MILJØ-PROJEKTER

15

Effects on Pollution of a Reduction or Removal of Lead Addition to Engine Fuel

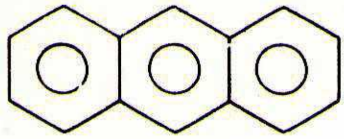
Appendices

November 1978

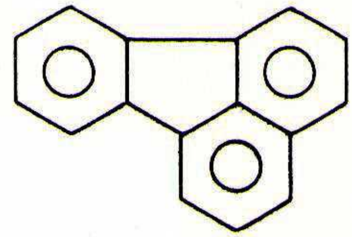
Performed by

Laboratory for Energetics, Technical University of Denmark and Chemistry Department, Risø National Laboratory
according to contract between
The European Economic Community and
The Danish National Agency of Environmental Protection, no. 131-75-10 ENV. DK.

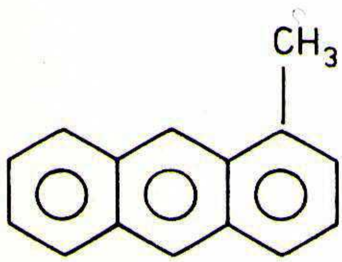
miljøstyrelsen · Strandgade 29 · 1401 København K · Tlf. (01) 57 83 10



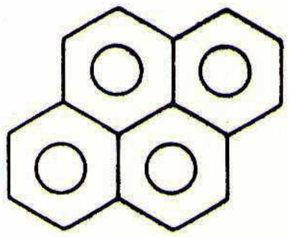
Anthracene



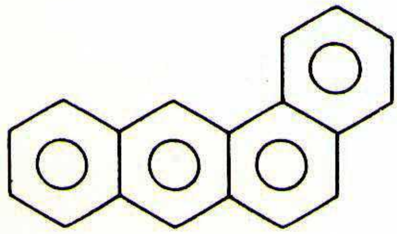
Fluoranthene



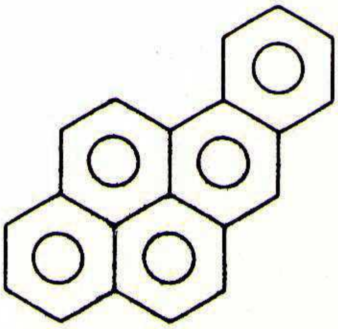
1-Methylanthracene



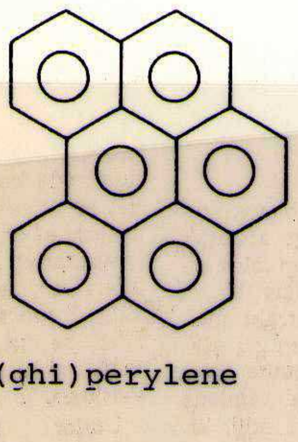
Pyrene



Benzo(a)anthracene



Benzo(a)pyrene



Benzo(ghi)perylene

The chemical structure of the seven polycyclic aromatic hydrocarbons (PAH), the emission of which is studied in detail in this report.

Øges kræftrisikoen, hvis blyet fjernes fra benzin?

Miljøstyrelsen, DTH og Risø offentliggør undersøgelse som led i EF-samarbejde

Af Jan Ingwersen, Peter Sunn Pedersen, Torben Nielsen, Elfinn Larsen og Jes Fenger

Bly er et giftigt stof, der kan påvirke dannelsen af de røde blodlegemer, stofskifteprocesserne og nervefunktionerne - blyforgiftning kan således have både physiologiske og psykiske virkninger. I løbet af de sidste 100 år er blyindholdet i atmosfæren steget kraftigt. Dette har sammenhæng med brugen af bly til forskellige tekniske formål, således medfører de senere års anvendelse af blyholdige benzinadditiver, antibankningsmidler, en alvorlig forurening.

Som middelværdi i perioden 1975-77 er forskellige steder i Storkøbenhavn målt koncentrationer i luften på 0.3-0.65 μg bly pr. m³. Målingerne er dog ikke foretaget i gadeniveau, og tidligere undersøgelser har vist, at koncentrationen her typisk kan være 3 gange højere - dv.s op til ca. 2 μg bly pr. m³.

Det tilladelige blyindhold i benzin blev 1. januar 1978 nedsat til 0,40 g pr. liter, og i første halvdel af 1978 er der ved målestationer i København, hvor blyforureningen fra biler er helt dominerende, blevet konstateret et fald i luftens blykoncentration på ca. 30%.

Den amerikanske miljøstyrelse (EPA) har for nyligt vedtaget, at fra 1982 må kvartals-middelværdien for blyindhold i byluft ingen steder overskride 1.5 μg/m³. Hvis trafikken forøges, er der risiko for, at disse normer overskrides. Hertil kommer, at den blyholdige benzin også indeholder dichlor- og dibromethan, »bly-scavengers«. Disse forbindelser er for nylig ved dyreforsøg påvist at være kræftfremkaldende. De vil først og fremmest udgøre en erhvervsrisiko for f.eks. tankpassere, men en mindre del vil også komme ud i atmosfæren.

Fjernes bly, må andet tilsættes

Alt andet lige bør blyindholdet i benzin derfor reduceres mest muligt, men problemet er ikke helt enkelt. Man kan vælge uden videre at reducere blyindholdet. Det vil kræve en sænkning af motorernes kompressionsforhold, hvorved de bliver mere brændstofkrævende. Desuden sker der en forøgelse af udsendelsen af forskellige stoffer, der kan medføre slimhindeirritation. Undlades blytilsætning til benzinen helt, fås ved visse motorer et forøget slid på ventilerne, der derfor må udskiftes hyppigt eller fremstilles i andre materialer. Bl.a. på grund af disse forhold er der indenfor EF blevet enighed om, at grænsen for det maksimale blyindhold i benzin ikke må sættes lavere end 0.15 g/l.

Man må derfor gå den anden vej og opretholde oktantallet (et mål for bankningsresistensen) ved at ændre på benzinens sammensætning af forskellige kulbrinter.

En af de økonomiske realistiske muligheder er at forøge indholdet af aromater. Herved risikerer man imidlertid at forøge udsendelsen af PAH (polycycliske aromatiske hydrocarboner), hvoraf nogle - f.eks. benz(a)pyren (Fig. 1) - er kræftfremkaldende.

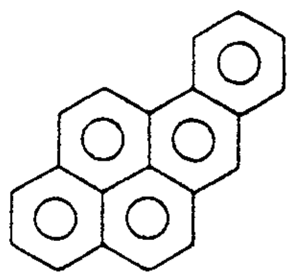


Fig. 1. Konstitutionsformlen for benz(a)pyren, der er opbygget af fem kondenserende benzenringe. Benz(a)pyren er et stærkt kræftfremkaldende stof, der findes i bilers udstødningsgas.

Projektet

Problemet er blevet studeret i en nyligt afsluttet undersøgelse, som blev finansieret på basis af en cost-sharing kontrakt mellem Miljøstyrelsen og EF. De to parter betalte hver halvdelen af de samlede udgifter på ca. 1 mill. kr. Det eksperimentelle arbejde og rapporteringen blev udført i samarbejde mellem *Laboratoriet for Energiteknik, DTH, Forsøgsanlæg Risøs Kemiafdeling* og *Miljøstyrelsen*. Den afsluttende rapport »Effect on pollution of a reduction or removal of lead addition to engine fuel« er netop udkommet som nr. 15 i Miljøstyrelsens miljøprojektserie.

Forsøgsopstillingen

Undersøgelsen blev af tekniske grunde baseret på rene laboratorieforsøg og blev koncentreret om de faktorer, der påvirker dannelsen og emissionen af PAH - i særdeleshed den fraktion, der er partikelbundet. Der blev anvendt en Ford Escort motor i en bænkopstilling. Udstødningsgassen blev fortyndet med ren luft i en vindtunnel, hvorefter der blev opsamlet partikler med en *diameter over 1 μm i cykloner*, og de mindre partikler på et filter. De opsamlede prøver indeholder flere hundrede komponenter, og det er umuligt i en undersøgelse af denne art at gøre kvantitativt rede for dem alle. Der blev derfor udvalgt 7 repræsentative PAH'er (se fig. 2), som blev målt ved hjælp af højtryksvæskechromatografi.

Under selve kørselen måltes endvidere med registrerende instrumenter udstødningsgassens totale indhold af polynukleare aromater, samt af kulilte, kvælstofilter m.m.

Hvad sker der i motoren?

Selvom der er publiceret en lang række undersøgelser af udstødningen fra benzinmotorer, er det endnu ikke fuldt klarlagt, hvor og hvordan de forskellige forbindelser dannes.

Der blev her bl.a. udført en række målinger med benzin eller smøreolie doped med benz(a)pyren. De viste, at hovedparten af de emitterede PAH dannes i forbrændingskammeret ved pyrolyse af brændstoffet. Hertil kommer benzinens naturlige PAH-indhold, der under de givne forsøgsbetingelser bidrog med op til 20%.

Under kørselen opsamles imidlertid i smøreolien ca. 10 gange så meget PAH, som det der udsendes gennem udstødningen. Da en del af olien kommer op i forbrændingskammeret, bevirker det en forøgelse af PAH-emissionen med tiden. Efter en kørsel svarende til 2500 km ved 60 km/h er emissionen af PAH-forbindelser vokset med gennemsnitlig 50% som følge af stigningen i smøreoliens PAH-indhold.

Endelig er motorens driftsbetingelser afgørende for PAH-emissionen. Således kan PAH ved lav motorbelastning oplagres i sodlag på cylindervæggen og eventuelt også i udstødningssystemet, hvorfra de re-emitteres ved høj belastning af motoren, f.eks. under accelerationer.

De tungeste PAH, hvortil hører de kræftfremkaldende, viste sig i det væsentlige at være bundet til partikler med en diameter på under 1 μm. De flygtigere PAH var derimod kun i ringere grad bundet til partikler (helt ned til under 30% for anthracen).

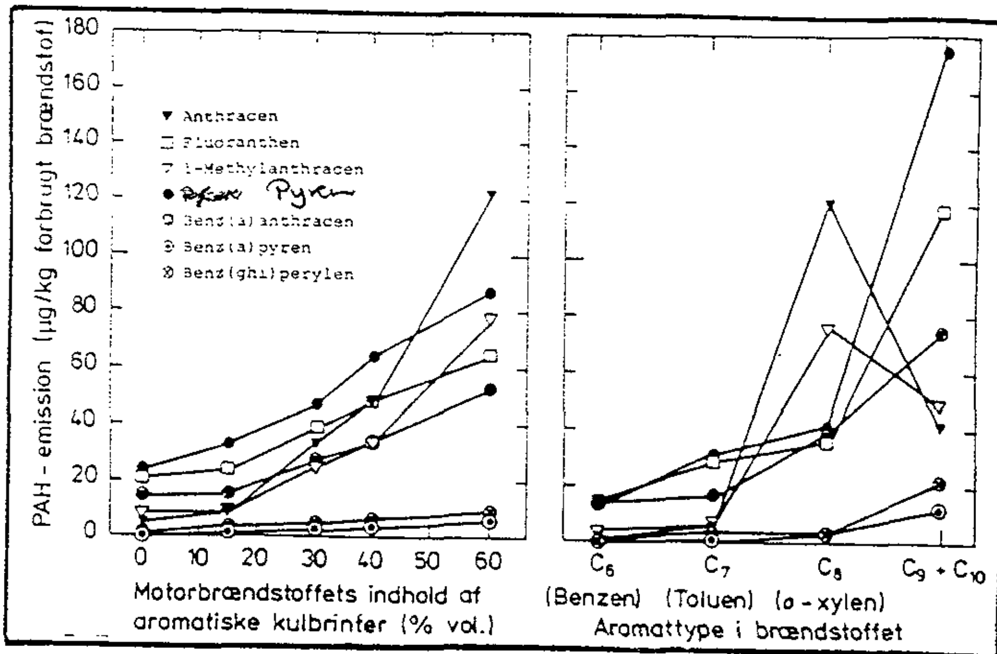


Fig. 2. betydningen af brændstoffets aromatindhold. Til venstre det relative indhold aromater, til højre den anvendte type

Forskellige brændstoffer

Det centrale i undersøgelsen var en sammenligning af udstødningsgassens PAH-indhold i forsøg, hvor der blev brugt brændstoffer af forskellig sammensætning, men med samme oktantal (97 RON). Disse brændstoffer blev fremstillet af BP Research Centre, Sunbury, England, efter forfatternes forskrift. De indeholdt som hovedkomponenter isooctan, n-heptan og en blanding af aromater. Aromatfraktionen bestod enten af benzen og tungere forbindelser med op til 10 kulstofatomer i et fast indbyrdes blandingsforhold eller af en enkelt af disse forbindelser. Endelig blev der tilsat blyadditiver, normalt svarende til 0.4 g bly pr. liter. Med disse specielle brændstoffer var det muligt at ændre én betydningsfuld parameter ad gangen - f.eks. bly- eller aromatindholdet. Det viste sig, at benzinens blyindhold i sig selv var uden større betydning for udstødningens indhold af PAH. Som det fremgår af fig. 2, er indholdet af aromater derimod helt afgørende.

Med stigende aromatindhold i brændstoffet, fås stigende emission af alle 7 målte PAH. Det er imidlertid ikke uvæsentligt, hvilke aromater der findes i brændstoffet. Mens kurverne i venstre del af fig. 2 er optaget med en fast blanding af C6- til C10-aromater, er kurverne i højre del optaget med en konstant mængde C6, C7, C8 eller C9 + C10. Generelt set fås stigende PAH emission med stigende molekylevægt. Det er ikke overraskende, at benzenringe med sidekæder lettere skulle kunne danne kondenserede ringsystemer.

Samlet vurdering

Ønskes blyindholdet i benzin, og derved også dichlor- og dibromethanmængden, sænket og oktantallet opretholdt ved forøgelse af benzinens aromatindhold, vil det medføre, at emissionen af PAH stiger.

Benzen og toluen danner mindre PAH ved forbrænding end de tungere aromater, men det vil ikke være ønskeligt at øge benzinens indhold af benzen, da arbejdsmiljøundersøgelser i USA har vist, at eksponering for høje koncentrationer af benzen giver en øget risiko for leukæmi.

På basis af målinger i udlandet må det formodes, at 10-20% af PAH indholdet i dansk byluft stammer fra biludstødning. En yderligere stigning vil derfor i dag kun give en beskeden procentisk stigning i byluftens indhold af PAH. Denne stigning vil kunne kompenseres ved regler for bilers kulbrinteemission. Endelig bør der sikres en betryggende behandling af brugt smøreolie.

■

Jan Ingwersen er civilingeniør og var i forbindelse med projektet ansat som videnskabelig medarbejder ved Laboratoriet for Energiteknik.

Peter Sunn Pedersen er civilingeniør, lic.techn. og ansat som lektor ved Laboratoriet for Energiteknik, Danmarks Tekniske Højskole.

