

Fuel improvements using kaolin as additive to pellets and chopped materials in residential boilers

IEA Task 32 – Workshop „Residential Wood Combustion“
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Structure

1. Method

- Test fuel production
- Combustion testing

2. Results (additives on several wood fuels, straw, other herbaceous fuels):

Emissions: PM impact

Emissions: CO impact

Emissions: HCl+SO₂ impact

3. Some other researchers' findings on kaolin additives

4. Conclusions

Raw materials

Wood pellets 6 mm
(from market)



Wheat straw pellets 8 mm



Poplar chips



Grass cobs 9 mm



Sunflower husk pellets 8 mm



Production of test fuel pellets

- Amandus Kahl 33-390 pellet plant was used for milling and pelletizing
- Mixing of raw materials with water and additive by a Stockmann 500 ESK extract-mixer
- The amount of kaolin was determined by stoichiometric calculations:
 - regarding the fixation of potassium in the ashes as silicates
 - with a safety factor of 12 and 50 %
- All pelletizing happened without binding agent



Fuels applied in test campaign

Wood pure



Wheat straw pure



Grass pure



Sunflower husk pure



Poplar pure



50% Wood
50% wheat straw



Wheat straw
3.45% kaolin



Grass
8.1% kaolin



Sunflower husk
2.8% kaolin



Poplar
1.5% kaolin



75% Wood
25% wheat straw



90% Wood
10% wheat straw



Grass
10.5% kaolin



Poplar chips



Additional combustion trials

Poplar pellets
mixed with kaolin



Blended pellets
50 % wood + 50 % wheat straw



Boiler for combustion trials: Guntamatic Powerchip 20/30 (year of construction 2010)

Nominal boiler heat power output:

- Wood chips 7-30 kW,
- Wood pellets 7-30 kW,
- Grain 7-25 kW,
- Miscanthus max. 7-25 kW

Moving grate

Source:
Guntamatic

Method

- Boiler and fuel feeding system was cleaned by vacuum cleaner and pressurized air
- Start and preheating phase of the boiler: approx. 2 h
- “Nominal” load operation (at least 70 %) for 8 h
- Continuous measurement of gaseous emissions
- PM: 4 × total particle emissions for 30 min (at 0-30 min, 150-180 min, 300-330 min and 450-480 min)
- Filtration temperature 180 °C; pre- and post-treatment of the filters at 180 °C, rinsing the probe with acetone
- Complete collection of all ash and slag for screening assessment

Ash chemistry with kaolin additive

Composition of kaolin used:

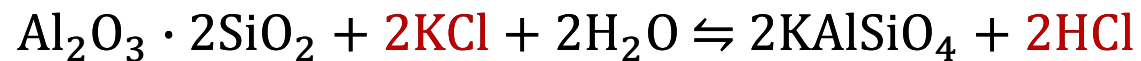
Kaolinit 87 %

SiO ₂	49,00 % +- 1,0 %
Al ₂ O ₃	35,00 % +- 1,0 %
Fe ₂ O ₃	0,50 % +- 0,1 %
CaO	0,20 % +- 0,1 %
MgO	0,10 % +- 0,1 %
MnO	< 0,01 %
K ₂ O	1,40 % +- 0,3 %
TiO ₂	0,70 % +- 0,1 %
Na ₂ O	< 0,02 %
P ₂ O ₅	0,03 %

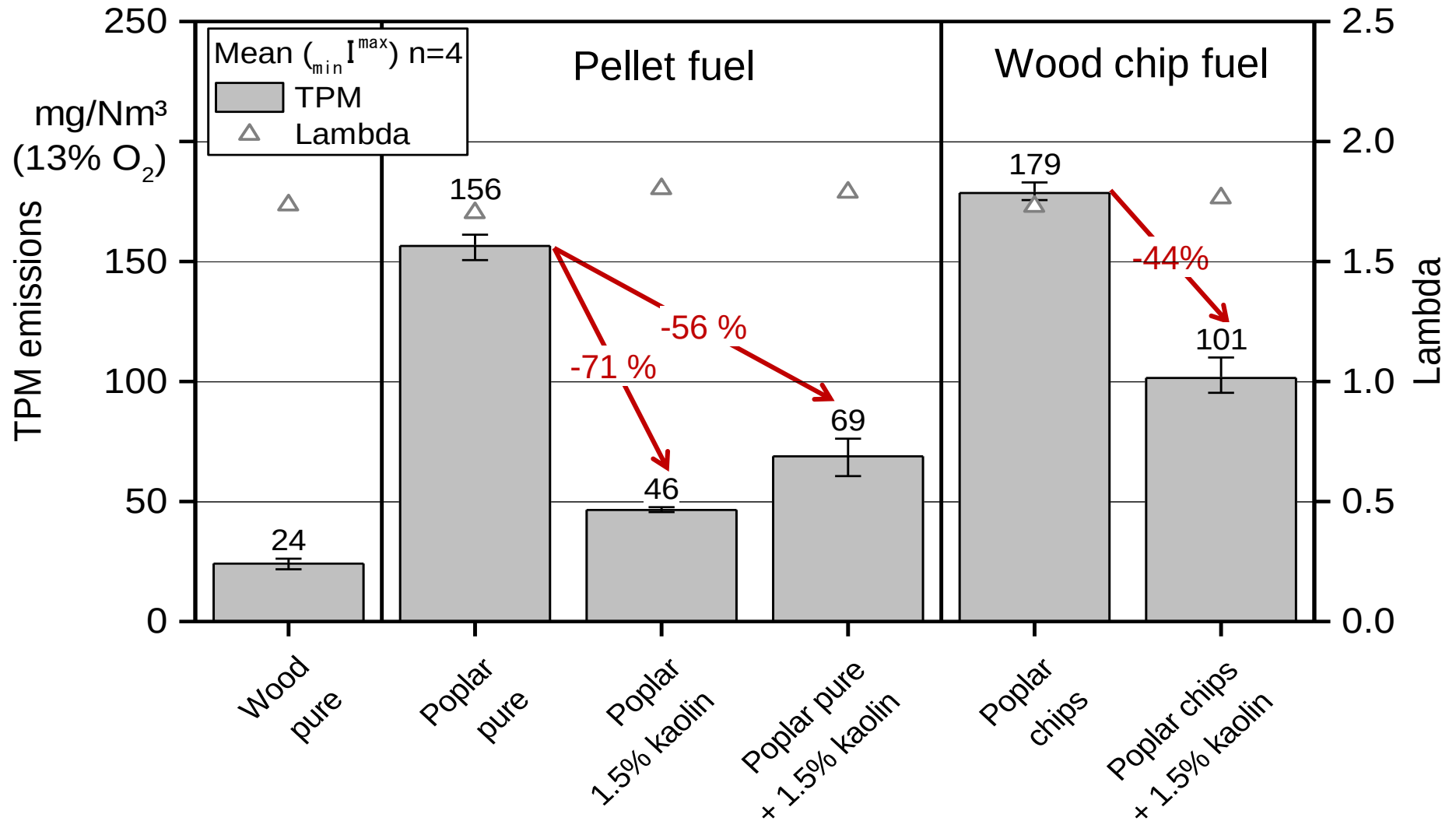
Source: Kamik Kaolin S2 Datenfile

Relevant reactions in ash bed:

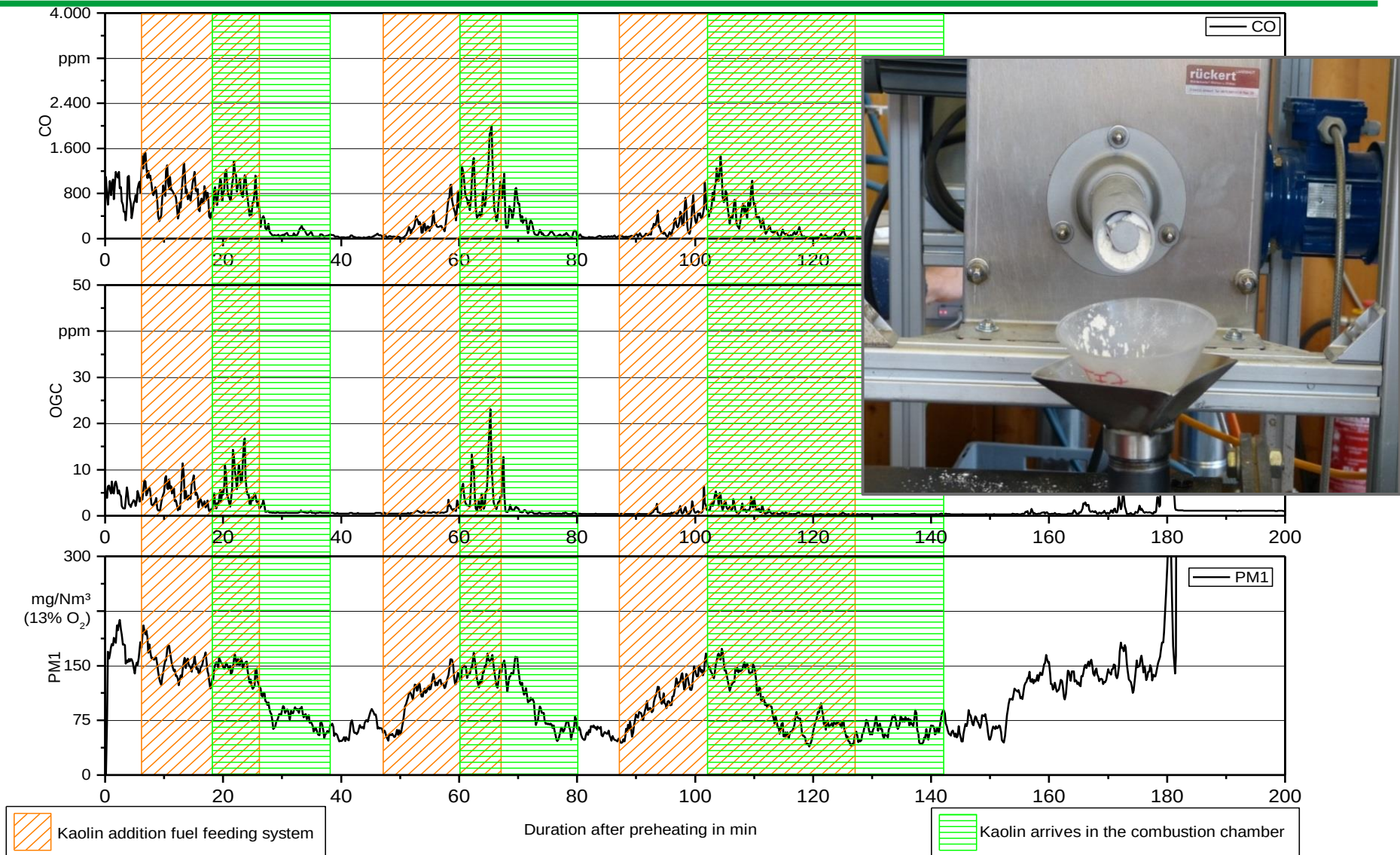
Kaolinit:



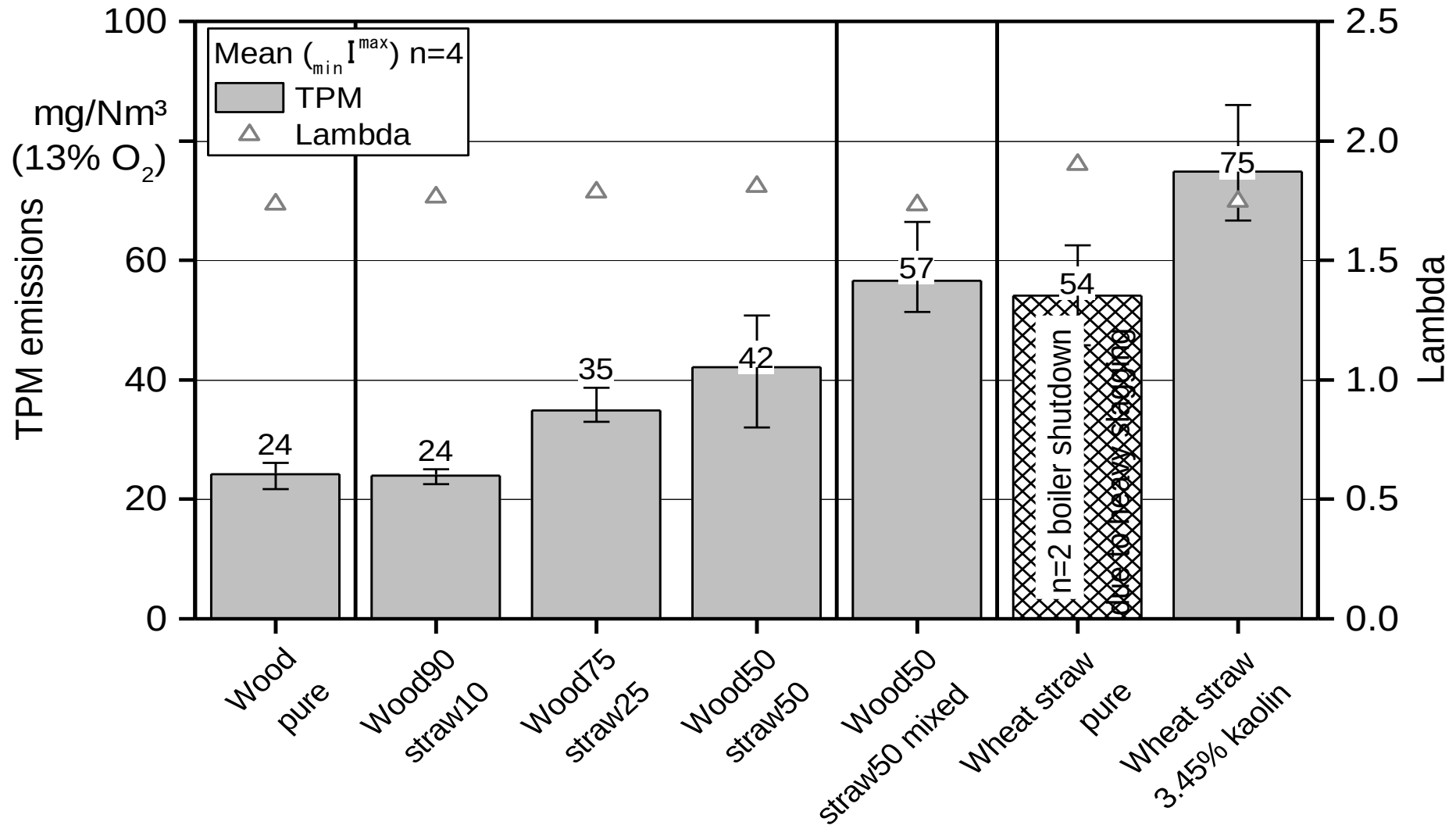
Kaolin impact on total particulate matter (TPM) emissions (1): Poplar fuels



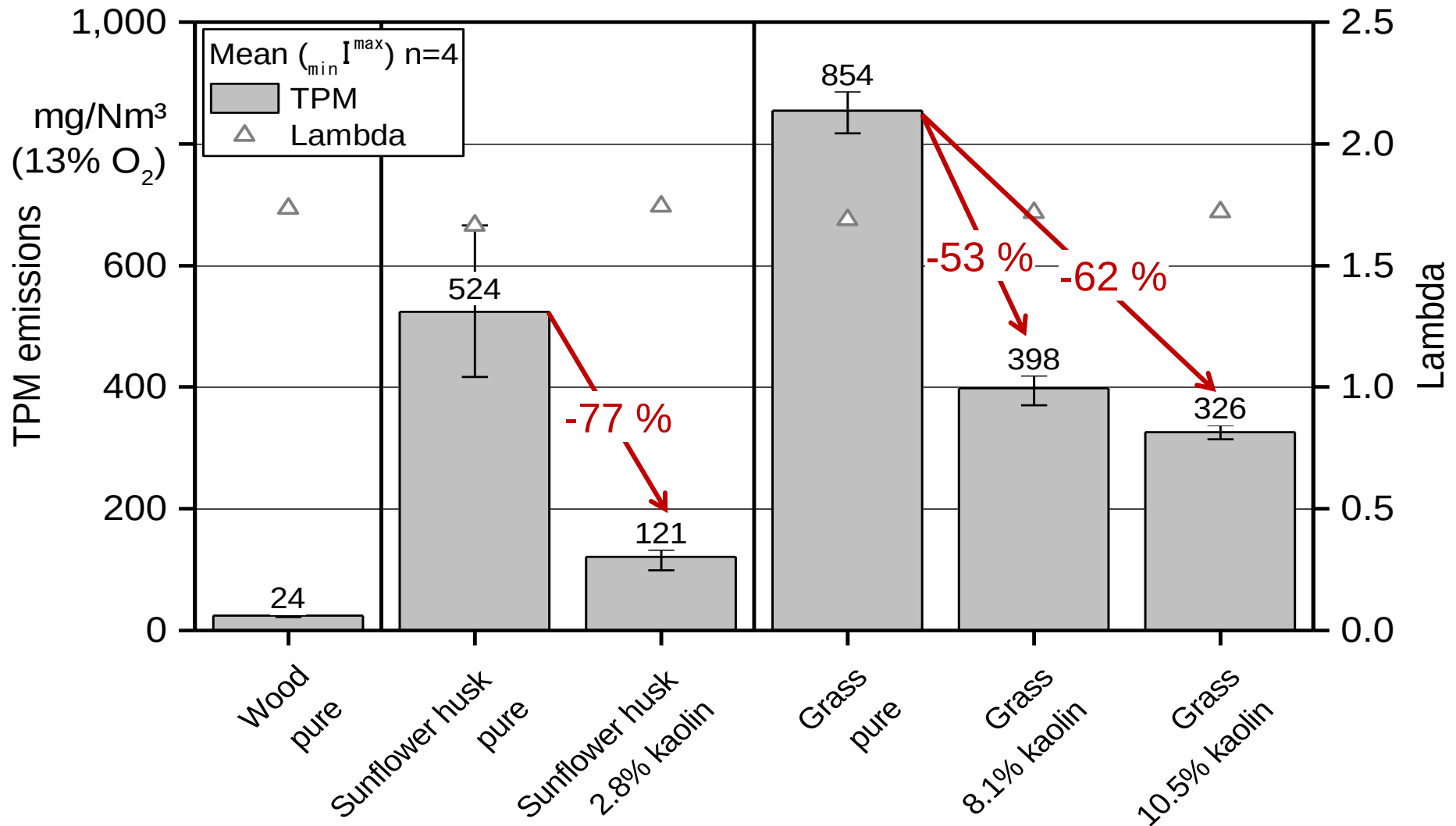
Demonstrating immediate impact on flue gas composition with/without kaolin additivation



