J. Czerwinski
HTA Biel
Switzerland

Nanoparticles in the exhaust gas of a chainsaw

NANOPARTICLES in the Exhaust Gas of a Chainsaw

by

Professor Jan Czerwinski

Head of the Laboratory for Internal Combustion Engines
And Exhaust Emission Control
University of Applied Sciences, Biel-Bienne, Switzerland

Workshop „Nanoparticle Measurement"

ETH-Zurich, August 7-8, 2000

Preliminary informations

The presented project about the emissions of chainsaws with detailed analysis of particulate emissions is a part of the efforts of the Swiss EPA (BUWAL)*) to diminish the emissions of the handheld machines with 2-stroke engines, [1].

Since the beginning of 90-ties a lot of R & D works have been done with the goal to introduce again the 2-stroke engine in the automotive sector [2], [3]. Although all those trials didn't succeed until now, they gave precious inputs to the 2-stroke technology in the traditional 2-stroke sectors, like small two-wheelers, chainsaws and small watercraft, [4], [5].

Some fundamental works of the Graz University of Technology (GUT) and the AVL Graz have to be mentioned, [6], [7]. [8], [9].

Most important handicaps of the SI-2-stroke engine concept form the point of view of emissions and of exhaust gas aftertreatment are:

- impossibility of a proper gas exchange without short-circuiting of a part of air-fuel-mixture (no 3-way-catalyst),
- mixture lubrication for a simple engine concept (heavy HC in exhaust gas).

Several research works about the particulate matter have been performed by the small 2-stroke manufacturers. The actual state of knowledge can be summarized as follows, [10], [11], [12]. [13]:

- about 98% of the particulate mass (PM) consists of the lub-oil residues (SOF),
- the 2-stroke particulate matter (PM) has a mutagenous potential,
- PM can be reduced roughly proportional with the reduction of the lub-oil ratio,
- PM depends on air-fuel-ratio, it is increased with the richer mixture,
- PM can be influenced to a limited extend by the fuel quality,
- oxidation catalyst can reduce PM of about 40 to 70% - this oxidation can be improved by the secondary air introduction in the exhaust pipe,
- oxidation of HC and SOF in the oxidation catalyst by the rich operation causes a supplementary production of CO due to the lack of oxygen. This effect can remarkably reduce, or even invert the CO-conversion efficiency,
- at cold start there is higher PM-emission and a higher part of solid PM,
- the deterioration factor of PM- and HC-emissions over the lifetime of the engine is very low. Those emissions depend mainly on the actual conditions of the machine: lub-oil content, mixture tuning, scavenging losses (engine construction),
- for different engines there is a large PM-emission dispersion of about factor 5.

In generally it has been stated, that the direct measurement of PM for legislation and control purposes is to complicated and it requires to much time and costs. Therefore it is proposed to replace the PM measurement by the correlations of PM with CO-, HC-values and lub-oil content, [12], [14].

*) Abbreviations see at the end of text

Experimental set-up

The engine data of the investigated chainsaws were:

STIHL	056	066
displacement	81.0 cm^3	91.6 cm^3
stroke/bore	38 / 52 mm	40 / 54 mm
rated power	4.1 kW	5.0 kW
rated speed	9000 Upm	9000 Upm
idling speed	2500 Upm	2500 Upm
max. speed	13000 Upm	13000 Upm

Fig. 1 – the exhaust gas components have been measured diluted and undiluted.
A direct measurement of the intake air flow is not possible without influencing the engine power. The air flow results indirectly form the measurements of fuel consumption, diluted exhaust gas flow and the dilution factor (CO_2 low/high). The dilution factor in the tunnel was between 20 and 30.

In addition to that the air excess factor λ was calculated from the emission parameters according to several formulas.
The gas sample for gravimetry (PM), as well as for the particles size distribution (PSD, PN) is branched form the dilution tunnel.

Particulate emissions analysis

Following methods of PM analysis were used:

- gravimetric measurement PM
- SMPS – PSD
- PAS – DC (NanoMet) *)
- analysis of filter residue
  (extractions, gas chromatography, mass spectroscopy)

PAS shows a signal, which is proportional to the total surface and to the chemistry of the surface of particulates. DC signal is proportional to the total surface independently of the chemical composition.

Measuring procedure

Fig. 2 – operating points at full load and at idling have been measured in the manner, that the weighted emission values of different legal test procedures could be expressed.

*) Abbreviations see at the end of text

Variation of A/F-ratio and of the lub-oil content

Fig. 3 – excessive mixture enrichment, by means of the mixture control screw has visibly negative effects: lower torque, higher specific fuel consumption, higher CO-, HC- and PM-values.
It is a justified requirement of the legislation to prohibit a free manual mixture adjustment in the future.

Fig. 4 – the content of the lubricant oil in the gasoline has a very strong influence on the particulate matter PM.

