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Particle Measurements from Wall Flow Traps at High Dilution Ratios

Second International ETH Workshop on Nano Particle Measurement.

ETH Zurich August 7th 1998

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Abstract

This contribution seeks to address the question as to whether diesel particulate traps generate additional nano sized particles in the real world conditions.

A dilutor system capable of giving the high dilution ratios seen after the tail pipe in the field is described, and the results using an uncatalysed wall flow ceramic trap and a Johnson Matthey Continuous Regenerating Trap are presented. Two dilution ratios were used with the uncatalysed trap.

In all cases the nano particles whilst being abundantly emitted from the engine, were orders of magnitude lower when the traps were fitted.

Introduction

Nano particle emissions from diesel engines are becoming of increasing interest. This is because they form the bulk of the number count of the particle emissions, and the current concern of the health investigators is in the number of particles inhaled.

The dramatic reductions in particulate mass achieved by the diesel manufacturers in recent years has meant less soot entrained in the exhaust stream. This may leave the volatile species free to condense into nuclei mode particles rather than associate with existing soot particles, hence increasing the fine particle count. Thus, particulate mass reduction does not equate with fine particle emission reduction.

The ability of traps to control the nano particle emissions has now become an important issue for the future, and is addressed in this contribution.

Nano Particle Emissions Measurement.

There is no internationally agreed terminology for defining small particles.

The usual US definition of small particle sizes seems to be:

Fine:	Less than 2.5 microns.
Ultra fine:	Less than 0.1 microns
Nano:	Less than 0.05 microns (or 50 nm)

The United Kingdom definitions **(1)** are similar:

Inhalable dust:	Less than	15	microns.
Respirable dust:	Less than	5	microns (MRC definition).
Fine particles:	Less than	2.5	microns.
Ultrafine particles	Less than	0.1	microns.

It would seem that the nano particles are those most influenced by the particle sampling technique. Nano sized particles in high concentrations form a large part of the total number count from diesel exhaust.

The exact nature of the nano particles is still the subject of debate. Sulphates, SOF, carbon and metals from lube oil additives in greater or less measure are all in view.

The task is to replicate the actual conditions in the atmosphere at the point of inhalation, during test bed measurement. Clearly the dilution conditions during stationary traffic will vary widely from high speed travel down a motorway, and therefore a number of different sampling modes may have to be considered if a representative test cycle procedure is eventually demanded. Nano sized particle formation and agglomeration is heavily dependant on post tail pipe atmospheric dilution rate and cooling, as well as on the ambient aerosol existing. The task is therefore a complex one, as it is known that the nano particles are easily manipulated by the exhaust sampling conditions.

It is now clear that complex post tail pipe reactions need to be better understood, and the effects of a number of sampling factors listed below need to be quantified. The physical characteristics of the particles change dramatically with the post combustion influences.

Factors to be taken into account which influence the gas to particle conversions are:

- Dilution
- Cooling
- Residence time
- Temperature
- Humidity
- Ambient aerosol

Dilution ratio, residence time, sampling temperature and post tail pipe aerosol development are currently the subjects of Perkins Technology sponsored programmes at the Universities of Minnesota and Birmingham.

No definitive test methodology is available yet, as a great deal more work needs to be done to fill in the gaps in knowledge. In this context therefore, the work presented here is tentative only.

Roadway conditions v EPA tunnel for particulate mass sampling.

Published work on the simulation of post tailpipe atmospheric influences during diesel exhaust particle measurement is sparse.

The conventional EPA dilution tunnel technique used for particulate mass sampling, may not be ideal for particle size investigations. The dilution ratios involved are very low (say 4 to 40:1) compared with post tailpipe dilution from a moving vehicle where dilutions of 1000:1 can occur within a second or two. **(2) Fig 1**. The aerosol in the dilution tunnel may therefore be held at an artificial level of concentration, perhaps more applicable to stationary traffic.

The high dilution ratio system of sampling used at Perkins Technology is a first order attempt to simulate atmospheric dilution conditions. The conventional EPA dilution tunnel is not used.

High Dilution Ratio Sampling Facility

The high dilution ratio facility used at Perkins Technology was designed in conjunction with the University of Minnesota **(3)**, Whilst the University are subsequently investigating alternative dilution techniques, this design has been frozen for a period within Perkins Technology so that comparative work can be done.

A two stage ejector dilutor is used as outlined in **Fig 2**. Mixing chambers are situated after each dilutor. For an overall dilution ratio of 1000:1, the first stage dilution would be about 24:1. The residence times in the stages of dilution are given in **(3).**

A heated sample line is used to avoid thermophoretic losses to the wall of the extension line from the exhaust pipe to the dilutor. The wall temperature is controlled to 300 deg C. The dilution system is mounted on the side of the portable trolley which carries the particle sizer, enabling the facility to be moved to different test beds.

<u>The particle sizer specification used is as follows</u>:

Scanning Mobility Particle Sizer. Type: 3934-C-3

Incorporating:	Electrostatic Classifier	Type: 3071A
	Condensation Particle Counter:	Type 3022A

The measurement range is from 7 to 1000 nm.

Reduction in Exhaust Particle Emissions.

The comprehensive studies sponsored by the UK Government and the Society of Motor Manufacturers and Traders on a very wide range of diesel engine types of various ages **(4)** showed that all the diesel engines tested emitted high concentrations of sub micron particles. It does not therefore seem likely that minor changes to the traditional diesel combustion systems will bring dramatic reductions in particle concentrations in the immediate future.

Diesel Particulate Trap Technology

Traditionally, the reduction of diesel particulate mass emissions to meet legislation has been by means of modifying the in cylinder combustion process. As legislative limits tighten, it may eventually become mandatory to use particulate traps.

