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An electrical Soot Trap for solid and condensed Nanoparticles with a continuous electrochemical Conversion of Soot and Hydrocarbons

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An electrical soot trap for solid and condensed nanoparticles with a continuous electrochemical conversion of soot and hydrocarbons

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I Description of the Diesel Soot Converter (DSC)

Principles of function:

In the DSC following principles of function are working together and yield the described advantages:

1. before the soot particles are precipitated inside the channels of a ceramic monolith by means of an electrical field, they have to be charged in an electrical discharge device; this device has the advantage that also electronegative Oxygen molecules are charged and precipitated together with the soot, thus increasing the partial pressure of Oxygen near the soot layer inside the channels to a large extend

2. the channels of the monolith are open on both ends yielding to a real "driving home device" and having a low and constant back pressure; these channels also give a laminar streaming condition which is necessary for electrical precipitation

3. the electrical field which allows precipitation inside the channels of the monolith can be adjusted in a way to produce a "soft" plasma; this plasma enables a continuous electrochemical oxidation of the soot

4. because this plasmainduced electrochemical oxidation is working down to 120°C, the soot trap can be placed at the end of the exhaust line allowing also the precipitation of condensed nanoparticles

Following new techniques had to be developed:

- a device which achieves a stable and controllable discharge up to 650°C
- a monolith which allows a strong electrical field inside the channels
- a soft plasma that can be generated inside the channels of this monolith

Characteristics of function

Nanoparticles are absorbed with a very high efficiency (> 99%) by turbulent electrical agglomeration; the DSC is placed of the end of the exhaust pipe, thus also absorbing all condensed nanoparticles, larger particles are precipitated theoretically with the same high efficiency, but secondary soot (most of it from the catalyst) is reducing the efficiency down to about 90% for MVEG, depending on the size of the monolith relative to the displacement; the oxidation rate is proportional to the absolute quantity of the soot in the monolith and therefore will increase with emission rate of the engine; no measurable additional heat is produced by the oxidation process in the monolith; if the temperature is below 120°C the monolith will sample the soot for about 500 km. Tests on the road are under way, covering till now some thousand miles with the best results. Attached figures show results with a 2 litre 140 Hp engine, where the volume of the monolith had been only 1,8 litre instead of the necessary size of four litre!

II Electrical demand and mechanical size of the DSC:

The electrical power demand depends on the size of the unit and is between 30 Watt for a 2 litre monolith and 50 Watt for a 4 litre monolith at the MVEG and 80 Watt to 150 Watt at full speed respectively.

The volume of the monolith should be about twice the piston displacement for MVEG and about three times the piston displacement for high way driving. So a two litre monolith has a diameter of about 115 mm, a three litre one about 135 mm und a four litre one of about 155 mm if one assumes a length of about 250 mm. Thus the whole device may have a diameter of about 130/150/170 mm respectively and an overall length including the charging section of about 560 to 570 mm.

III Advantages of the DSC compared to mechanical SiC-traps

- the DSC is a driving home device
- the DSC needs no additives
- the DSC is regenerating continuously
- the DSC has a small and constant back pressure
- the DSC absorbs nanoparticles very efficiently
- the DSC absorbs condensed hydrocarbon particulate
- the DSC does not produce any sulphur acid particles
- after the DSC the gas loses totally the smell of Diesel driven cars
- the DSC needs no connection to the electronics of the engine
- the DSC needs no Common Rail
- the DSC can be installed in an used car

IV The physics of high pressure plasma soot burning

Richardson electrons and reduction of the work function

Richardson electrons are emitted at any temperature, especially if the work function (this is the energy necessary to get an electron out of the surface) is lowered below 1 eV by doping of the ceramic; besides that the roughness of the walls yields a further local reduction of the work function by a much higher electrical field at special elevated points of the walls lying on the negative side of the channel

Stimulation of the photo effect

The quantum flux of the plasma-induced chemical oxidation reactions induce the photo effect (if a quantum with an energy above the work function hits the wall an electron is emitted) on the negative side of the channel, which is high because of the low work function

Acceleration of emitted electrons

In-between the mean free path the emitted electrons are accelerated toward the soot layer in the electrical field of the channel:

Number of collisions for electrons before getting absorbed	10^5
Mean free path for electrons between two collisions	6.10^{-6} cm
Distribution of free path between two collisions	10^{-6} - 10^{-4} cm
Electrical field in-between the channels	2 – 3 kV/cm
Between two collisions added kinetic energy	0.002 – 0,3 eV

Increased partial pressure for oxygen on the soot substrate

Oxygen absorbs electrons most likely, because it is most electronegative molecule in the exhaust gas. These negative oxygen ions get immediately hydrated in the form

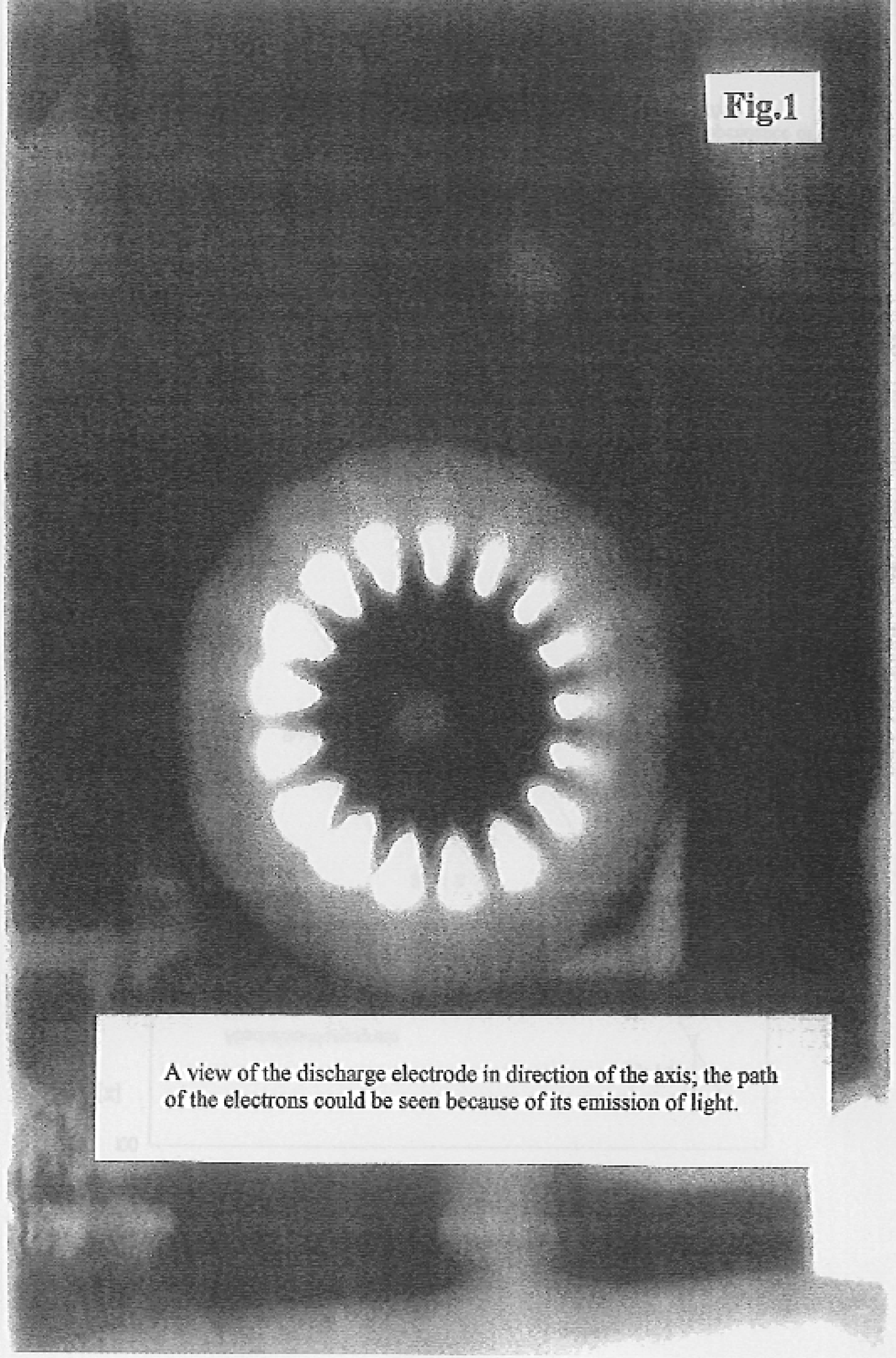
$$O_2^-.(H_2O)_{7\text{-}9}$$

and are therefore precipitated in a distribution comparable with the soot particles. The oxygen is absorbed by the soot layer or remains near the soot because of the laminar streaming condition in the channel.

