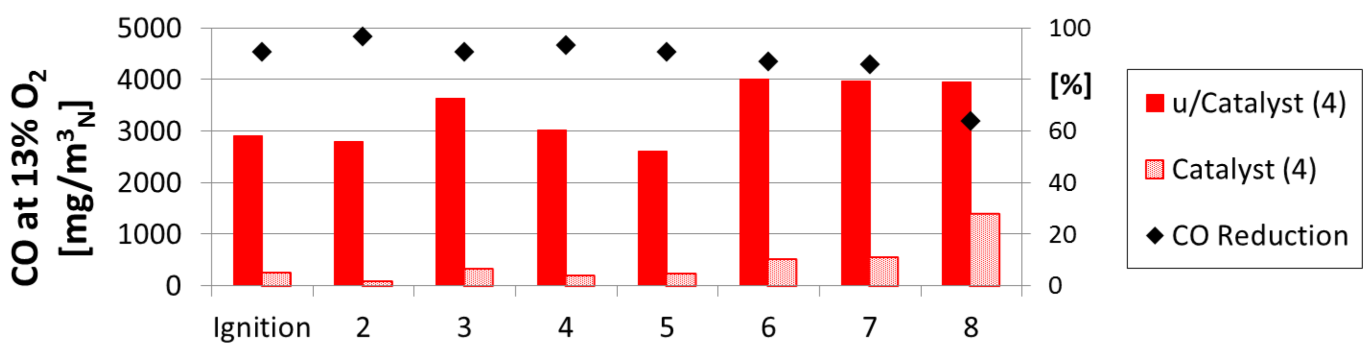
Test run with stove integrated catalyst with 4 pieces of mesh catalyst

