Nanoparticle Emissions during Regeneration of DPF-Systems

- **passive regenerations: DOC + SCR; CSF alone**
- **active regenerations: standstill burner; fuel injection & DOC**

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Support: BAFU, BfE, Swiss Oil
Partners: EMPA, JRC, DINEX, HUG, HUSS, TTM, AFHB

The fatty acid methyl esters (FAME's) – in Europe mostly RME *) (Rapeseed methyl ester) – are used in several countries as alternative biogene Diesel fuels in various blending ratios with fossile fuels (Bxx). Questions arise often about the influences of these biocomponents on the modern exhaust aftertreatment systems and especially on the regeneration of Diesel particle filters (DPF).
In the present work different regeneration procedures of DPF systems were investigated with biofuels B0, B20 & B100.
The tested regeneration procedures were:

- passive regenerations: DOC + CSF; CSF alone,
- active regenerations: standstill burner; fuel injections & DOC.

During each regeneration on-line measurements of limited and unlimited emission components (nanoparticles & FTIR) were conducted.

The passive DPF regenerations by means of catalytically coated DPF's (CSF ... catalyzed soot filter), or a combination of oxidation catalyst (DOC) upstream and a CSF downstream are preferred for retrofitting as simplest solution, if the conditions of engine operation allows it. Especially the engine application has to result in sufficient frequency of higher exhaust gas temperatures, which enable the light-off and sufficient duration of the catalytical oxidation of the collected particle mass. The low sulphur content of the fuel and the appropriate lube oil quality have to guarantee the long-duration efficiency of the catalytic coatings.

Active regeneration of DPF with burner has an advantage to be independent of engine operating conditions, catalytic coatings and fuel quality. It can be applicable for difficult situations, like low load operation with high sulfur fuel.

Regeneration with fuel injection (fuel aerosol generator) and oxidation catalyst (DOC) also offers the advantages of being mostly independent of engine operating conditions, but with the restriction of exhaust gas temperature, which has to be above the light-off temperature of the DOC. The catalytically supported fuel oxidation requires low sulfur fuels to enable the necessary long life of the catalytic coating.

It can be stated that the increased portion of RME in fuel provokes longer time periods to charge the filter with soot. This is due to the lower PM-emissions of the engine, as well as to the higher reactivity and higher SOF-portion of the particle mass from RME.

With the passive regeneration system with stronger catalytic activity (DOC + CSF) there is a stronger NO_2-production with B100 and due to the NO_2-supported oxidation of PM the balance point temperature is approx. 20°C lower, than with B0.
For the active regenerations the time courses of emissions and temperatures are closely connected with the chosen regeneration strategy – switching, timing and intensity (of burner, or fuel aerosol generator).

A higher portion of biocomponent causes usually a stronger break-down of the instantaneous DPF filtration efficiency during the regeneration procedure – this is an effect of stronger artefact of spontaneous condensation after DPF.

In summary there is no negative short term effect of bio-blend-fuels on the investigated regeneration procedures. Some recommendations for a successful long term operation, basing on other works and literature are given at the end of the paper.

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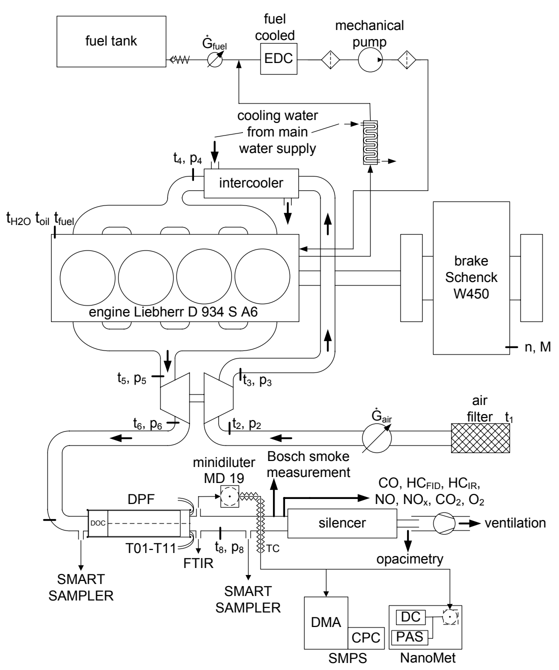
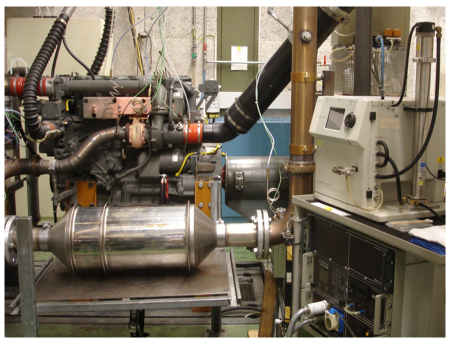
Measuring set-up:



Engine dynamometer and standard test equipment



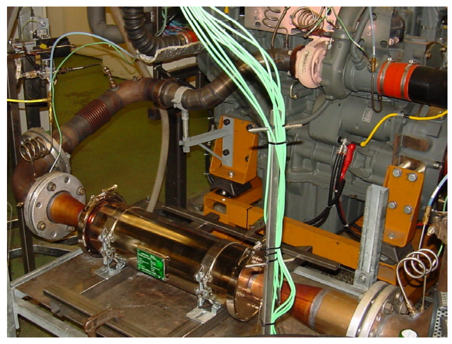
LIEBHERR engine D934 S and equipment for nanoparticle measurements in the engine room

Test engine

Manufacturer:	Liebherr Machines Bulle S.A., Bulle/Fribourg
Type:	D934 S
Cylinder volume:	6.36 Liters
Rated RPM:	2000 min^{-1}
Rated power:	111 kW
Model:	4 cylinder in-line
Combustion process:	direct injection
Injection pump:	Bosch unit pumps
Supercharging:	Turbocharger with intercooling
Emission control:	none (exhaust gas aftertreatment according to the requirements)
Development period:	2005

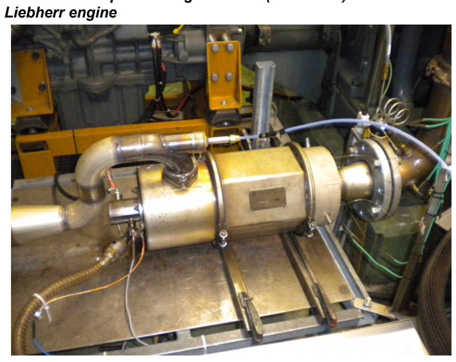
Tested DPF systems:

- HUG mobiclean RS, DOC+CSF (DPF with catalytic coating)
- HUG mobiclean RS, CSF only



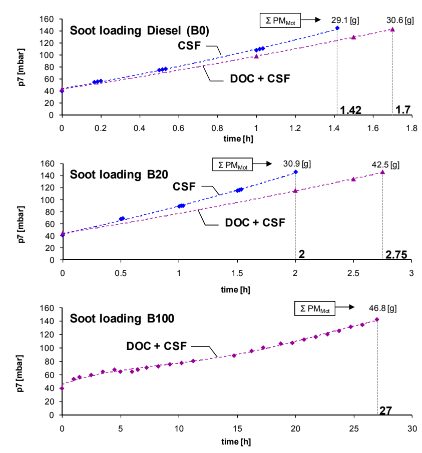
HUG DPF with passive regeneration (DOC+CSF) on the Liebherr engine

- HUSS MK system with standstill burner regeneration
- HUSS MD system with fuel injection+DOC

