ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

THERMOMANAGEMENT
by
RETROFIT
EXHAUST THROTTLING

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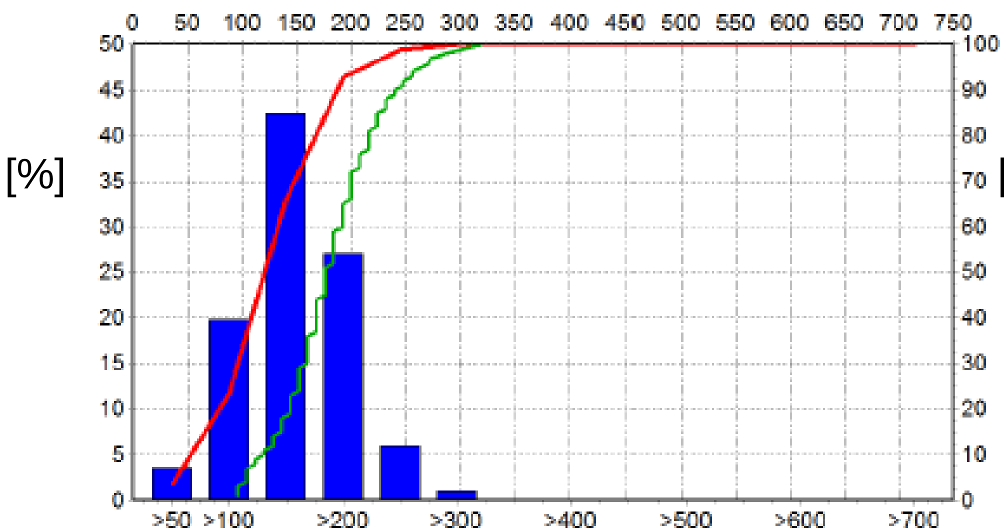
6^{th} VERT FORUM – EMPA, March 20, 2015

The Problem
(Example Bogotá)

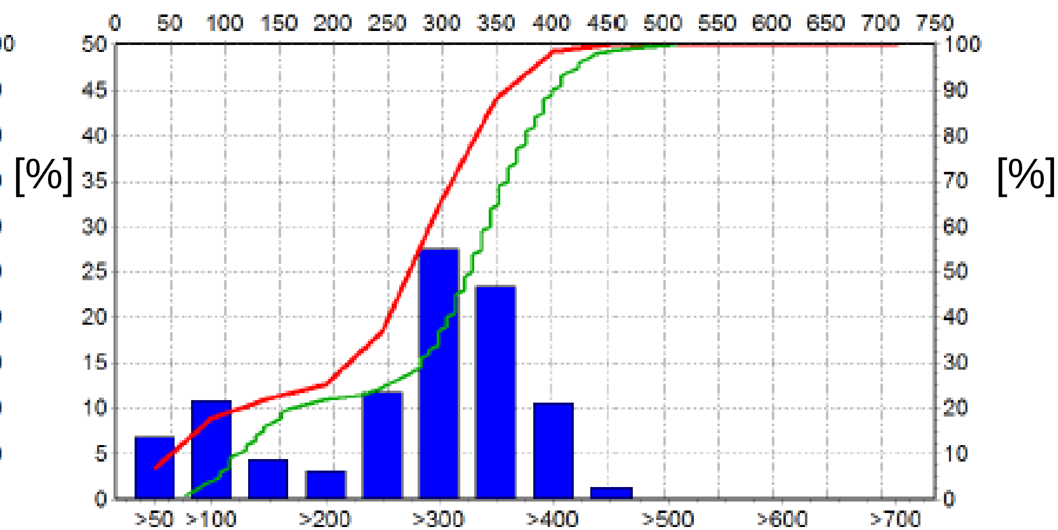
Frequency distribution + cumulation

Local bus



Exhaust gas temperature [°C]