Torben Nielsen er cand. scient. og ansat på Kemiafdelingen, Forsøgsanlæg Risø.

Eifinn Larsen er civilingeniør og ansat på Kemiafdelingen, Forsøgsanlæg Risø.

Jes Fenger er civilingeniør, dr.phil og ansat ved Miljøstyrelsens Luftforureningslaboratorium.

Effects on Pollution of a Reduction or Removal of Lead Addition to Engine Fuel

Appendices

November 1978

Dette hæfte er trykt på genbrugspapir.
This report is printed on recirculated paper.

En kortfattet udgave på dansk kan fås ved henvendelse til Miljøstyrelsen.
A short version in Danish is available on request from the National Agency of Environmental Protection.

ISSN 0105-3094
ISBN 87-503-2771-2
ISBN 87-503-2773-9

Fu 00-91

SCANTRYK, KBHVN
TELEFON 01-30 06 01

CONTENTS

APPENDIX A

Details of experimental set-up

General Remarks

This Appendix contains detailed information regarding the experimental set-up, excluding the on-line UV-fluorescence measuring system for monitoring of PNA-emission, that is described in appendix B. Fuels and lubricants are described in Appendix D.

Engine set-up

Engine: Ford Escort 4-stroke cycle petrol engine with gearbox, No. 2261E-3-0001- 5F4/E02, 4 cylinders in line, Bore/Stroke = 80.98/53.29 mm.
Swept volume 1098 cm^3
Compression ratio 9:1
Complys with ECE R.15 emission standards
Lubricant capacity (influding cooler) 3.75 litres.
Lubricant consumption in test condition: 0.035 litres/test.

The ignition system was converted to a Piranha optoelectronic ignition system. The engine cooling water system was connected to the laboratory cooling water plant, thermostat controlled to maintain constant engine temperature. The engine lubricant was cooled by means of a Bowman oil cooler type EC 140-3145-4, thermostat controlled to maintain constant oil temperature. The special exhaust manifold and exhaust pipe were made from Viggin Inconel Alloy 600 (75.0% Ni, 15.5% Cr., 8.9% Fe, 0.05%C), a high temperature heat and corrosion resistant alloy. The exhaust pipe was wrapped with copper tube, through which cooling water was led to provide the correct temperature profile (see later).

Dynamometer: Carl Schenck AG Eddy-current dynamometer with mechanical scale, type W 150, max. 150 kW at max. 10 000 RPM, with 6 step time schedule control unit.

Measurements on engine set-up. (Results, see Appendix D).

Engine power output: Determined from dynamometer scale reading (M kp) and speed of revolution (N RPM), the latter determined by Jaquet tachometer.

Exhaust gas temperatures at engine exhaust manifold exit ($T_{ex,m}$) and at end of exhaust pipe just before entering the dilution tube ($T_{ex,t}$) determined using thermocouples and an Ultrakust Thermophil 4435. In the test condition, corresponding to 60 kph steady speed road load in fourth gear, exhaust gas temperature at the exhaust manifold was to be about 610°C and at the dilution tube (before dilution) 160-180°C, according to measurements performed in dry, warm weather on an engine of the same type in a corresponding car, driving at 60 kph on the open road. At the same time the oil temperature was also measured in order to determine the temperature the oil should have in the test conditions.

Fuel flow to engine M_F determined from the time (stop watch) used for consuming 100 cm^3 of fuel, and fuel density (see fuel specifications in Appendix D).

Intake air flow to engine M_A determined from the pressure drop across a standard DIN sharp edge orifice (DIN-standard No. DIN 1952), Pressure drop determined using an Askania WS-minimeter precision water gauge (range 0-200 mm H_2O, scale division 0.01 mm H_2O).

Air/Fuel-ratio determined from intake air flow M_A and fuel flow M_F as $A/F = M_A/M_F$.

Engine coolant temperature T_C determined at exit from engine using a Smith cooling water temperature instrument.

Engine lubricant temperature determined by a thermocouple in the engine sump, entering through the engine oil dip stick tube.

Gaseous exhaust emissions

A sample outlet was provided at the engine exhaust manifold outlet. After cooling in a glass cooler (condensate was drained) the sample was directed through a glass fibre filter (Whatman GF/A) into the exhaust gas analysis equipment of the Laboratory. In this equipment, the sample was further cooled in a refrigerator to remove the remaining water vapour in order to protect the analyzers. The following instruments were used:

Beckman 215A NDIR-CO-Analyzer (modified) with 2 cells.
Ranges: 0.3%, 1.1%, 3.0% and 11% CO.

Beckman 215A NDIR-CO_2-Analyzer (modified).
Ranges: 5%, 20% CO_2.

Beckman 215A NDIR-C_6H_{14}-Analyzer (modified).
Ranges: 500 ppm, 2 000 ppm C_6H_{14}.

Scott 116 FID Total Hydrocarbon Analyzer.
Ranges: from 1 ppm C_1 to 100 000 ppm C_1.

Thermo-Electron 10 A Chemiluminescence NO/NO_x-Analyzer.
Ranges: from 10 ppm to 10 000 ppm NO and NO_x.

Scott 150 Paramagnetic Oxygen Analyzer.
Ranges: from 1% to 25% O_2.

Samples were also extracted from the exhaust pipe close to the dilution tube (but before dilution) and from the diluted gas, sampled by the isokinetic probe in the dilution tube (used for the determination of dilution ratio).

Particle collection equipment

The overall function of this system was to allow the collection of particulate matter from an isokinetically sampled portion of diluted exhaust gas, which was cooled down to below 40°C by dilution (20 times) with filtered ambient air. Each of the main components are described below.

The diluent air preparation system consisted of a prefilter (NOVENCO type ZFB-66, F-85), a microfilter with a collection efficiency of more than 99.999 per cent by the DOP test method (0.3 μm diameter particles after the filter, NOVENCO type ZFB-66, 1D-1000-11) and a heating surface (NOVENCO ZVL-66/Svend A. Nielsen, max. capacity 17.5 kW). Using the latter, the temperature of the diluent air could be corrected, but in order to obtain the lowest possible temperature of the sample and because room temperature in the laboratory was fairly constant, this was not used in most cases.

At the entrance to the dilution tube, the filtered air passed through a section for formation of turbulence in order to ensure rapid mixing with the exhaust gas. Figure A.1 shows this section.

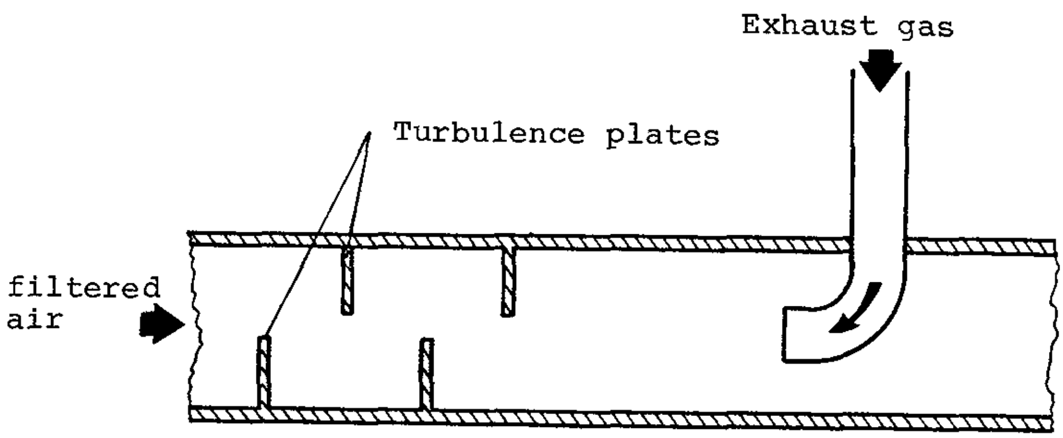


Figure A.1: Section for formation of turbulence and exhaust gas injection in the dilution tube.

The dilution tube was made of 0.125 m inner diameter stainless steel tube. The total length was 3.5 m (0.5 m Section formation of turbulence; distance from exhaust gas injection point to position of the isokinetic probe was 2.55). Counter current injection of the exhaust gas was used in order to increase mixing rate, following the findings of Beltzer et al. (1974), who developed and tested a very similar dilution tube (inner diameter 0,109 m, length 2,30 m). The efficiency of the mixing in the dilution tube was tested by operating the system normally (thus injecting hot exhaust gas) and measuring the temperature and the concentrations of CO, CO_2, O_2, HC and NO_x over the cross section of the dilution tube at the isokinetic sampling probe position. As shown in Figure A.2, the mixing was uniform within the experimental accuracy and the dilution tube thus was found suitable for the present use.

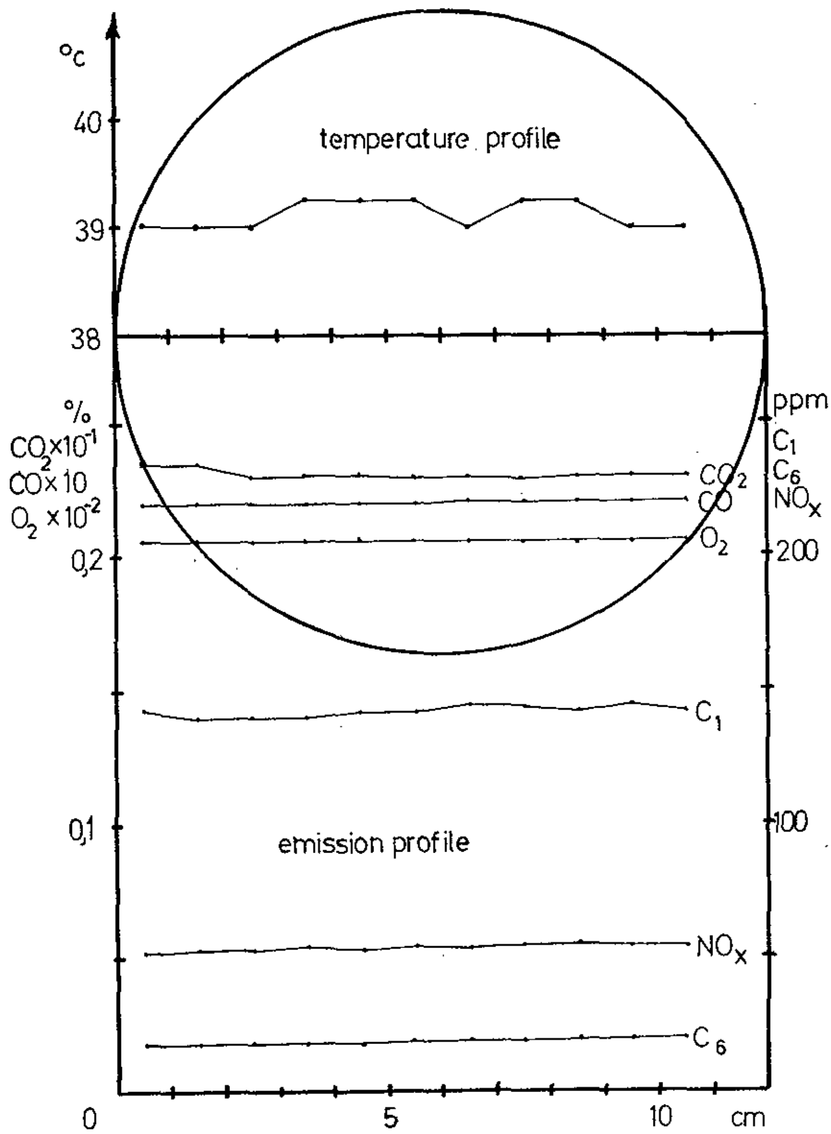


Figure A.2. Temperature and concentration profile in the dilution tunnel at the position (lengthwise) of the isokinetic sampling probe. Within the accuracy of the measurements, the mixing between exhaust gas and filtered air was uniform.

Particulate deposition in the dilution tube, i.e. sampling losses, was not determined, but in the very similar tube of Beltzer et al. (1974), loss of particulate (of 3.5 μm diameter) was found to be less than 1 per cent.

A NOVENCO centrifugal blower (type CPC-500/100, 4200 RPM, 11.0 kW, 2800 RPM, max. capacity 2000 m^3/hour at ΔP = 900 mm H_2O) was used to suck the diluted exhaust gas through the tube. The flow rate of filtered ambient air (and thus dilution ratio) was controlled by a cascade butterfly valve positioned between the heating surface and the turbulence formation section of the tube (see Figure 1 in the main report). Under normal operating conditions with 20 to 1 dilution ratio, the average velocity in the tube was 16.2 m/sec and the corresponding Reynolds number N_{Re} = 122,000.

Isokinetic sampling probe

The isokinetic sampling probe is to a certain extent constructed as suggested by the Air Pollution Laboratory, National Agency of Environmental Protection, RisØ. The inner diameter is 31.3 mm and the outer diameter is 50 mm. Because the probe fills a considerable part of the dilution tunnel it was necessary to take into account the fact that the pressure difference from the inside to the outside of the probe will not be zero when sampling is isokinetic.

The particle collection system is shown in Figure A.3. The isokinetically sampled diluted exhaust gas first passed through a cyclone battery (2), and then through a large absolute glass fibre membrane filter (3) (Whatman, type GF/A, diameter 29,3 cm). Following this, the sample passed a swirl flow meter (Fischer-Porter, type D10SG2111G) for the measurement of instantaneous flow rate (9) (which had to be 45 m^3/h) and total volume sampled (10). The sample then passed the pump (5) (Becker, type SV 180, 2.2 kW, max. capacity 100 m^3/h at ΔP = 250m bar), the capity of which was controlled by the by-pass valve (6) and finally re-entered the dilution tube (1) at the entrance to the large blower (8), which directed the total flow to the laboratory exhaust plant through the exit pipe (12).