The barrier to the use of on highway particulate traps has been the lack of a viable regeneration system to burn off the soot from the trap. The Johnson Matthey Continuously Regenerating Trap (CRT), shown in **Fig. 3** uses a catalyst to convert the NOx in the exhaust to NO2, this is then reacted with the soot built up on the trap to give a continuous regeneration.

The CRT is in use on over three thousand vehicles in Europe, and presently is the only viable trap system for on highway use with diesel engines. It is costly, and not therefore currently eligible for the light duty market. It is also subject to the following restrictions:

Virtually sulphur free fuel.
Post Euro1 engines.
Turbocharged engines.

The CRT incorporates a highly active oxidation catalyst.

The dramatic reductions in mass particulate emissions using wall flow ceramic traps is well documented, but the reductions in particle numbers has been the subject of debate, particularly as to whether additional nano particles are formed during passage through the trap.

This paper records some of the measurements made using the a conventional Corning wall flow trap and also the a CRT unit, at high dilution ratios.

Trap Specifications.

Bare trap.

Corning Substrate.	Uncatalysed.
Material:	EX80.
Cell density:	100 cpi.
Size:	9 inch dia x 12 inch length.
Porosity;	48 per cent.
Mean pore size:	13 microns.
Test fuel:	0.05 per cent sulphur.

CRT:

Type :	ETO3933A EFTF 2829E
Test fuel:	0.0003% Sulphur.

Engine specification.

Perkins T4.40 Phaser engine.

4 cylinders 4 litres capacity Turbocharged intercooled.

Certified to US 1994 emissions standard.

Bosch MW fuel pump.

Rating: 81 kW at 2600 RPM.

Particle Size Measurements

1). <u>Bare Trap.</u>

The trap was run for 30 minutes before the test series to obtain a significant level of soot loading on the trap, without a serious rise in back pressure. The rise in back pressure during the tests was relatively small as the test engine had a very clean exhaust.

The results are shown on log log plots. The same information with a linear particle number concentration scale would of course illustrate the dramatic reductions in particle emissions better, but some of the information would tend be lost.

Figs 4 and 5 show the number size distributions recorded using a 1000:1 dilution ratio over the engine load range at rated speed and peak torque speed, with and without the bare (uncatalysed) trap fitted. The reduction in the nano particles of several orders of magnitude at all conditions will be noted.

These measurements were repeated later using a 100:1 dilution ratio, with the same clean up of the nano particles, as recorded in **Figs 6 and 7.**

It will be appreciated that changing the dilution ratio also changes other parameters of measurement as well. Significant variations in dilution temperature and residence time in the dilution process are also implied. The test was run to see the effect of a fairly radical change in the sampling process.

CRT

Figs 8 and 9 show the number size distributions recorded using a 1000:1 dilution ratio over the engine load range at rated speed and peak torque speed, with and without the trap fitted. The removal of the nano particles at all conditions will again be noted.

Discussion

The three sets of data had a significant time interval between them. Also the dilution air, whilst known to be relatively dry was not controlled, and some variation may be attributable to this. In line dilution air humidity measurement at the dilutor vent line is being designed into the system currently.

The effects of the very low sulphur fuel were investigated, but the changes varied with engine operating condition, and a clear trend was not discernible.

However, the overall results from the wall flow trap both uncatalysed and in CRT, form show that with the sampling technique aimed at approximating to the post tail pipe dilution conditions, the nano particles do not appear to be emitted.

The technique used is not claimed to be definitive, and it is recognised that the actual post tail pipe conditions will vary widely, and it may well be that the presently diverse methods of sampling used by other workers all represent some particular condition found in actual use. A definitive test methodology clearly awaits elucidation of the post tail pipe fate of the aerosol, and how this can be replicated in the test bed measurement.

References

1). **Holgate ST.** Non Biological Particles and Health. UK Department of Health. Committee on the Medical Effects of Air Pollutants.
London: The Stationery Office. 1995.

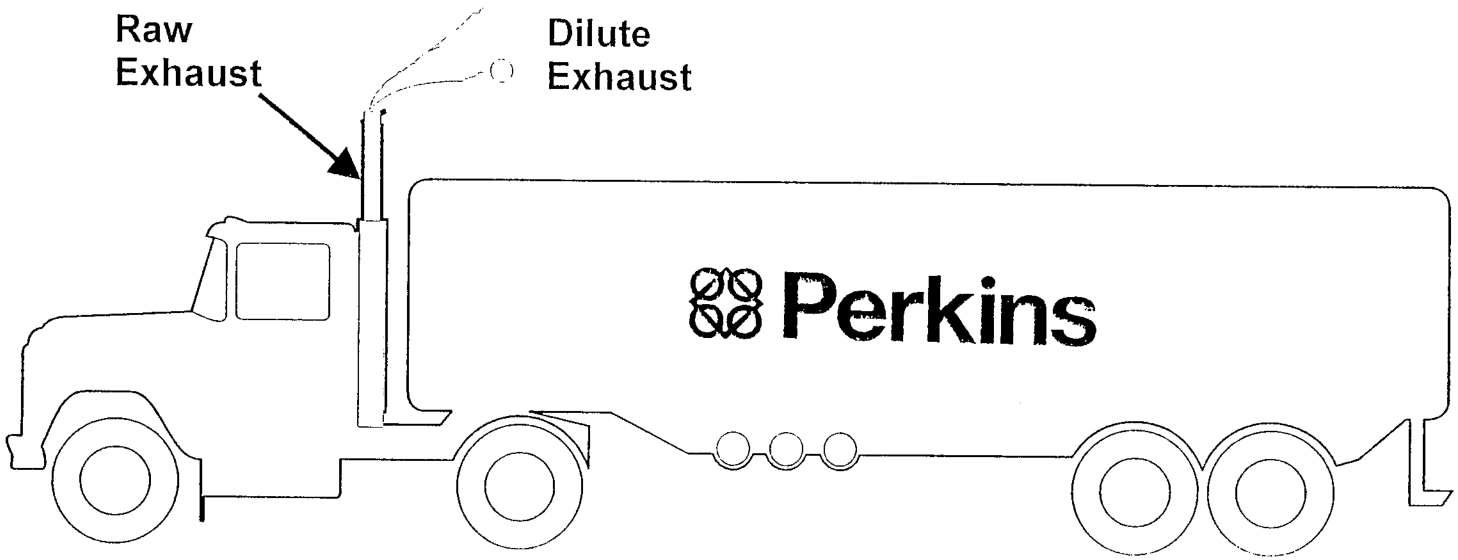
2). **Dolan DF, Kittelson DB.** Roadway Measurements of Diesel Exhaust Aerosols. Society of Automotive Engineers. Technical paper 790492. 1979