Burning reaction

A part of the accelerated electrons stimulate the oxidation reaction in the soot layer, if there is also a oxygen molecule nearby. A part of the energy of this reaction is released as quantum radiation, stimulating some further photo effects on the negative wall. So any oxidation of one carbon atom may cause further oxidation processes if there is enough soot around.

Fig.1



A view of the discharge electrode in direction of the axis; the path of the electrons could be seen because of its emission of light.

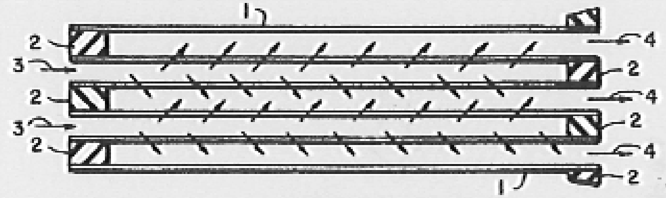


Fig.2

The working principle of the mechanical soot filter: a ceramic honeycomb with porous walls, which are closed alternately on the first or on the second end of the channel.

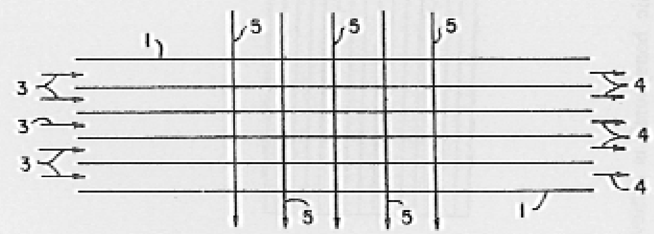
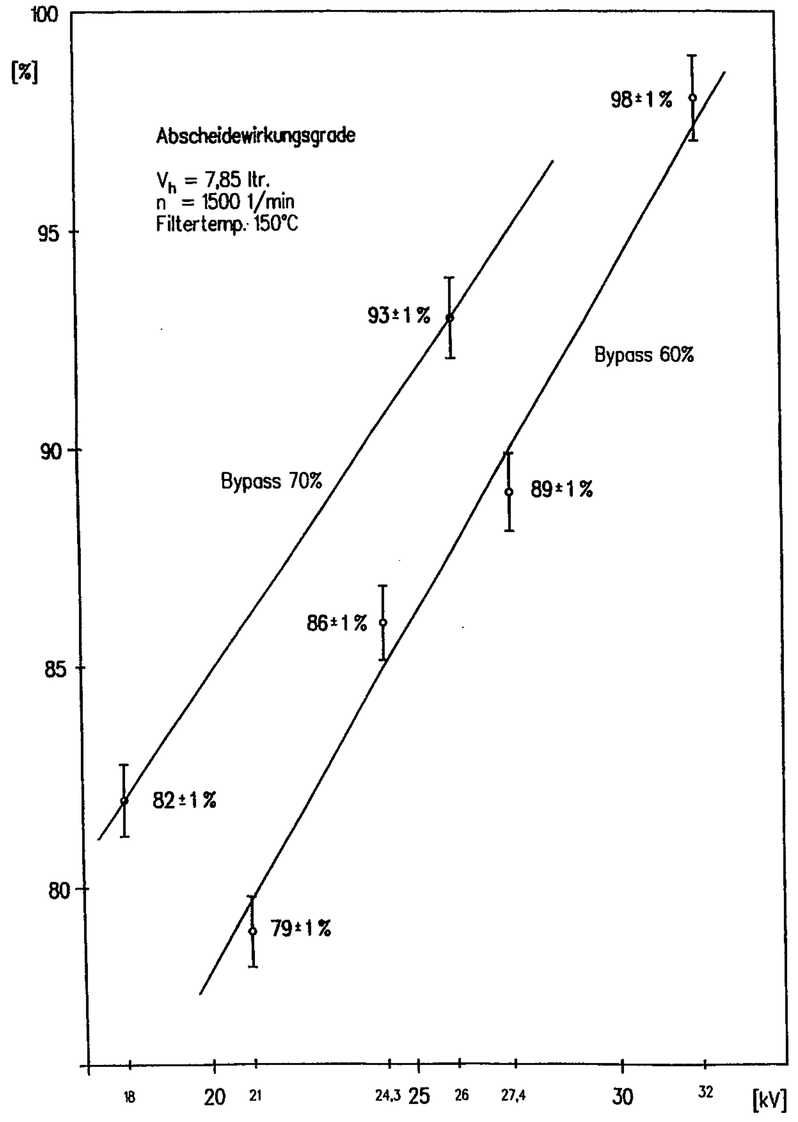


Fig.3

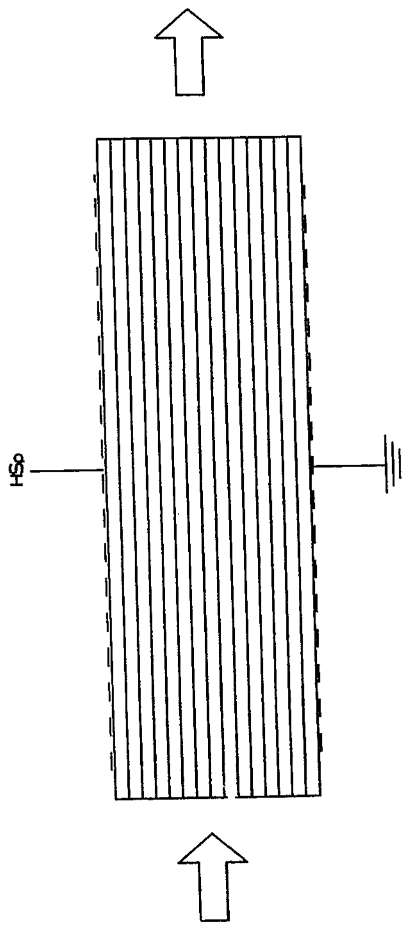
The working principle of the electrical soot filter: a ceramic honeycomb with dense walls and on both ends open channels.

Fig.4



Measured trapping efficiency of an electrical soot filter: it has a linear dependence of quantity of exhaust gas or size of the honeycomb and can reach nearly 100%.

Fig.5



The electrical field inside the channels of the ceramic honeycomb is achieved by applying two electrodes on the monolith.

Keramikmonolith

Fig.6

The structure of the ceramic honeycomb is designed to achieve a homogenous electric field inside the channels.

