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Primary- and Secondary Measures for Manually Fired Stoves – An Overview

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CleanAir II - Workshop

Gabriel Reichert

CleanAir II

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Primary- and Secondary Measures
Definitions

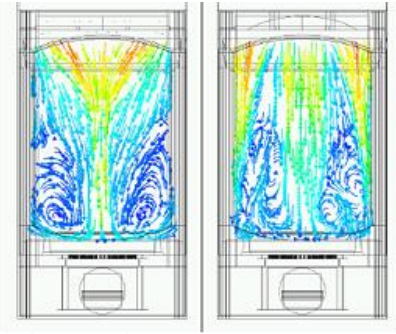
- Primary Measures → **Prevention** of emissions

- Secondary Measures → **Reduction** of emissions
  - Wet techniques (not yet relevant for stoves)
  - Dry techniques

➢ Focus is on manually fired stoves and their most relevant emissions:
  ➢ **CO**, **VOC** (**OGC**) and **TSP**

Primary Measures
Approach for Stoves

- "**3-T-Rule**", especially by optimized combustion chamber design:
  - **Time** – sufficient time for flue gases in the hot combustion zone → e.g. design of baffle plates
  - **Temperature** – sufficient temperature level → e.g. insulation of combustion chamber
  - **Turbulence** – optimal mixture of flue gases and combustion air → e.g. air staging, design of air nozzles



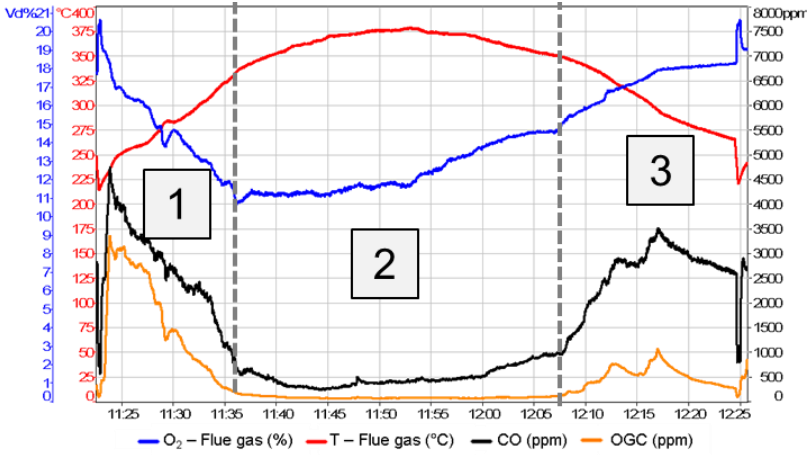
Source: BEST

- **Sufficient** (not too much and not too less) **combustion air** → e.g. Management of combustion air by automatic regulation systems

➢ Optimization of combustion conditions in order to **prevent** emissions downstream the main combustion chamber

Primary Measures
Limitations

- **Limitations** of primary measures due to:
  - High share of transient combustion conditions (start, stop, load changes, etc.)
  - Manual operating conditions
  - Flue gas draught effects
  - Fuel effects



1. Start phase / **2.** Main burning phase / **3.** Burn out phase

Source: BEST GmbH

- ➢ It is very difficult to achieve optimal combustion conditions over the whole time of heating operation (or even only over one fuel batch)
- ➢ **Primary optimization**: Most effective during the main burning phase at best-practice heating operation → **Support** and **Synergies** by Secondary Measures

Secondary Measures (dry techniques)
Overview (Selection of most relevant)

- CO and VOC (OGC) emissions
  - **Catalysts**, e.g. honeycomb catalysts
- TSP emissions
  - **Built-in components** (“***Einbauten***”)
  - **Electrostatic precipitators** (**ESP**)
  - **Fabric filters**

Source: BEST, honeycomb catalysts on metallic (left) and ceramic (richt) carriers

✓ The **perfect secondary measure/ technology** would be or is featured by:
- No need for electrical current (especially for manually fired stoves)
- Low pressure drop (natural draught conditions)
- High efficiency for gaseous emissions and small particles (< 1 µm ae.d., majority of TSP of stoves)
- Cheap, long lifetime without maintenance, not sensitive referring to user maloperation

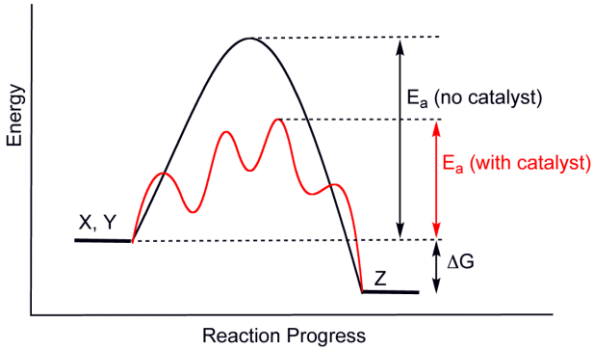
➢ Unfortunately, **none** of the available technologies can fulfill all of those wishes!