3). **Abdul-Khalek IS, Kittelson DB, Graskow BR, Wei Q and Brear F.**
Diesel Exhaust Particle Size: Measurement Issues and Trends.
Society of Automotive Engineers. Technical Paper 980525.
February 1998

4). **Moon DP and Donald JR.** UK Research Programme on the Characterisation of Vehicle Particulate Emissions. A report produced for the Department of the Environment, Transport and Regions (DETR) and the Society of Motor Manufacturers and Traders (SMMT).
Report Number ETSU R98. September 1997.

Dilution ratios in a travelling vehicle may reach 1000: within 1-2 seconds

EXHAUST DILUTION



This is far above that used in dilution tunnels for PM mass measurement

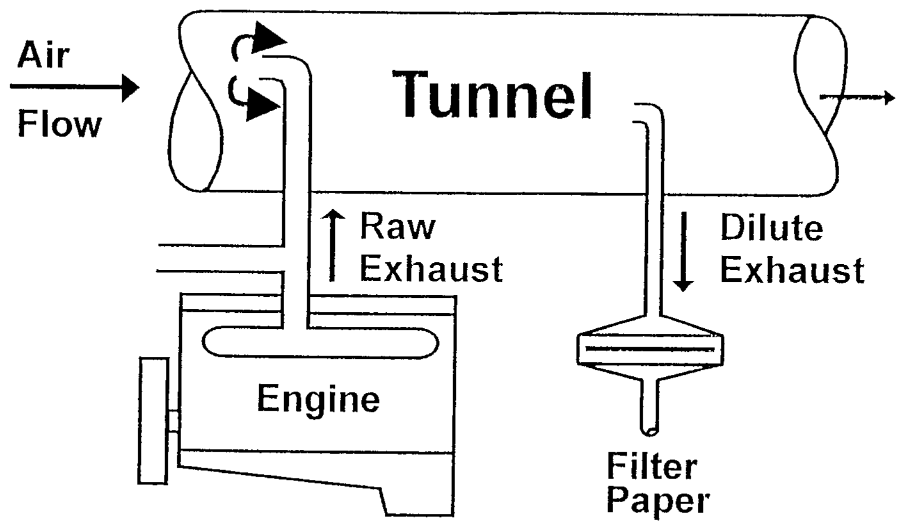
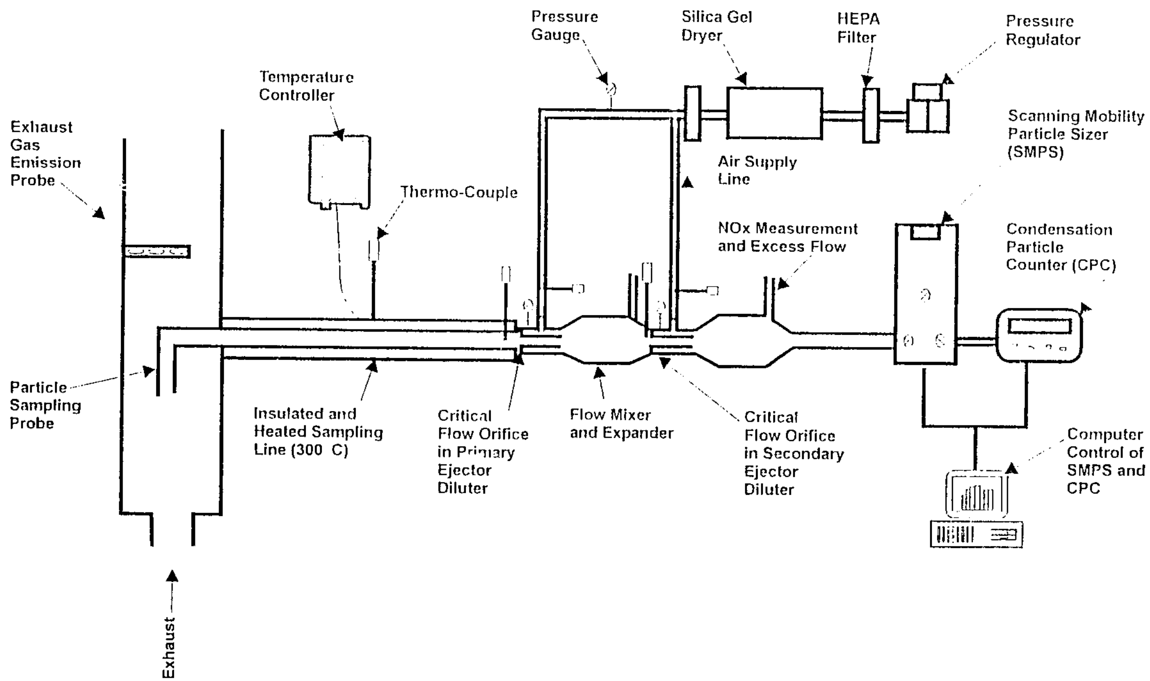