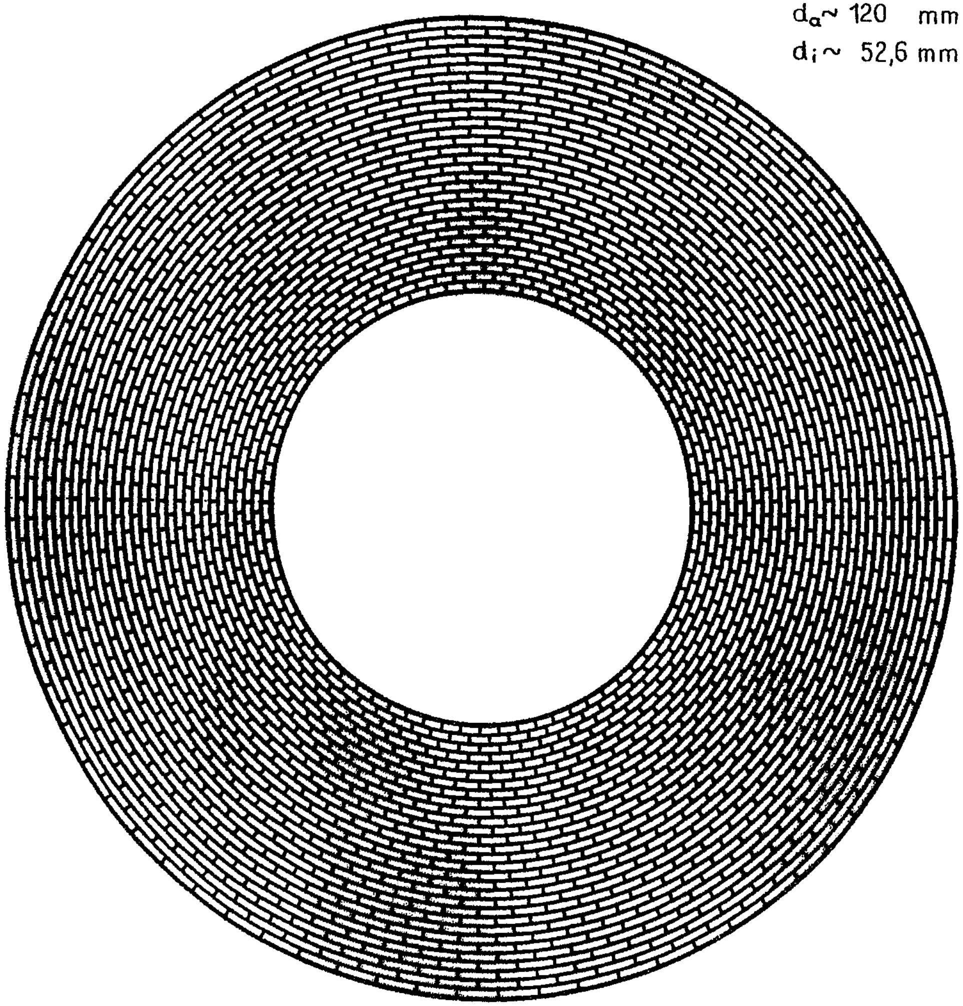
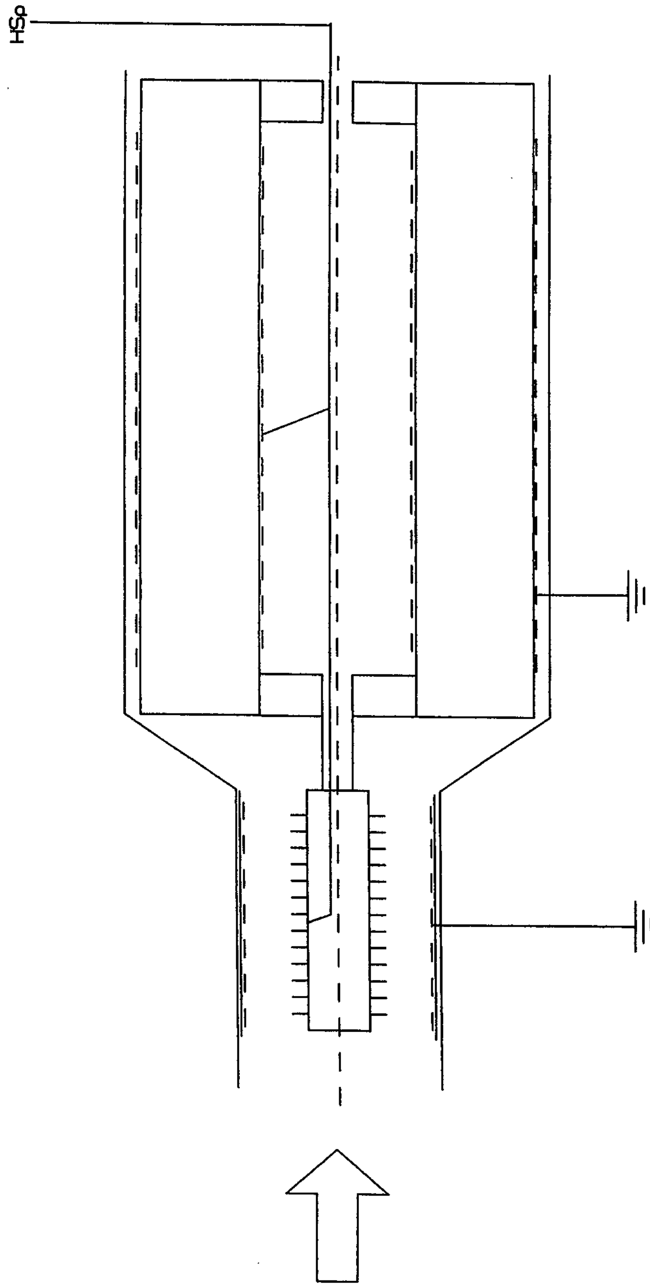


Fig.7



The discharge electrode and the honeycomb are connected electrically in parallel.

To proof the burning of the soot by negative plasma, the soot in the exhaust gas before and after the trap was measured at the same time. By inverting the polarity of the device, after about two additional hours of sampling the honeycomb was filled up and the sampled soot was breaking through indicated by a sudden burst of soot in the measuring line after the trap.

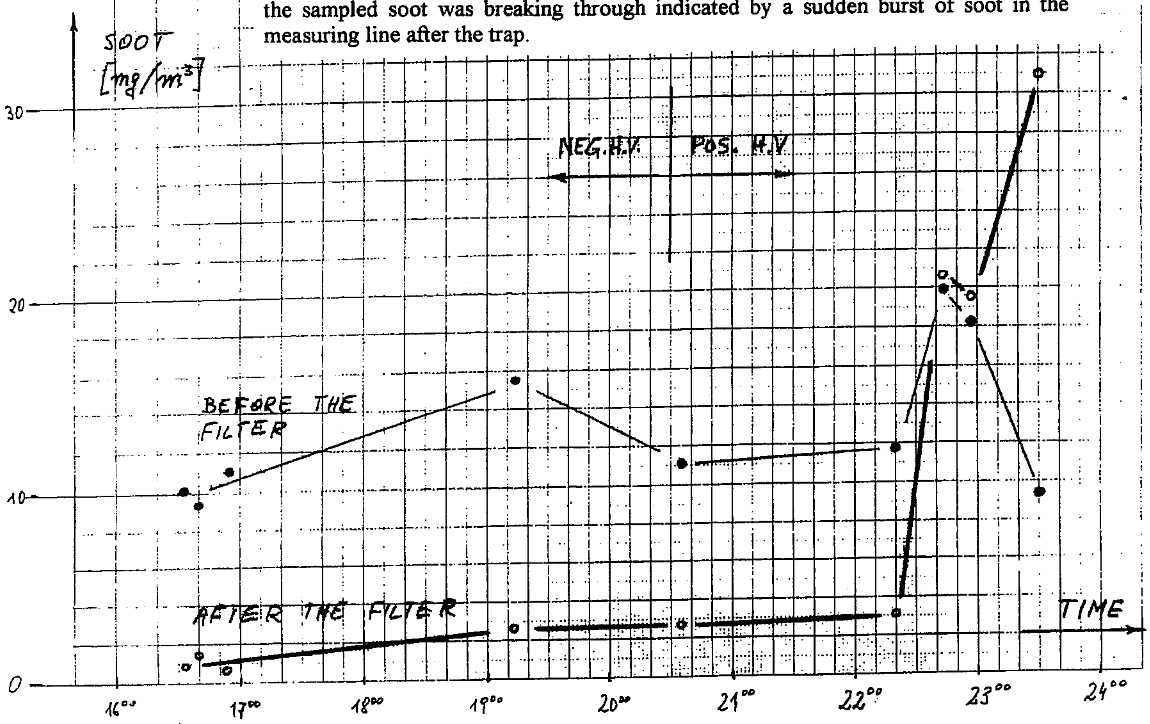
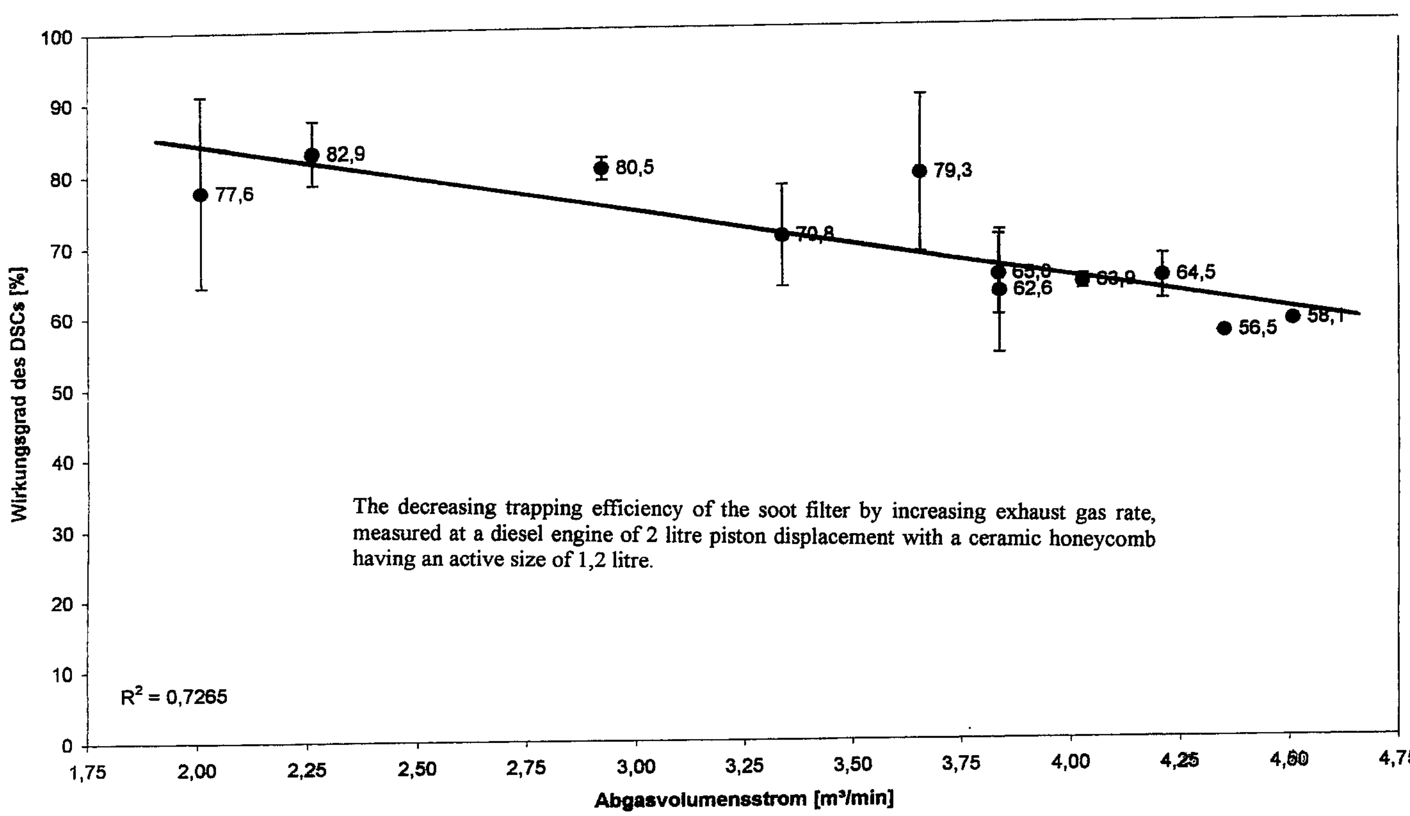