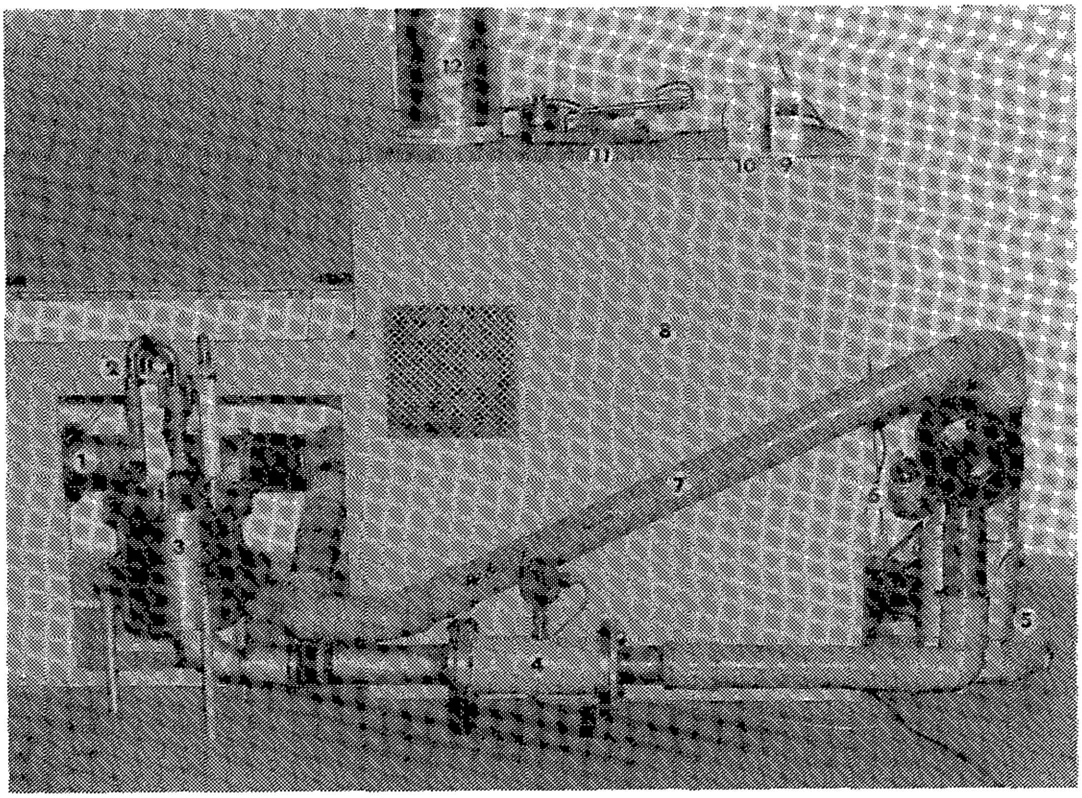


Figure A.3. The particle collection system:

1. Dilution tube
2. Cyclone battery
3. Total filter housing
4. Fischer-Porter swirl flow meter
5. Sample extraction pump
6. By-pass valve for pump
7. Return flow pipe
8. Noise-insulated housing for dilution tube blower
9. Flow rate indication instrument
10. Total volume sampled indication instrument
11. Precision differential pressure manometer
12. Exit pipe

The absolute filter housing was designed for the present investigation because the commercial filters available were too small and did not give a satisfactorily good and even distribution over the filter surface. Thus the present filter housing had 3 evenly distributed entrance openings (one from each cyclone) and a rather large mixing volume above the filter membrane, which was supported by a fine stainless steel grid at the rear. This design gave an even distribution of particulate matter over the filter surface as inspected visually.

The cyclone battery consisted of three cyclones in parallel, as shown in Figure A4. The diluted exhaust enters the battery through the pipe (1) to the manifold (2), where the sample is divided into the three cyclones (Airflow Developments - B.C.U.R.A.) (3) and from there out at (5) into the membrane filter. The cyclones are constructed throughout of stainless steel and at a flow rate of 15 m^3/h the separation point is 1 μm. The corresponding pressure drop is 800 mm H_2O.

Total collection equipment. For two single measurements, the particulate collection system described above was provided with two freeze-traps (in series) in order to determine the amount of PAH's not collected by the particulate collection system. The freeze-traps were made of glass and cooled on the outside by an alcohol/dry-ice mixture. The freeze-traps were put into the system between the filter housing and the swirl flow meter, and the exhaust gas temperature at the exit of the second freeze trap was -3°C, so that practically all the water vapour in the diluted gas was condensed and collected in the freeze-traps.

References

BELTZER, M., CHAMPION, R.J. and PETERSEN, W.L. (1974) Measurement of vehicle particulate emissions. SAE-paper No. 740286 (Society of Automotive Engineers, New York).

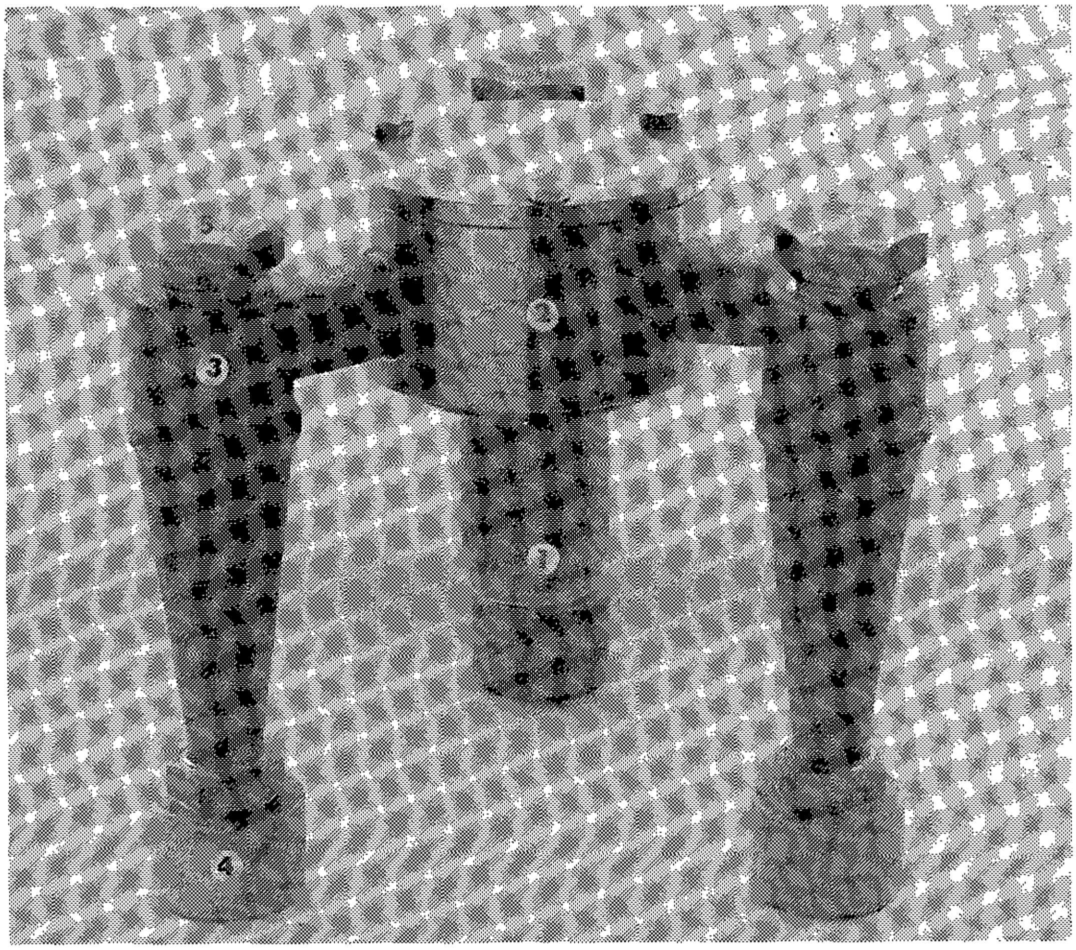


Figure A.4. The cyclone battery.

1. Entering pipe
2. Manifold
3. Cyclone
4. Botton cap
5. Exit (here closed with a screw-cap, ready for transport to Risø)

APPENDIX B

On-line fluorescence detector for PNA

The fluorescent compounds in the exhaust were monitored with a UV-fluorescence instrument placed directly after the manifold. Due to the overlapping, unresolved spectra of the compounds in question (cf. e.g., Sawicki 1969), only an overall response could be obtained.

Since fluorescence yields differ for various compounds, an absolute calibration for a single compound is of doubtful value. Therefore the instrument was only used for relative measurements, and for monitoring the emission stability during the individual tests.

The construction of the detector (fig. B.1) is in principle as described by Malbin et al. (1973); only the optical system is slightly more complicated: The light source, A, is a 200 W high pressure Mercury lamp, with a spectrum containing both ultra-violet and visible light. Light is mainly emitted at the two electrodes, and by focusing the light of a particular wavelength two spots will appear. The light is passed through the collimator lenses, B, and a band pass filter, C, which selects the UV 253.7 nm line. The filter does not completely stop the light of other wavelengths. The dispersion of the lenses of the transmitter in conjunction with the pinhole, E, and the spatial filtering ability of the receiver facilitate a further filtering of the light. After focusing with the lense, D, the filtered UV-light is modulated by the mechanical chopper, F, with a frequency of about 425 c/s. The lense, G, restores a parallel beam, which is bend 90^{o} in the mirror, H, and refocussed by the lense, I, in a small volume in the UV measuring cell, J.

The cell, which is shown in detail in fig. B.2, is made of Inconel 600 and furnished with a light trap for the incoming light. Both the incoming (exiting) and the outgoing (emitted) light are passed through quartz windows (Suprasil I); they are protected from contamination by cones and by a special arrangement which continuously blows filtered atmospheric air over the surfaces.

The fluorescent light is transmitted through the lenses K, M, and O to the photo-multiplier P. Between K and M is placed a filter L, which stops scattered light with a wavelength below that of the fluorescent light. Pinhold N determines together with pinhole E the measuring volume, which is about 1 mm^3.

The photo-multiplier with μ-metal shield and preamplifier (Q) and voltage divider is mounted together with the pinhold, N, and the lens, O, in an insulated water cooled housing in order to reduce the dark-current and thus the shot-noise. The housing is furnished with a double-window in front of the photo-cathode in order to prevent dew-formation.

The subsequent processing of the signal is performed in a phase sensitive detector, R, which demodulates the signal from the preamplifier, Q, by means of a reference signal from the chopper, F. The detector is a PAR lock-in amplifier model HR-8 with a type A preamplifier. Finally, the signal is recorded (S). A block diagram of the electrical configuration is shown in fig. B.3. Figures B.4 and B.5 are photographs of the optical part and the UV-fluorescence measuring cell, respectively.

REFERENCES

MALBIN, M.D., DOBY, A.F., and HASKELL, W.W. (1973). On-line detection of polynuclear aromatic hydrocarbons in automotive exhaust. I. Evaluation of catalytic converters. Presented at the 66th Annual Meeting of the Air Pollution Control Association, Chicago, Illinois, June 24-28, 1973.

SAWICKI, E. (1969). Fluorescence analysis in air pollution research. Talanta 16, 1231-1266.

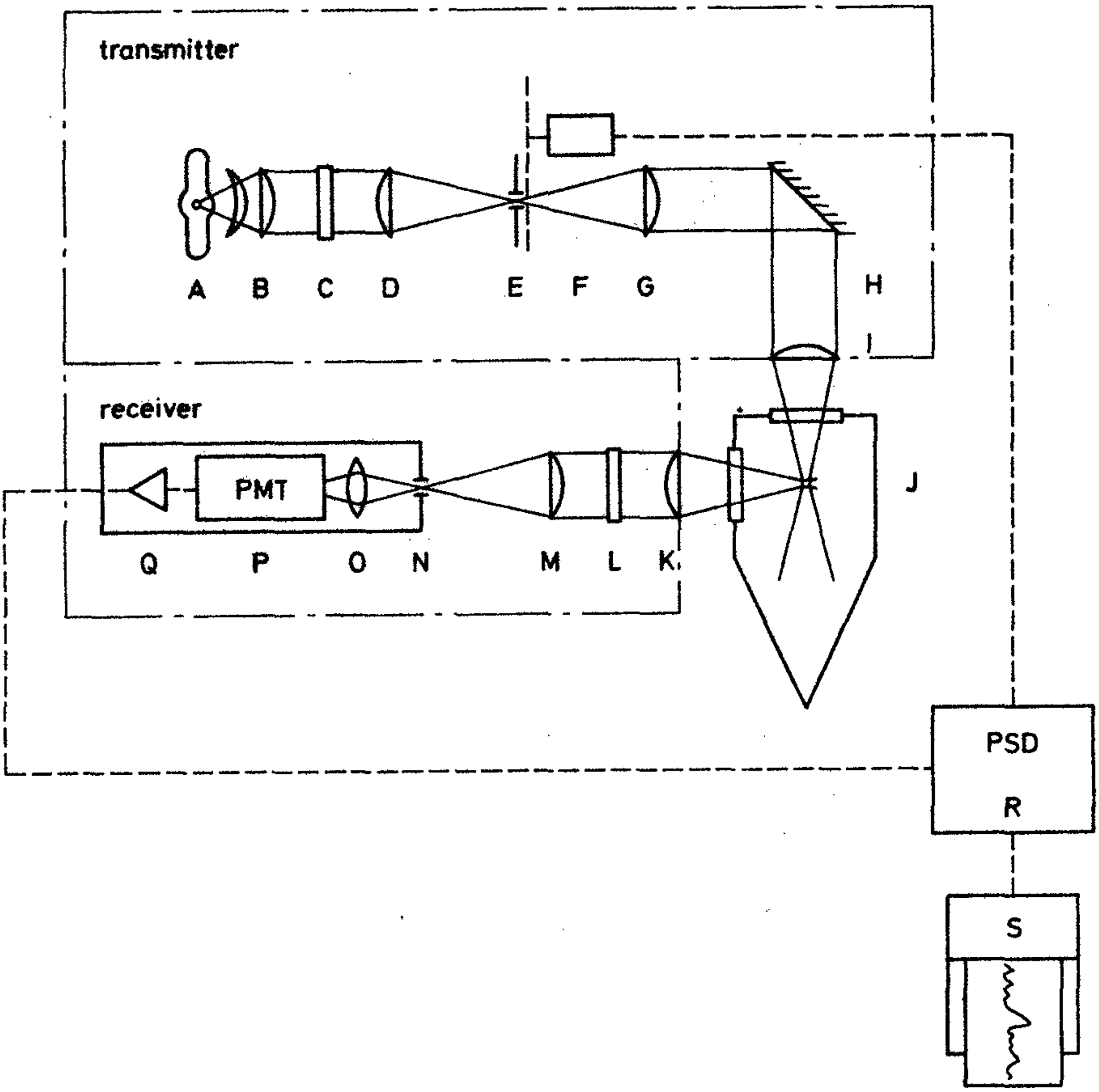


Fig. B.1. Principle of the fluorescence detector. The parts A-I constitute the "light-transmitter" and parts K-Q the "light-receiver". They are built in a common light-tight casing shown open in fig. 4. The fluorescence is produced in the measuring cell J, which is shown in more detail in fig. B.2. For a full explanation of the symbols, see the text.