FIG 1

Perkins



TWO STAGE EJECTOR DILUTOR
FOR DIESEL EXHAUST PARTICLE MEASUREMENT

FIG 2

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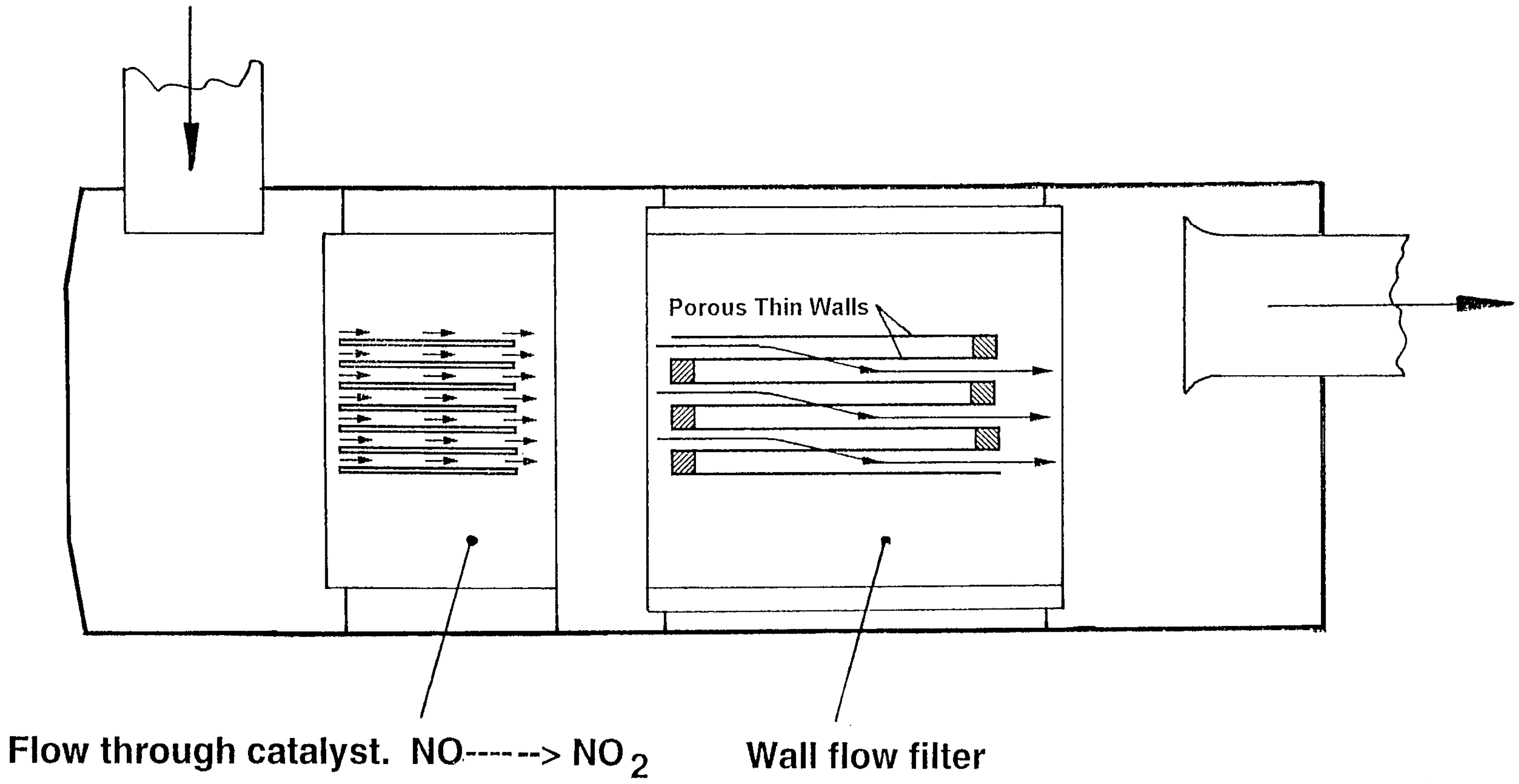