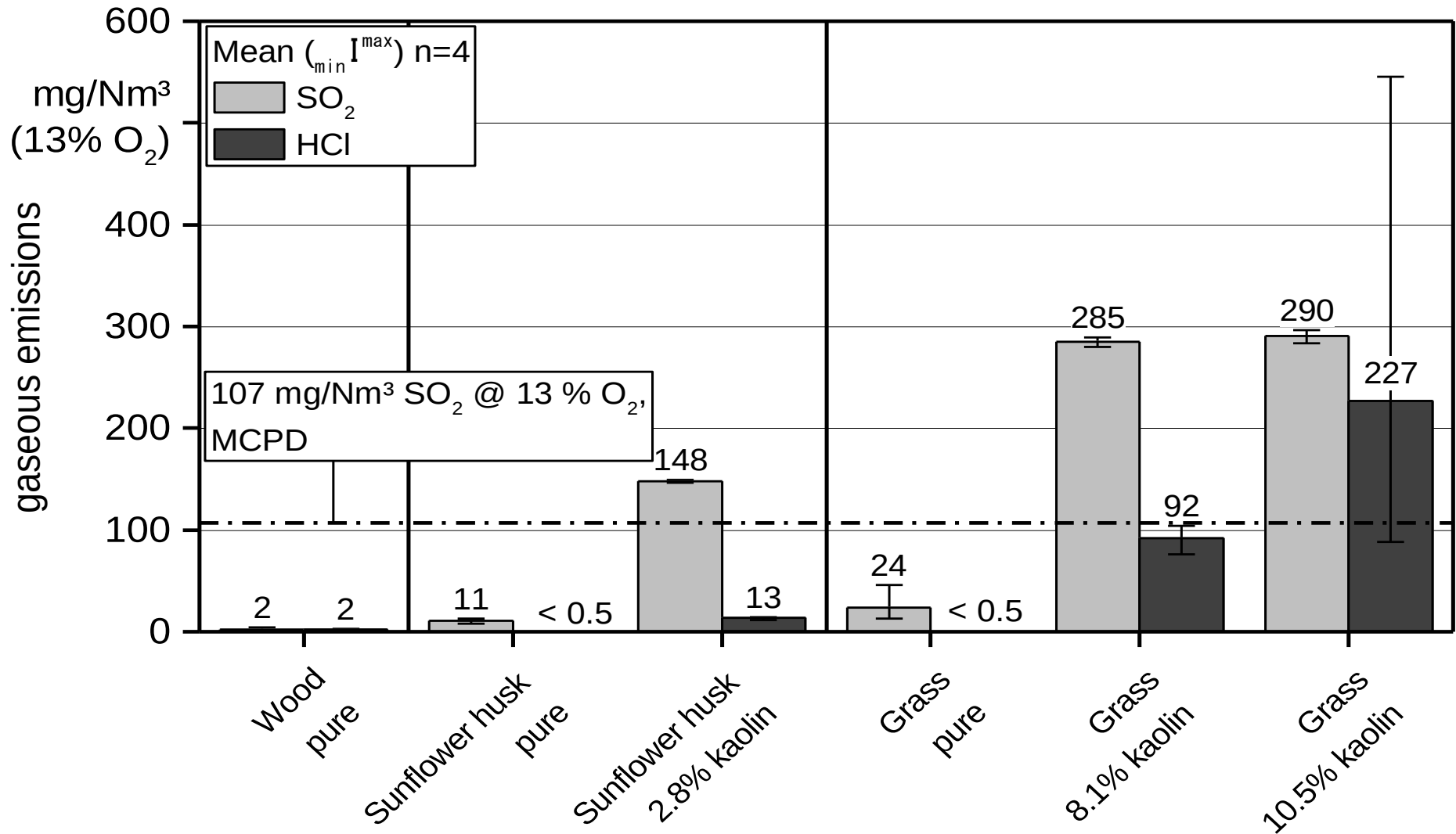
Kaolin impact on total particulate matter (TPM) emissions (2): Wheat straw pellets



Kaolin impact on total particulate matter (TPM) emissions (3): Herbaceous fuel pellets