Results stove integrated catalyst
Carbon monoxide



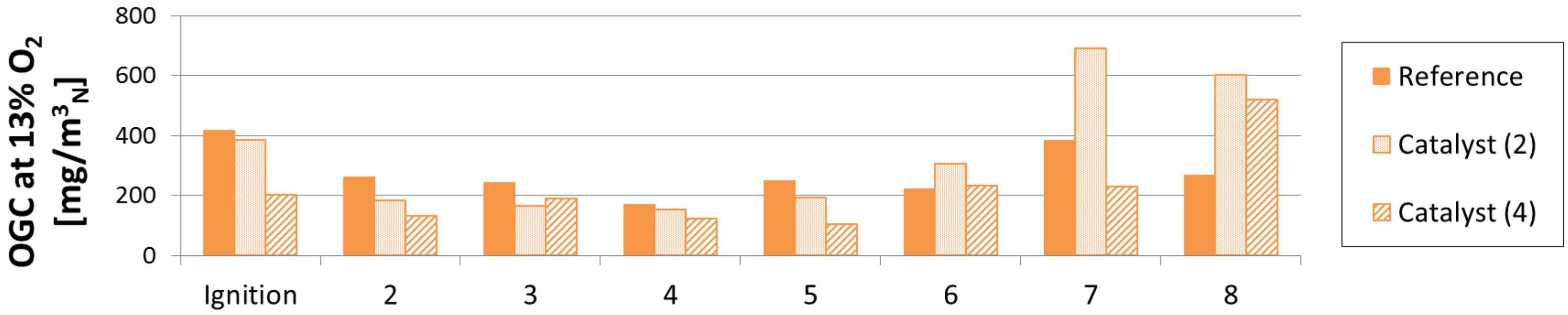


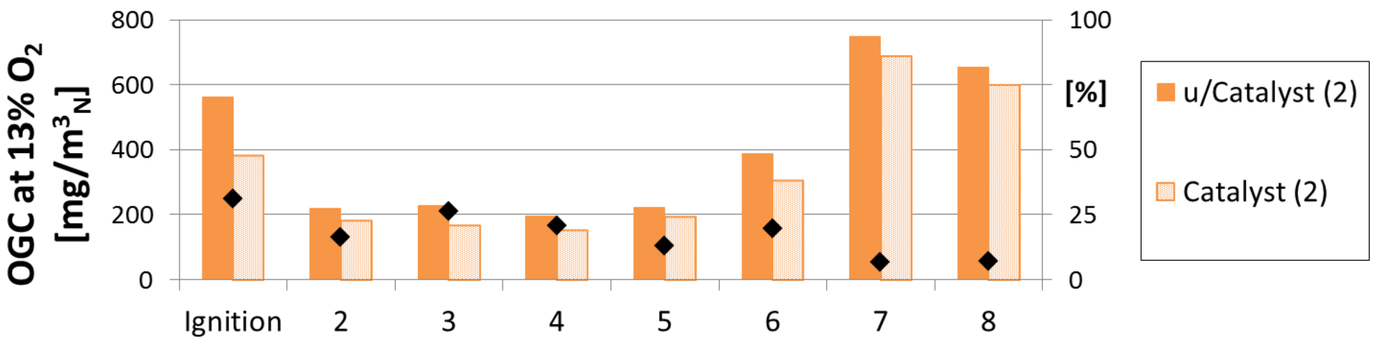
Test run with 2 pcs. mesh catalyst



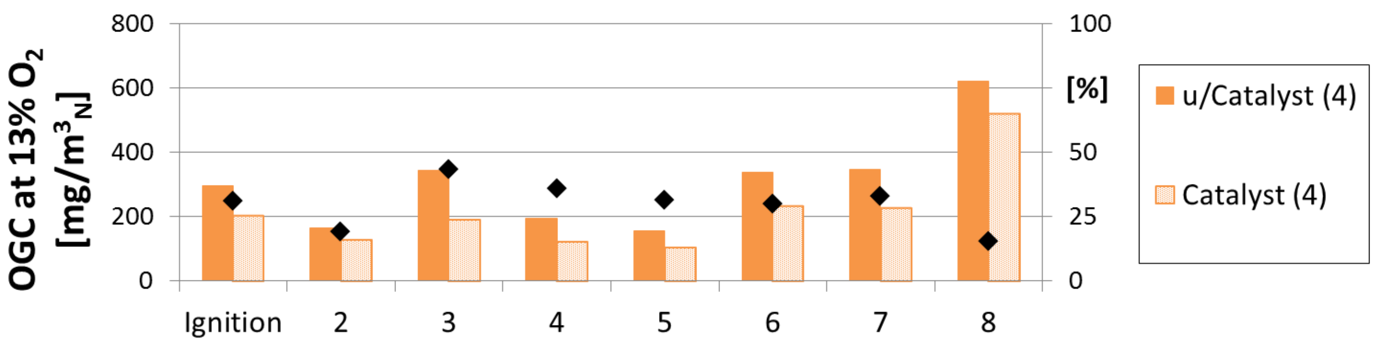
Test run with 4 pcs. mesh catalyst

Results stove integrated catalyst
Hydrocarbons



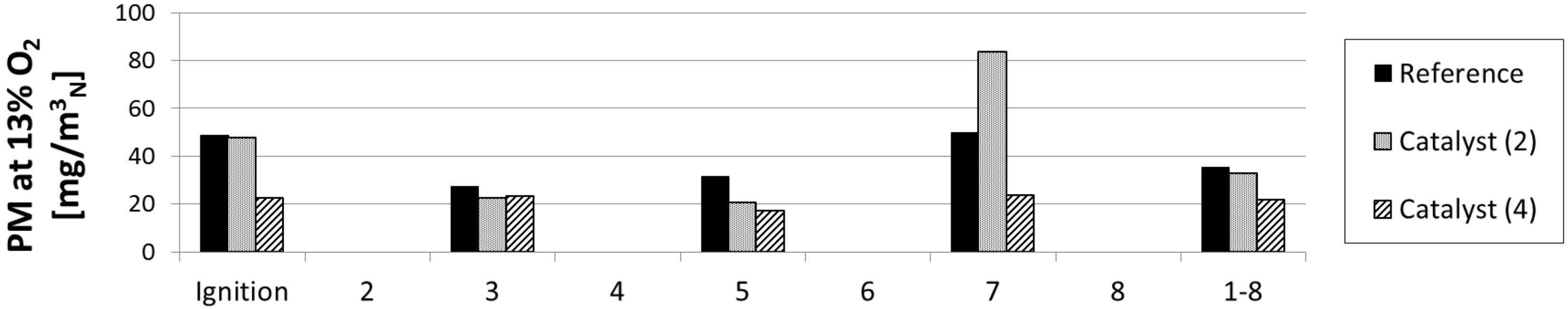


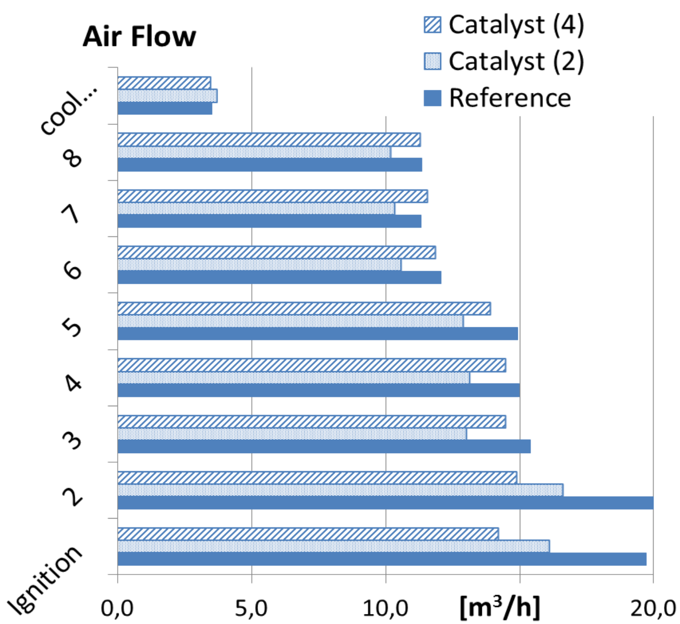
Test run with 2 pcs. mesh catalyst

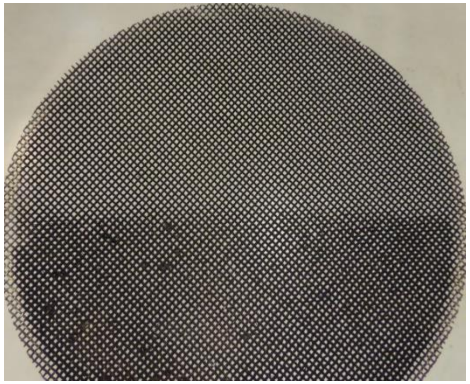


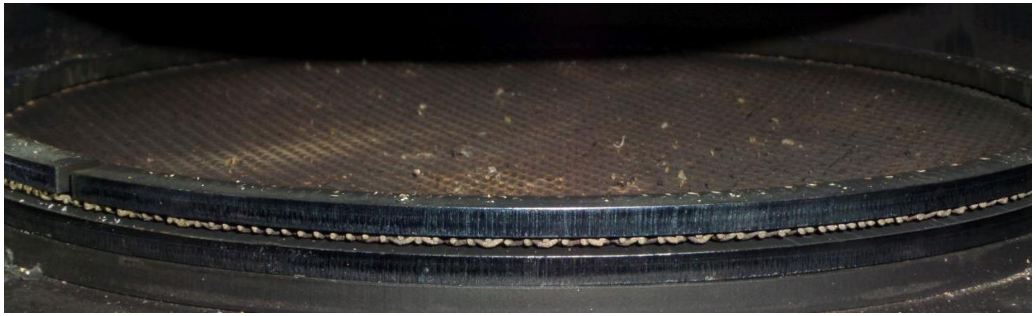
Test run with 4 pcs. mesh catalyst

Results stove integrated catalyst
Particles

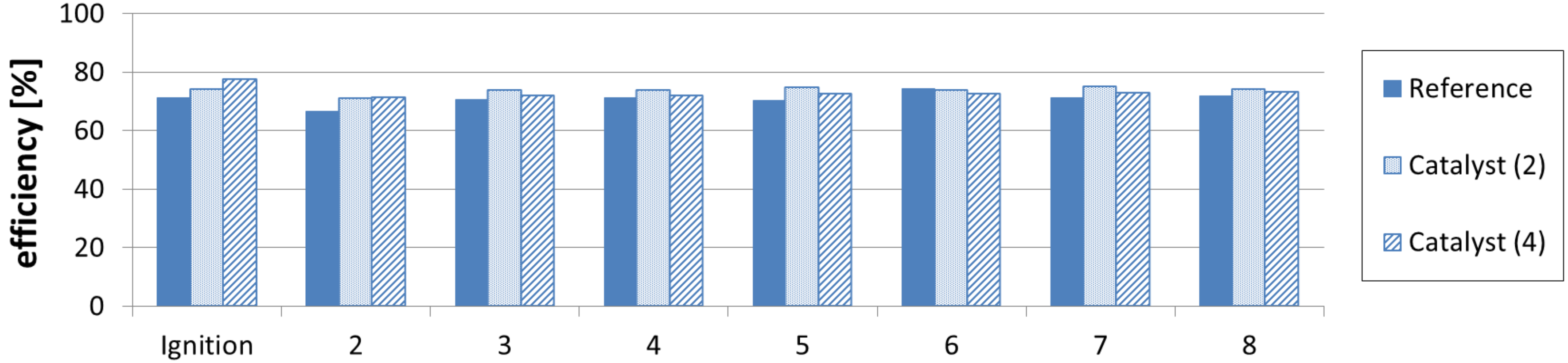