CONTINUOUSLY REGENERATING TRAP SCHEMATIC

FIG 3

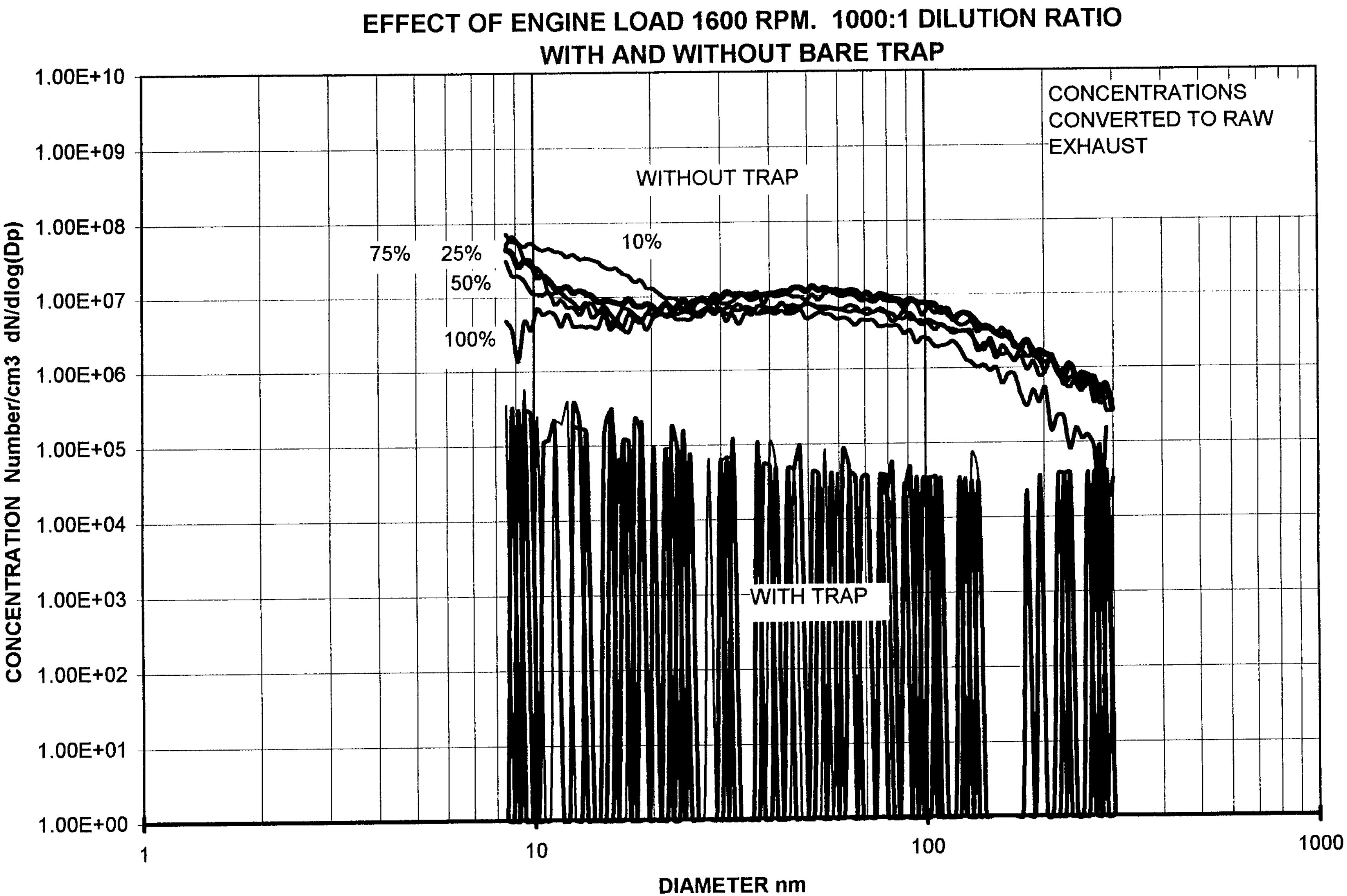

FIG.4

ZURIC10b

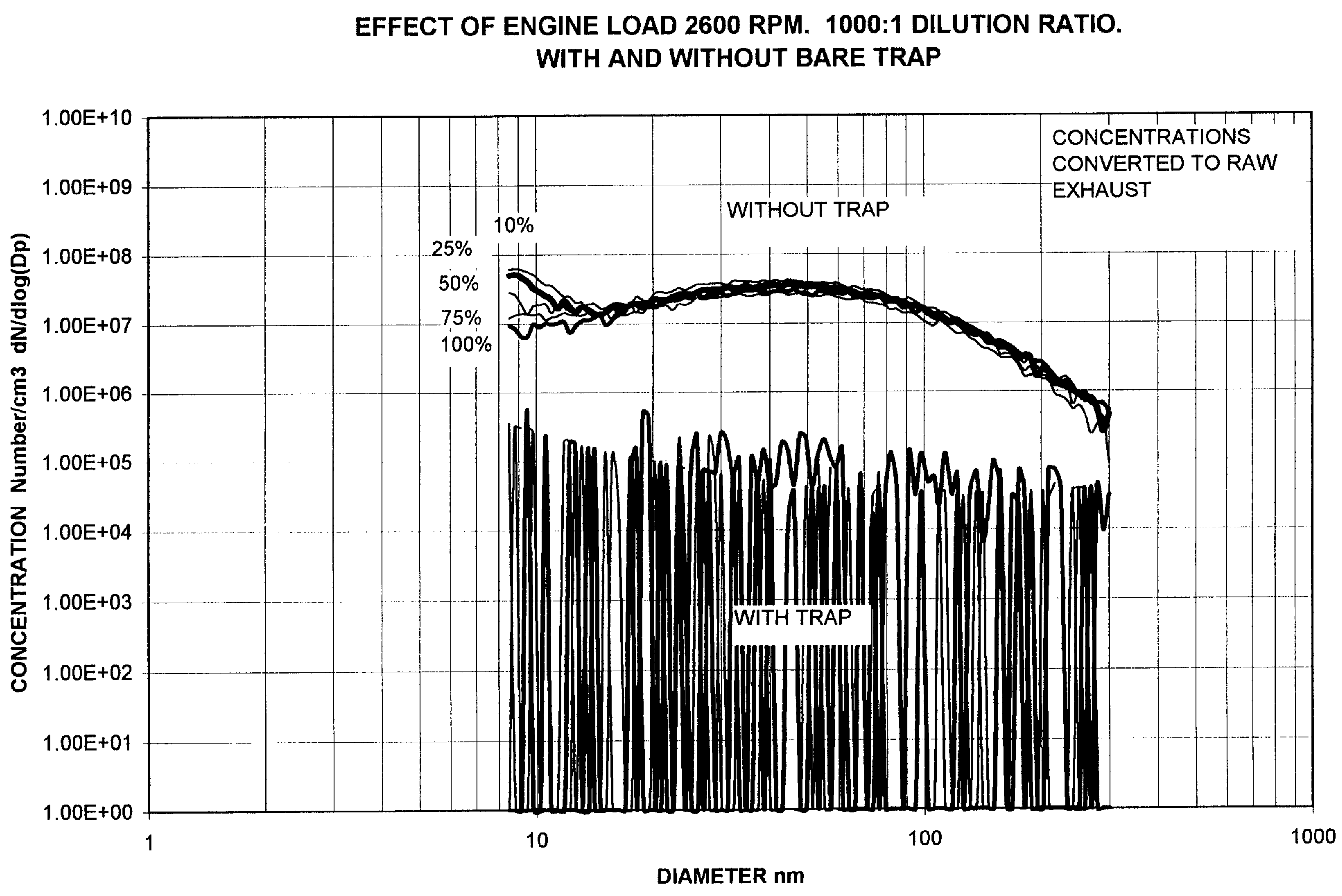
EFFECT OF ENGINE LOAD 2600 RPM. 1000:1 DILUTION RATIO.
WITH AND WITHOUT BARE TRAP
CONCENTRATIONS CONVERTED TO RAW EXHAUST
WITHOUT TRAP
WITH TRAP
10%
25%
50%
75%
100%
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1
10
100
1000
CONCENTRATION Number/cm3 dN/dlog(Dp)
DIAMETER nm