Fig.9

Wirkungsgrade des DSC-20 in Abhängigkeit vom Abgasvolumensstrom

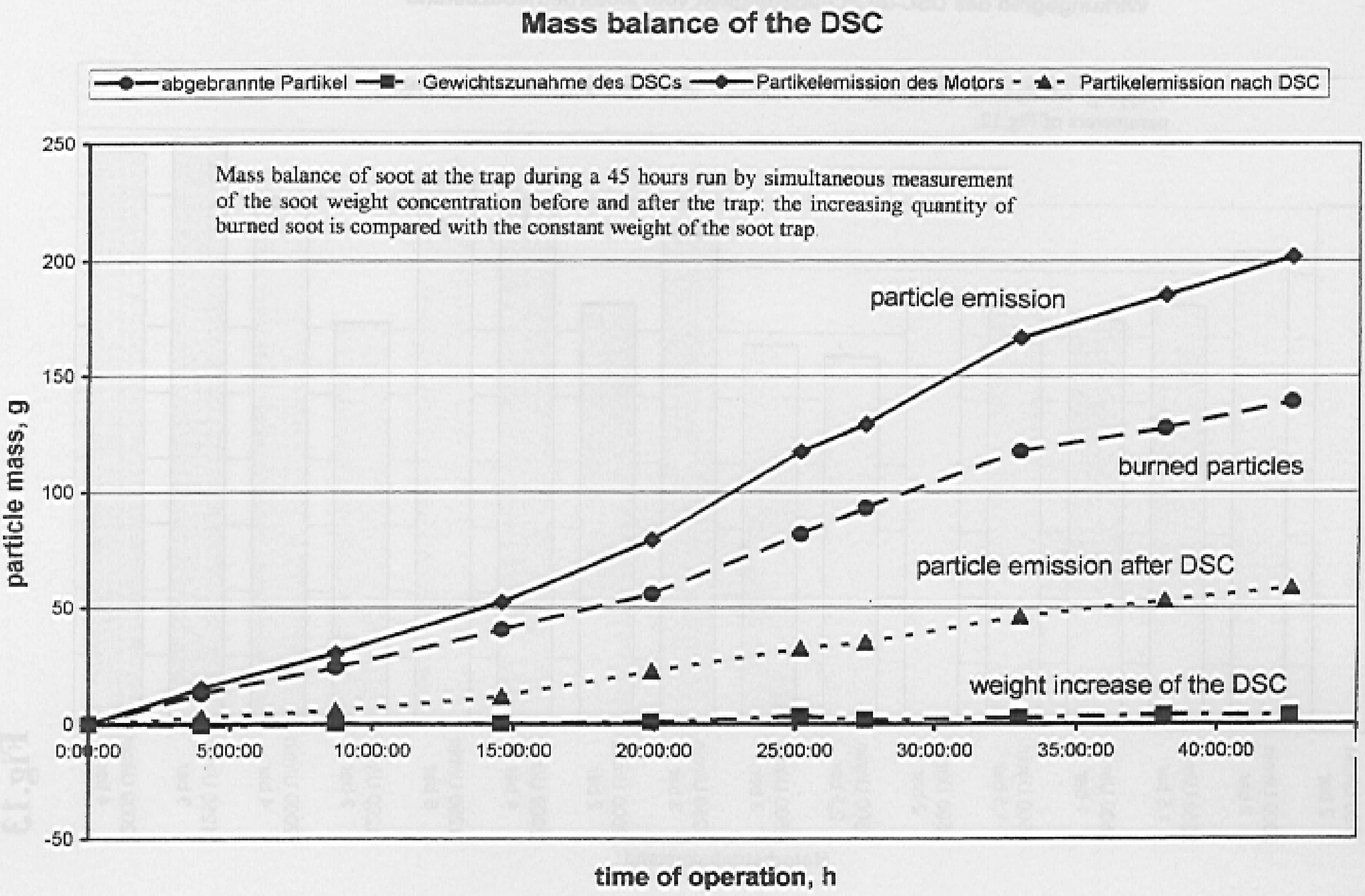


The decreasing trapping efficiency of the soot filter by increasing exhaust gas rate, measured at a diesel engine of 2 litre piston displacement with a ceramic honeycomb having an active size of 1,2 litre.