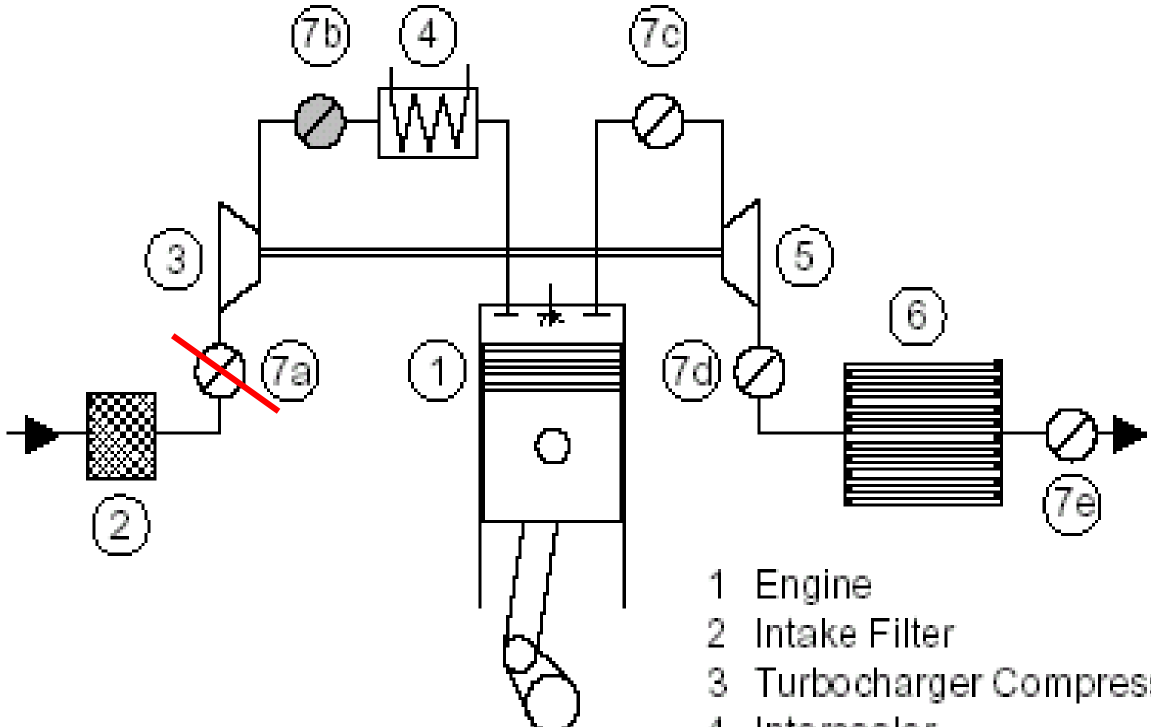
Main line bus



Exhaust gas temperature [°C]

Methods to Increase the Exhaust Gas Temperature

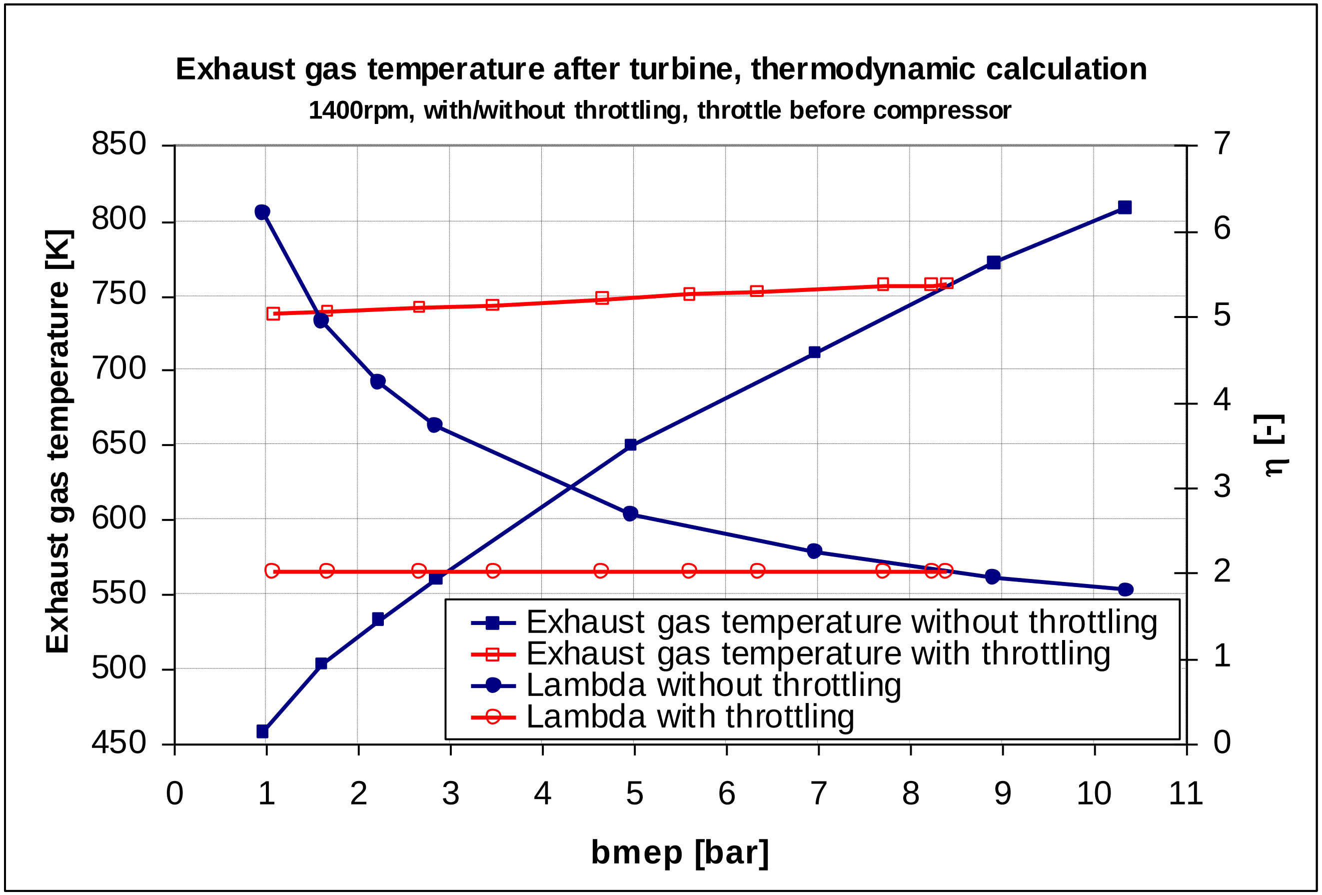
- **Heat added** by electrical heating, burner, catalytic combustion of additional fuel
- **Heat recovery** by additional oxidation of combustible exhaust gas components
- **Additional engine load,** e.g. by a greater demand of electrical power
- **Change of start of injection**
- Reduction of the air surplus (lower λ) by **throtteling**