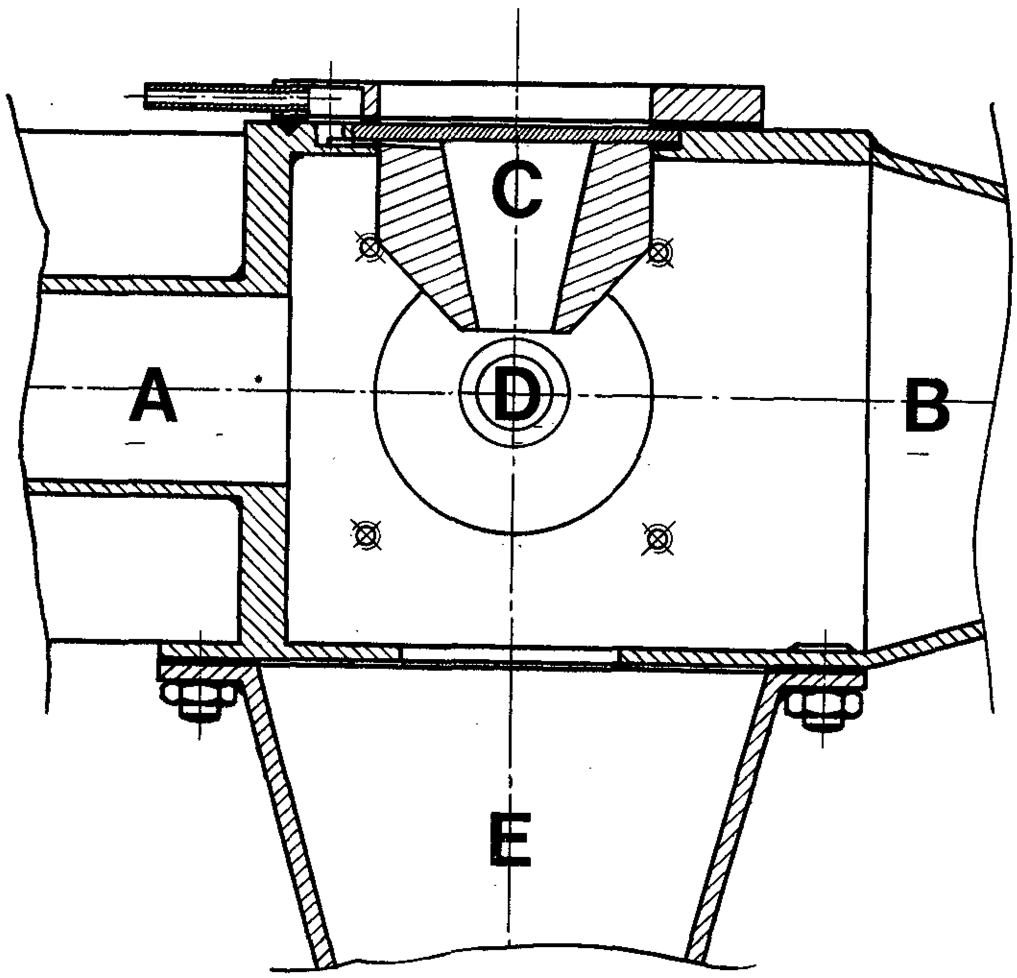


Fig. B.2. Cut through the UV-fluorescence cell. The exhaust passes from A to B. The incoming exciting light enters through the system C (described in the text), passes the reaction zone D, and is trapped in a cone E. The outgoing (fluorescent) light passes a system similar to C at a right angle to the paper.

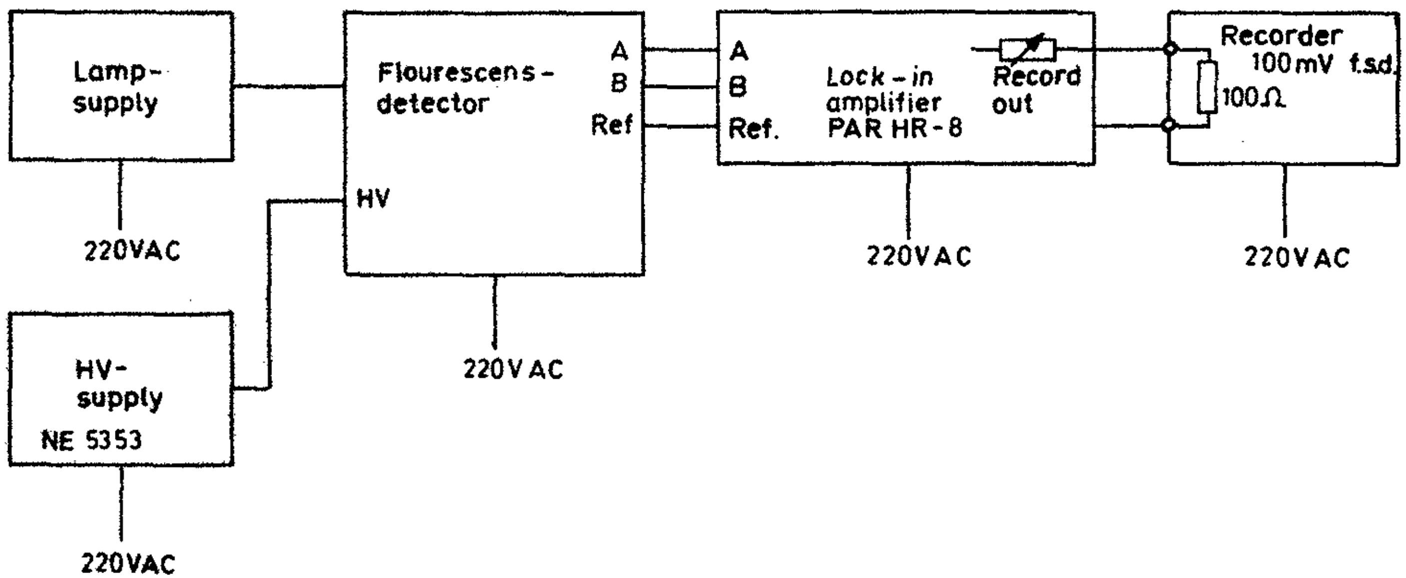
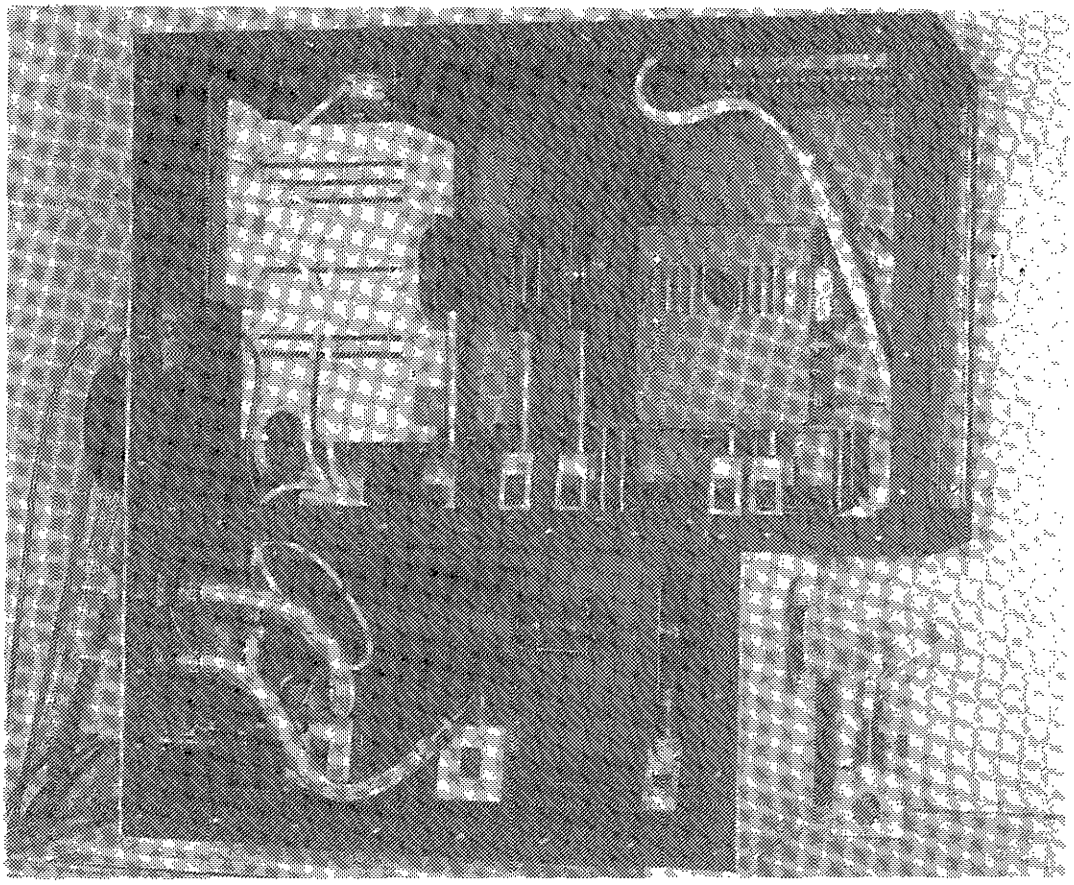
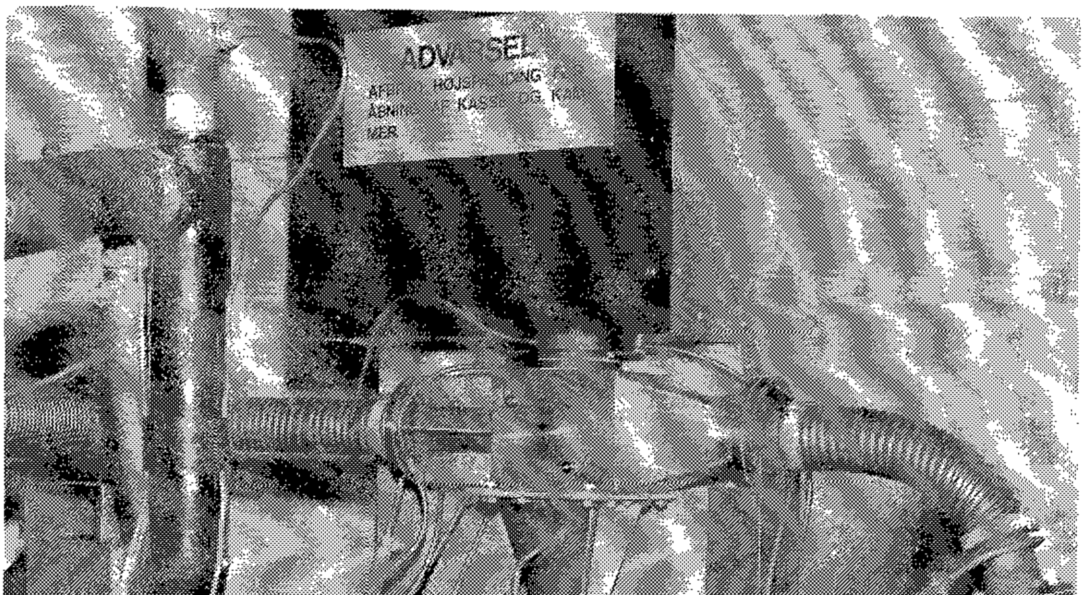


Fig. B.3. Block diagram of the electrical part of the fluorescence detector.



<u>Fig. B.4</u>. The optical part of the fluorescence detector with the light lid removed.



<u>Fig. B.5</u>. The UV-fluorescence cell placed in the experimental set-up.

APPENDIX C*

Determination of polycyclic aromatic hydrocarbons by means of high-performance liquid chromatography with fluorescence detection.

Introduction

Several methods for determining benzo(a)pyrene (BaP) and other polycyclic aromatic hydrocarbons (PAHs) have been described (Sawicki 1969, Schaad 1970, Zander 1975, Sauerland et al. 1977). Many recent works utilize gas chromatography with highly efficient glass columns or capillary columns to separate the PAHs, which are then measured by a flame ionization detector or a mass spectrometer (Bjørseth 1977, Grimmer et al. 1977, Sauerland et al. 1977, Winkler et al. 1977).

In the last few years, the rapid development of high pressure pumps and microparticulate columns for high-performance liquid chromatography (HPLC) has resulted in a steadily growing interest in applying this technique (Thoms and Zander 1978). HPLC has mainly been used in connection with on-line UV absorbance detection, and this combination has been utilized for the analysis of PAHs in airborne particulate matter (Boden 1976, Krstulovic et al. 1976), smoke condensates (Haeberer et al. 1975, Radecki et al. 1978), tars (Sauerland et al. 1977, Grant and Meiris 1977), and mineral oils (Goldstein 1976). Although not all compounds are well resolved into individual peaks by this method, measurements of the absorbance at two or more wavelengths have made it possible to determine the amounts of the most important PAHs (Krstulovic et al. 1976, Grant and Meiris 1977).

The development of on-line fluorescence detectors seems to offer possibilities of an improved procedure (Johnson et al. 1977,

*Appendix C is a modified version of a paper to be published by Torben Nielsen in Journal of Chromatography

Slavin et al. 1977). Fluorescence detectors are generally more sensitive and therefore require smaller samples and less sampling time. Furthermore, by changing the fluorescent conditions, selectivity can be found between the various compounds (Johnson et al. 1977 Slavin), et al. 1977, and hence it is easier to analyze poorly resolved components. Only few publications have dealt with the analysis of PAHs using the combination of HPLC and fluorescence detection in actual samples (airborne particulate matter (Fox and Staley 1976, Das and Thomas 1978), sediments (Wise et al. 1977) petrols (Lloyd 1975), engine oils (Lloyd 1975, Wheals et al. 1975), and water (Hagenmeier et al. 1977)). The detection procedure is normally hampered by the finding that, for example, air samples contain fluorescent compounds other than PAHs. The PAH fraction must be separated from these compounds in order to avoid a high background fluorescence. The PAHs are purified from other organic compounds by thin-layer chromatography (TLC), separated by HPLC and measured by on-line fluorescence detection.

Experimental

Chemicals: Reference compounds (see Table C.I) were obtained from different suppliers. Each compound was checked by comparing its UV absorption spectrum with those in the literature (Clar 1964). The methanol and cyclohexane used in this study were from Ferak (p.a.); the hexane, toluene, ether, and dioxane from Merck (p.a.). The cyclohexane was purified by elution through a column packed with aluminium oxide (aluminia Woelm N - Super I). No interferring fluorescence was observed by analyzing blank samples.

The equipment for HPLC detection: The equipment consisted of a Waters pump 6000 A, a Rheodyne 7120 sample injector with a 20 µl loop, a Nucleosil[R] 5 C_{18} precolumn 6 cm x 0.46 cm, a Zorbax[TM] ODS column 25 cm x 0.46 cm, and a Perkin Elmer LC 1000 fluorescence detector. The chromatogram was displayed on a Kipp - Zonen BD 41 recorder. The eluent (methanol: water, 8:1) was filtered through a mobile phase filter before the entrance to the pump. Between the injection loop and the pre-column was placed a Rheodyne column inlet filter, and the samples were filtered through a 0.2 µm Millipore filter FG before injection to prevent the deterioration of the columns as a result of particles in the injected solutions.

Extraction: The particulates in automobile exhaust gases were separated and collected in two fractions. One was collected on cyclones of stainless steel and mainly contained particles with a diameter above 1 µm, the other was collected on glass fiber filters (Whatmann G/FA) and consisted mainly of particles of less than 1 µm in diameter. The PAHs on the filters and the cyclones were extracted ultrasonically in cyclohexane (Seifert and Steinbach 1977). Cyclohexane was preferred to other organic solvents because it was expected that these would dissolve undesirable polar compounds to a higher degree. The collected extracts were dried over sodium sulphate, filtered and concentrated in a rotavapor to a few ml. The rest of the cyclohexane was evaporated to 0.1 ml at 35°C in a stream of nitrogen.