Fig.10

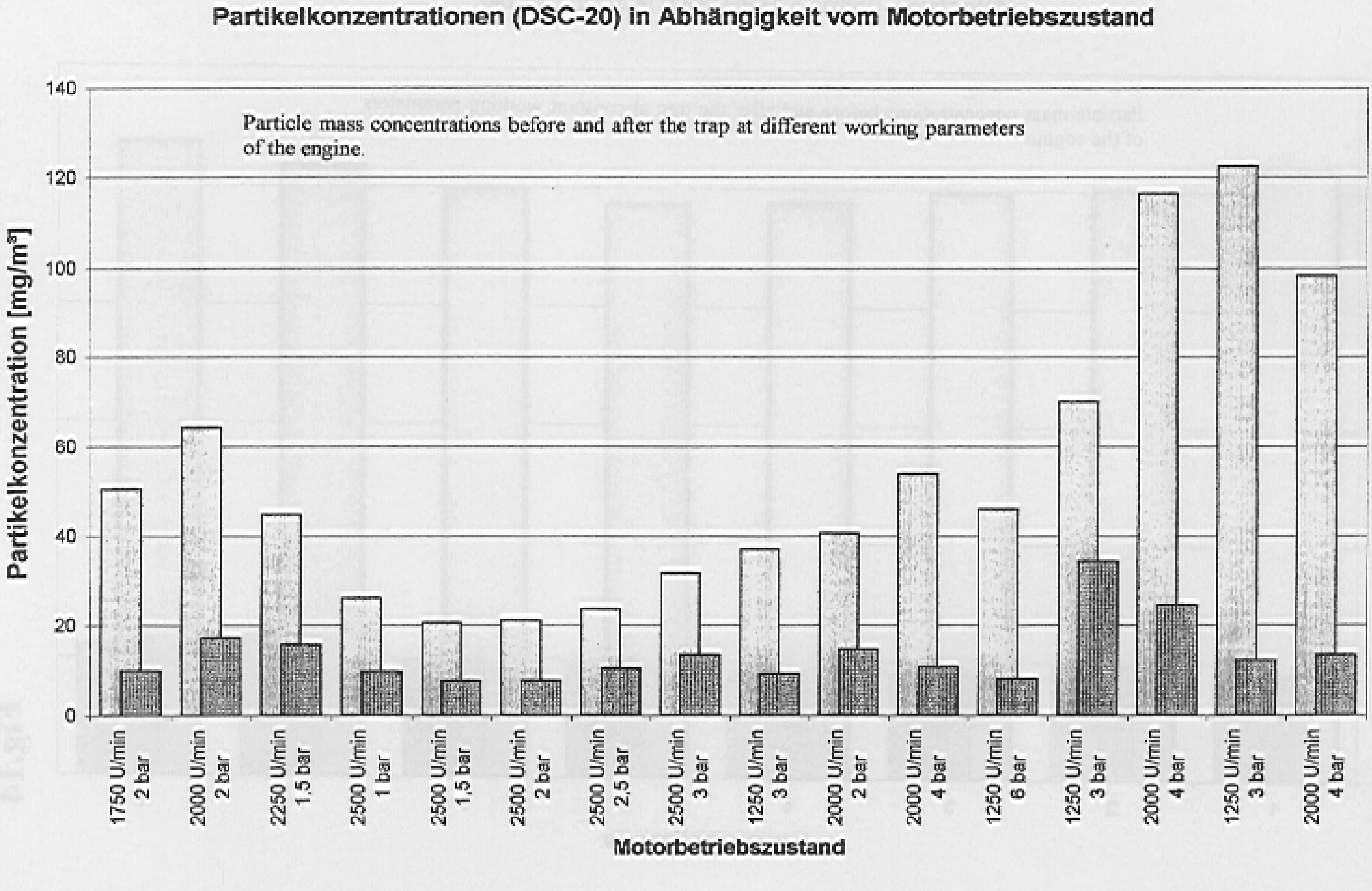
Erstellt von Bt am 17-04-98

Filtprot3, Abgasvolumensstrom



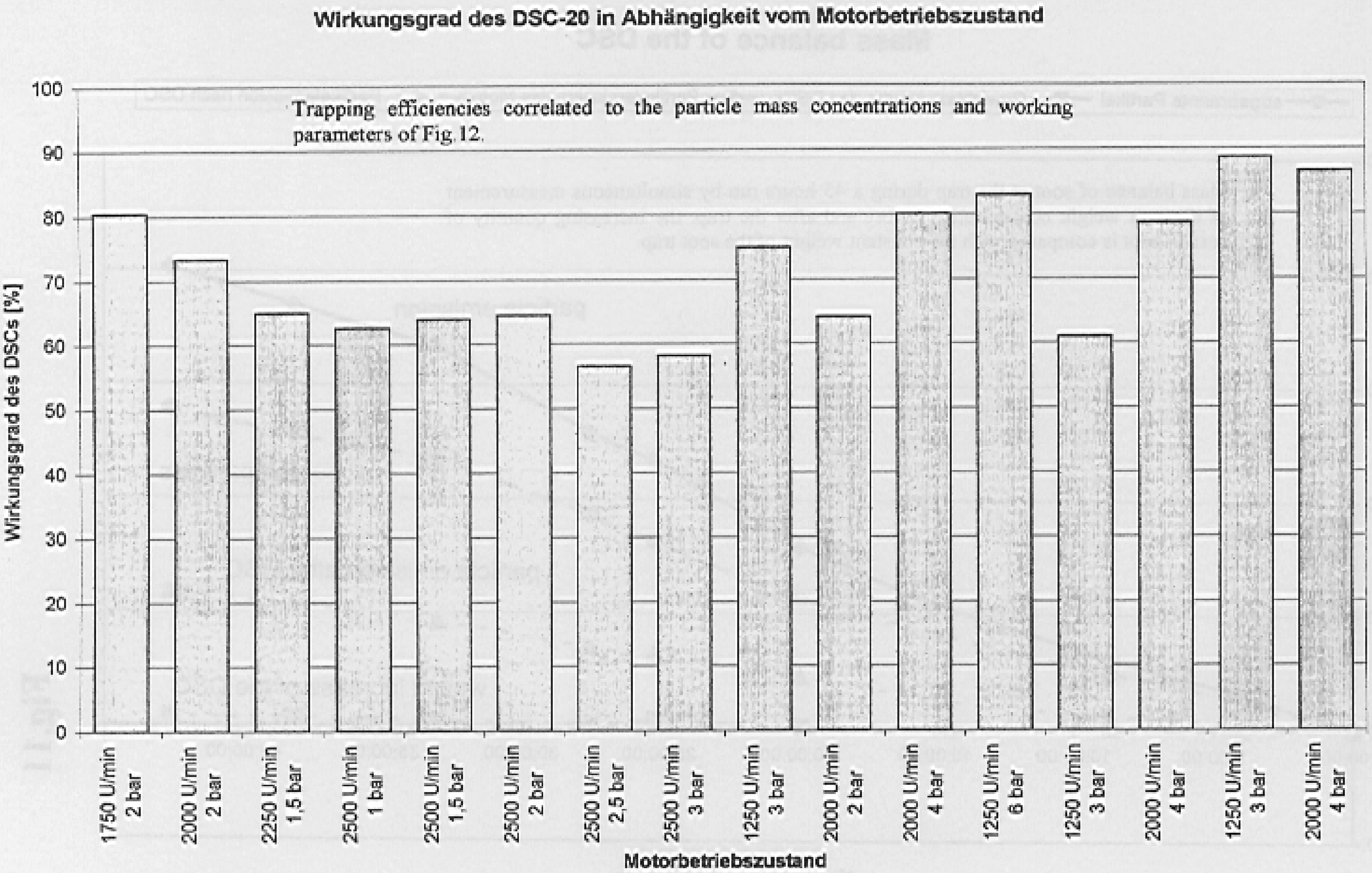
Mass balance of the DSC
abgebrannte Partikel
Gewichtszunahme des DSCs
Partikelemission des Motors
Partikelemission nach DSC
Mass balance of soot at the trap during a 45 hours run by simultaneous measurement of the soot weight concentration before and after the trap: the increasing quantity of burned soot is compared with the constant weight of the soot trap.
particle emission
burned particles
particle emission after DSC
weight increase of the DSC
particle mass, g
time of operation, h

Fig.11



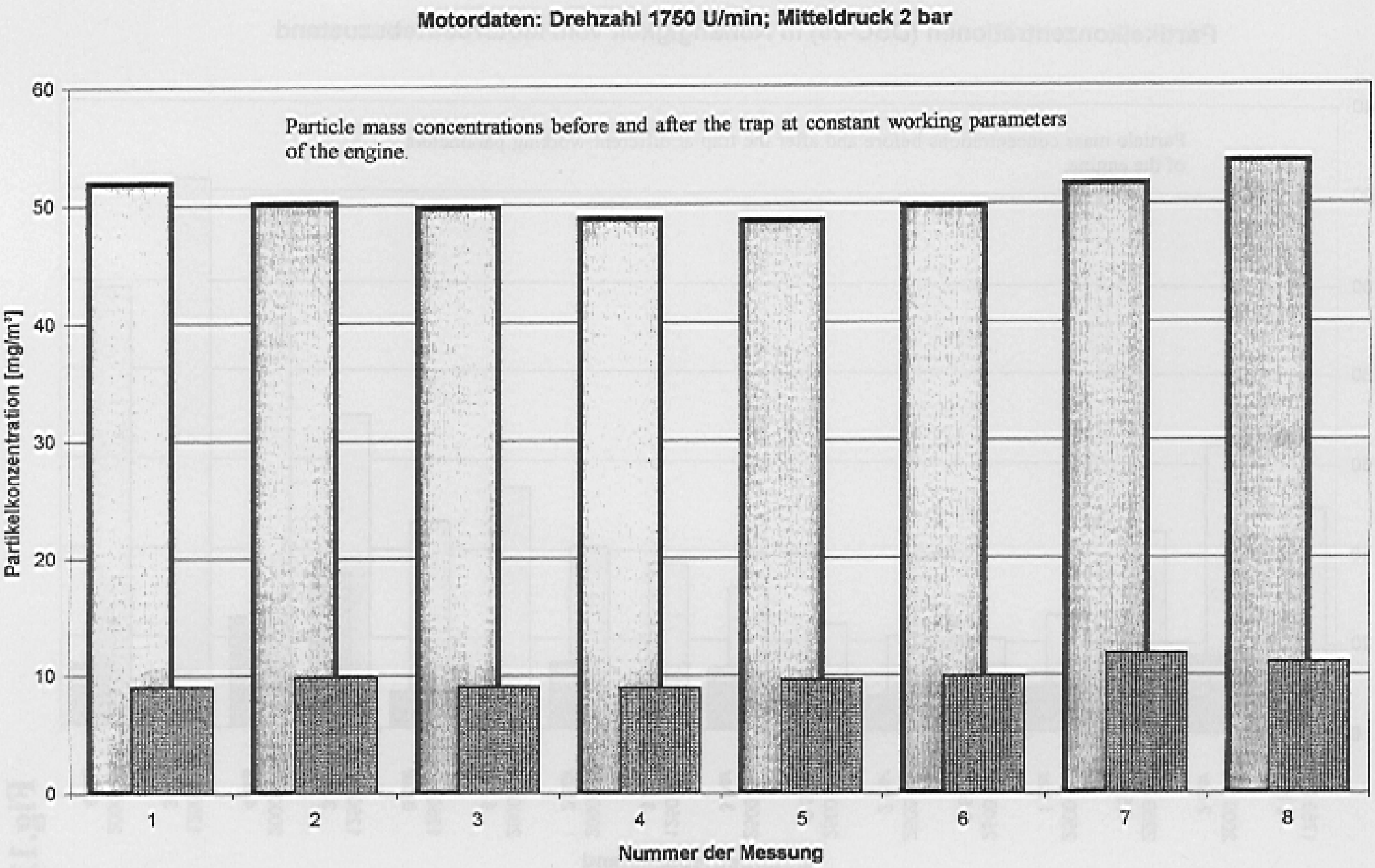
Partikelkonzentrationen (DSC-20) in Abhängigkeit vom Motorbetriebszustand
Particle mass concentrations before and after the trap at different working parameters of the engine.
Partikelkonzentration [mg/m³]
1750 U/min 2 bar
2000 U/min 2 bar
2250 U/min 1,5 bar
2500 U/min 1 bar
2500 U/min 1,5 bar
2500 U/min 2 bar
2500 U/min 2,5 bar
2500 U/min 3 bar
1250 U/min 3 bar
2000 U/min 2 bar
2000 U/min 4 bar
1250 U/min 6 bar
1250 U/min 3 bar
2000 U/min 4 bar
1250 U/min 3 bar
2000 U/min 4 bar
Motorbetriebszustand