1 Engine
2 Intake Filter
3 Turbocharger Compressor
4 Intercooler
5 Turbocharger Turbine
6 Particulate Trap
7a – 7e Gas Flow Throttle

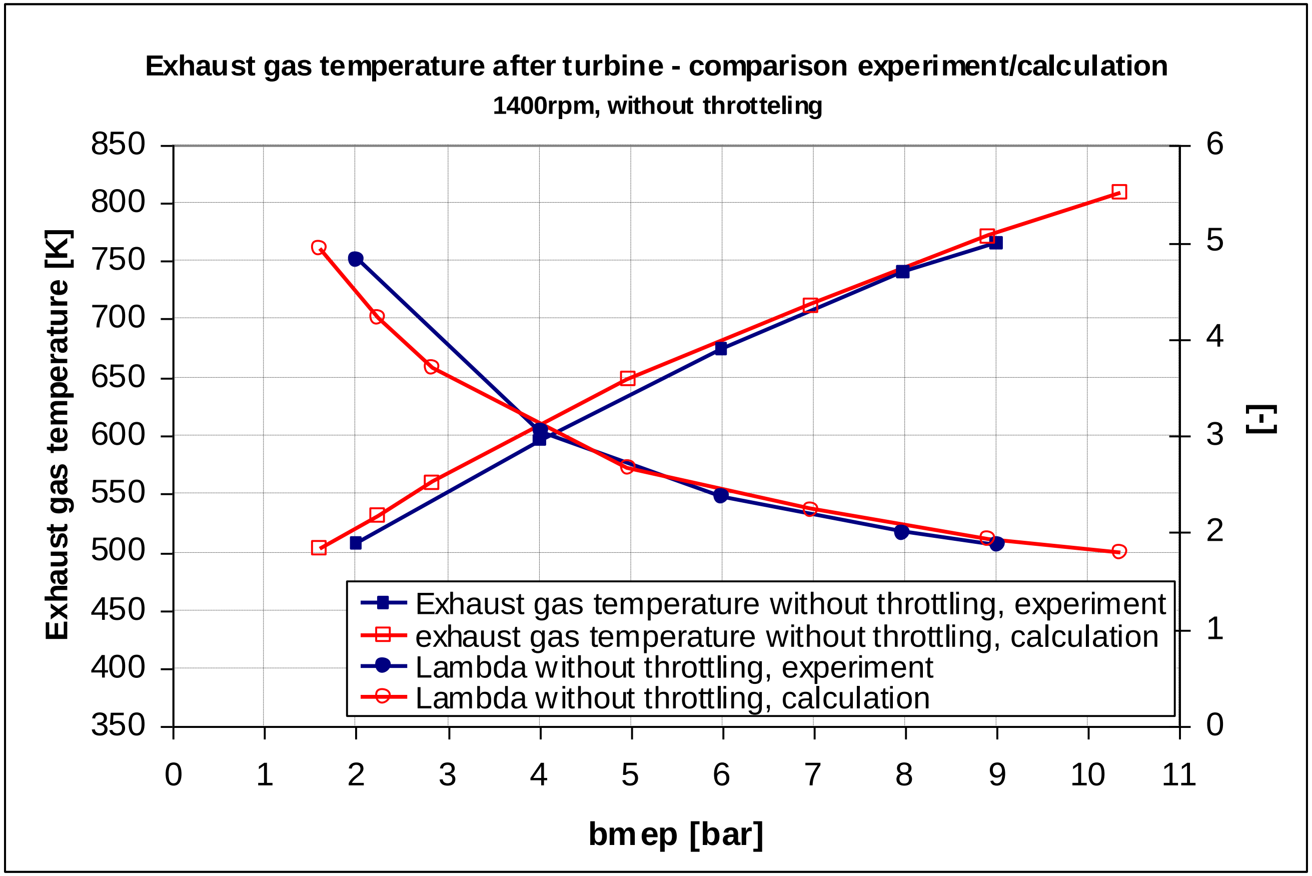
Intake Throttle Arrangement

Exhaust Gas Temperature with and w/o Throttling for Constant Excess Air (computational model)