Kaolin impact on SO₂ and HCl emissions (1): **Herbaceous fuel pellets**

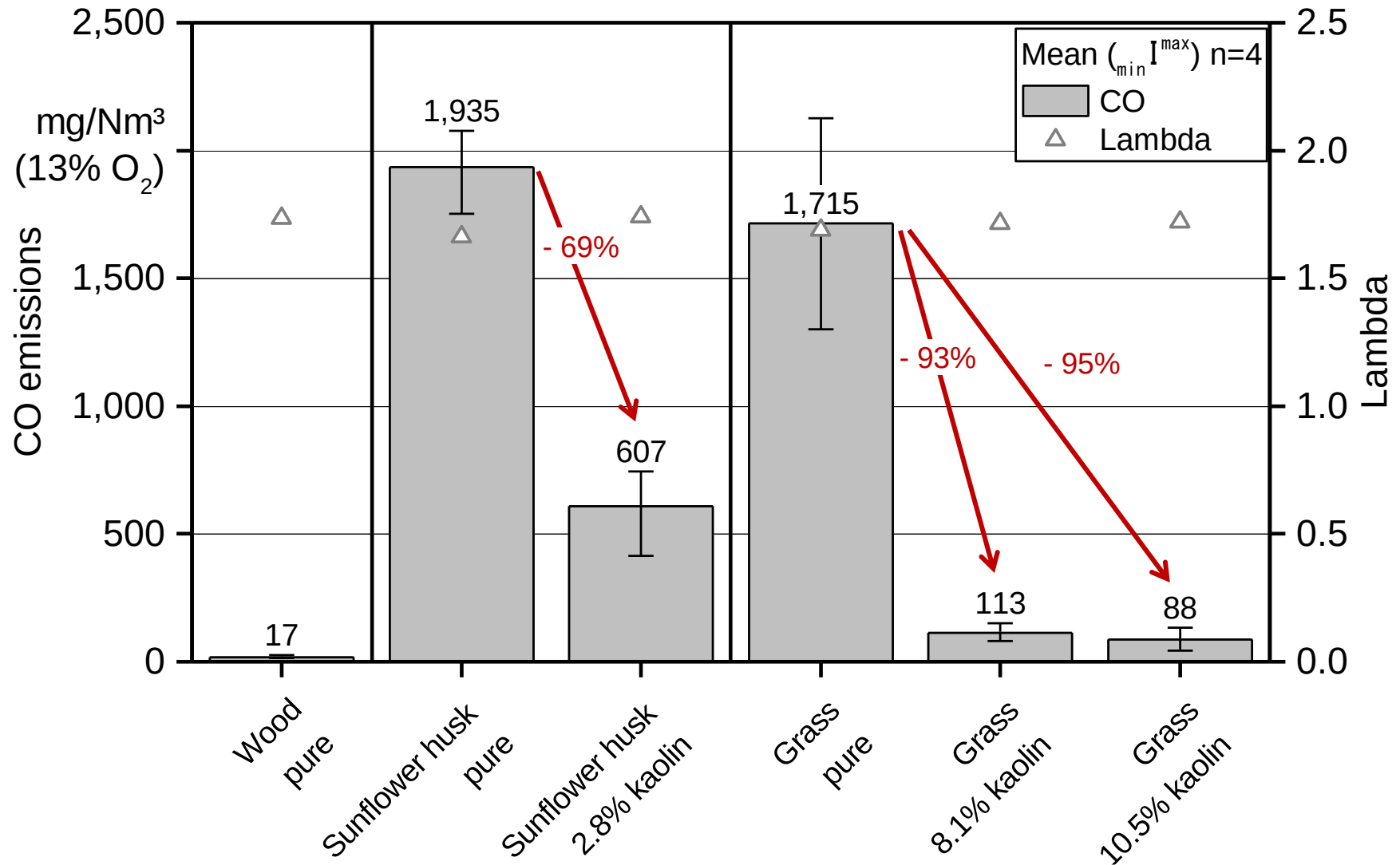


Chemical explanation for enhanced HCl and SO₂ release

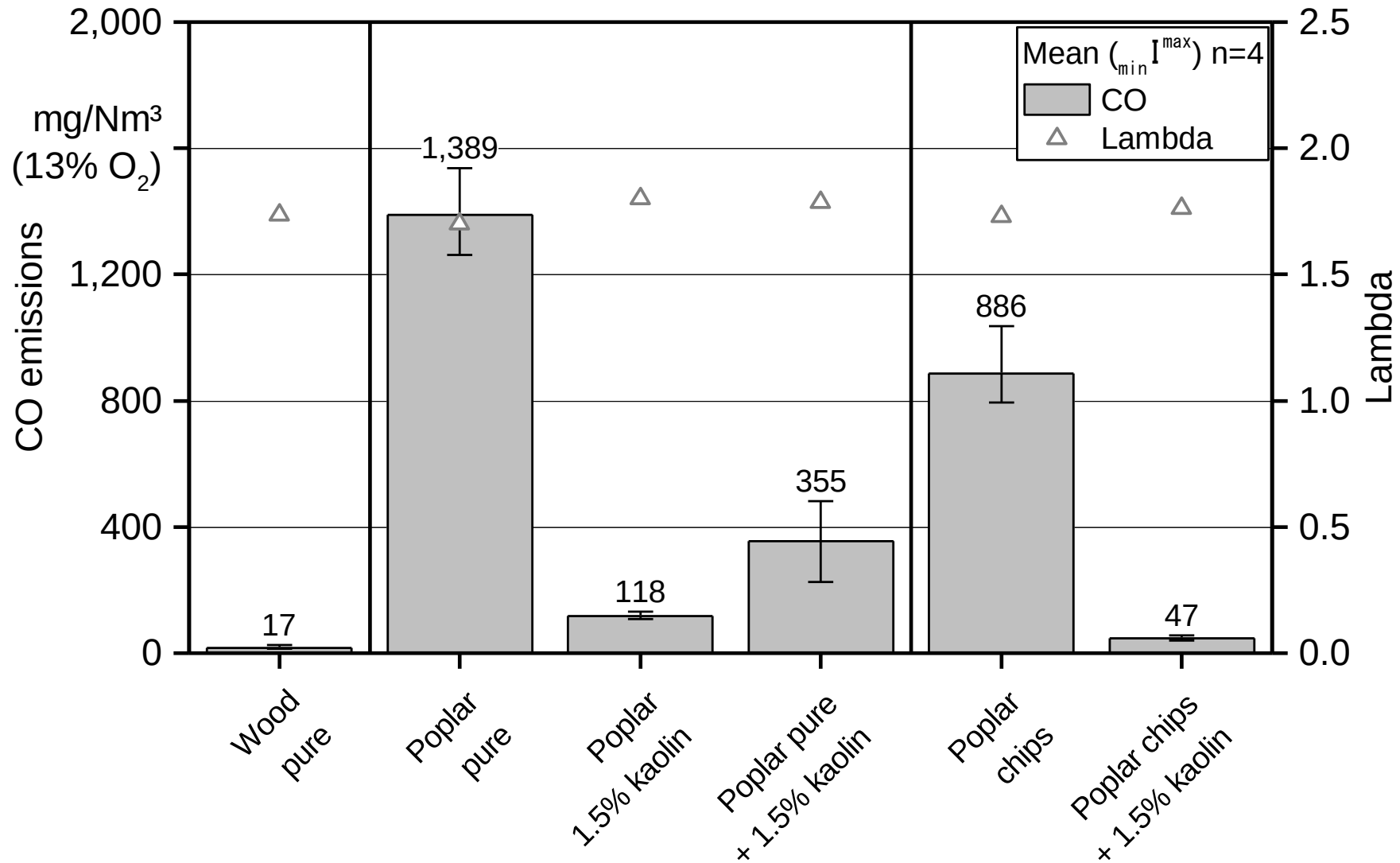


Source: Kaltschmitt, et al., *Energie aus Biomasse* 2016

Kaolin impact on CO emissions (1): Herbaceous fuel pellets

