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Modelling of Soot Distribution in GPFs and its Influence to the Accuracy of Radio Frequency and Δ*p* Sensors

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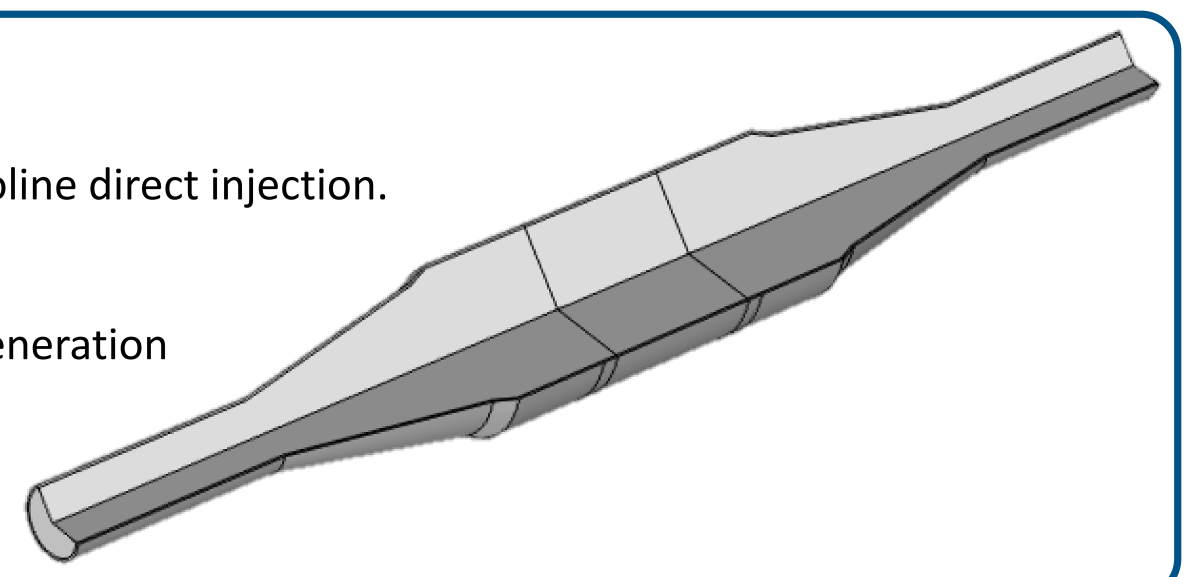
Motivation

- Stringent ***emission standards*** force vehicle manufacturer to serialize ***Gasoline Particle Filters*** (GPFs) in engines with gasoline direct injection.
- Soot loading has to be monitored to prevent high back pressure and overheating during regeneration
- Like in diesel application evaluation of the ***differential pressure*** is possible, but difficult at low mass flows and during regeneration
- Novel approach is a ***radio frequency (RF)*** based technique which enables a ***direct soot mass determination.***