Limited emissions

Fig. 5 – compares the weighted emission values (ISO 8178 G3) of a STIHL 066 chainsaw with different actual and future limit values. This chainsaw fulfills the EUROMOT 1 requirements. To attain the EUROMOT 2 values an oxidation catalyst would be probably sufficient, but for the CARB values (2000-2005) other supplementary measures would be necessary.

During the presented investigations a special gasoline without aromats and with a very low sulphur content was used. This gasoline named "Aspen" lowers the CO-, HC- and PM-emissions.

Nanoparticulates

Fig. 6 – examples of PSD-spectra show the maximum values of number concentration, which are similar, or slightly higher, as for a typical diesel engine.

Fig. 7 and Fig. 8 – the higher lub-oil content (4%) causes lower integrated particulates numbers in the size range 20-200 mm. That means, that the higher particulate mass with 4% oil originates from bigger particles. In the separate partial size spectra, Fig. 8, the highest counts for 4% oil in the size range of biggest particles 80-200 mm art to see. The higher oil content moves the PSD-spectra to the bigger particles sizes.
In opposite to that the special fuel Aspen moves the PSD-spectra to the lower particles sizes.

Fig. 9 – richer mixture provokes slightly higher integrated PN (20-200 mm). The effect of moving the PSD to the bigger aerodynamic diameters is also visible in upper part of Fig. 11.

Fig. 10 – higher oil content at idling increases strongly the integrated PN (20-200 mm). In the lower part of Fig. 11 is to see, that the PSD-spectra at idling have other character than at full load and the higher oil content (4%) increases the PN in all partial spectra.

The results of NanoMet-on-line-sensors and the differential analysis of filter residue confirmed that there were no solid parts in the particulates.

Summary

- higher lub-oil content
  - increases strongly the PN emission
  - increases the peak values of PN at idling and shifts the PSD to the bigger sizes at full load

- mixture control screw
  - richer mixture tuning increases very much CO- and PM
  - moves the PSD at full load to the bigger sizes
  - increases slightly the integrated PN (20-200 mm) at full load

- special gasoline
  - reduces PM
  - reduces the integrated PN (20-200 mm)
  - shifts the PSD to the smaller sizes

- NanoMet / filter residue
  - confirm that about the totality of the nanoparticulates and of the PM consists of the lub-oil residues (SOF)

- Perspectives of the technical development to meet the future emission standards
  - oxidation catalyst
  - improvements of 2-stroke engines (scavenging, fuel injection, lubrication)
  - application of small 4-stroke engines

Acknowledgement

The author would like to express his gratitude for the support of the project to:

- BUWAL (Swiss EPA), Dr. A. Stettler, Mr. M. Wyser–Heusi
- TTM Mr. A. Mayer
- ETHZ-Matter Engineering. Dr. U. Matter, Mr. Th. Mosimann
- Oekozentrum Langenbruck. Dr. U. Wieser
- EMPA Organic Chemistry, Mr. P. Matrel
- STIHL, Mr. M. Bortfeld

References

[1] Jan Czerwinski, Pierre Comte, Sandro Napoli: Schadstoffemissionen von Kettensägen mit eingehender Analyse der Partikelemissionen. BUWAL Messkampagne Emissionminderung 2-T-Benzinmotoren. Abgasprüfstelle Fachhochschule Biel, Bericht B069, Feb-2000.

[2] Fahrzeugmotoren im Vergleich. VDI Bericht 1066, 2-Takt-Motoren, Dresden, Juni 1993.

[3] Entwicklung von 2-Takt-Motoren. Tagungsunterlagen Haus und Technik, Essen, Veranstaltung Nr. 30-731-056-6, Sept. 1996

[4] *Nuti M.:* Emissions from Two-Stroke Engines. SAE book Nr. R-223 ISBN 0-7680-0215-X.

[5] SETC – Small Engine Technology Conference. Proceedings. SAE P-348 Madison, Sept. 1999.

[6] *Laimböck F. J.:* The Potential of Loop-Scavenged, Spark-Ignition, Two-Stroke Engines. Graz University of Technology (GUT), SAE SP-847, Sept. 1990.

[7] *Beidl Ch. V.:* Abgasmessung an Kettensägen. Institut für Verbrennungskraftmaschinen und Thermodynamik, TU Graz, interner Bericht 1990.

[8] *Laimböck F. J., Meister G, Grilc S.:* CFD Application in Compact Engine Development. Graz University of Technology (GUT), SAE 982016.

[9] *Laimböck F. J., et .al.:* AVL SDIS Mk. II – Low Cost Automotive FI Applied to 2-Stroke Engines for Future CARB-Regulations. AVL / GUT, Graz, SAE 1999-01-3285.

[10] *Sakai T., Nakajima T., Yamazaki H.:* O-PM / Emitted Matters Caused by Two-Troke Engine Oil and its Reduction. Japan Automobile Research Institute (JARI). SAE 1999-01-3260 / JSAE 9938015.

[11] *Palke D. R., Tyo M. A.:* The Impact of Catalytic Aftertreatment on Particulate Matter Emissions from Small Motorcycles. ASEC Manufacturing SAE 1999-01-3299 / JSAE.