Petrols and lubricating oils: 10.0 ml of the special petrol was evaporated to 0.3 ml in a stream of nitrogen, and this was used in the following clean-up procedure; 100 µl crankcase oil was diluted with 10 ml cyclohexane, and the solution was purified by the liquid-liquid extraction method described by Grimmer et al. (1973). The cyclohexane extract was dried over sodium sulphate, filtered and concentrated to 0.1 ml.

Thin-layer chromatography: The thin-layer chromatography (TLC) pre-fractionation procedure was a modification of that used by Brocco et al. (1970). The TLC plates (20 cm x 20 cm, 0.25 mm thick, from Macherey-Nagel SIL G-25 HR) were activated at 100°C for 1 hour. The concentrated extract was applied as a band (6-8 mm wide), and a standard PAH mixture consisting of anthracene, 1-methylanthracene, fluoranthene, benzo(a)pyrene, and benzo(ghi)perylene was spotted onto each TLC plate. The plates were developed by ascending elution in hexane, air drying in the dark for 5 minutes, followed by elution in toluene: cyclohexane 1:1. It is advantageous to elute the plates in hexane first in order to avoid overloading if the content of non-volatile, non-polar compounds is high. By means of the elution in the toluene-cyclohexane mixture, the PAH fraction was separated from up to 6 other fractions of fluorescent compounds (see Fig. C.1). The compounds in the 6 bands were not identified, but tests with known standards indicated that they may consist of nitrogen and oxygen heterocycles and substituted PAHs (phenols, anisols). The silica gel with the PAH fraction was scrapped off the plate and eluted twice with 3 ml ether. The combined extracts were filtered, concentrated to 0.1 ml in a stream of nitrogen, and diluted with a mixture of methanol and dioxane (3:2).

High-performance liquid chromatography: Highly efficient separations of the PAHs are obtained with HPLC on an octadecylsilyl (ODS) (Krstulonic et al. 1976, Slavin et al. 1977, Fox and Staley 1976, Wheals et al. 1975, Das and Thomas 1978), or an octadecyldimethylsilyl (RP 18) (Hagenmeier et al. 1977) stationary phase of microparticles (5-7 μm) in connection with a polar mobile phase. A decrease in the capacity of the column after prolonged use has been reported (Hagenmeier et al. 1977) but the reasons for this are not clear (Smith and Vaughan 1976). Therefore, a short, protective pre-column was introduced. However, following the described procedure, 600 analyses gave no decrease in the capacity. The separation of the PAHs was improved by the introduction of the pre-column. Figure C.2 shows the separation of 8 standard compounds. Figure C.3 shows that a separation is obtained even between the three isomers 1-, 2-, and 9-methylanthracene. Table C.I tabulates the relative retention times for 23 PAHs.

The characteristics of the chromatographis system were as follows:

The capacity factor of benzo(ghi)perylene was

$$k' = \frac{V - V_o}{V_o} = 14.2$$

the theoretical plate number for benzo(a)pyrene was

$$N = 16\left(\frac{V}{W}\right)^2 = 13000$$

and the resolution between the isomers benzo(e)pyrene and benzo-(a)pyrene was

$$R = \frac{V_2 - V_1}{\frac{1}{2}(W_1 + W_2)} = 4.7.$$

Fluorescence

Oxygen quenching. The mobile phase was deoxygenated by bubbling argon through the eluate for at least one hour. It was then deaerated ultrasonically and kept under an argon atmosphere that was slowly renewed. This was necessary to prevent that the presence of small amounts of oxygen in the mobile phase quenched the fluorescence (Sawicki 1969, Fox and Staley 1976) especially that of pyrene (see Fig. C.2). In this way it was possible to ensure that the response of the standard mixtures did not change by more than a few per cent throughout a working day.

Detection

The fluorescence of the PAHs was measured with an excitation at 340 nm and an emission at 425 nm, and by the combination 363/435 nm. The choice of the excitation and emission wavelengths depends upon the properties of the fluorescence detector, the separation of the PAHs and the PAH profile of the samples. Table C.I tabulates the detection limits for 23 PAHs 340/425 nm and 363/435 nm. The selectivity of the fluorescence detector is also demonstrated by the HPLC/fluorescence trace of a sample of automobile exhaust collected on a glass-fibre filter at 340/425 nm (Fig. C.4), and at 363/435 nm (Fig. C.5). For instance, the peak of 1-methylanthracene is almost hidden by the peak of pyrene at 340/425 nm, while at 363/435 nm the peak of pyrene is suppressed. However, even the conditions selected were not optimal for the determination of benzo(a)pyrene; the detection limit for this was at least five times less than attained with gas chromatographic methods (Winkler et al. 1977).

Identification

The identity of the components in the samples was determined by comparing the retention times and the emission spectra obtained by a stop-flow technique with those of standard PAHs (Slavin et al. 1977). Thus, anthracene, fluoranthene, 1-methylanthracene, pyrene, benzo(a)anthracene, benzo(a)pyrene and benzo(ghi)perylene were identified at 340/425 nm, and anthracene, fluoranthene, 1-methylanthracene, benzo(a)anthracene, benzo(a)-pyrene, and benzo(ghi)perylene were identified at 363/435 nm as components in automobile exhaust gases.

Quantitation

The quantitation of the PAHs in the samples was performed by comparing the measured peak heights with those of a standard mixture. In all cases examined, the response of the fluorescence detector was linear over three decades with the amount of PAHs injected. An important effect interferring in trace analysis is that arising from absorption of the fluorescent light by another nonfluorescent component (Sawicki 1969). A column with low capacity (the number of theoretical plates was about 2000) was used to investigate whether any component absorbed the light emitted from another component in the cases where the two components were poorly resolved and the fluorescence of the first was suppressed. However, no evidence of this phenomenon was observed in the different combinations with relevant concentrations. It must, therefore, be assumed that the concentrations of the components in the measuring cell are sufficiently small to avoid inner-filter or concentration effects (Sawicki 1969). This assumption was, furthermore, verified by the fact that the emission spectra of the components identified in the samples were not distorted, and also by the fact that the results from analyzing the samples at two different combinations of excitation and emission wavelength were consistent (Table C.II).

The reason why there is a larger amount of BaP at 340/425 nm is that BaP is poorly resolved from an unknown compound (see Fig. C.4). At 363/435 nm the fluorescence of this compound is suppressed (see Fig. C.5) and hence the analysis of BaP is not distorted. Since the peak of benzo(a)anthracene is not completely resolved from that on the front side, the analyses of benzo(a)-anthracene probably gave slightly elevated results.

Control Experiments

The recoveries obtained by this method were tested by processing known quantities of the standards through the clean-up procedure. Table C.III shows the percentual recovery for a triplicate determination. As a further assessment of the repeatability of the method, a set of 2 equivalent filter and 3 equivalent cyclone extracts was analyzed (Table C.IV). Table C.V gives the variation coefficients for the determinations of the PAHs in a filter sample. The mean reproducibility for the filter samples was ± 12% (Table C.IV) and for the cyclones ± 24% (Table C.VII). Figures C.4 and C.5 show typical chromatograms of PAH in the filter samples.

REFERENCES

BJØRSETH, A. (1977). Analysis of polycyclic aromatic hydrocarbons in particulate matter by glass capillary gas chromatography. Anal. Chim. Acta 94, 21-27.

BODEN, H. (1976). The determination of benzo(a)pyrene in coal tar pitch volatiles using HPLC with selective UV detection. J. Chromatogr. Sci. 14, 391-95.

BROCCO, D., CANTUTI, V. and CARTONI, G.P.: Determination of polynuclear aromatic hydrocarbons in atmospheric dust by a combination of thin-layer and gas chromatography. J. Chromatogr. 49, 66-69.

CLAR, E. (1964). "Polycyclic Hydrocarbons". Academic Press. London.

DAS, B.S. and THOMAS, G.H. (1978). Fluorescense detection in high performance liquid chromatographic determination of polycyclic aromatic hydrocarbons. Anal. Chem. 50, 967-73.

FOX, M.A. and STALEY, S.W. (1976). Determination of polycyclic aromatic hydrocarbons in atmospheric particulate matter by high pressure liquid chromatography coupled with fluorescense techniques. Anal. Chem. 48, 992-98.

GOLDSTEIN, G.S. (1976). Separation of polycyclic aromatic hydrocarbons in liquid chromatography on cross-linked polyvinylpyrrolidone. J. Chromatogr. 129, 61-72.

GRANT, D.W. and MEIRIS, R.B. (1977). Application of thin-layer and high-performance liquid chromatography to the separation of polycyclic aromatic hydrocarbons in bituminous materials. J. Chromatogr. 142, 339-51.

GRIMMER, G., HILDEBRANDT, A. and BÖHNKE, H. (1973). Investigations on the carcinogenic burden by air pollution in man. III. Sampling and analytics of polycyclic aromatic hydrocarbons in automobile exhaust gas. 2. Enrichment of the PNA and separation of the mixture of all PNA. Zentrallbl. Bakteriol. Parasitenk. Infektionskr. Hyg., I. Abt. Orig. B 158, 35-49.

GRIMMER, G., BÖHNKE, H. and GLASER, A. (1977). Polycyclische aromatische Kohlenwasserstoffe im Abgas von Kraftfahrzeugen. Eine Bestandaufnahme. Erdöl, Kohle 30, 411-17.

HAEBERER, A.E., SNOOK, M.E. and CHORTYK. O.T. (1975). High-pressure liquid chromatography of polynuclear aromatic hydrocarbons of cigarette smoke condensate. Anal. Chem. Acta 80, 303-9.

HAGENMEIER, H., FEIERABEND, R. and JÄGER, W. (1977). Bestimmung polycyclischer aromatischer Kohlenwasserstoffe in Wasser mittels Hochdruckflüssigkeitschromatographie. Z. Wasser Abwasser-Forsch. 10, 99-104.

JOHNSON, E., ABU-SHUMAYS and ABBOTT, S.R. (1977). Use of fluorescense detection in high-performance liquid chromatography. J. Chromatogr. 134, 107-19.

KRSTULOVIC, A.M., ROSIE, D.M. and BROWN, P.R. (1976). Selective monitoring of polynuclear aromatic hydrocarbons by high pressure liquid chromatography with a variable wavelength detector. Anal. Chem. 48, 1383-86.

LLOYD, J.B.F. (1975). Nitrogen heterocycle and polynuclear hydrocarbon fluorescence and adsorption effects in the presence of silica gel. Applications in high-pressure liquid and micro-column chromatography. Analyst 100, 529-39.

RADECKI, A., LAMPARCZYK, H., GRZYBOWSKI, J. and HALKIEWICZ, J. (1978). Separation of polycyclic aromatic hydrocarbons and determination of benzo(a)pyrene in liquid smoke preparations. J. Chromatogr. 150, 527-32.

SAUERLAND, H.-D., STADELHOFER, J., THOMS, R. and ZANDER, M. (1977). Neueres aus der Analytik der mehrheringen Aromaten. Erdöl, Kohle 30, 215-18.

SAWICKI, E. (1969). Fluorescense analysis in air pollution research Talanta 16, 1231-66.

SCHAAD, R.E. (1970). Chromatographic (karzinogener) polyzyklischer aromatischer Kohlenwasserstoffe. Chromatogr. Rev. 13, 61-82.

SEIFERT, B. and STEINBACH, I. (1977). Dünnschicht-chromatographische Routinebestimmung von Benzo(a)pyrene im Schwebstaub mit "in situ"-Auswertung. Fresenius Z. Anal. Chem. 287, 264-70.

SLAVIN, W., WILLIAMS, A.T.R. and ADAMS, R.F. (1977). A fluorescence detector for high pressure liquid chromatography. J. Chromatogr. 134, 121-30.

SMITH, R.N. and VAUGHAN, C.G. (1976). High-pressure liquid chromatography of cannabis. Quantitative analysis of acidic and neutral cannabinoids. J. Chromatogr. 129, 347-54.

THOMS, R. and ZANDER, M. (1977). Hochdruck-Flüssigkeitschromatographie von polycyclischen Aromaten. Eine Überblick. Erdöl, Kohle, 403-5.

WHEALS, B.B., VAUGHAN, C.G. and WHITEHOUSE, M.J. (1975). Use of chemically modified microparticulate silica and selective fluorimetric detection for the analysis of polynuclear hydrocarbons by high-pressure liquid chromatography. J. Chromatogr. 106, 109-18.

WINKLER, E., BUCHELE, A. and MÜLLER, O. (1977). Verfahren zur Bestimmung des Gehaltes an polycyclischen aromatischen Kohlenwasserstoffen in Mais mit Hilfe der Kapillargaschromatographie. J. Chromatogr. 138, 151-64.

WISE, S.A., CHESLER, S.N., HERTZ, H.S., HILPERT, L.R. and MAY, W.E. (1977). Chemically-bonded aminosilane stationary phase for the high-performance liquid chromatographic separation of polynuclear aromatic compounds. Anal. Chem. 49, 2306-10.

ZANDER, M. (1975). Analysis of polycyclic aromatics. Intern. J. Environ. Anal. Chem. 4, 109-23.