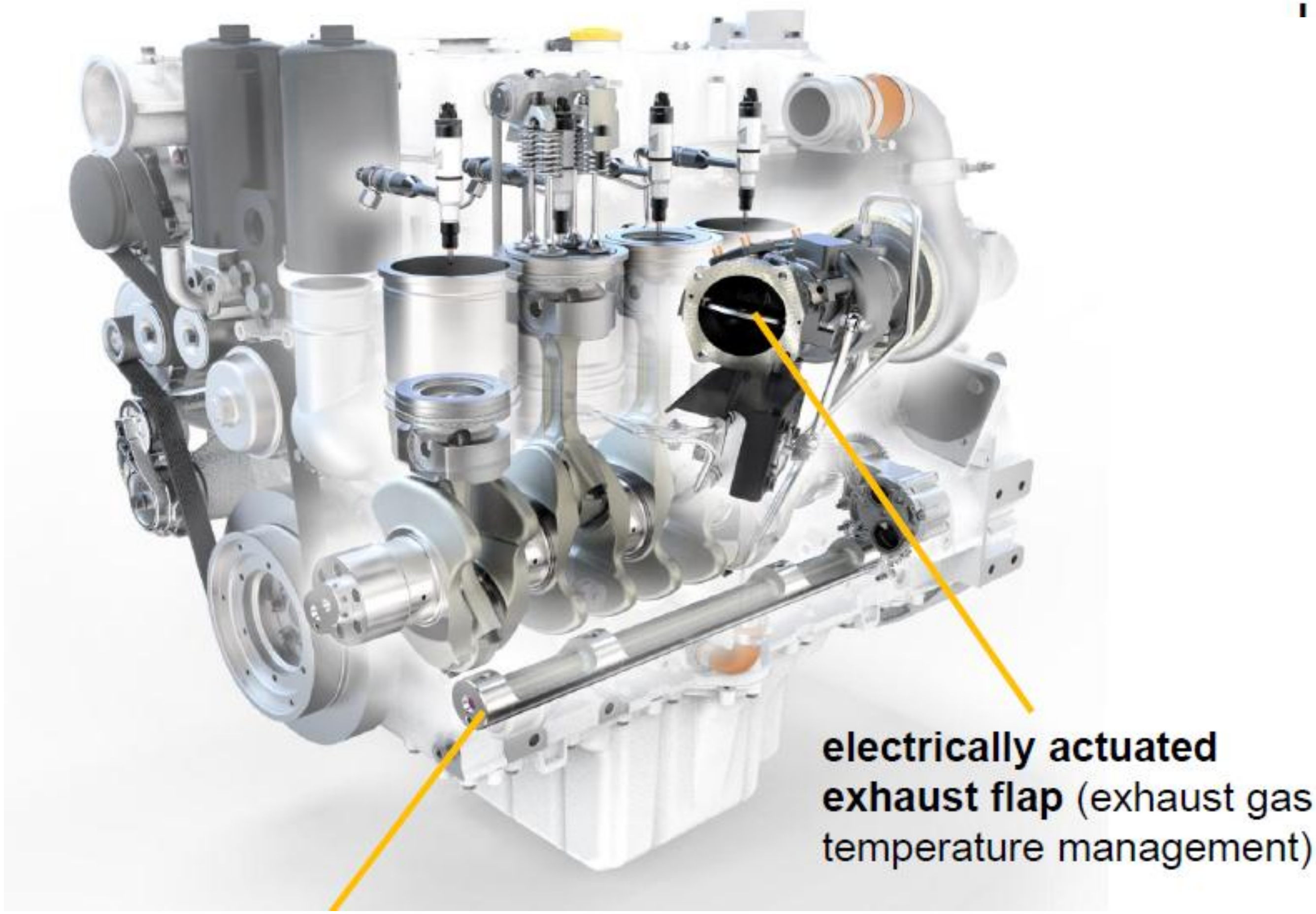
(Source: SAE 2003-01-0381)

Exhaust Gas Temperature after Turbine without Throttling; Comparison of Experiment and Computational Simulation



(Source: SAE 2003-01-0381)

2014: Throttling Becomes Standard with Euro 6



(Source: Cummins)

VERT – Throttle – Project 2014/15

- One position throttling concept (on/off)
- Easy to retrofit
- Low cost – available compounds
- Development of optimized strategy
- Development of optimized design
- Applicable to all retrofit cases
- Temperature lift > 50°C
- Low fuel economy penalty
- Can be integrated in a filter case
- Can be controlled by filter-OBC