[12] Particulate Matters of Small Nonroad SI engines. Husquarna AB, EC DG XI Expert Group on Exhaust Emissions from Non-Road Mobile Machinery Engines, Bruxelles 1. Oct. 1999, Attachment 7.

[13] Laimböck, F., Trigg, R, et. al.: HYC - A Hybrid Concept with Small Lean Burn Engine, Electrically Heated Catalyst and Asynchronous Motor for Enhanced Performance and ULEV Level Emissions.
SAE Techn. Paper 991330, AVL Graz, Yamaha Motors Europe, Technical University Graz.

[14] Miersch W.: State-of-the-art with regard to the pollutant emissions from engines for mobile machinery and equipment. Abgasprüfstelle Berlin-Adlershof, EC DG XI Expert Group on Exhaust Emissions from Non-Road Mobile Machinery Engines, Bruxelles 1. Oct. 1999, Attachment 4.

Abbreviations

BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss EPA)
DC	diffusion charging sensor
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt
EPA	Environmental Protection Agency
ETHZ	Eidgenössische Technische Hochschule Zürich
PAS	photoelectric aerosol sensor
PM	particulate matter, particulate mass
PN	particles number
PSD	particles size distribution
SMPS	scanning mobility particles sizer
SOF	soluble organic fraction
TTM	Technik Thermische Maschinen

Fig. 1

Experimental set-up and the measured parameters for chainsaws

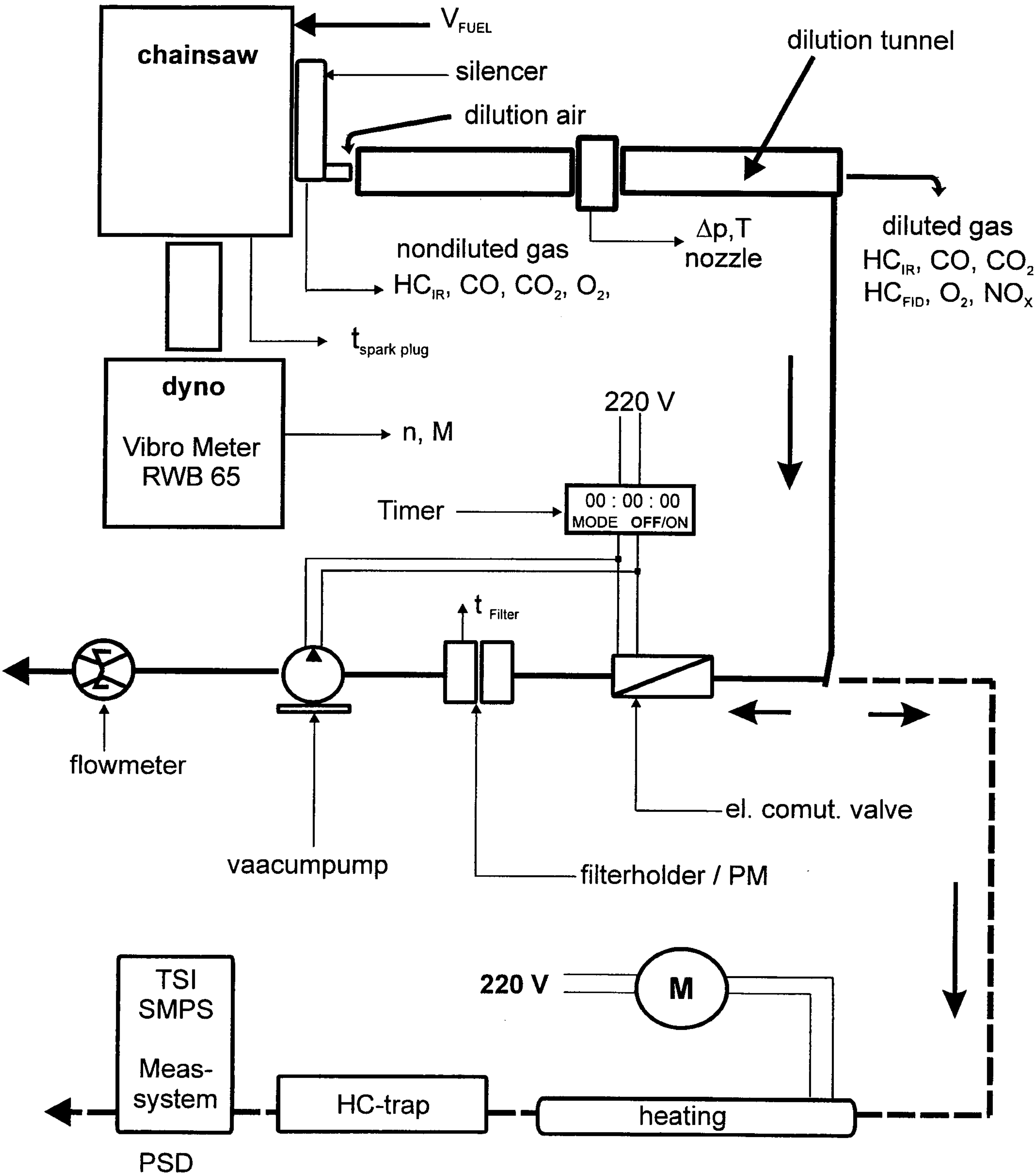
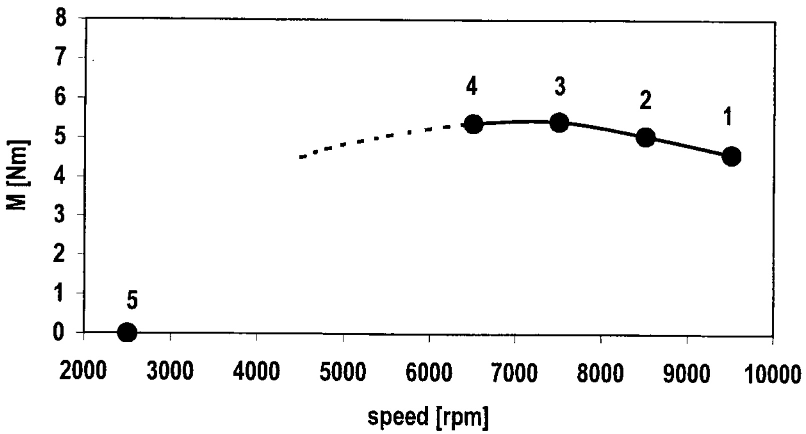