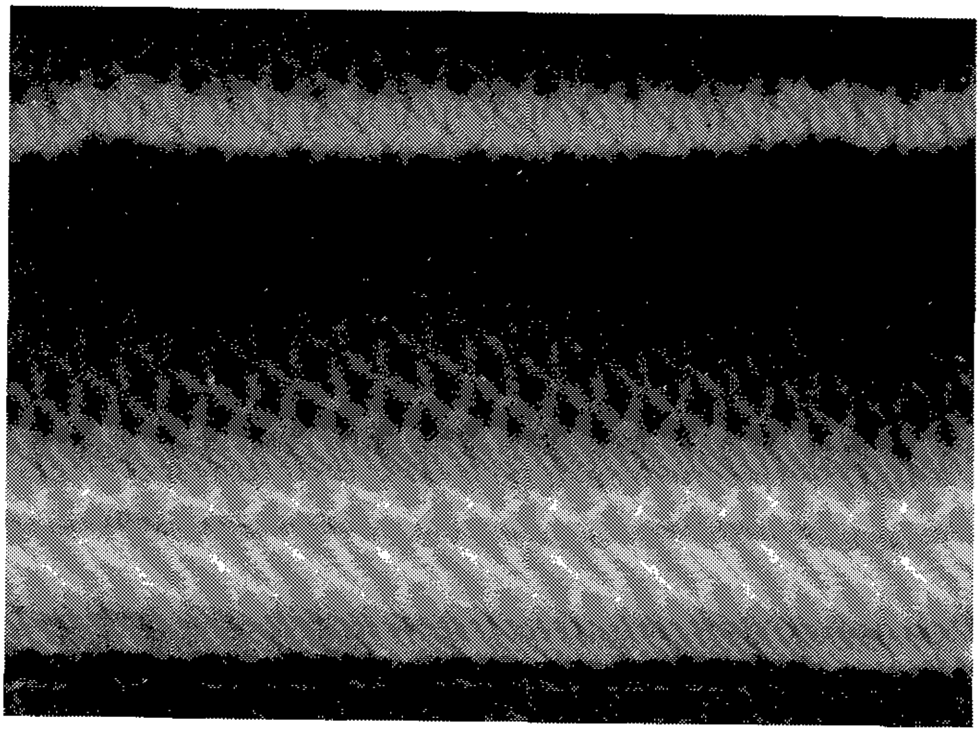
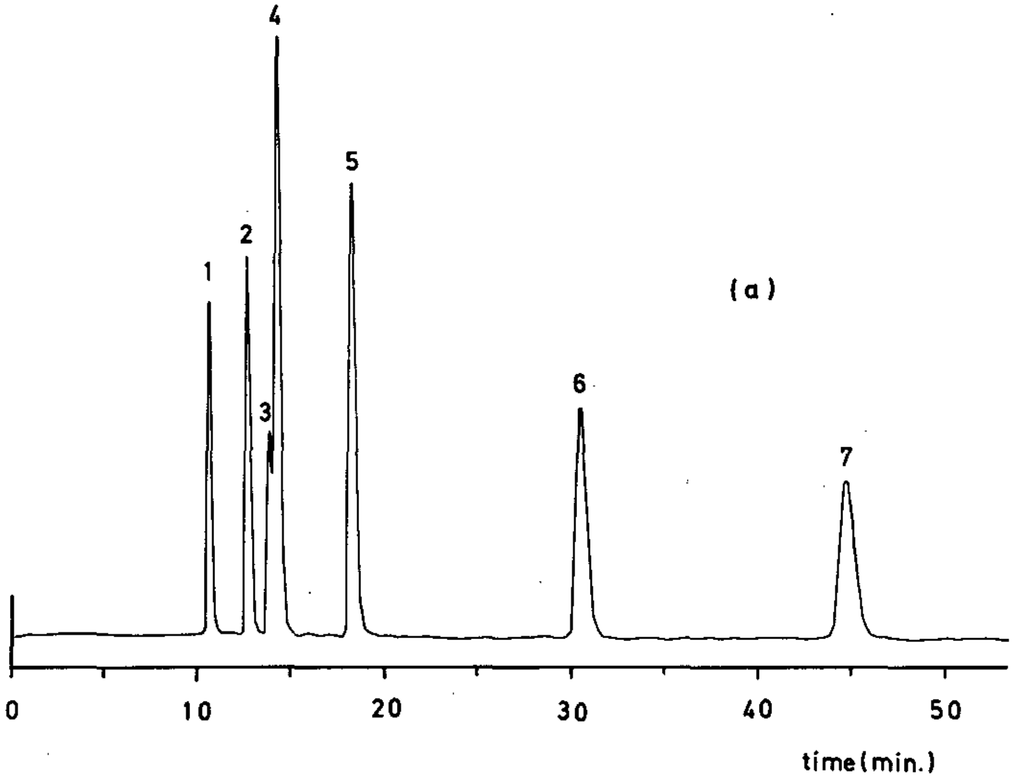
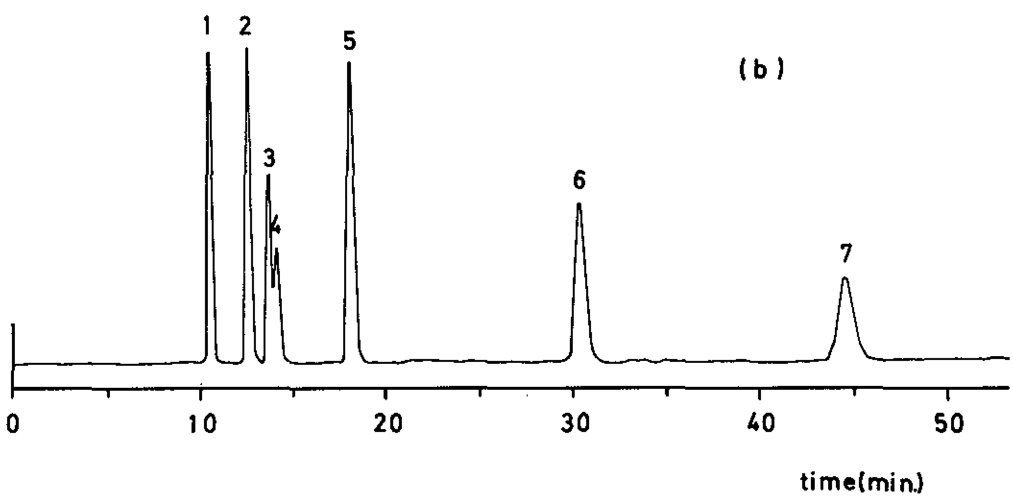


Fig. C.1. The separation of the PAHs from other fluorescent compounds with thin-layer chromatography. The upper band is the PAH-fraction. The figure is reduced to about 65%.



<u>Fig. C.2a</u>. Chromatogram of a standard PAH mixture at 340/425 nm. For the chromatographic conditions, see Table C.I. Identity of the peaks: 1. anthracene, 2. fluoranthene, 3. 1-methylanthracene, 4. pyrene, 5. benzo-(a)anthracene, 6. benzo(a)pyrene, 7. benzo-(ghi)perylene.



<u>Fig. C.2b</u>. The same as Fig. C.2a, only the solvent is not deoxygenated.

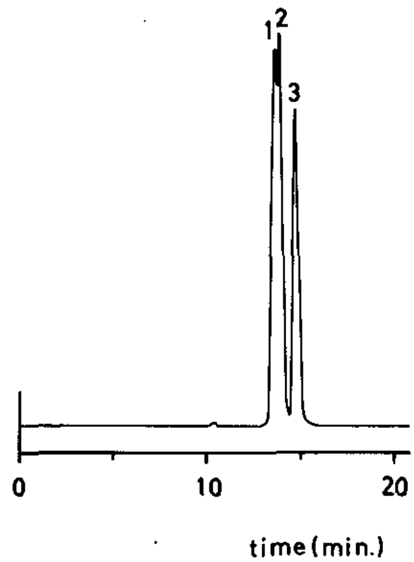


Fig. C.3. Chromatogram of the three methylanthracenes at 363/435 nm. For the chromatographic conditions, see Table C.I. Identity of the peaks: 1. 1-methyl, 2. 9-methyl, 3. 2-methylanthracene.

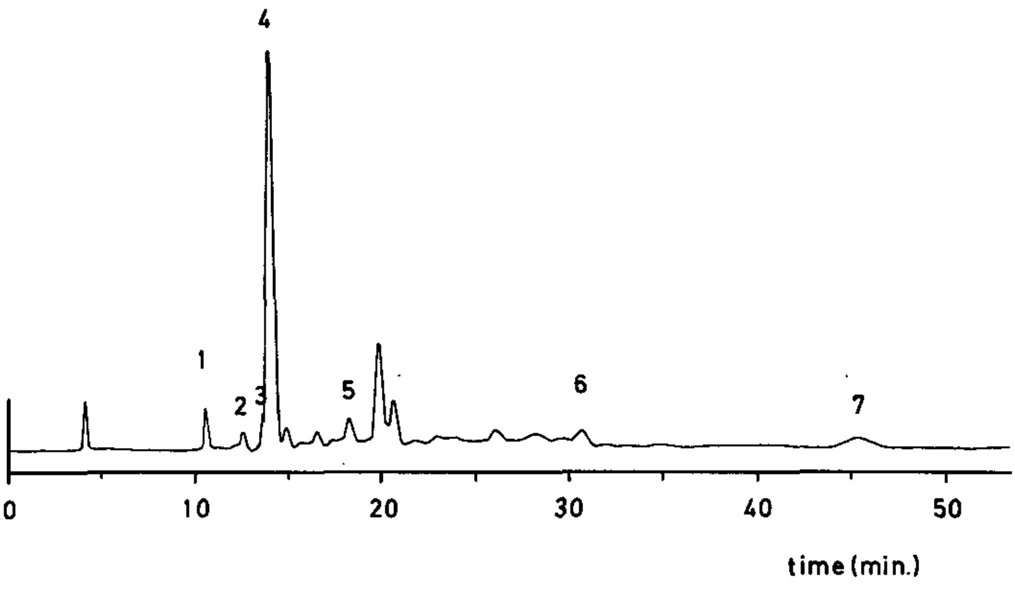


Fig. C.4. Chromatogram of a filter sample at 340/425 nm. For the chromatographis conditions, see Table C.I. Identity of the peaks: 1. anthracene, 2. fluoranthene, 3. 1-methylanthracene, 4. pyrene, 5. benzo(a)anthracene, 6. benzo-(a)pyrene, 7. benzo(ghi)perylene.

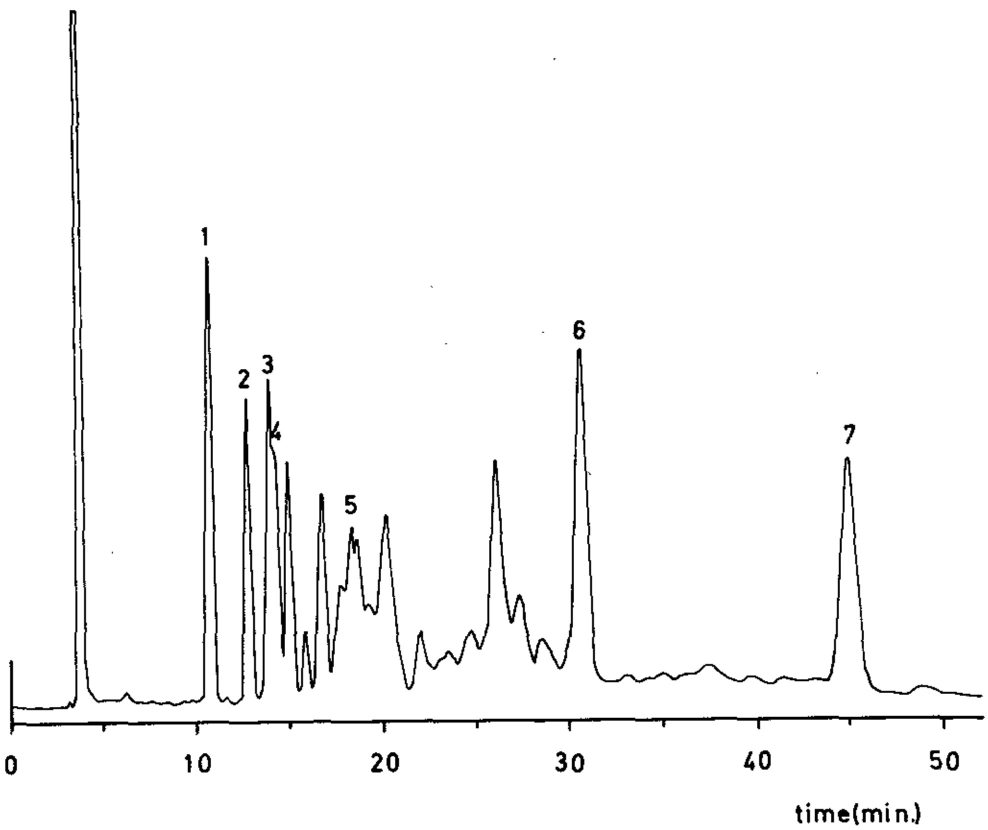


Fig. C.5. Chromatogram of a filter sample at 363/435 nm. For the chromatographic conditions, see Table C.I. Identity of the peaks: 1. anthracene, 2. fluoranthene, 3. 1-methylanthracene, 4. pyrene + 9-methylanthracene, 5. benzo(a)-anthracene, 6. benzo(a)pyrene, 7. benzo(ghi)-perylene.

Table C.I. Retention time and sensitivity data for polycyclic aromatic hydrocarbons. Pre-column, Nucleosil[R] 5 C_{18} 6 cm x 0.46 cm, main-column, Zorbax[TM] ODS 25 cm x 0.46 cm. Solvent, methanol: water, 8:1, at 1.0 ml/min. Pressure 1700 p.s.i. Temperature 21°C.

Compound	Relative retention time[(a)]	Detection limits[(b)] (ng)	
		340/425 nm	363/435 nm
phenanthrene	0.93	5	1000
anthracene	1.00	0.2	0.2
fluoranthene	1.20	0.6	0.4
1-methylanthracene	1.31	0.3	0.2
9-methylanthracene	1.34	0.2	0.2
pyrene	1.35	0.06	0.2
2-methylanthracene	1.42	0.4	0.4
2,3-benzofluorene	1.69	3	200
benzo(a)anthracene	1.75	0.3	0.7
chrysene	1.76	7	50
triphenylene	1.76	100	-
benzo(ghi)fluoranthene	1.78	0.3	0.7
9,10-dimethylanthracene	1.83	0.2	0.09
benzo(j)fluoranthene	2.2	> 2000	> 2000
benzo(e)pyrene	2.4	1	30
perylene	2.5	6	0.3
benzo(k)fluoranthene	2.6	0.2	0.2
benzo(a)pyrene	2.9	0.1	0.05
1,2,3,4-dibenzanthracene	3.1	2	10
1,2,5,6-dibenzanthracene	3.6	0.5	3
benzo(ghi)perylene	4.3	0.3	0.2
indeno(1,2,3-c,d)pyrene	4.6	20	-
coronene	5.7	40	50

[(a)] Anthracene about 11½ min.

[(b)] Considered to be the amount injected to give a peak with a height double that of the random baseline noise level.

Table C.II. The amounts of PAHs on a filter sample analyzed at different combinations of excitation and emission wavelengths.

Compound	Amount (µg)	
	340/425 nm	363/435 nm
anthracene	17.9	17.7
fluoranthene	14.9	15.1
1-methylanthracene	12	12.0
pyrene	20.5	-
benzo(a)anthracene	11.3	11.7
benzo(a)pyrene	2.7	2.3
benzo(ghi)perylene	1.6	1.5

Table C.III. Recovery test of three standard PAHs mixtures.

Compound	Amount (µg)	Recovery (%)				
		I	II	III	Mean	s.d.(%)
anthracene	6.59	83	93	81	86	7
fluoranthene	5.94	98	98	96	97	1
1-methylanthracene	8.82	90	97	87	91	6
pyrene	2.18	98	102	98	99	2
benzo(a)anthracene	15.38	100	99	98	99	1
benzo(a)pyrene	1.15	102	97	96	98	4
benzo(ghi)perylene	6.21	100	101	99	100	1

Table C.IVa. The repeatability of the analysis of the PAHs in 2 equivalent cyclohexane extracts of a filter.