Secondary Measures (dry techniques)
CO, VOC (OGC)

- **Catalysts**: Oxidation of CO and VOC (at lower temperature levels)

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \qquad C_mH_n + (m + \frac{n}{4})O_2 \rightarrow mCO_2 + \frac{n}{2}H_2O$$

- Principle
  - Reduction of activation energy (E_a) → **Acceleration** of Reaction mechanisms
  - Catalyst itself is not consumed
  - Reaction kinetics are affected by the catalyst, but **not** the thermodynamics (Free reaction enthalpy (ΔG) is equal with and without the catalyst)



Source: https://en.wikipedia.org/wiki/Catalysis (Date: Jan. 2020)

- Advantages
  - Conversion: CO: up to 80% / OGC: ~ 20 – 40%
  - Catalyst might also influence TSP emissions (but not the main effect)

- Disadvantages
  - Sensitive regarding blocking and limited lifetime (deactivation mechanisms)

Secondary Measures (dry techniques)
TSP (Total Suspended Particles)

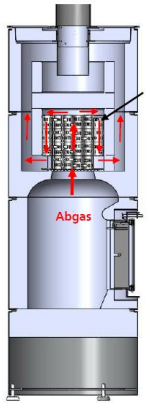
- **Built-in components** (“***Einbauten***”)
  - Ceramic or metallic elements integrated downstream the combustion chamber

- Principle
  - Optimization of combustion conditions within the built-in component module
  - CO and VOC oxidation by sufficient temperatures
  - Agglomeration of particles on the surfaces
    - Filter for inorganic PM
    - Oxidation of organic PM

} „***Oxidative- and filtering reactor***“

- Requirements
  - Temperature higher than 500°C & Pressure drop < 3Pa

- Experiences/ Lab Test results
  - Reduction of TSP: ~ 50%
  - Reductive effect also on CO and OGC emissions observed



Module with built-in components

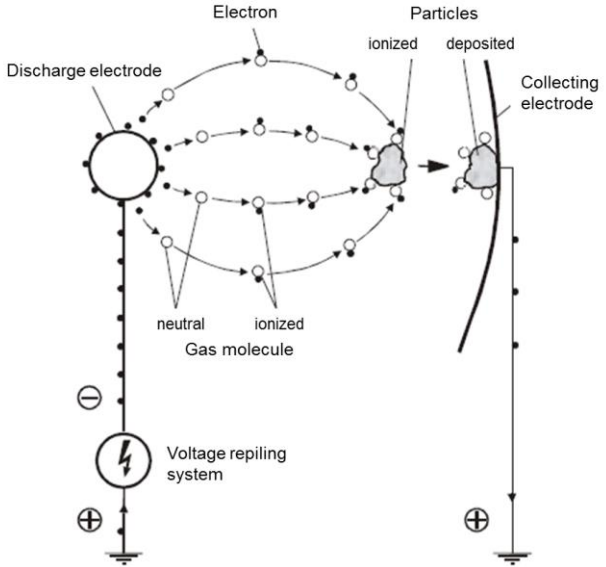
Source:

https://www.fnr-server.de/ftp/pdf/berichte/22010413.pdf (Date: Jan. 2020)

Secondary Measures (dry techniques)
TSP (Total Suspended Particles)

- **Electrostatic precipitators** (**ESP**)

- Principles:
  - Electrically ionization of particles by the discharge electrode and subsequent deposit of the ionized particles at the collecting electrode
- Advantages
  - Reduction of TSP: ~ 70 – up to 90% (< 20 mg/m_N^3)
  - Low pressure drop
- Disadvantages
  - High voltage and electrical current necessary
  - Reductive effect for soot and tar **less**

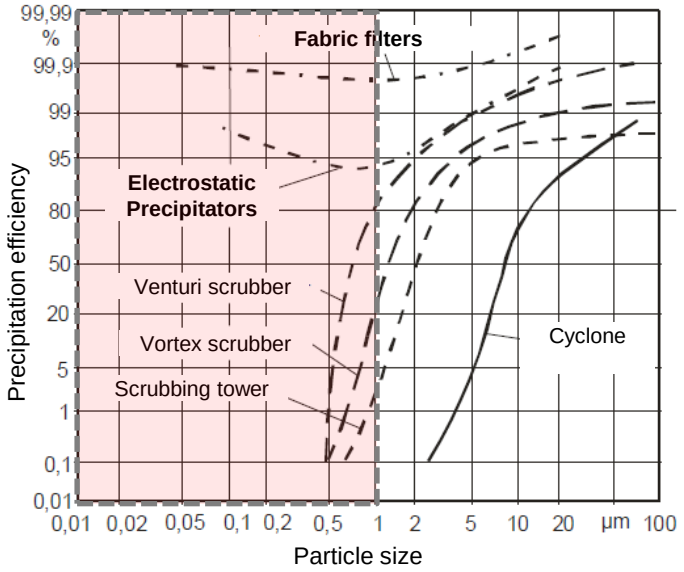


Source: KALTSCHMITT et al. 2009 (translated in English)

Secondary Measures (dry techniques)
TSP (Total Suspended Particles)

- **Fabric filters**

  - Principles
    - Deposit and accumulation of particles on the surface of the filter precipitator material
    - Deposit mechanisms
      - Filtering effect defined by the porosity of the material
      - Adhesive power of particles
  - Advantages
    - Reduction of TSP: up to 99%
  - Disadvantages
    - High pressure drop & maintenance efforts



Source: KALTSCHMITT et al. 2009 (translated in English)

Primary- and Secondary Measures for Stoves
Summary & Conclusions

- Primary measures work always, **if** operating conditions are in the required range,
- Primary measures are comparatively cheap, need often no electrical current and maintenance, **but**…
  - Primary measures work often not properly, **if** the operating conditions deviate from the optimal range, e.g. during transient operating phases and off-specification heating operation

- Consequently:
  - For minimal emissions, especially in real-life operation, primary optimization is limited and needs to be supported and combined with secondary measures using appropriate secondary emission abatement technologies
  - Synergetic effects of primary and secondary measures should be used

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Thank You For Attention

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