Financing, Design and Tests

- **Overall budget:** **Fr. 90'000.-**
- **Financing:** **VERT and FOEN** (Federal Office for the Environment)
- **Contributions:** **Hug Engineering** (Filters)
  Nöthiger Electronic (Datalogging)
- **Tests:** **Delegated to Belicon Fahrzeug-forschung, FH Landshut, Prof. Dr. R. Pütz**
- **3 Phases:** **Tests without DPF, Design and Tests with DPF**
- **Start:** **August 2014 - January 2015**

Strategies

A: **Throttling at low idle ($\lambda \leq 3$) + motoring**

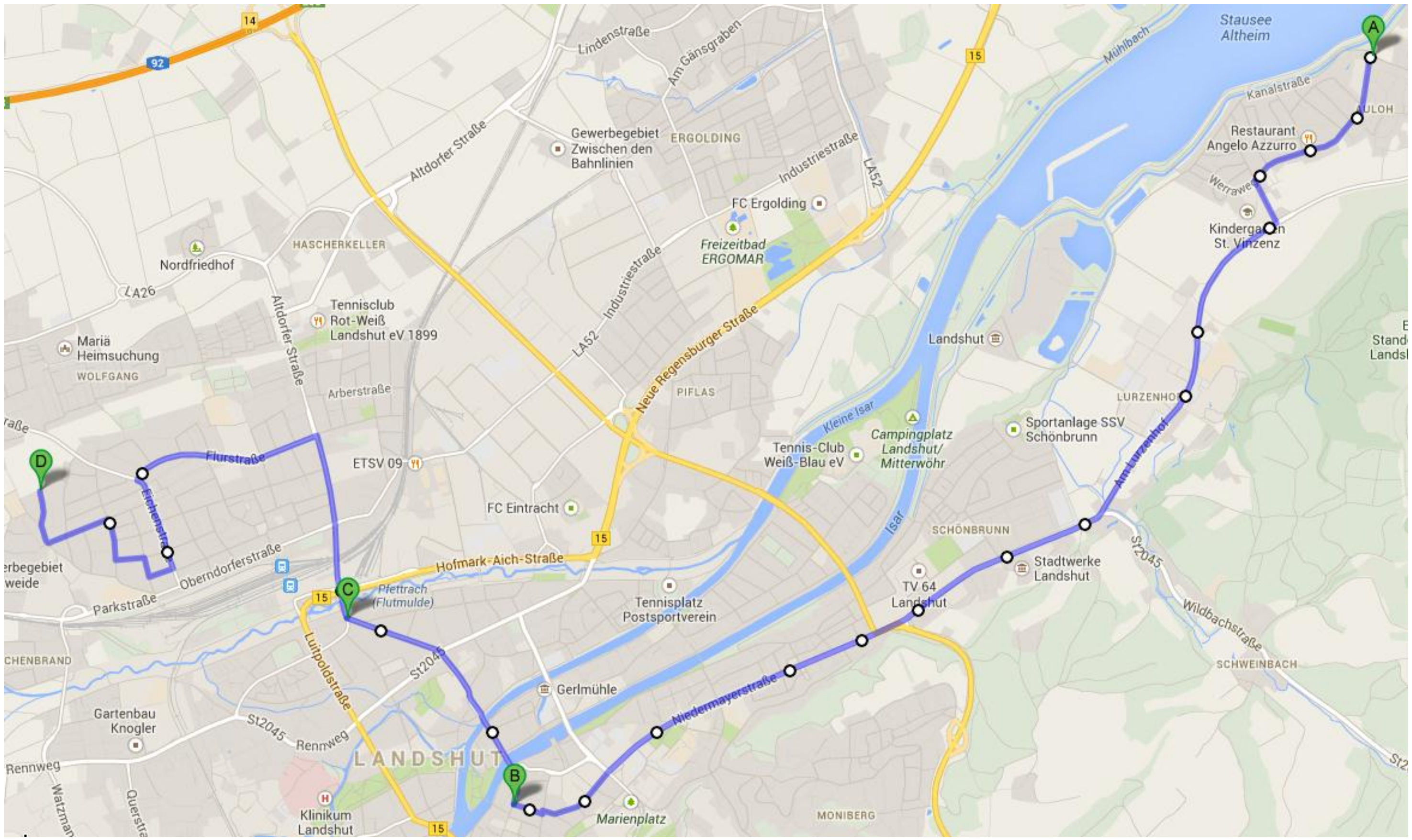
B: **Few throttling at low idle + motoring + throttling at light load (e.g defined by a certain vehicle speed)**

Test Vehicle (Euro II)