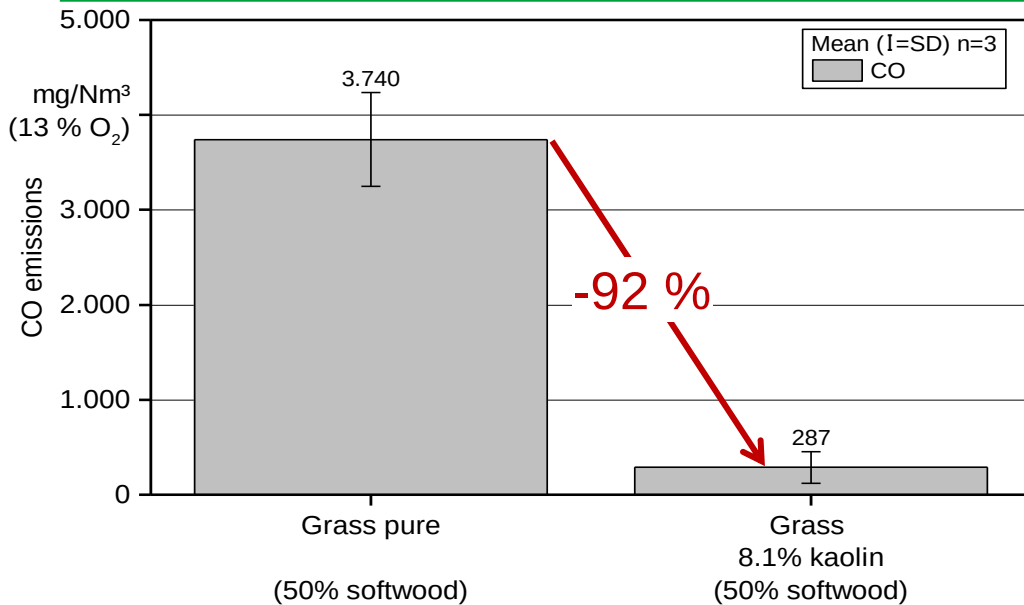


Kaolin impact on CO emissions (2): Poplar fuels (pellets/chips)



Other researchers' findings - Trials at Umeå University Sweden:

Grass-wood-mixture-pellets + kaolin



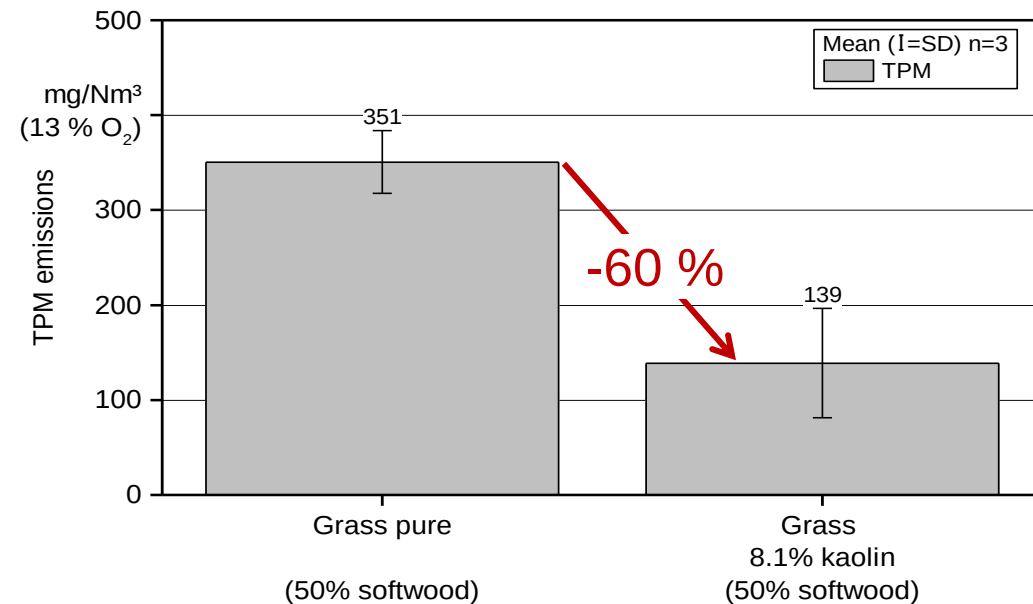
Source: Christoffer Boman,
Partner in Eranet-Project „BioFlex!“