Compound	Amount (μg)			
	I	II	Mean	s.d.(%)
anthrancene	2.71	2.65	2.68	2.0
fluoranthene	2.76	2.77	2.77	0.3
1-methylanthracene	1.53	1.42	1.48	6.6
pyrene	4.47	4.43	4.45	0.8
benzo(a)anthracene	2.27	2.30	2.29	1.2
benzo(a)pyrene	0.34	0.35	0.35	2.6
benzo(ghi)perylene	0.83	0.79	0.81	4.4
			Mean	3%

Table C.IVb. The repeatability of the analysis of the PAHs in 3 equivalent cyclohexane extracts of a cyclone.

Compound	Amount (μg)				
	I	II	III	Mean	s.d.(%)
anthracene	0.35	0.30	0.33	0.33	9
fluoranthene	0.45	0.44	0.44	0.44	1
1-methylanthracene	0.22	0.19	0.21	0.21	9
pyrene	0.61	0.61	0.63	0.62	2
benzo(a)anthracene	0.38	0.35	0.35	0.36	5
benzo(a)pyrene	0.026	0.025	0.024	0.025	5
benzo(ghi)perylene	0.098	0.084	0.093	0.092	9
				Mean	6%

Table C.V. The variation coefficients for a triplicate determination of the PAHs in a filter extract. The determinations were performed on three different days.

Compound	Amount (μg) I	II	III	Mean	s.d.(%)
anthracene	12.8	13.0	12.0	12.6	4.7
fluoranthene	30.3	30.4	30.9	30.5	1.2
pyrene	95.5	96.3	98.7	96.8	2.0
benzo(a)anthracene	9.8	9.4	8.8	9.3	6.3
benzo(a)pyrene	4.20	4.21	4.30	4.2	1.4
benzo(ghi)perylene	12.3	12.2	12.4	12.3	1.0
				Mean of s.d.	3%

Table C.VI. The overall reproducibility of the engine conditions, the collection of particle-bonded PAHs on the filter, and the chemical analysis. All values are standard deviations in percent. They may be slightly too high because of differences in PAH content of the lubricant. The column numbers refer to Appendix D.

	10-3 14-3 A,B	17-3 A,B	24-4 & 25-4 B	27-4 A,B	8-5 A,B	10-5 A,B	11-5 A,B	19-5 A,B	Mean
anthracene	3	13	27	0.4	27	25	0.2	1.3	12
fluoranthene	10	15	23	0.8	30	13	0.7	0.0	12
1-methylanthracene	-	-	25	2	40	9	14	0.7	15
pyrene	16	9	30	0.5	34	1.0	8	0.8	12
benzo(a)anthracene	12	5	25	3	15	15	13	0.8	11
benzo(a)pyrene	3	10	18	33	19	22	0.0	7	14
benzo(ghi)perylene	1.1	11	17	8	13	13	1	4	9
Mean	8	11	24	7	25	14	5	2	12

Table C.VII. The overall reproducibility of the engine conditions, the collection of particle-bonded PAHs in the cyclone, and the chemical analysis. All values are standard deviations in per cent. They may be slightly too high because of differences in PAH content of the lubricant. The column numbers refer to Appendix D.

Compound	10-3 14-3 A,B	17-3 A,B	24-4 & 25-4 B	27-4 A,B	8-5 A,B	9-5 A,B	10-5 A,B	11-5 A,B	19-5 A,B	Mean
anthracene	13	17	107	48	12	14	38	23	40	35
fluoranthene	8	5	95	39	0.9	3	16	25	18	23
1-methylanthracene	-	0	85	35	4	6	30	18	27	26
pyrene	15	17	83	15	8	6	13	21	24	22
benzo(a)anthracene	18	11	118	15	12	1.7	11	15	20	25
benzo(a)pyrene	12	7	83	5	8	3	3	19	6	16
benzo(ghi)perylene	8	20	21	0	53	6	13	84	9	24
Mean	12	11	85	22	14	6	18	29	21	24

APPENDIX D

Details of experimental results, fuel and lubricant data

Contents: Page

General Remarks

This appendix contains the detailed results of the experimental investigation and detailed information regarding the experimental fuels and lubricants used for the investigation.

Experimental results

The detailed experimental results are given in the form of data sheets each corresponding to a single measurement. Each such data sheet contains information regarding engine condition, type of fuel and lubricant, gaseous emissions and the results of the analysis of filter and cyclone collected PAHs. Details of fuels and lubricant composition do not appear on these sheets, but are referred to on the sheets or will have to be found in the corresponding section of this appendix. Further details of engine condition etc. are given in Appendix A.

Since the information given on the sheets appear in a rather condensed form, an explanation of the symbols etc. used is given in the following (in order of appearance on the sheets).

Engine condition is indicated by the following parameters:

$\underline{P}$: engine power output
$\underline{N}$: corresponding engine revolution speed
$\underline{T}_{ex,m}$: exhaust gas temperature at engine exhaust manifold
$\underline{T}_{ex,t}$: exhaust gas temperature at dilution tunnel entrance
$\underline{M}_F$: rate of fuel flow to engine
$\underline{M}_A$: rate of intake air flow to engine
A/F-ratio: air/fuel-ratio
$\underline{T}_c$: temperature of engine coolant at exit
$\underline{P}_{amb}$: barometric pressure during the experiment
$\underline{T}_{amb}$: temperature of ambient air during the experiment
Hum.: relative humidity of ambient air

Fuel is specified by the following information:

Type: brief indication of fuel type, stating name of fuel (if this is one of the main fuels) or indicating mixtures of two main fuels. If doping is used, this will also be indicated.

g Pb/litre: indication of fuel tetraalkyllead content. Ratio between tetramethyllead (TML) and tetraethyllead (TEL) is always TML/TEL = 3/1, so that 0.4 g Pb/litre means 0.3 g lead as TML and 0.1 g lead as TEL.

vol.% aromates: indicates total fuel aromatic hydrocarbon content, calculated from blend component data and mixing ratio.
C_6: total benzene (C_6H_6) content on volume basis
C_7: total toluene (C_7H_8) content on volume basis
C_8: total content of o-xylene (C_8H_{10}) on volume basis
$C_9 + C_{10}$: total content of C_9 and C_{10} aromatic hydrocarbons (see table D.4 for composition).

BaP: total content of benzo(a)pyrene in fuel, normally calculated from the component data

Analysis on page: if the fuel used has been separately analyzed for PAHs, the results of this analysis will be found on the page indicated. If so, the BaP value stated is based on this analysis

Oil. This section specifies the lubricant used in the engine:

Type: indicates type of lubricant and doping, if applied.

Lubricant temp.: temperature of lubricant in engine sump.

BaP: total content of benzo(a)pyrene in the lubricant, if this has been analyzed. If so, the results of this analysis will be found on the page indicated.

Used xx hours before test: Normally, the lubricant is changed for each single measurement, so that the lubricant has only been used in the engine during conditioning (normally 4 hours). In some cases, however, the lubricant may have been used in the engine for a longer period.

Gaseous emissions. This section specifies the results of the emission measurements, performed at undiluted samples of exhaust gas, sampled in the exhaust manifold, close to the exhaust pipe. Furthermore, results of measurements of "PNA-emission" using the on-line UV-fluorescence equipment, are given in terms of output voltage.

CO: carbon monoxide-concentration (Non Dispersive Infra Red measurements = NDIR).

HC(NDIR): concentration of unburned hydrocarbons as hexane-equivalent, determined by the NDIR-method.

NO_x: concentration of nitrogen oxides ($NO+NO_2$), determined by the chemiluminescense-method.

CO_2: concentration of carbon dioxide (NDIR measurements).

HC(FID): concentration of unburned hydrocarbons as C_1 equivalent, determined by Flame Ionization Detector.

O_2: oxygen concentration (paramagnetic method).

PNA (UV-reading): output from on-line UV fluorescence PNA-detector, monitoring content of polynuclear aromates (PNA) in the exhaust gas.

Particulate/PAH-emissions. This section contains details of the filter and cyclone sampling of particulate matter and the results of the subsequent analysis for 7 different polycyclic aromatic hydrocarbons (PAH).

Sampling data: Rate: flow rate through isokinetic probe and cyclone-battery/filter during sampling.
Volume: the total volume of diluted exhaust gas drawn through cyclones and filter. Temp.: temperature of diluted exhaust gas in the sampling equipment.

Dilution ratio: ratio between diluted gas flow and exhaust gas flow, equal to ratio between NO_x-concentration in exhaust gas and diluted gas.

Particulate matter on filter: this is the amount of particulate matter collected on the filter, i.e. the amount of particles smaller than 1 µm, determined from before/after measurements of filter weight.

Diagram: shows a graphic representation of the results of the analysis for the 7 PAHs collected with particles on the filtre and in the cyclones. The diagram for each PAH shows the amount on the filtre and in the cyclones as a percentage of the corresponding amount in the reference condition (see table 3 in the main text). Thus, the diagram mainly shows deviations in PAH level and profile compared to the reference condition. The mean relative value ("Mean") and its standard deviation ("St.Dev.") is given in the right side of the diagram.

Filter: total amount of each PAH on particles collected on the filter, in µg/test.

Cyclones: total amount of each species on particles collected in the cyclones, in µg/test.

Sum: the sum of the two aforementioned amounts of each PAH on filter and in cyclones, in µg/test.

% Filter: The fraction "Filter"/"Sum" expressed in per cent.

Research fuels

A number of different fuels have been used during the investigation, including a commercial petrol of 99 RON. This fuel was only used for running in the engine and for some preliminary experiments on the analytical technique. An analysis of the PAH-content of this fuel was carried out (see table D.1).

Except for the 99 RON-fuel, the research fuels were produced exclusively for the present investigation by the BP Research Centre Blending Unit at Sunbury, England, who also supplied the fuel specifications given. All fuels have a (nominal) octane rating of 97 RON, corresponding to the engine demand as specified by the engine manufacturer, and the lead-content (if any) composed by 75 percent (by weight) of lead as tetramethyllead (TML) and 25 percent (by weight) of lead as tetraethyllead (TEL). The fuels can be divided into: DTH Base Fuel, DTH Base Fuel A and DTH Test Fuels. These are described in the following.

DTH Base Fuel contained 0.4 g Pb/litre (i.e. 0.3 g Pb/litre as TML and 0.1 g Pb/litre as TEL). The aromatic hydrocarbon content of this fuel (36 percent by volume) was obtained by using a catalytic reformate (77 percent by volume), the rest of the fuel (23 percent by volume) being butanes (4 percent) and a n-heptane/isooctane blend, with the n-heptane/isooctane-ratio adjusted to give an octane rating of the fuel of 97 RON. For time-reasons this fuel was used for the long-term engine stabilization test and for some of the preliminary experiments. Due to the high proportion of non-aromatic hydrocarbons in the catalytic reformate (39 percent), this was found not to be flexible enough especially for the test fuels.

DTH Base Fuel was characterized by the following specifications (Sunbury Reference No. W77/1345) (see also table D.1. for PAH-content):

Blend composition:

Butanes	4% vol.
Isooctane (>99.9 %wt. purity)	8% vol.
n-heptane (>99.9 %wt. purity)	11% vol.
97 RON Catalytic Reformate W77/506	77% vol.
Density at 20°C	0.753 kg/l

Distillation

Initial Boiling Point	32.0°C
10% volume recovered at	62.5°C
40% volume recovered at	98.0°C
95% volume recovered at	162.0°C
Final Boiling Point	178.0°C
Recovery	98.0% vol.
Residue	0.9% vol.
Loss	1.1% vol.
Recovered at 70°C	15.0% vol.
Recovered at 100°C	42.5% vol.
Recovered at 140°C	83.5% vol.
Reid Vapour Pressure	0.58 bar
TEL content	0.10 g Pb/l
TML content	0.30 g Pb/l

FIA Analysis/Calculated from component data

Aromatics	36.0/40.0% vol.
Olefins	0.0/0.0% vol.
Saturates	64.0/60.0% vol.

Octane Ratings

Research Method	96.5
Motor Method	89.5
Sensitivity	7.0
RON(100°C)	82.3

Summary of GLC data for 97 RON Catalytic Reformate (Sunbury Reference No. W77/506):

Benzene	4.4% wt.
Toluene	18.7% wt.
Ethylbenzene	3.6% wt.
Xylenes	20.9% wt.
C_9-aromatics	11.9% wt.
C_{10}-aromatics	2.0% wt.
Total aromatics	61.4% wt.
Olefins	0.6% wt.
Saturates	37.9% wt.

<u>DTH Base Fuel A</u> contained 0.4 g Pb/litre. The aromatics hydrocarbon fraction of this fuel was obtained by blending benzene, toluene, <u>o</u>-xylene and a fixed blend of C_9 and C_{10} aromatic hydrocarbons. The relative proportions of the four blending components were chosen as $C_6/C_7/C_8/C_9+C_{10}$ = 8/30/40/22, which was close to the corresponding amounts in the aromatic fraction of the catalytic reformate of DTH Base Fuel. 40 percent (by volume) of the aromatic blend was mixed with 60 percent n-heptane/isooctane-blend, the latter adjusted to yield an octane rating of 97 RON after the addition of 0.4 g Pb/litre.

DTH Base Fuel A was characterized by the following specifications (Sunbury Reference No. W78/33) (see also table D.1 for PAH-content):

<u>Blend composition</u>

Isooctane	43.75% vol.
n-Heptane	16.25% vol.
Benzene	3.2% vol.
Toluene	12.0% vol.
o-Xylene	16.0% vol.
C_9+C_{10} aromatic blend*	8.8% vol.
Density at 20°C	0.764 kg/litre

*: heavy aromatic discards. For composition, see table D.4 (Sunbury Reference No. W77/1757).

FIA Analysis

Aromatics	38.1% vol.
Olefins	0.2% vol.
Saturates	61.7% vol.
Nominal lead content as TML	0.3 g Pb/l
Nominal lead content as TEL	0.1 g Pb/l
Determined lead content	0.38 g Pb/l
Research octane number	97.8

DTH Base Fuel A was also used, doped with benzo(a)pyrene in order to study the effects of fuel PAH-content. The doped fuel only deviated from the specifications given above and in table D.1 as regards BP content. Table D.2 shows the analysis of PAH-content for the doped fuel.

DTH Test Fuels were subdivided into 3 groups:

1) A1 - A6, that deviated from DTH Base Fuel A in amount or type of aromatic content. DTH Test Fuel A1 contained 60 percent (by volume) of the same aromatic blend as DTH Base Fuel A, while DTH Test Fuel A2 contained no aromatics (i.e. a pure n-heptane/isooctane-blend with 0.4 g Pb/l); DTH Test Fuel A3 contained 40 percent benzene as the aromatic fraction, while for DTH Test Fuel A4 this was toluene, for DTH Test Fuel A5 o-xylene and for DTH Test Fuel A6 this was the C_9+C_{10} aromatic blend (table D.4).

2) Pb1 and Pb2, that deviated from DTH Base Fuel A in lead content. DTH Test Fuel Pb1 contained no lead, DTH Test Fuel Pb2 contained 0.8 g Pb/l.