Technische Daten	
Hersteller	EvoBus GmbH
Erstzulassung	12.06.1996
Typ	Mercedes Benz O 405 N
Sitz- / Stehplätze	36 / 0 (im Schulbuseinsatz), sonst 66
Länge / Breite / Höhe [mm]	11910 / 2500 / 2935
Leergewicht [kg]	10450
Techn. Zul. Gesamtgewicht [kg]	13600 (im Schulbuseinsatz), sonst 18000
Motor (aufgeladener Diesel mit LLK)	OM 447 hLA
Motorleistung [kW/PS] **bei [1/min]**	157/214 bei 2200
Hubvolumen [cm³]	11967
Zylinder	6
Getriebe (Serie) / Typ	4-Gang Voith / Automatik
EU Abgasnorm	EURO II

School Bus of the City of Landshut

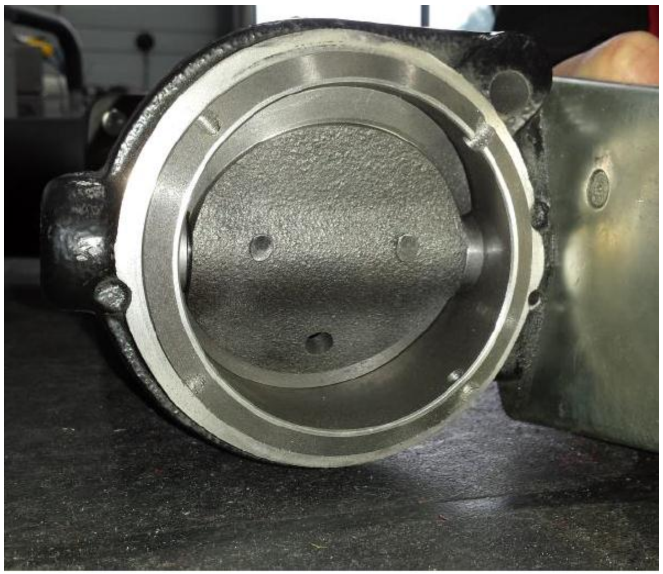
Test Route – Landshut Line 3

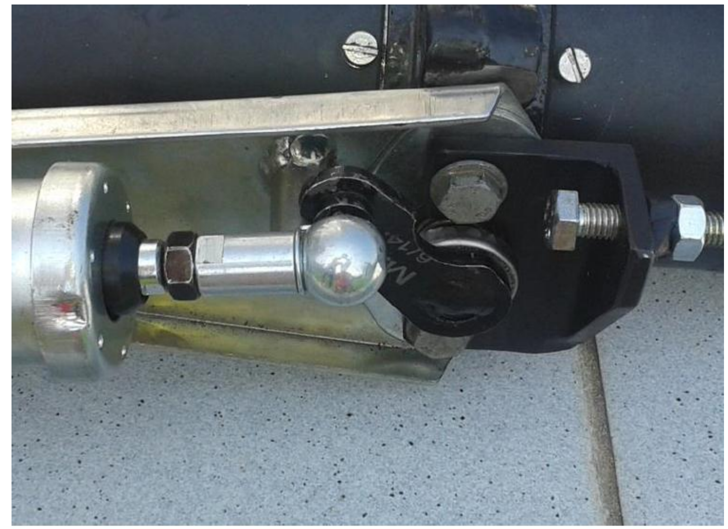


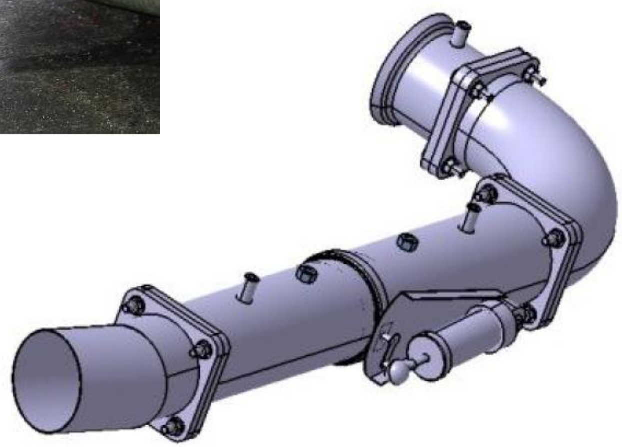
Total length: 14.5 km Stops: 30 ΔH: 25 m

IVECO Standard Exhaust Throttle

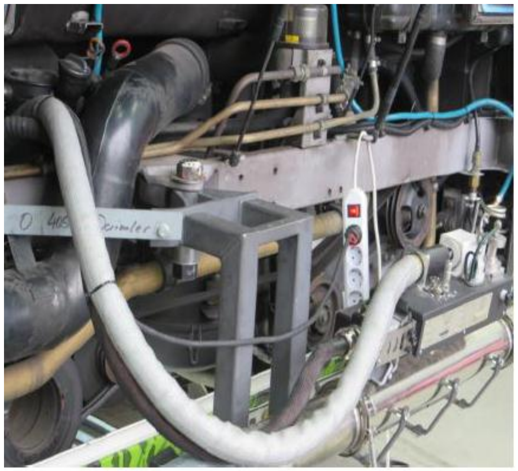
(pneumatic on/off, 8 mm hole)