Fig. 2

Full load characteristic of the chainsaw STIHL 066 and the measured operating points



STIHL 056

Point	n	M
	[rpm]	[Nm]
5	2600	idling
4	6500	4.81
3	7500	4.72
2	8500	4.39
1	9500	3.80

STIHL 066

Point	n	M
	[rpm]	[Nm]
5	2500	idling
4	6500	5.37
3	7500	5.42
2	8500	5.06
1	9500	4.59

Fig. 3

Results at full load 7500 rpm with different mixture tuning

λ_{lean}=0.72 λ=0.62 λ_{rich}=0.55

Chainsaw STIHL 066, 2% oil

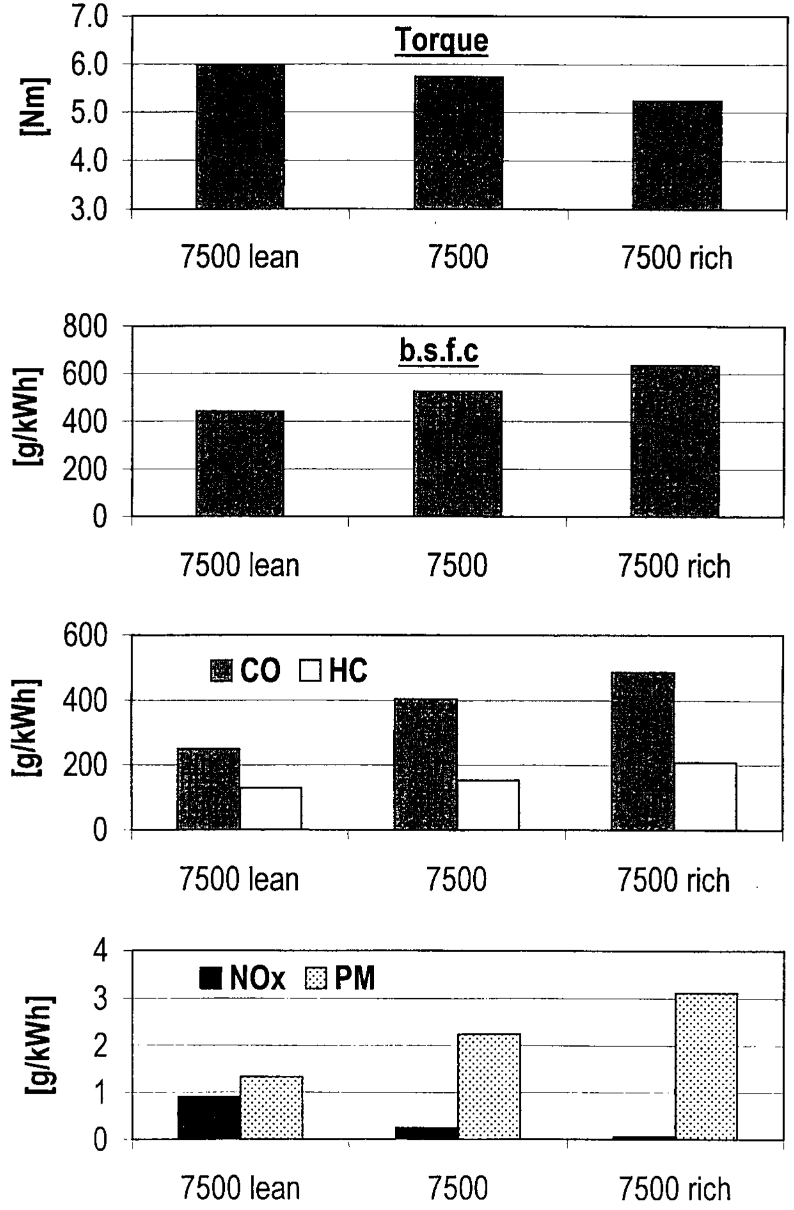


Fig. 4

Exhaust emissions at idling with 2% and 4% oil in fuel

Chainsaw STIHL 066

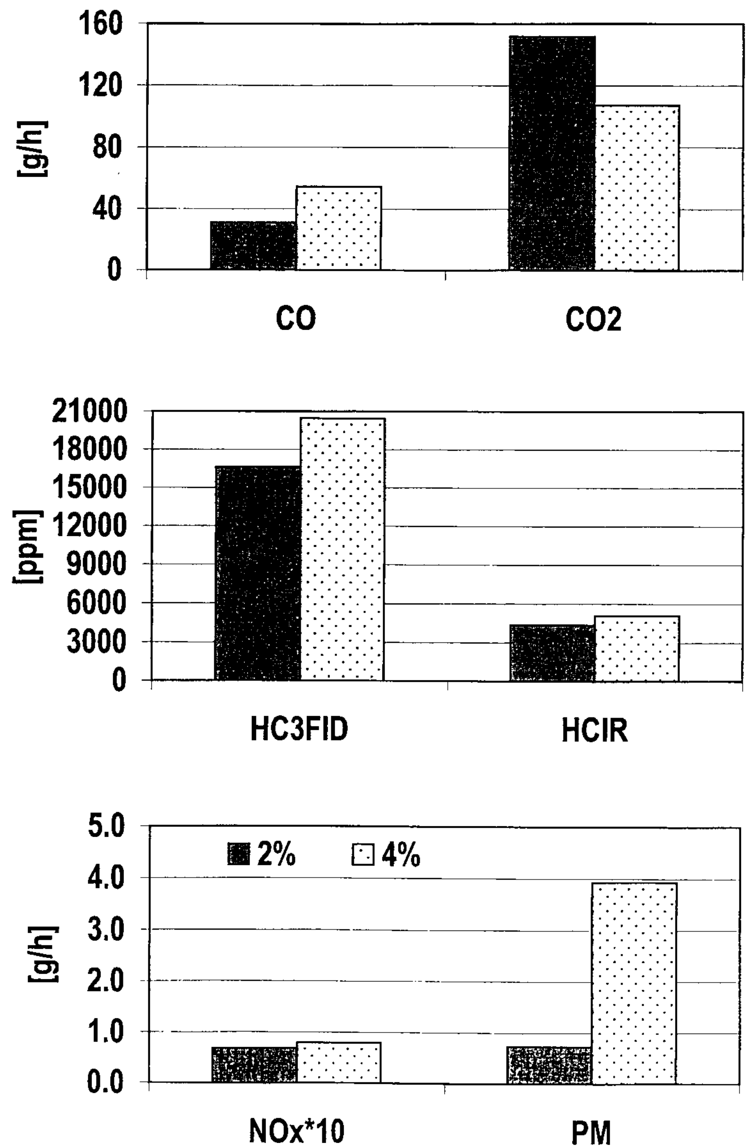


Fig. 5

Exhaust emission values in ISO 8178 G3 test

Chainsaw STIHL 066, weighting (90/10)*

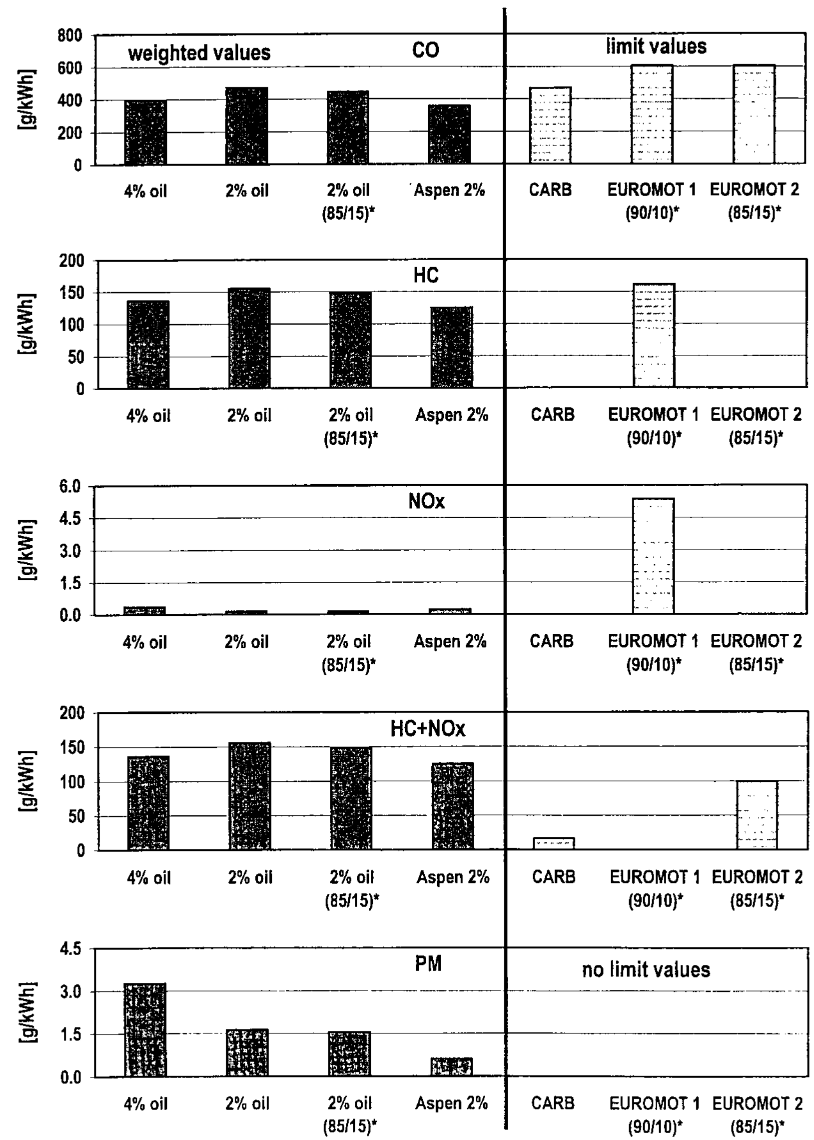


Fig. 6