FIG.5

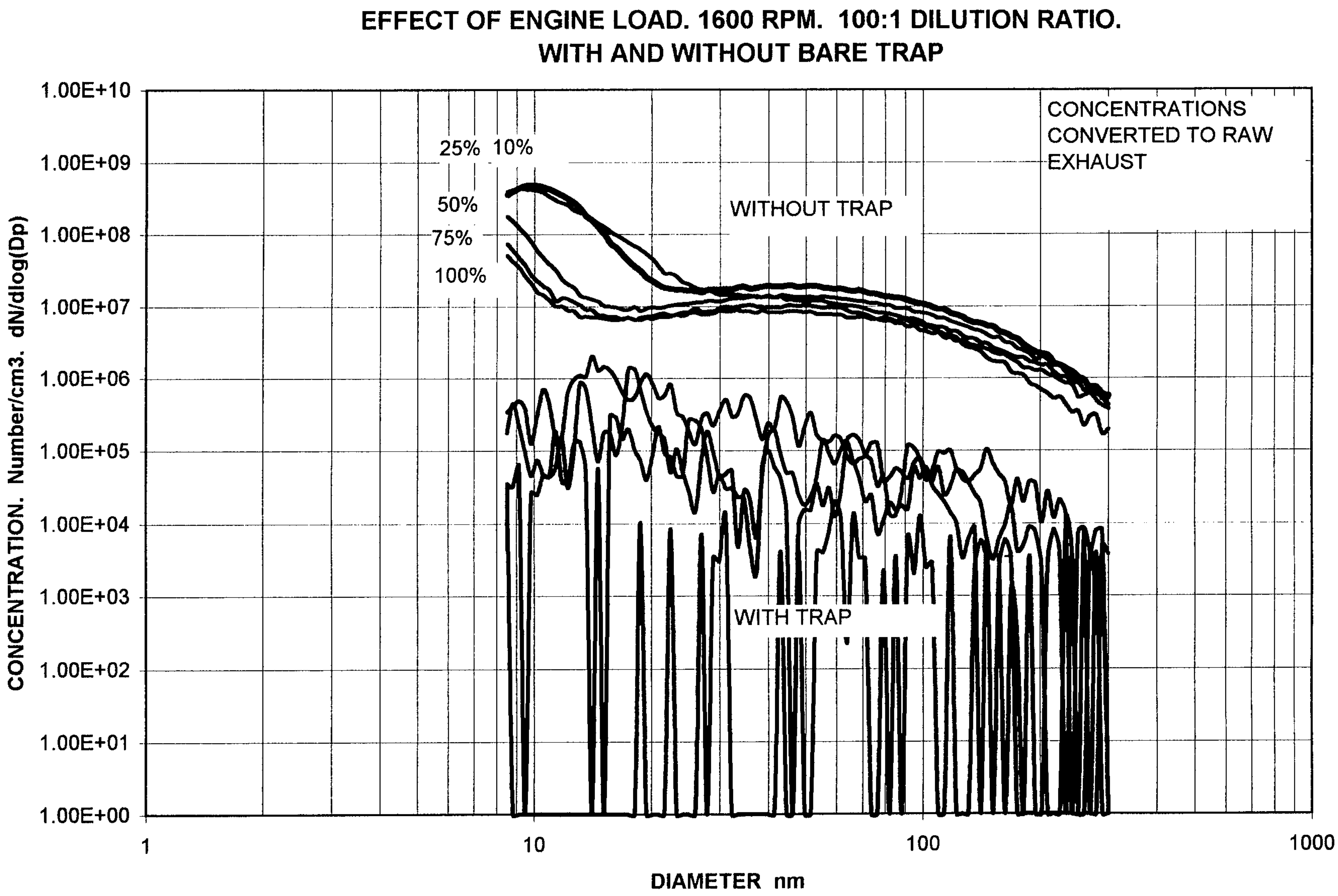
EFFECT OF ENGINE LOAD. 1600 RPM. 100:1 DILUTION RATIO.
WITH AND WITHOUT BARE TRAP
CONCENTRATION. Number/cm3. dN/dlog(Dp)
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1
10
100
1000
DIAMETER nm
25% 10%
50%
75%
100%
WITHOUT TRAP
WITH TRAP
CONCENTRATIONS
CONVERTED TO RAW
EXHAUST