Fig.12



Wirkungsgrad des DSC-20 in Abhängigkeit vom Motorbetriebszustand
Trapping efficiencies correlated to the particle mass concentrations and working parameters of Fig.12.
Wirkungsgrad des DSCs [%]
100
90
80
70
60
50
40
30
20
10
0
1750 U/min 2 bar
2000 U/min 2 bar
2250 U/min 1,5 bar
2500 U/min 1 bar
2500 U/min 1,5 bar
2500 U/min 2 bar
2500 U/min 2,5 bar
2500 U/min 3 bar
1250 U/min 3 bar
2000 U/min 2 bar
2000 U/min 4 bar
1250 U/min 6 bar
1250 U/min 3 bar
2000 U/min 4 bar
1250 U/min 3 bar
2000 U/min 4 bar
Motorbetriebszustand

Fig.13



Motordaten: Drehzahl 1750 U/min; Mitteldruck 2 bar
Particle mass concentrations before and after the trap at constant working parameters of the engine.
Partikelkonzentration [mg/m³]
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
Nummer der Messung

Fig.14

Motordaten: Drehzahl 1750 U/min; Mitteldruck 2 bar

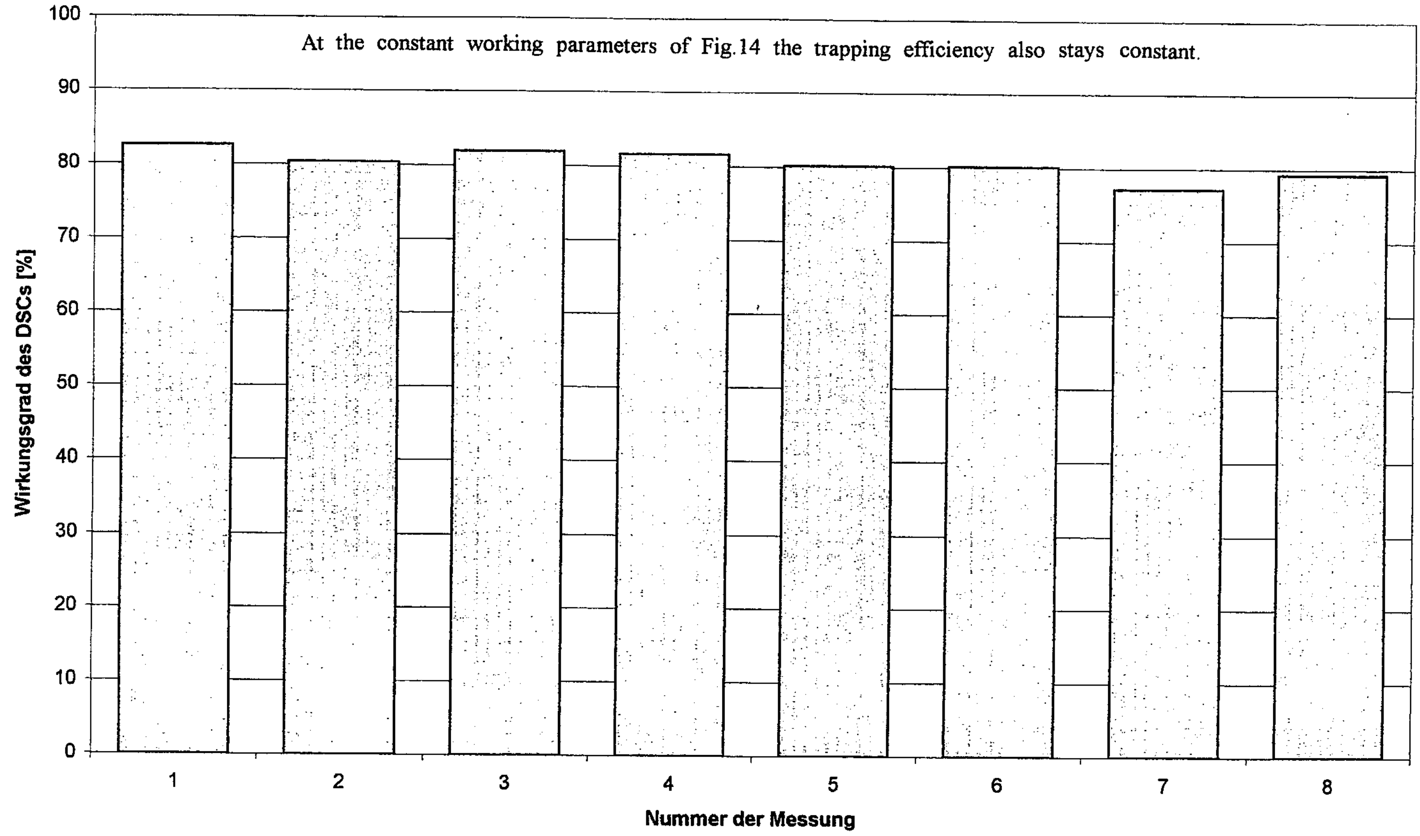
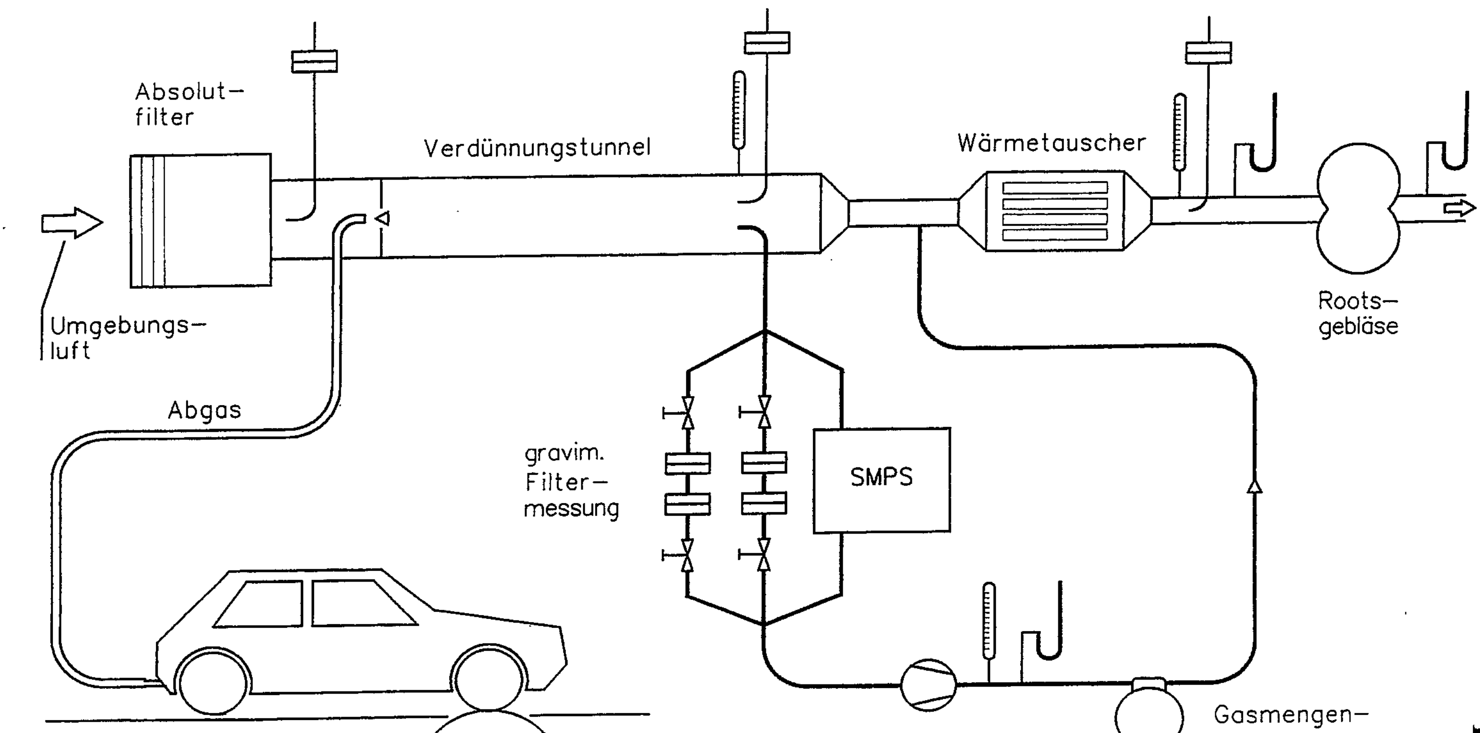