Particles size distributions (PSD) at 9500 rpm / 7500 rpm - full load

Chainsaw STIHL 066, HC-trap, Aspen 2% oil

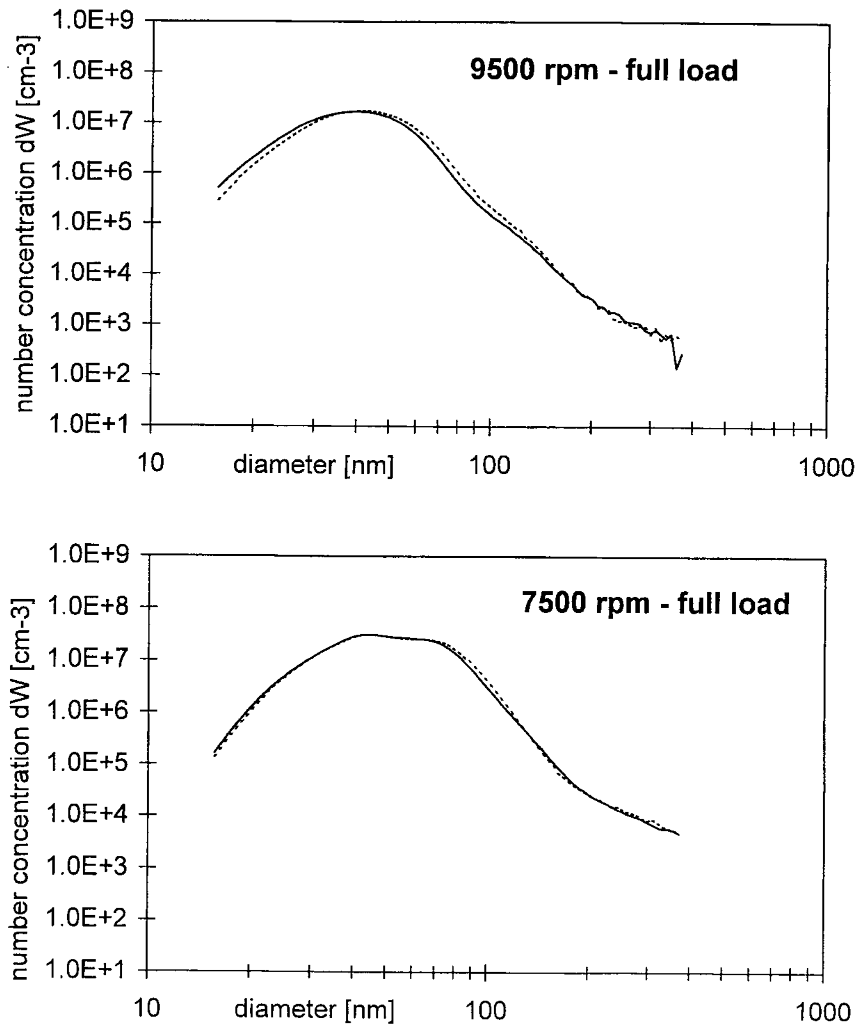


Fig. 7

Integrated particles numbers in the size spectrum 20 - 200 nm

Chainsaw STIHL 066, with HC-trap

$1/cm^3$	9500 rpm full load	7500 rpm full load
4% oil	**6.13E+08**	**6.84E+08**
2% oil	**6.72E+08**	**8.44E+08**
2% oil - Aspen	**3.56E+08**	**7.78E+08**