FIG.6

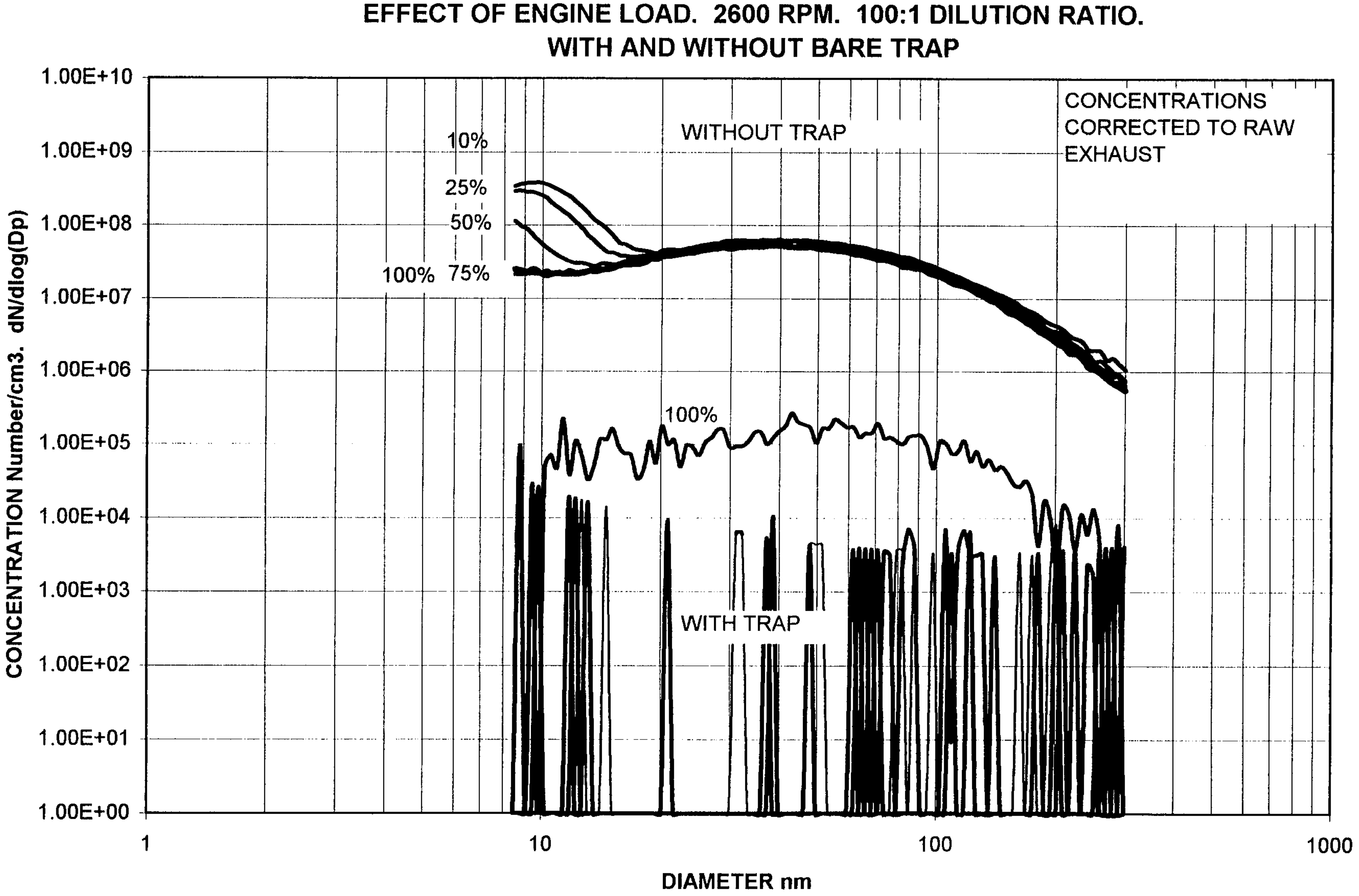
EFFECT OF ENGINE LOAD. 2600 RPM. 100:1 DILUTION RATIO.
WITH AND WITHOUT BARE TRAP
CONCENTRATION Number/cm3. dN/dlog(Dp)
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1
10
100
1000
DIAMETER nm
CONCENTRATIONS CORRECTED TO RAW EXHAUST
WITHOUT TRAP
10%
25%
50%
100%
75%
100%
WITH TRAP