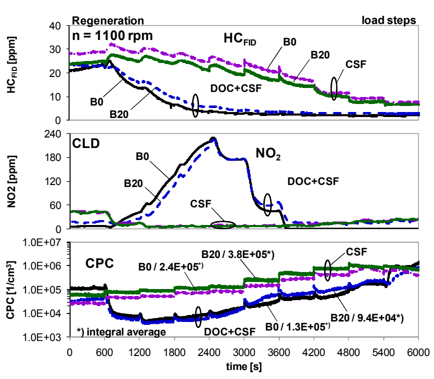


HUSS DPF-system with active regeneration (burner) on the Liebherr engine

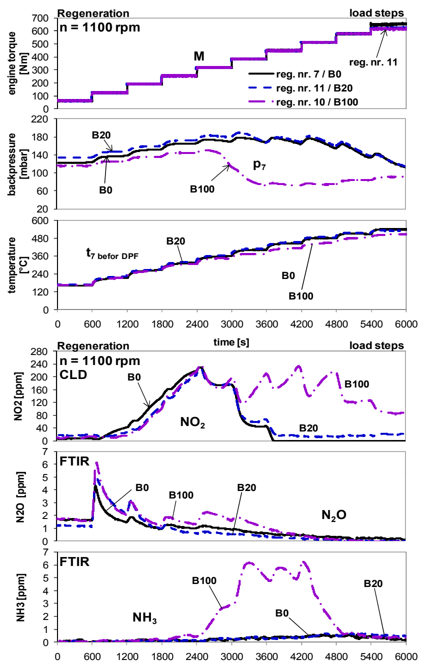
Passive regenerations, HUG DPF's



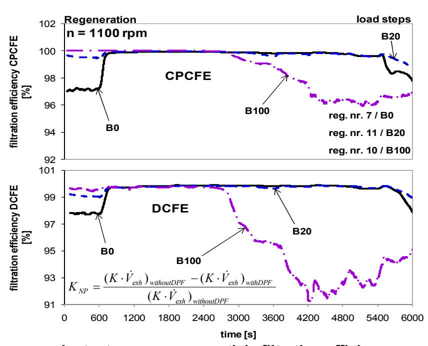
Backpressure during soot loading cycle



Regeneration with (DOC + CSF) vs. (CSF) with B0 & B20



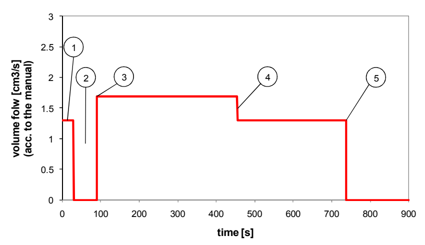
Regenerations with (DOC + CSF) & B0, B20 & B100



$$K_{NP} = \frac{(K \cdot \dot{V}_{exh})_{withoutDPF} - (K \cdot \dot{V}_{exh})_{withDPF}}{(K \cdot \dot{V}_{exh})_{withoutDPF}}$$

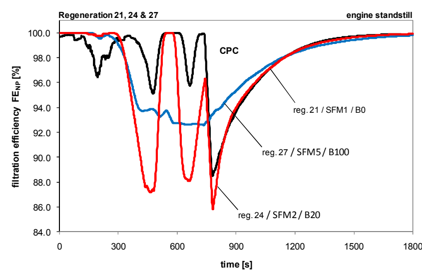
Instantaneous nanoparticle filtration efficiency during the regeneration procedures with (DOC+CSF) & B0, B20, B100

Active regenerations, HUSS DPF's



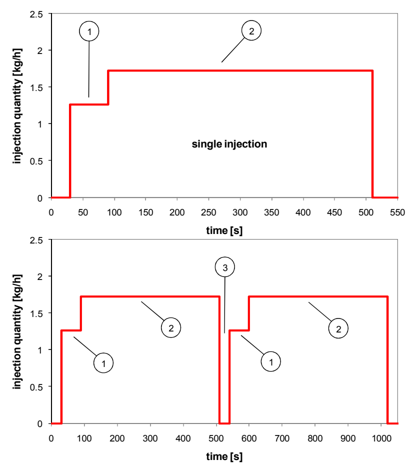
1. glow plug precooling, air pump on ~ 0.5 min
2. glow plug start (no air pump) ~ 1.0 min
3. start of fuel & air supply, ignition, flame ~ 6.0 min
4. switch off fuel (air pump on) ~ after 7.5 min
5. switch off air pump ~ after 12.5 min