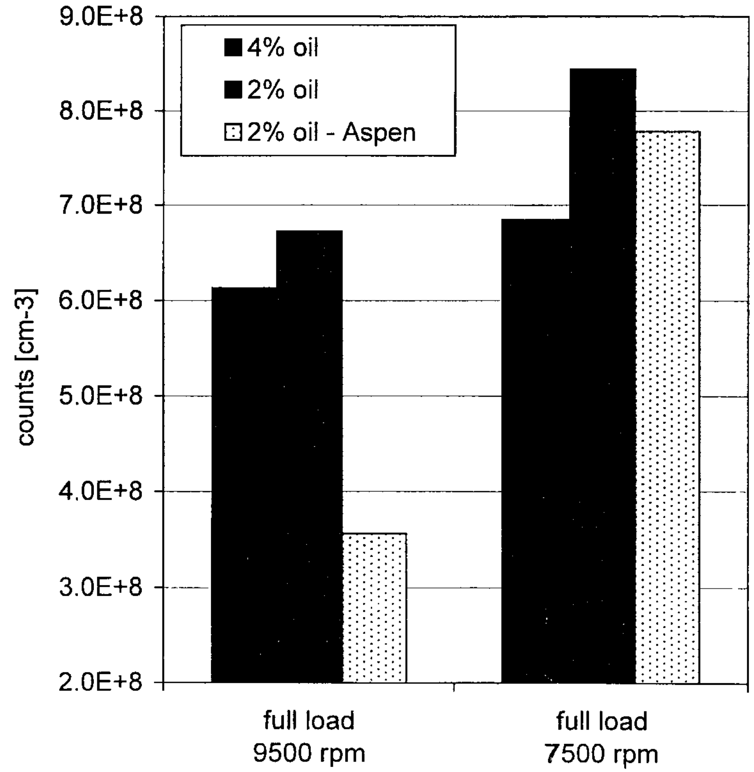


Fig. 8

Particles counts in respective size spectra
9500 rpm / 7500 rpm - full load
Chainsaw STIHL 066, with HC-trap

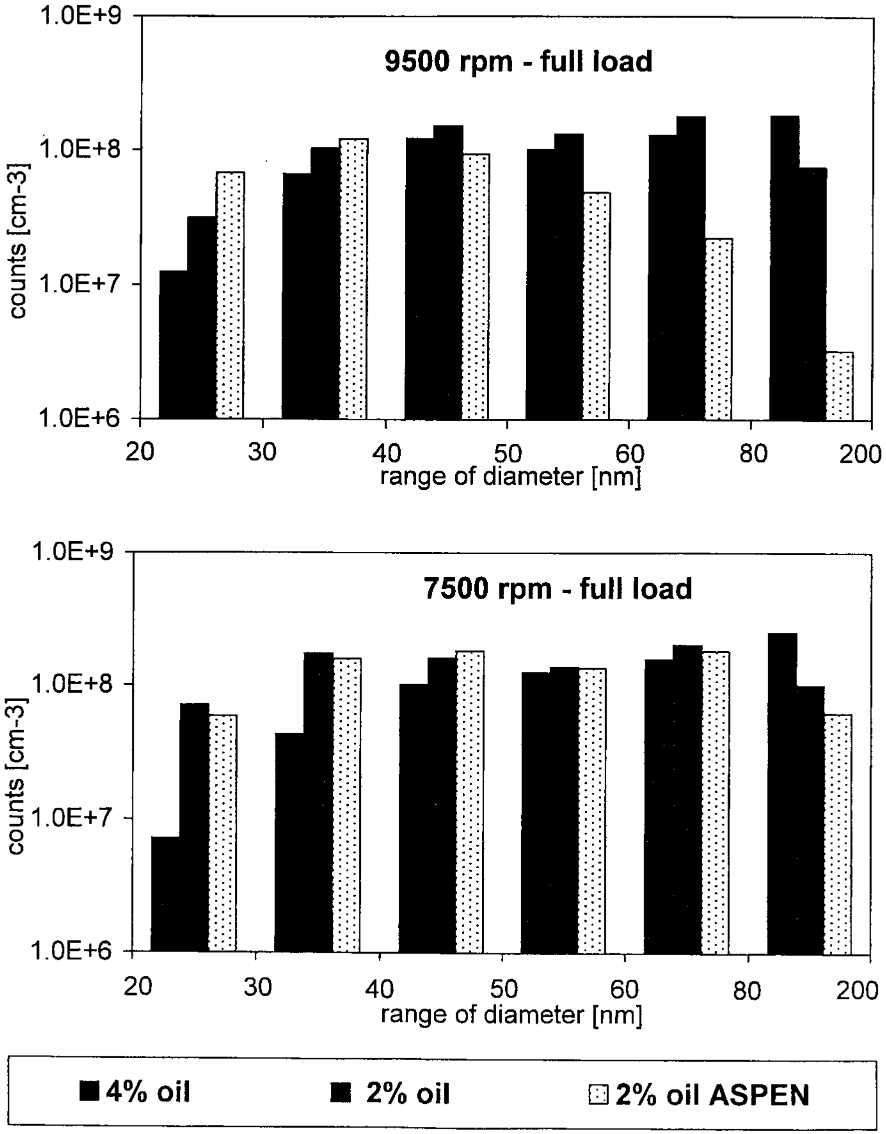


Fig. 9

Integrated particles numbers
in the size spectrum 20 - 200 nm
full load lean / rich
Chainsaw STIHL 066, with HC-trap