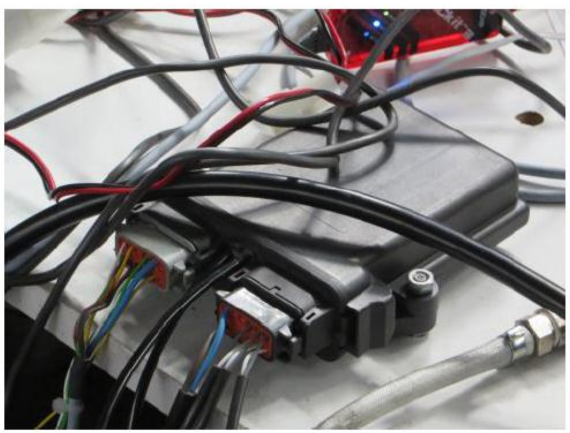


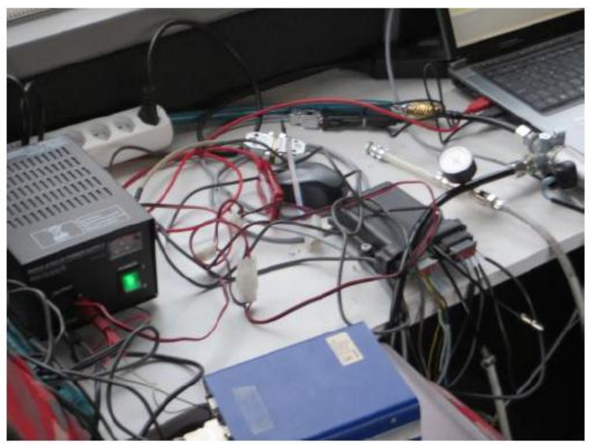




Onboard Emission Measurement Equipment + Datalogging + Lambda



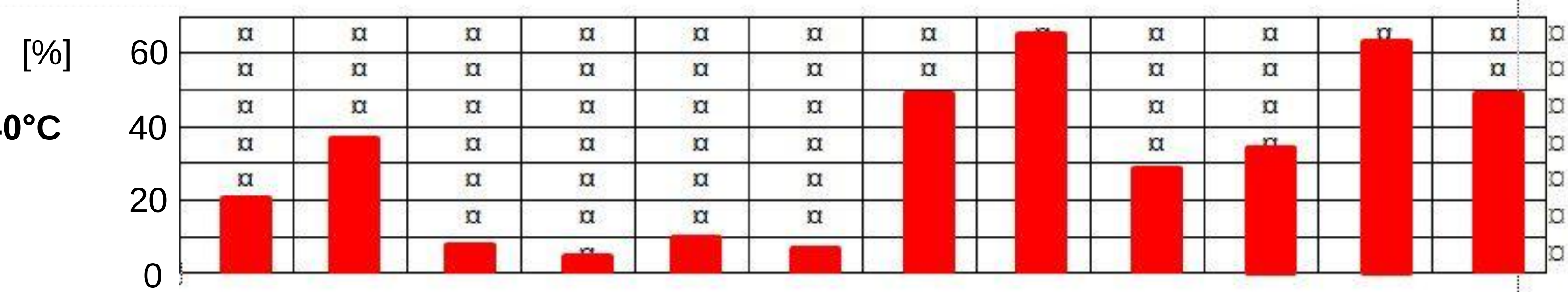




Temperature Increase

Phase 1 (without DPF)

Test point	1	2	3	4	15	16	17	18	19	20	21	22
Average speed, ca. km/h	18	18	12	12	12	12	18	18	12	12	12	12
Isolation												
Throttle during idling												
Including coasting												
Low load til 20 km/h												
Low load til 25 km/h												
Median temperature [°C]	209	233	191	182	174	194	229	257	224	229	250	241
Dwell time ≥ 240°C [%]	20.1	36.4	7.3	5.1	10.7	6.7	49.0	65.7	28.7	35.0	63.4	49.2
Dwell time ≥ 300°C [%]	0.0	6.6	0.3	0.0	0.2	1.1	9.0	12.3	2.6	6.1	11.7	8.3