Regeneration procedure with standstill burner (system MK)



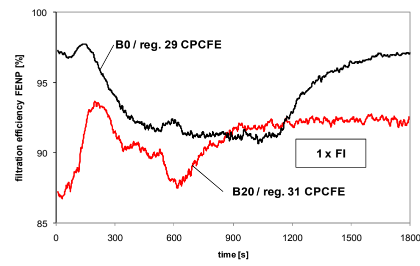
$$FE_{NP} = \frac{(K)_{withoutDPF} - (K)_{withDPF}}{(K)_{withoutDPF}}$$

Comparison of instantaneous equivalent CPC-reduction rates during the standstill burner regeneration with different bio-contents



1. preinjection 60 sec
2. main injection 420 sec
3. pause 30 sec

Fuel injection strategies for regenerations of system Huss MD with fuel injection + DOC



$$FE_{NP} = \frac{(K \cdot \dot{V}_{exh})_{withoutDPF} - (K \cdot \dot{V}_{exh})_{withDPF}}{(K \cdot \dot{V}_{exh})_{withoutDPF}}$$

CPC filtration efficiency during regeneration with B0 & B20, fuel injection + DOC

Conclusions

Regenerations with (DOC+CSF):

- with the same soot loading procedure the necessary time to load the DPF for Δp = idem increases with the bio-content of fuel (here for $\Delta p \approx 100$ mbar: B0 1,7h; B20 2,5h; B100 27h),
- the reasons for slower soot charging with biocomponents are:
  - lower engine-out PM-emissions,
  - higher reactivity of PM and partial oxidation during soot loading with DOC,
  - with high bio-content (here B100) lowering of exhaust gas temperature to the temperature-window of the highest NO_2-production in DOC, easier NO-NO_2 oxidation with B100 and the intensified NO_2-continuous regeneration.
- the repeatability of regeneration results and of the instantaneous filtration efficiencies is very good, except for the 1st step,
- the differences in the 1st step can be explained with the dispersion of the preliminary state of soot loading at the beginning of respective regeneration,
- with B100 there are some effects, which would not be detectable with B20:
  - there is more NO_2 with B100 because of lower t_{exh} (near to the maximum of NO_2-production), more NO_x and more easy NO-NO_2 oxidation,
  - the intensity of regeneration with B100 from 5th step (approx. 340°C) is higher; the drop of backpressure quicker than with the other fuels,
  - the increase of NP-emissions due to regeneration with B100 starts in the 4th step – spontaneous condensates after DPF and/or break-through of smallest size NP nuclei mode.

Regenerations with (CSF):

- soot loading with B20 needs longer time (2h), than with B0 (1,4h),
- soot loading with CSF takes a little shorter time, than with (DOC+SCF),
- the regeneration procedures and emissions are well repeatable,
- there is lower dispersion of curves of instantaneous FE and of temperature traces in step 8 with B20, than with B0.

Regeneration with standstill burner:

- the time-courses of emissions and temperatures are closely connected with the regeneration startegy,
- the nanoparticle penetration during the flame period is stochastically increased – the equivalent filtration efficiency reduced,
- the biocomponents increase the NO_x - & NO_2 - values during the flame period.

Regeneration with fuel injection + DOC:

- longer duration of fuel injection (double FI) prolongs respectively the period of high temperature level for the regeneration,
- the longer regeneration period is depicted with the higher emissions of CO, HC, DC & NH_3, in the respective time interval,
- at higher OP there is a higher level of exhaust temperature and of NO_x,
- after stopping the fuel injection there is an intense production of NO_2 due to t_{exh} decreasing into the level of NO_2-maximum,
- during the regeneration period (period of FI) there is a break-down of NP-filtration efficiency, which correlates with the single, or double FI-period and which is more intense for DC,
- with B20 there is a lower NP-filtration efficiency in the first phase of regeneration procedure – this is an effect of stronger artefact of condensates after DPF, due to the changed HC-matrix of B20.

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