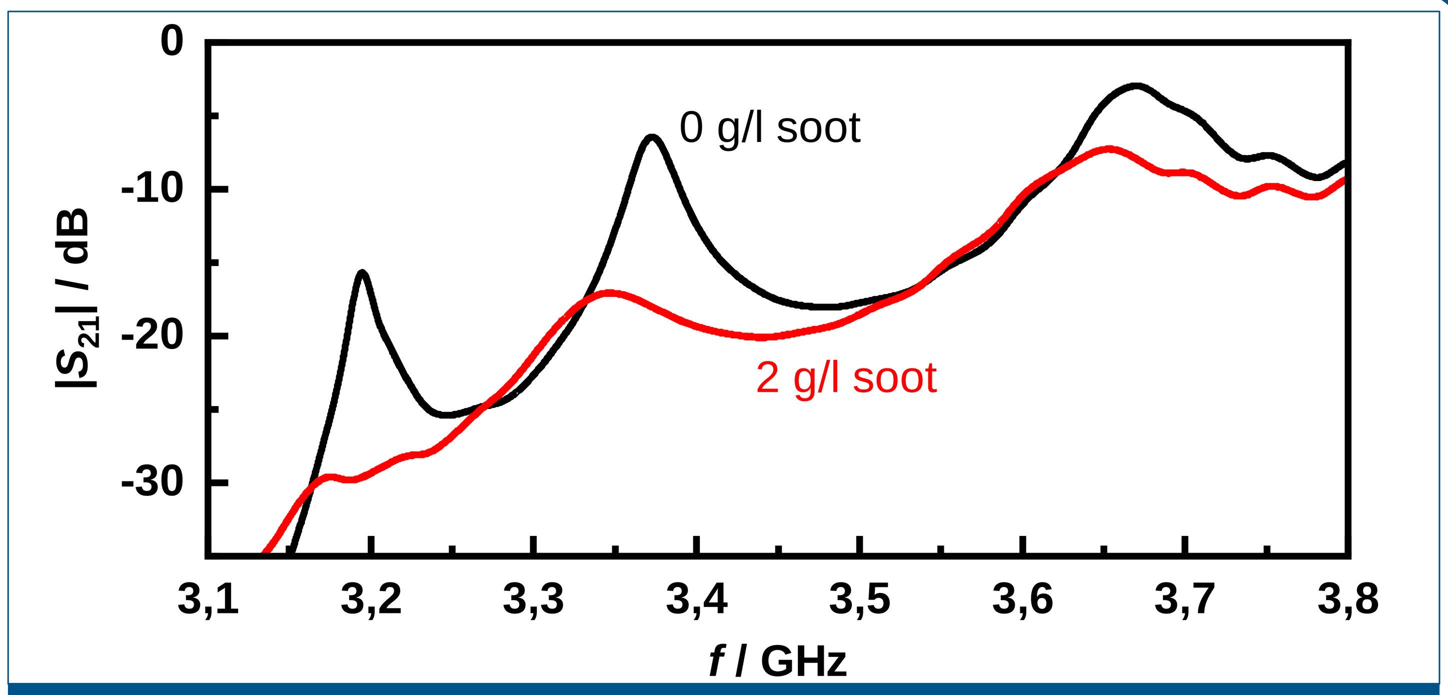
➢ **Simulation of the exhaust gas system to maintain a deeper knowledge of the sensor behavior**



What is the RF sensor?

- Excitation of ***electromagnetic resonances*** in the filter canning by two antennas.
- Propagation behavior of electromagnetic waves in filter is dependent on its electrical properties.
- Relationship between ***resonance parameters*** and the ***transmitted power*** and dielectric soot properties.
- Functionality demonstrated in diesel engines [1], successful initial tests with gasoline applications [2]
- ***No dependence*** on the exhaust gas flow like Δ*p* sensors, but influenced by temperature
- Evaluation of different parts of the frequency spectrum possible, e.g. resonance frequency or mean gain between the antennas

➢ **Can the RF sensor determine the soot mass better than the Δ*p* sensor?**



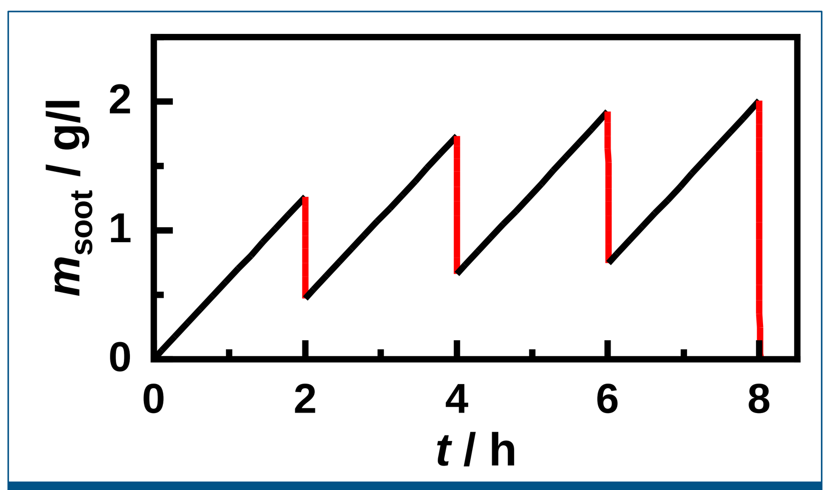
Transmission spectrum of a GPF without soot loading and with approx. 2 g/l at 500 °C