Dwell time ≥ 240°C

Emissions and Fuel Consumption

Phase 1 (without DPF), average speed: 12 km/h

	Zyklus	v_{mittel} [km/h]	NO [g/km]	NO_2 [g/km]	NO_x [g/km]	THC [g/km]	CO [g/km]	CO_2 [g/km]	Verbrauch [l/100km]
No throttling	3	12	13,19	1,47	14,66	2,159	1,523	1089,610	41,43
	4	12	13,13	1,14	14,27	2,103	1,231	1058,240	40,24
	7	12	13,59	1,18	14,77	2,183	0,679	1106,152	42,06
	8	12	13,12	1,14	14,26	2,113	0,561	1085,636	41,28
Throttling	**15**	12	12,47	1,23	13,70	1,867	0,003	1025,090	38,98
	16	12	11,98	1,18	13,16	1,864	0,001	948,684	36,07
	19	12	8,76	0,76	9,52	1,567	0,238	935,630	35,58
	20	12	9,94	0,75	10,69	1,536	0,592	965,967	36,73
	21	12	9,30	0,70	10,00	1,446	0,854	993,506	37,78
	22	12	9,05	0,58	9,63	1,452	0,690	935,343	35,56

HUG Filters

Filters

- **Oxi cat (OXI OST),** 200 cpsi, high Pt content
  + Filter (FCX, A4), beschichtet, 100 cpsi, SiC

- **Mobiclean R (FCA, A1),** beschichtet, 100 cpsi, SiC

- **Mobiclean R (FNC, A5),** unbeschichtet, 100 cpsi, SiC

Additive

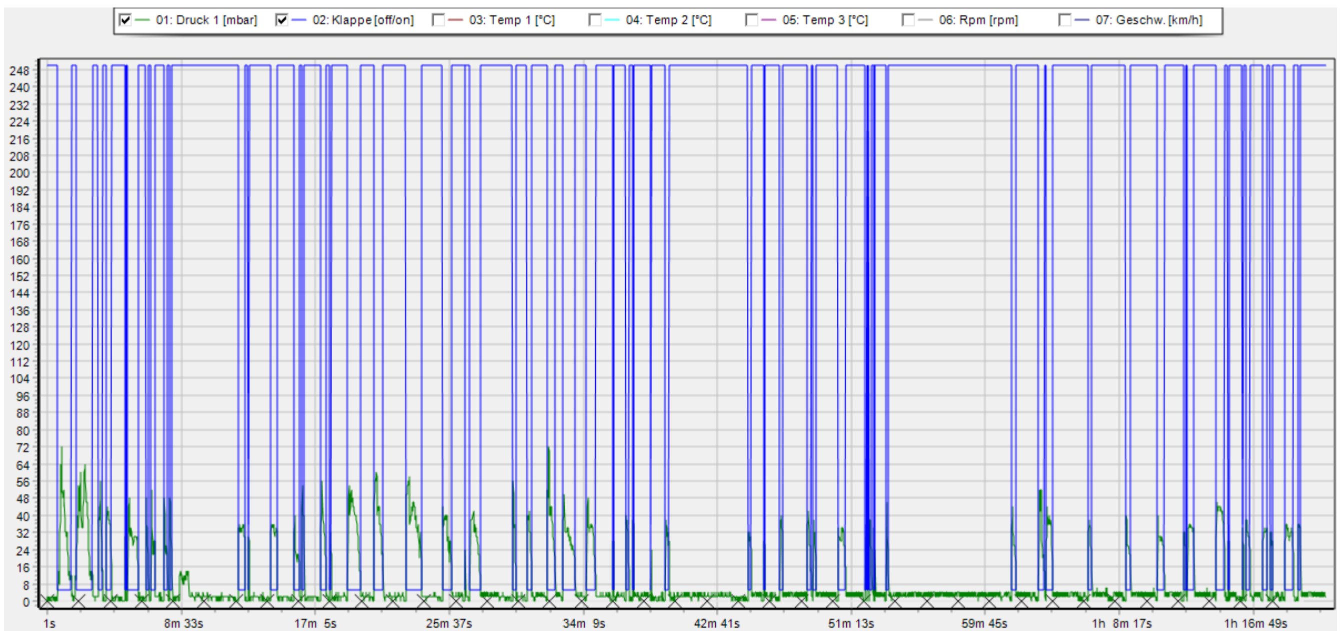
Satacen (Innospec), 30 ppm iron per 200 l diesel fuel

Filter Installation

Test Results with DPF

Filter	Additiv	Gegendruck vor Filter [mbar], Abregeldrehzahl		
		nach Einbau	nach Berussen	Fahrtende
OST OXI + FCX	nein		70	56
OST OXI + FCX	ja		56	96
FCA	ja	22	55	72
FNC	ja	34	56	48

Green line:
Backpressure
(Filter OST OXI + FCX)



CONCLUSIONS

- A very simple throttle can lift the exhaust temperature 50-80 °C
- All emissions are improved
- Fuel economy is improved – a big surprise
- Throttle can be integrated in a filter casing
- On/off-control easy by Filter OBC with input of vehicle speed, backpressure, temperature

Continuation

- **This technology has the potential for higher temperature increase**
- **The throttling strategy needs further optimization, among others to reduce acceleration penalties**
- **The surprising effects of emission and fuel consumption reductions must be investigated – where is the limit?**
- **The concept has to be tested in combination with an EGR system**
- **The financing of a follow up project is actually evaluated**