$1/cm^3$	7500 rpm lean	7500 rpm rich
2% oil	**3.09E+08**	**3.35E+08**

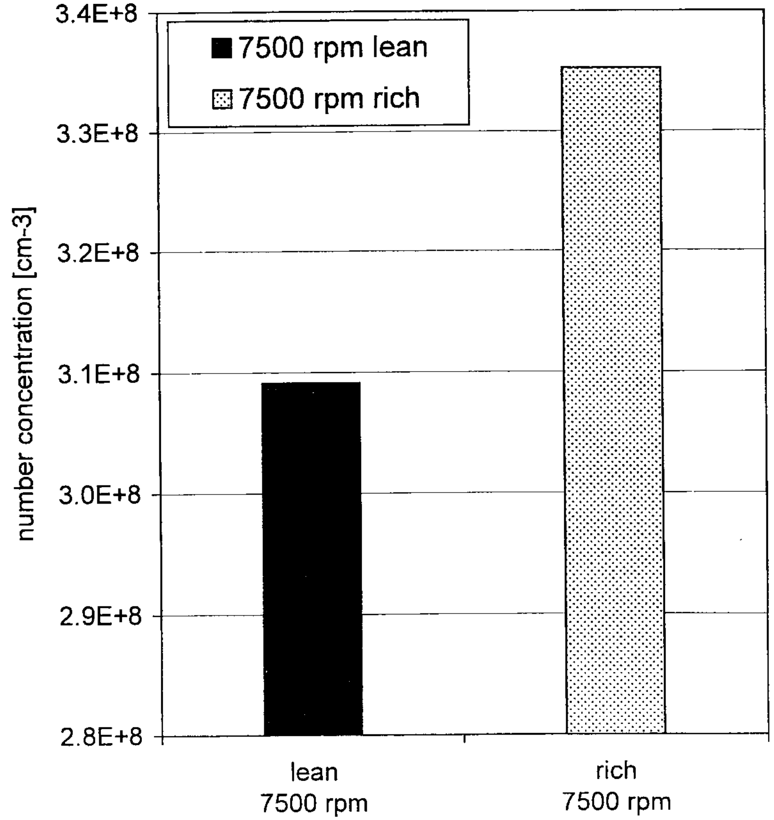


Fig. 10

Integrated particles numbers in the size spectrum 20 - 200 nm idling 2% oil / 4% oil
Chainsaw STIHL 066, with HC-trap

$1/cm^3$	idling 2% oil	idling 4% oil
	6.52E+08	**2.44E+09**

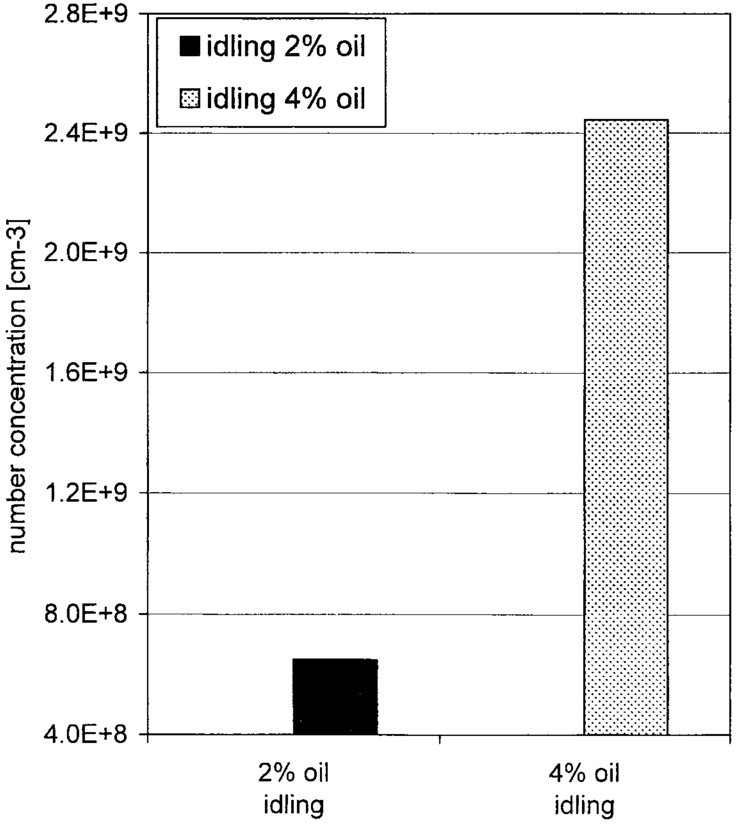


Fig. 11

Particles counts in respective size spectra
7500 rpm full load lean/rich / idling
Chainsaw STIHL 066, with HC-trap