Simulation model

- Simulation of the GPF and the areas downstream and upstream with ***COMSOL Multiphysics***
- Modelling of all flow channels leads to very high computational effort
  → GPF as homogeneous medium
- Calculation of ***turbulent gas flow***, temperature distribution, ***particle tracing*** upstream of the GPF and ***chemical reaction*** during regeneration
- Transfer of temperature and soot loading to a ***RF simulation model***

Engine operation

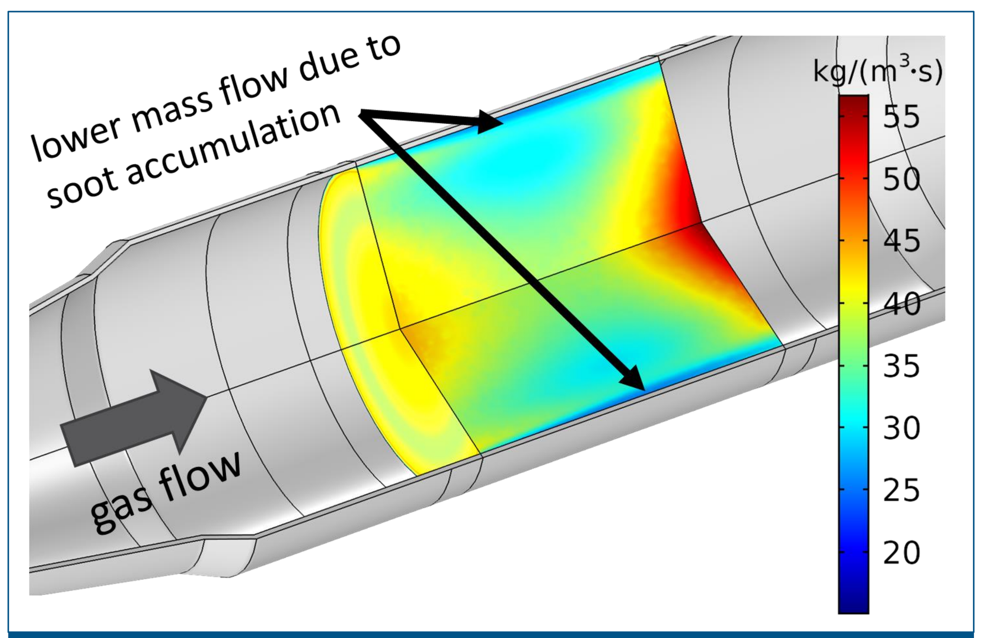
- Simulation of a constant mass flow
- Continuous soot loading over 8 h
- ***Partial regenerations*** every 2 h by adding 2 % oxygen for 5 s
- Complete regeneration after 8 h



Simulated soot mass stored in the GPF

Results

- ***Soot distribution*** as well as ***flow conditions*** in all operating modes can be observed
- Determination of mass error based on measured sensor data in relation to loading without partial regenerations
- Both sensors measure ***too low soot mass*** after first partial regeneration
- Δ*p* sensor shows a significantly higher error than the RF sensor shortly after regeneration
- RF sensor with an almost constant error during soot loading