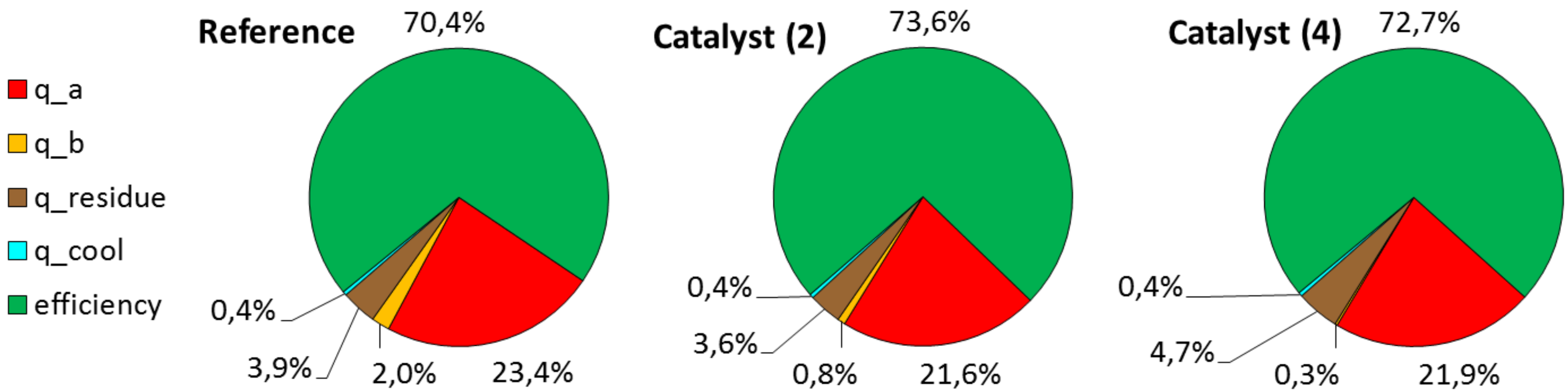






Results stove integrated catalyst Efficiency





Notes:

- Total stove efficiency for testing cycle including thermal losses (q_a), chemical losses (q_b), losses from unburnt material at the grate (q_residue) and cool down losses (q_cool)
- Single batch efficiencies without cool down losses

Conclusions

- **Mesh catalyst**
  - **Significant emission reduction possibilities (regular & “safety net”)**
  - **Wide design choice opportunities**
- **Catalyst durability**
  - **Stable conversion efficiency during first 200h of operation (extended evaluation period needed, especially in real field use)**
  - **Simply cleaning will remove deposits and restore initial conditions**
- **Catalyst placement is crucial**
  - **Near combustion zone for fast reaching & staying above required temperatures, but still easy accessible for cleaning/exchange**
- **Catalyst disadvantages**
  - **Noticeable flow resistance → use constrictions (potential flue gas fan)**
  - **High catalyst cost will increase stove price → limited market**

Evaluation of metal based mesh catalysts for stoves

Further information can be found at

http://www.tfz.bayern.de/en/162907/index.php

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