Fig.15

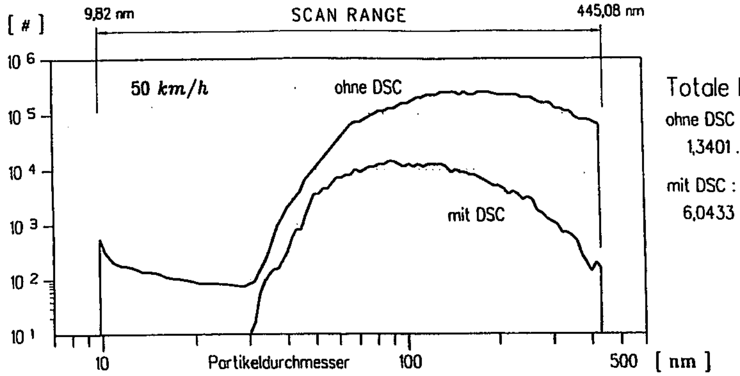


A realistic set up for the measurement of the size distribution of nanoparticles: the SMPS was applied exactly at the same place where the mass concentration of the soot is measured in the MVEG.

Fig.16

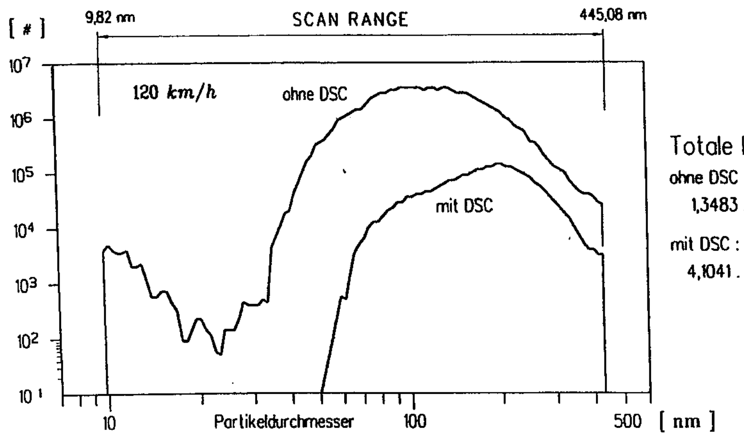
Fig.17

The measurement of the nanoparticles was turned out with and without trap at two constant velocities: 50 km/h and 120 km/h. The big and constant trapping efficiency for very small particles is also seen as the smaller and decreasing efficiency for large particles because of the to small honeycomb size. The trapping efficiency at medium sized particles is influenced strongly by electro-turbulent agglomeration, which is increasing at larger gas velocities. Honeycomb volume 1.8 litre, piston displacement 2 litre, 140 Hp.



Totale Konzentration:
ohne DSC :
1,3401 . 10^5 [#/cm³]
mit DSC :
6,0433 . 10^3 [#/cm³]

Abscheidegrad im Bereich zwischen 10 nm und 30 nm besser als 99 % !
Mittlerer Abscheidegrad im dargestellten Bereich: 95,5 % !

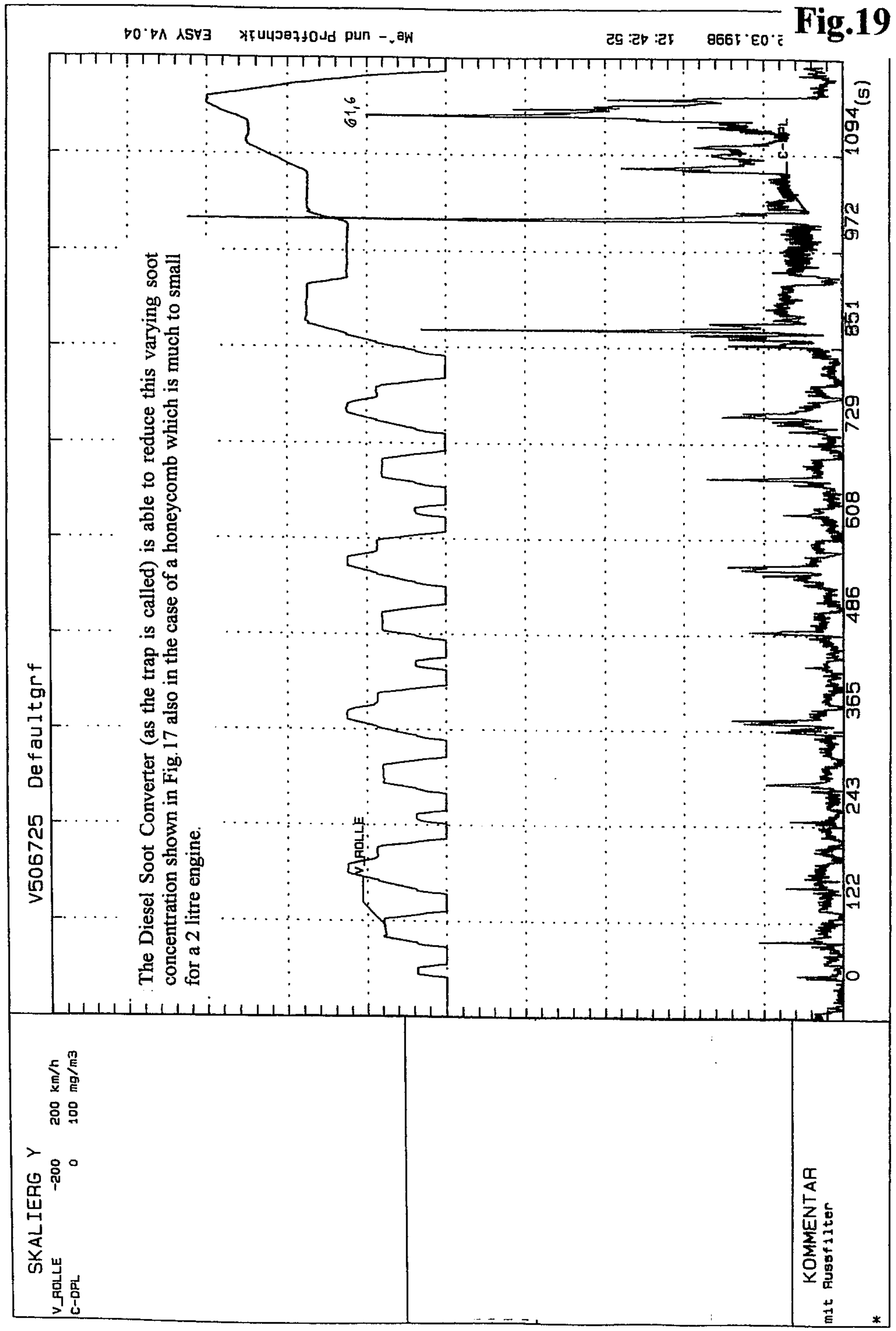


Totale Konzentration:
ohne DSC :
1,3483 . 10^6 [#/cm³]
mit DSC :
4,1041 . 10^4 [#/cm³]

Abscheidegrad im Bereich zwischen 10 nm und 50 nm besser als 99 % !
Mittlerer Abscheidegrad im dargestellten Bereich: 97,0 % !

1401
99Hu

Fig.19



The Diesel Soot Converter (as the trap is called) is able to reduce this varying soot concentration shown in Fig.17 also in the case of a honeycomb which is much to small for a 2 litre engine.