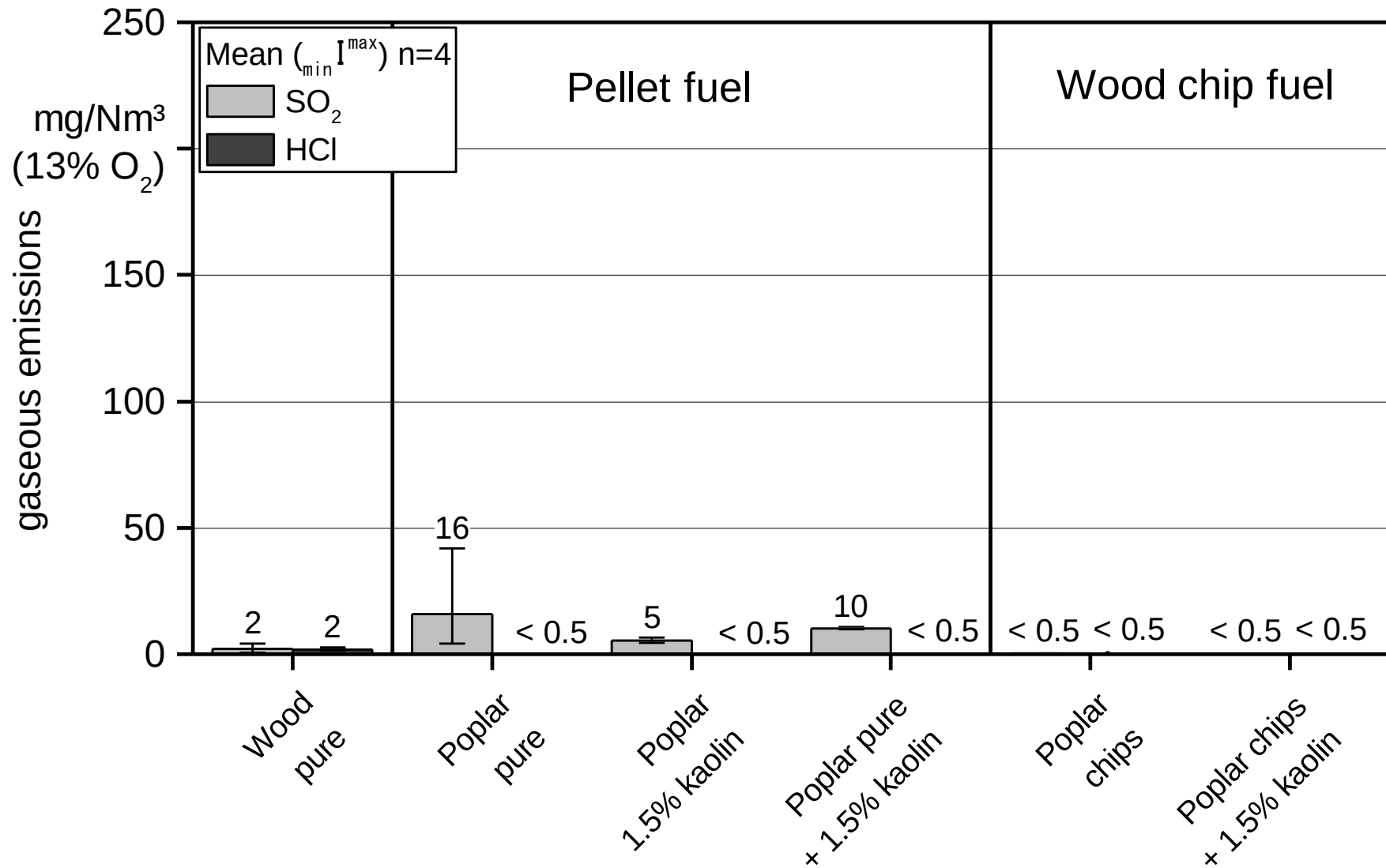
Umeå University

Pellet boiler used in UMEA:

- VEDSOL Combifire,
- Heat output: 15 kW,
- underfeed pellet burner cup with rotating ring at the top
- fuel was produced at TFZ



Kaolin impact on SO₂ and HCl emissions (2): Poplar fuels

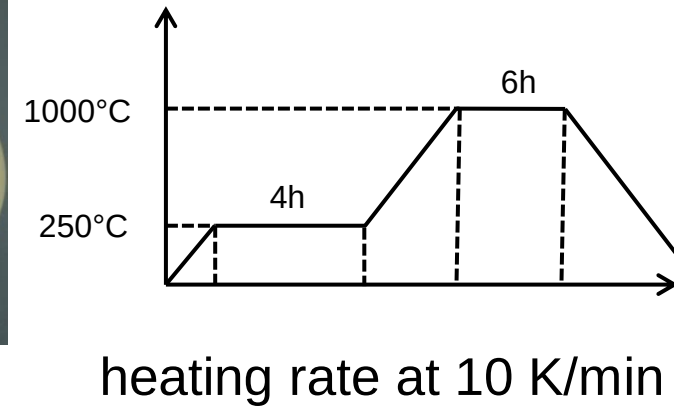


Comparison of slagging behavior lab test according to PASSA-method

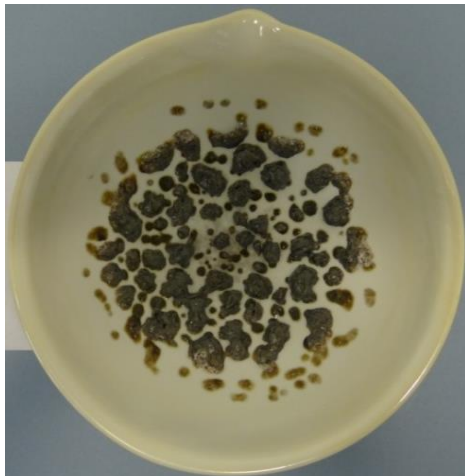
Wheat straw pure



Wheat straw + 3.45 % kaolin

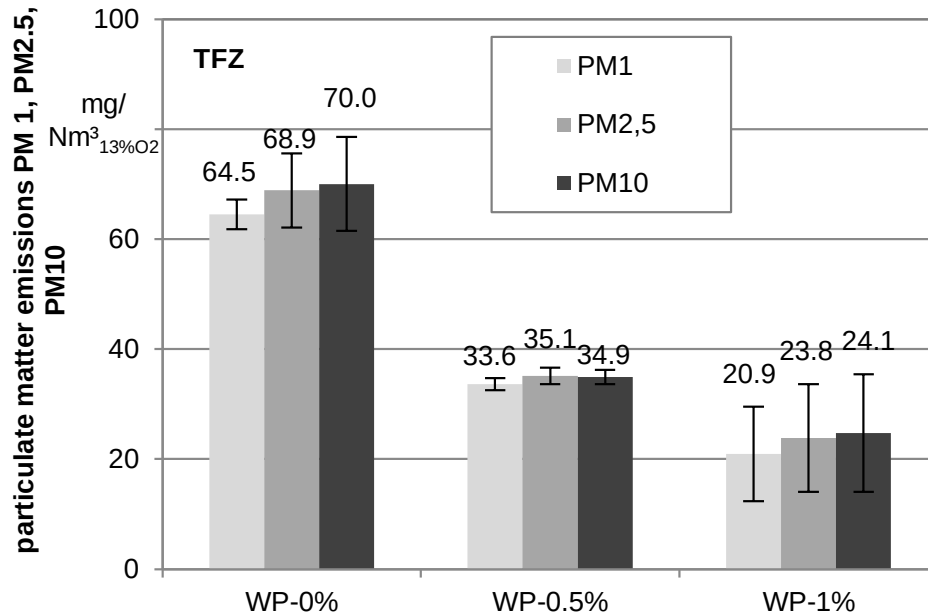


Careful ash removal
with brush



Previous research on kaolin additivation

Particle size fraction emissions with wood pellet additivation by kaolin



Wood pellet (WP) fuel preparation:

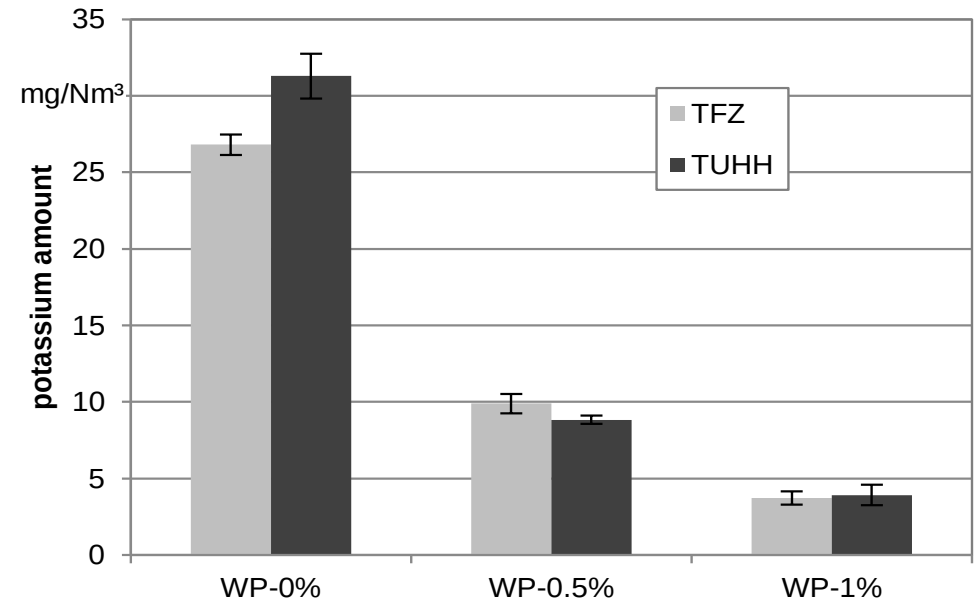
WP-0 (no additive, 0,9 % ash content)

WP-0.5 (0.5 % kaolin)

WP-1 (1 % kaolin)

Pellet boiler used: Windhager, VAE 120, 12 kW

Total potassium emission in boiler/stove



TUHH: Partner measurements at 8.6 kW pellet stove (Haas+Sohn HSP1.17) using same fuel

Published: Huelsmann, T.; Mack, R.; Kaltschmitt, M.; Hartmann, H. (2019): Influence of kaolinite on the PM emissions from small-scale combustion. Biomass Conversion and Biorefinery 9 (1), pp. 55-70

Conclusions

- Additivation with kaolin largely reduces particle- and CO-emissions.
- Separately added kaolin to the boiler is slightly less effective than additivation before pelletization.
- Additivation with kaolin can raise SO₂ and HCl emissions. This is a problem for Cl- and S-rich fuels.
- With agricultural and poplar fuels in with conventional boilers the use of additives alone is mostly not sufficient to meet European PM-emission limits. Combination with ESP or filter is required.
- Fuel blending with softwood reduces slag formation of wheat straw, but high wood shares are needed (>75 %).
- Kaolin additive can largely reduce slag related problems.

Guidelines and other publications



Guidelines for advanced fuel and boiler design



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Report within the scope of the ERA-NET Bioenergy Project "BIOFLEX" – Clean and flexible use of new difficult biomass fuels in small to medium-scale combustion

March 2019

Download guideline:

<https://bioflex-eranet.eu/publications/>

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Research paper

Combustion behavior and slagging tendencies of kaolin additivated agricultural pellets and of wood-straw pellet blends in a small-scale boiler

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ABSTRACT

The aim of this study was the modification of agricultural biofuels to allow for low emission combustion in domestic biomass boilers without slagging or other ash related problems. Four agricultural biomasses were additivated with kaolin. Fuel blends were produced from wheat straw and woody biomass. All fuels were combusted in a 30 kW biomass boiler while emissions and slag formation were measured. Due to additivation or fuel blending, total particle and CO emissions were reduced by 53–77% and 69–95%, respectively. At the same time, slag formation (determined as the mass of agglomerates > 3.15 mm) strongly declined. For fuels containing high amounts of sulphur or chlorine, kaolin additivation may lead to increased HCl and SO₂ emissions. Moreover, NO_x formation may be higher during combustion of additivated fuels (up to 21%). Overall, additivation with kaolin or blending of fuels might be an interesting option for the utilization of agricultural biomasses. The selection of the optimal upgrading method should consider the chemical and physical biomass properties and address the minimum amount of additive or blending ratio to achieve a sufficient reduction of emissions and slagging.

1. Introduction

Biomass currently provides the highest share of renewable energy to heating systems in the EU (i.e. about 95% of renewable heat). The national renewable energy action plans (NREAP) of different European countries indicate that the use of biomass in the heating sector is expected to increase [1]. As the potential of woody biomass for energy production is limited [2], higher shares of agricultural fuels may be used in the near future, e.g. in small (< 500 kW) and medium-scale (0.5–10 MW) combustion applications. These fuels comprise agricultural residues, agricultural by-products and energy crops that are usually considered "difficult" in terms of fuel quality and combustion behavior, but also wood fuels from short rotation coppice, e.g. from poplar and willow plantations, that are also known to perform badly in small-scale boilers [3]. Due to a typically more challenging chemical fuel composition (e.g. higher mass fraction of aerosol forming elements, nitrogen, sulfur and chlorine) compared to forest wood, agricultural fuels may lead to higher gaseous and particle emissions during combustion as well as to increased disturbances of the boiler (e.g. boiler shutdown or error messages) caused by slagging, elevated mass fraction of ash in the fuels and corrosive substances (e.g. HCl, SO₂) in the flue gas [4]. Especially for small-scale boilers which are typically optimized for high quality woody biomass, agricultural fuels might be a challenge. The combustion behavior of agricultural fuels in domestic boilers might be improved by adapting the combustion unit itself through primary or secondary measures [5] or by improving fuel properties. The focus of this study was on fuel upgrading. This was performed by

(I) additivation of fuels with kaolin and by
(II) blending of fuels with softwood.

These approaches aim at the reduction of particle emissions and at an improvement in slagging tendency during combustion by manipulation of chemical fuel properties through mixing of the fuels with an additive (additivation) or with another biomass of high quality (blending) [6–14]. The following paragraphs summarize the considerations behind these approaches.

According to recent literature, aerosol formation (and therefore particle emissions) during combustion of biomass is strongly related to the abundance of so called "aerosol forming elements" in fuels, i.e. on the amount of the alkali elements potassium (K) and sodium (Na), the trace elements zinc (Zn) and lead (Pb) as well as sulphur (S) and

Abbreviations: a.r., as received; d.b., dry basis; DIN, German Institute of Standardisation; NCV, net calorific value; TPM, total particulate matter; STC, standard testing conditions (0 °C, 1013 hPa, on dry basis at 13% O₂); TFZ, Technology and Support Centre in the Centre of Excellence for Renewable Resources
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**Full scientific report (in German)
will be released in February 2020:**

„Schwierige Pelletbrennstoffe für
Kleinf Feuerungsanlagen -
Verbrennungstechnische Optimierung
durch Additivierung und Mischung“

TFZ Report No. 65

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Thanks for listening!

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