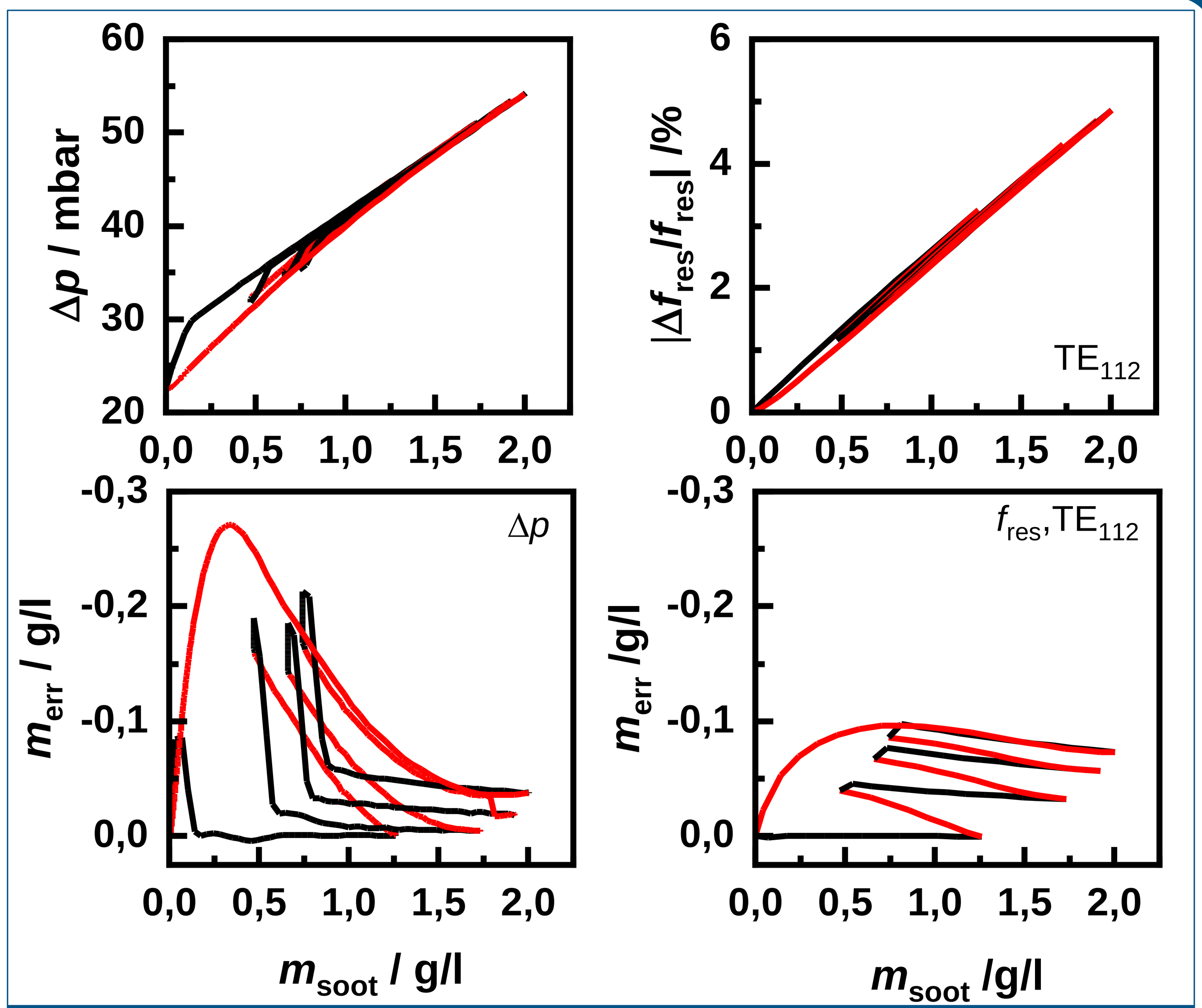
Exhaust gas flow through the GPF after first regeneration

Systematic error of the <u>Δ*p* sensor</u> due to:

- Soot accumulation in filter pores (deep bed filtration) or soot cake with different back pressure
- Different regeneration and loading behavior

Systematic error of the <u>RF sensor</u> due to:

- Accumulation of soot at the outer section of the GPF due to lower temperature / slower reaction kinetics
- Lower sensitivity near filter canning when evaluating a singular resonance due to the electric field distribution



Simulated sensor signals and resulting error in mass determination (based on soot loading without regeneration) due to the partial regenerations; left: Δ*p* sensor; right: RF sensor

Conclusion / Outlook

- **Successful modelling of an exhaust system to analyze possible systematic error sources of the Δp and the RF sensor**
- **Accuracy of RF sensor could be improved by evaluating additional resonances or the averaged spectrum**

Acknowledgements

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References

[1] A. Sappok, L. Bromberg, J.E. Parks, V. Prikhodko: Loading and Regeneration Analysis of a Diesel Particulate Filter with a Radio Frequency-Based Sensor, *SAE Tech. Pap.*, **2010-01-2126** (2010), doi: 10.4271/2010-01-2126
[2] M. Dietrich, C. Jahn, P. Lanzerath, R. Moos: Microwave-Based Oxidation State and Soot Loading Determination on Gasoline Particulate Filters with Three-Way Catalyst Coating for Homogenously Operated Gasoline Engines, *Sensors*, **15**, 21971–21988 (2015), doi: 10.3390/s150921971

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