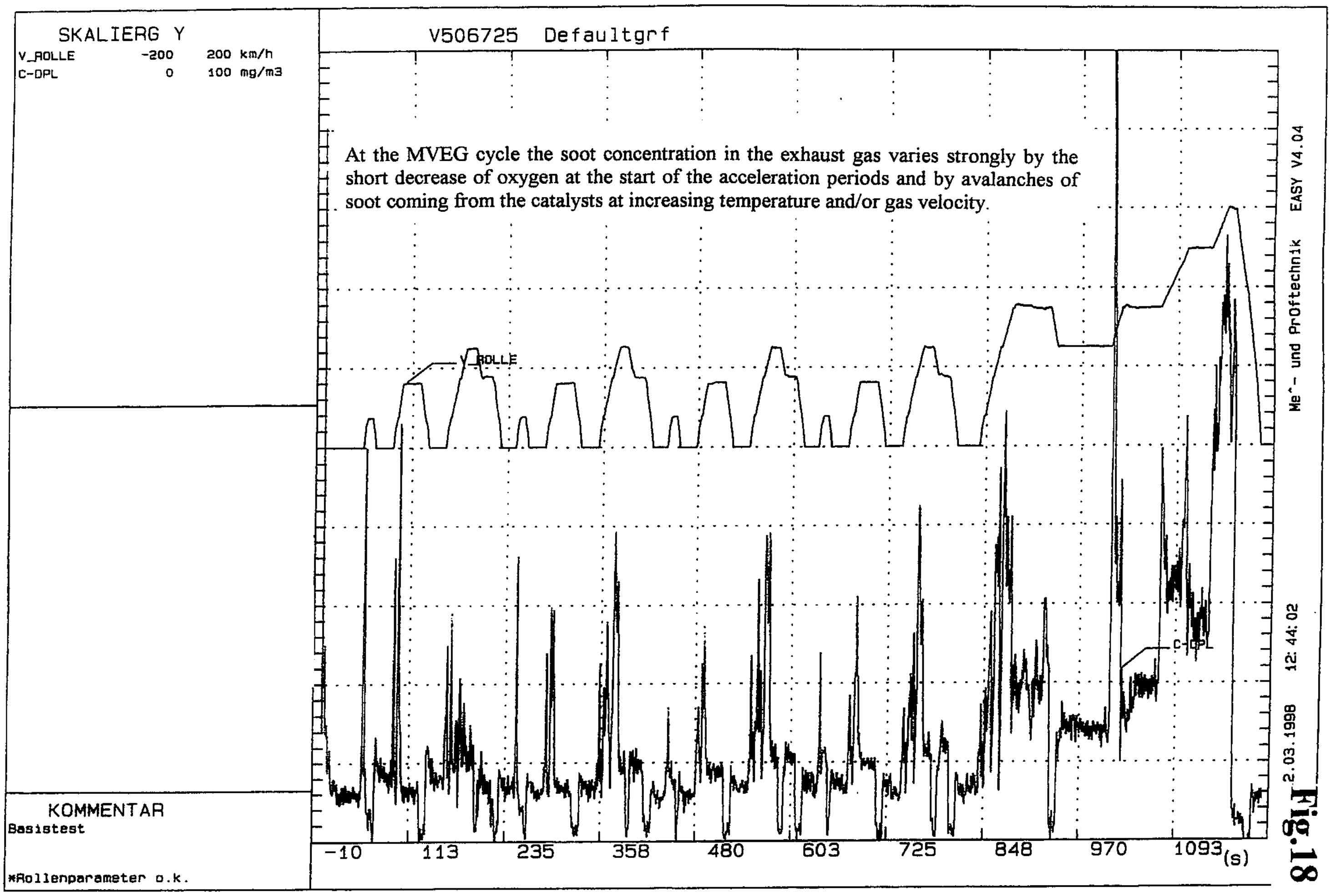


Fig.18

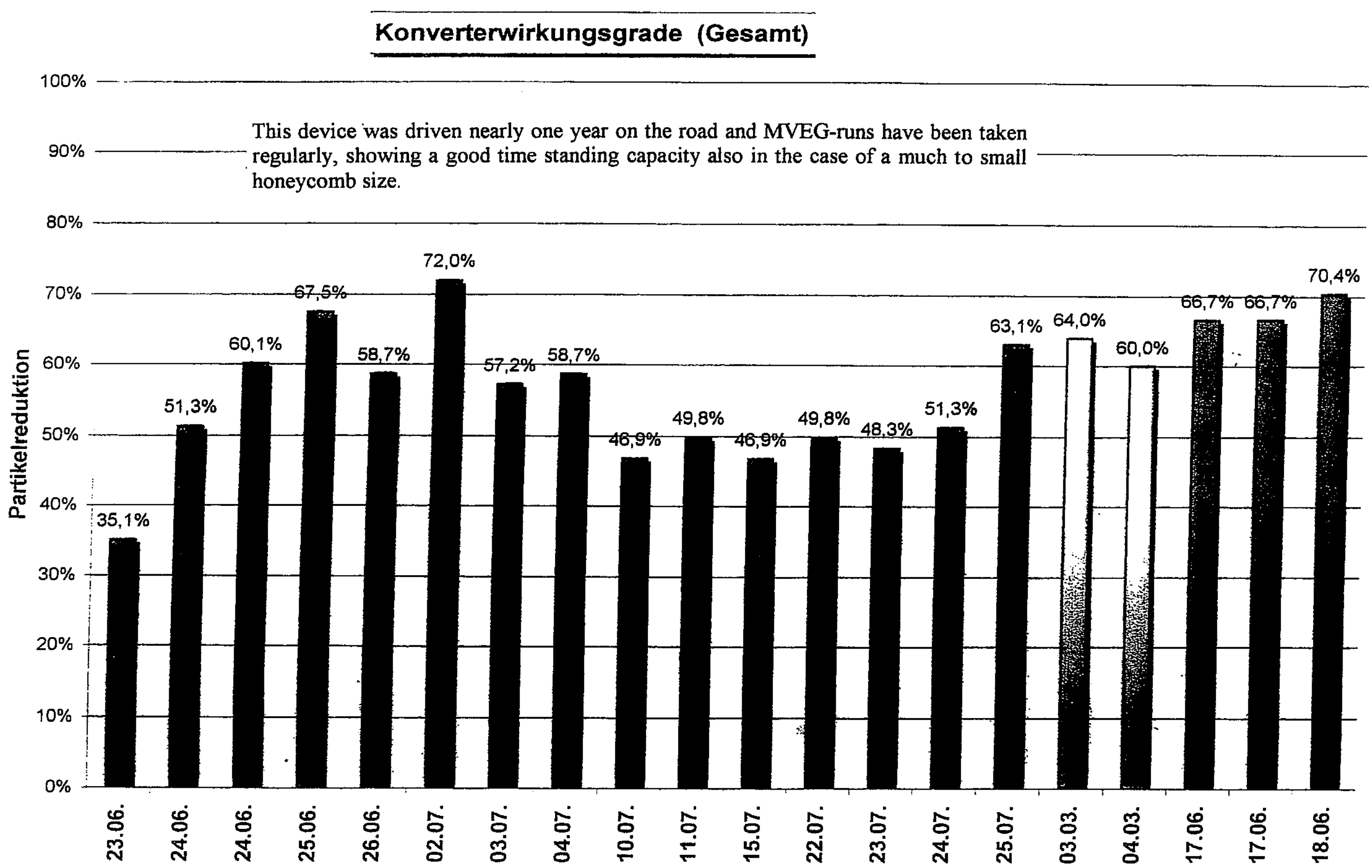


Fig.20

29-06-98

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Herrn
DI Andreas Mayer

Fohrhölzlistraße 14 b
CH-5443 Niederrohrdorf

30.08.1999

Lieber Herr Mayer,

Finden Sie bitte in Beilage das Manuskript meines Vortrages:

An electrical soot trap for solid and condensed nanoparticles with a continuous electrochemical conversion for soot and hydrocarbons

Ich möchte Ihnen noch einmal zu dieser sehr guten Veranstaltung gratulieren und werde nächstes Jahr sicher wieder dabei sein.

Ich bin gerne bereit, Ihnen einen DSC zur Verfügung zu stellen. Allerdings habe ich die letzte Einheit (!) BMW versprochen und werde sie dieser Tage ausliefern. Ich habe auch einige wenige größere Monolithen (wie sie für einen 140 PS Motor notwendig sind) bestellt, ihre Lieferung wird allerdings erst Ende des Jahres erfolgen, so daß ich fertige und getestete Einheiten frühestens Anfang nächsten Jahres ausliefern kann.

Sollten Sie Interesse und die entsprechenden Mittel zur Verfügung haben, bin ich auch bereit, Ihnen eine Einheit nicht nur für einige Zeit zur Verfügung zu stellen, sondern sie Ihnen auch zu verkaufen. Da ich zur Zeit ohne Sponsor bin, ist dies für mich sogar die angenehmere Lösung, da ich die von Corning in Einzelarbeit gefertigten Monolithen selbst bezahlen muß, was mich pro Stück (ohne Mechanik, Einbau und Elektronik) etwa SF 10 000.- kosten wird.

Mit Herzlichen Grüßen

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Herrn
DI Andreas Mayer

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CH-5443 Niederrohrdorf

20.09.1999

Lieber Herr Mayer,

Ich habe in meinem Manus einen häßlichen Fehler und lege Ihnen sowohl die zu ersetzende Abbildung (wenn es Ihnen nicht zu viel Mühe macht), als auch ein neues Manus bei. Es betrifft den Vortrag:

An electrical soot trap for solid and condensed nanoparticles with a continuous electrochemical conversion for soot and hydrocarbons

Gleichzeitig möchte ich Sie nochmals an das Manus über die in den Zellen entdeckten Nanopartikel (ich glaube, Herr Muhle oder Herr Heyder hielten den Vortrag) erinnern.

Mit Dank und herzlichen Grüßen