FIG.7

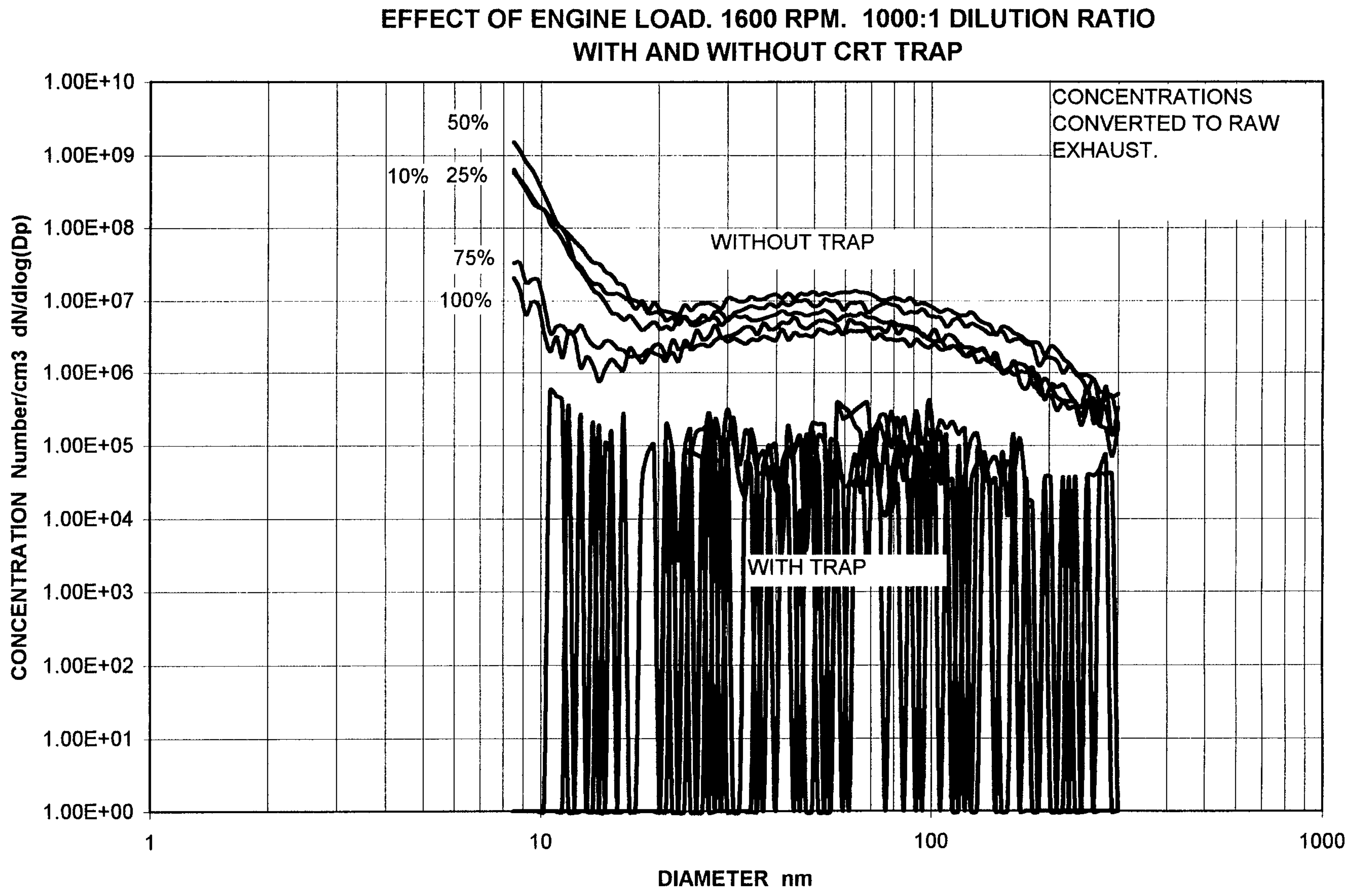

FIG.8

ZURICH2B

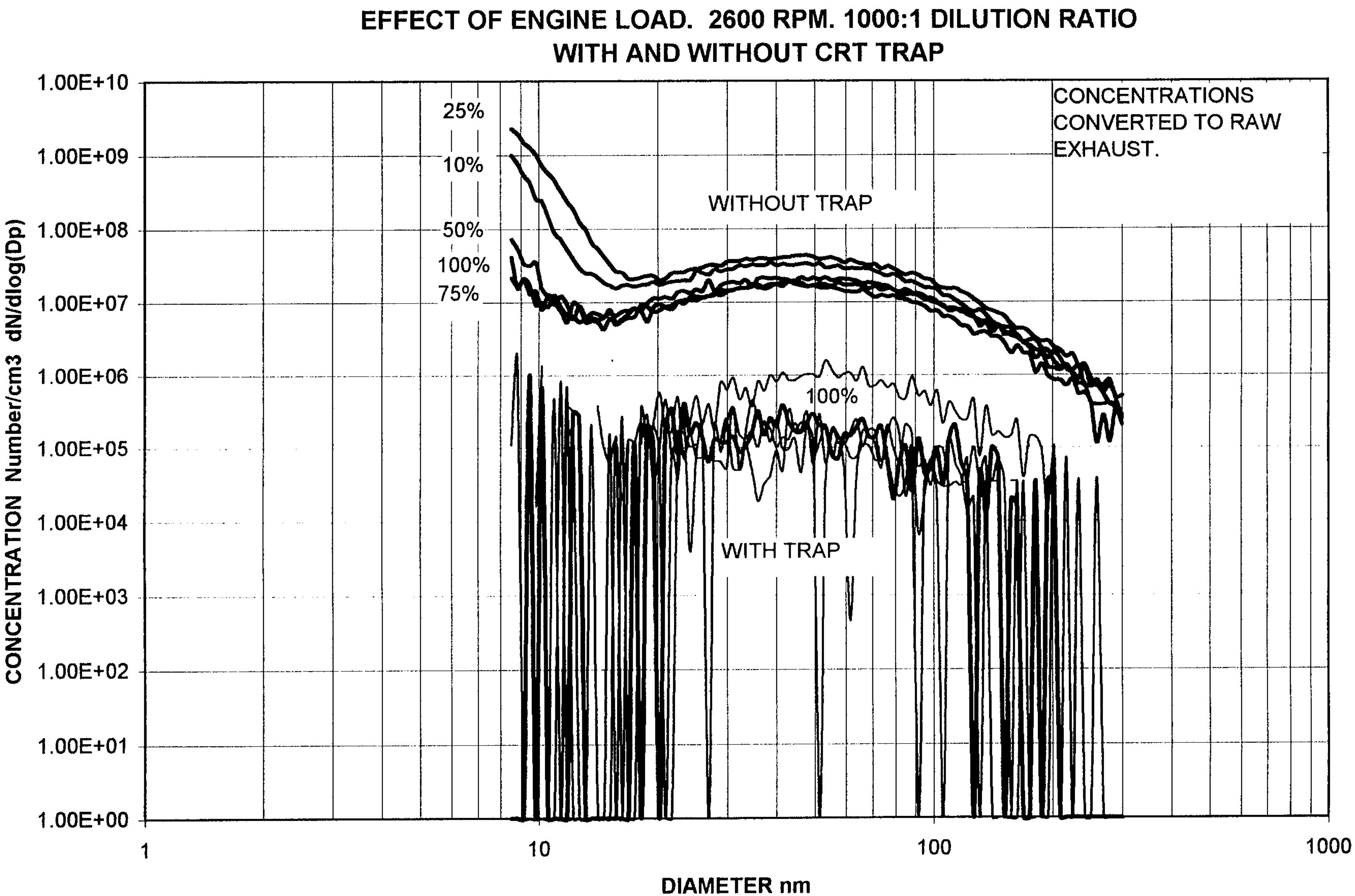
EFFECT OF ENGINE LOAD. 2600 RPM. 1000:1 DILUTION RATIO
WITH AND WITHOUT CRT TRAP
CONCENTRATION Number/cm3 dN/dlog(Dp)
1.00E+10
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1
10
100
1000
DIAMETER nm
25%
10%
50%
100%
75%
WITHOUT TRAP
100%
WITH TRAP
CONCENTRATIONS CONVERTED TO RAW EXHAUST.

FIG.9