3) C1 and C2, that deviated from DTH Base Fuel A in lead content and amount of aromatics. DTH Test Fuel C1 contained 60 percent (by volume) of the same aromatic mixture as DTH Base Fuel A, but no lead, while DTH Test Fuel C2 contained only 20 percent aromatics, but 0.8 g Pb/l.

These fuels were used for the variation of fuel parameters, since it was possible to vary the aromate content of the fuel by using different mixtures of A1 and A2, to vary the type of aromatics by using A3, A4, A5 and A6 and to vary the lead content by using different mixtures of Pb1 and Pb2. Finally, a combined variation of lead and aromatic content was performed by using different mixtures of C1 and C2.

Since normally only one single measurement was performed with each of the mentioned Test Fuels or each specific mixture of these, no detailed specification will be given for the blends used (a total of 20 different fuels). However, the data sheet for each measurement contains the information necessary for the calculation of the most important specifications, based on the information given in tables D.1, D.2, D.3 and D.4.

Lubricants

For all experiments (except two measurements), a commercial multigrade lubricating oil was used. Among the different possible lubricants, a SAE 15w-50 lubricating oil was chosen, because this is likely to become a fairly typical lubricant in Europe in the future. For the actual lubricant, the following specifications were given:

Name: BP Visco 2000 Sport, SAE 15w-50 engine oil.
Fulfill API SE/CC specifications.

Sulfated Ash	0.55% wt.
Zinc content	0.12% wt.
Magnesium content	0.073% wt.
Phosphorous content	0.11% wt.
Density at 15°C	0.888 kg/l
Flash Point (PMC)	210°C
Pour Point	-33°C
Viscosity at 50°C	82 cSt
Viscosity index (ASTM D 2270)	190

A number of PAH-analyses were carried out on samples of this lubricant. Before being used in the engine, the PAH content was very low (see table D.5), while during the use in the engine, the PAH content increased with time of use. Table D.5 also shows the PAH content of a sample of this lubricant, doped with benzo(a)-pyrene.

To investigate the effects of lubricant chemical structure, a synthetic lubricant was used for a few measurements. This was the BP Enerjet 523, a lubricant developed specially for the Olympus 593 turbojet engine used in the supersonic Concorde air-plane. Enerjet 523 is an advanced high-temperature lubricant, based on "hindered" esters. Table D.6 contain the product specification of Enerjet 523. Further details can be found in Byford and Edgington (1971) and Errington (1972).

REFERENCES

BYFORD, D.C. and EDGINGTON, P.G. (1971). The development of special oils for the power plants of supersonic transport 8'th World Petroleum Conference, Moscow, June 1971.

DORAN, T. and McTAGGART, N.G. (1974). The combined use of high efficiency liquid and capillary gas chromatography for the determination of polycyclic aromatic hydrocarbons in automotive exhaust condensates and other hydrocarbon mixtures. Journal of Chromatographic Science, 12, 715-721.

ERRINGTON, G. (1972). 523: Events leading to the development of BP Enerjet 523 - an advanced high-temperature synthetic lubricant. Air BP, No. 55, 2-7.

Table D.1. Results of PAH analysis of DTH Base Fuel, DTH Base Fuel A and the components used in DTH Base Fuel A and DTH Test Fuels. Analysis performed by BP Research Centre, Sunbury; method described by Doran and McTaggart (1974).

Sunbury Reference No. Units: ppm (wt.)	W78/189 Toluene	W78/190 n-Heptane	W78/191 Benzene	W78/192 Isooctane	W78/193 C_9+C_{10}-aromatic	W78/194 O-Xylene	W77/1345 DTH Base Fuel	W78/33 DTH Base Fuel A
Fluoranthene		0.006		0.008	7.20		2.67	1.47
Pyrene		0.017	<0.001	0.033	15.60		12.61	3.10
1,2,Benzofluorene		0.004		0.024	3.85	0.002	0.92	0.49
3,4,Benzofluorene		0.004			1.56		0.91	0.55
Benz(a)anthracene		<0.001					0.46	0.16
Chrysene	0.002	0.006	<0.001	0.009	4.36	<0.001	1.39	0.49
Benzo(a)fluoranthene		0.003		0.003	4.24		1.07	0.60
Benzo(e)pyrene		0.002		0.003	3.39		1.42	0.51
Benzo(a)pyrene					1.37		0.47	0.14
Perylene					0.02		<0.01	0.02
Dibenzo(ah)perylene					0.43			
Benzo(ghi)perylene					4.55		2.08	0.36

Table D.2. Resulta of PAH analysis of fuels, performed at Risø National Laboratory.
Units: µg per ml fuel

Fuel: / Compound:	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene
Commercial 99 RON	1.84	2.54		4.81	1.12	0.31	0.87
DTH Base Fuel 8-3	1.58	2.73		12.5		0.39	1.31
DTH Base Fuel 29-3	1.53	2.86	0.69	12.9	0.65	0.36	1.23
DTH Base Fuel A	0.87	1.81	0.50	3.09	0.28	0.12	0.38
DTH Base Fuel A dop.	1.18	2.22	0.56	3.16	0.33	2.81	0.50
DTH Test Fuel A2	0.014	0.035	0.009	0.099	0.017	0.003	0.004
DTH Test Fuel A3	0.012	0.020	0.007	0.044	0.012	0.004	0.007
DTH Test Fuel A4	0.009	0.013	0.003	0.030	<0.004	0.002	0.003
DTH Test Fuel A5	0.029	0.008	<0.003	0.024	0.005	0.0008	<0.003
DTH Test Fuel C2	0.37	0.78	0.21	1.50	0.12	0.046	0.16
DTH Test Fuel Pb2	0.84	1.76	0.47	3.39	0.31	0.11	0.38

Table D.3. Limited inspection data and blend composition of DTH Test Fuels. Data supplied by BP Research Centre, Sunbury.

DTH Test Fuel No.: Sunbury Reference No. W78/	A1 131	A2 114	A3 115	A4 116	A5 136	A6 117	Pb1 132	Pb2 139	C1 140	C2 141
Blend composition:										
Isooctane %vol	20.0	87.0	45.0	40.0	50.0	38.0	51.0	38.0	25.0	60.0
n-Heptane %vol	20.0	13.0	15.0	20.0	10.0	22.0	9.0	22.0	15.0	20.0
Benzene %vol	4.8	0.0	40.0	0.0	0.0	0.0	3.2	3.2	4.8	1.6
Toluene %vol	18.0	0.0	0.0	40.0	0.0	0.0	12.0	12.0	18.0	6.0
o-Xylene %vol	24.0	0.0	0.0	0.0	40.0	0.0	16.0	16.0	24.0	8.0
C_9+C_{10} aromatic fraction %vol	13.2	0.0	0.0	0.0	0.0	40.0	8.8	8.8	13.2	4.4
Density at 20°C kg/litre	.800	.689	.763	.758	.769	.765	.764	.763	.799	.726
FIA Analysis:										
Aromatics %vol	58.7	-	39.9	37.9	39.2	38.9	39.0	38.7	58.7	19.0
Olefins %vol	0.2	-	0.2	0.2	-	0.2	0.2	0.2	0.2	-
Saturates %vol	41.1	100.	59.9	61.9	60.8	60.9	60.8	61.1	41.1	81.0
Calculated TML content g Pb/l	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.6	0.0	0.6
Calculated TEL content g Pb/l	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.2
Determined lead content gPb/l	0.41	0.39	0.39	0.38	0.38	0.41	<0.01	0.80	<0.01	0.82
Research octane number RON	97.0	97.2	98.2	97.5	98.2	97.9	97.3	97.2	97.0	97.1

Table D.4. Analysis of C_9+C_{10} aromatic fraction (blend component). GLC-analysis performed by BP Research Centre, Sunbury. (Sunbury Reference No. W77/1757).

Compound	% wt.
Paraffins+Naphtenes+Olefins	0.14
Benzene	0.04
Isopropylbenzene	0.27
o-Xylene	0.07
n-Propylbenzene	5.44
1-Methyl-3-ethylbenzene 1-Methyl-4-ethylbenzene	30.74
Isobutylbenzene	0.15
1,3,5-Trimethylbenzene	10.81
1-Methyl-2-ethylbenzene	7.24
1,2,4-Trimethylbenzene	30.73
1,4-Diethylbenzene 1-Methyl-2-iso-propylbenzene 1-Methyl-3-*n*-propylbenzene	1.31
1-Methyl-4-*n*-propylbenzene	0.38
1,3-Diethylbenzene	0.16
n-Butylbenzene	0.22
1,3-Dimethyl-5-ethylbenzene	1.09
1-Methyl-2-*n*-propylbenzene 1,2,3-Trimethylbenzene	5.65
1,4-Dimethyl-2-ethylbenzene	0.61
1,3-Dimethyl-4-ethylbenzene	0.61
1,2-Dimethyl-4-ethylbenzene	0.99
Indane	0.91
1,2-Dimethyl-3-ethylbenzene	0.19
1,2,4,5-Tetramethylbenzene	0.69
1,2,3,5-Tetramethylbenzene	0.94
1,2,3,4-Tetramethylbenzene	0.24
C_{11} Aromatic	0.38

Table D.5. Results of PAH analysis of lubricants, performed at Risø National Laboratory.

Units: µg per ml lubricant.

Lubricant:	Compound:	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene
BP Visco 2000 Sport	Unused	<0.4	0.9	-	1.1	-	0.08	0.3
	After 20 h	2.7	4.8	1.9	12.6	1.3	0.89	2.9
	After 30 h	3.6	7.1	2.9	24.4	1.8	1.2	4.6
	After 40 h	3.9	9.0	3.8	29.2	2.3	1.6	6.0
	After 60 h	6.6	13.8	5.8	62.0	4.9	2.7	11.6
	After 80 h	5.9	14.3	4.5	57.6	4.8	2.5	9.6
	After 110 h	8.1	26.3	7.9	91.1	12.7	3.8	15.5
	Doped with B(a)P	2.5	3.4	1.3	8.2	1.8	2.0	0.88
	8-6 Sample	2.2	5.7	1.7	14.7	1.5	0.7	1.5
Enerjet 523 (5 h).		3.0	4.0	1.0	3.4	2.0	0.38	1.20

Table D.6. Product specification of BP Enerjet 523. Data supplied by BP Research Center, Sunbury.

Test		Result	Limit	Method
Kinematic viscosity:				
at 210°F maximum	cSt	5.23	5.50	IP 71
at 100°F minimum	cSt	27.6	25.0	ASTM D445
at -40°F maximum	cSt	9709	13000	
Specific gravity 60°F/60°F		0.964	Report	IP 160 ASTM D1298
Pour point - maximum	°F	<-70	-65	IP 15 ASTM D97
Total acid No.	mgKOH/g	0.42	Report	IP 177 ASTM D664
Saponification value	mgKOH/g	321	Report	IP 136 ASTM D94
Sediment maximum	%wt	<0.005	0.005	-
Autogeneous ignition temperature - minimum	°F	743	734	ASTM D2155
Flash point - minimum	°F	425	410	IP 34 ASTM D93
Water content	ppm	250		
Foaming tendency:				IP 146 ASTM D892
(i) at 75°F - maximum	ml	10	25	
(ii) at 200°F - maximum	ml	20	25	
(iii) at 75°F after test at 200°F - maximum	ml	5	25	
Foam stability:				
(i) at 75°F - maximum	ml	nil	nil	
(ii) at 200°F - maximum	ml	nil	nil	
(iii) at 75°F after test at 200°F - maximum	ml	nil	nil	
Lucas lead corrosion test 8 hours at 150°C	mg/in^2	0.24	2.0	

MEASUREMENT NO. 7-4 Standard condition

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 160 C
	M_F: 2.44 kg/h	M_A: 35.7 kg/h	A/F-ratio: 14.63	
	T_C: 75 C	P_{amb}: 763 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12 %	C_8: 16 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

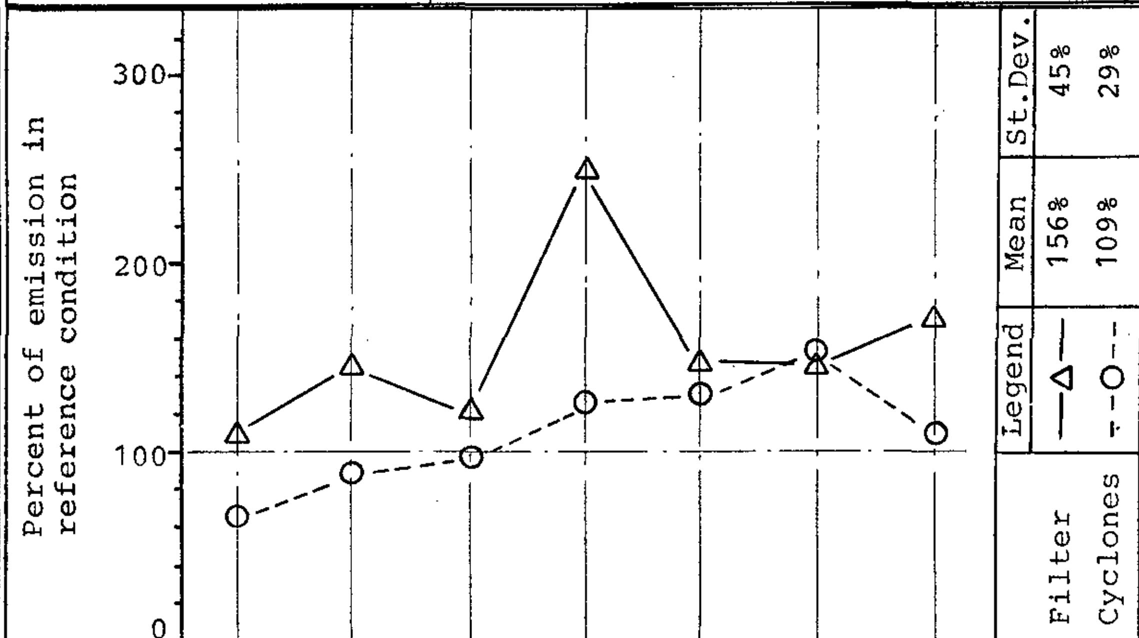
CO: 1.10 vol.%	HC(NDIR): 255 ppm C_6	NO_x: 1313 ppm
CO_2: 12.9 vol.%	HC(FID): 4000 ppm C_1	O_2: 1.55 vol.%

PNA (UV-reading): exhaust gas 3.0 mV. Reference 2.0 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.128 g



Amount of PAH collected	Anthracene	Fluoranthene	1-Methylanthracene	Pyrene	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(ghi)perylene	Unit
Filter	18.5	22.9	14.8	53.5	17.4	2.09	4.01	µg/test
Cyclones	0.91	1.79	1.03	3.11	1.90	0.11	0.17	µg/test
Sum	19.4	24.7	15.8	56.6	19.3	2.20	4.18	µg/test
%Filter	95	93	93	95	90	95	96	% of sum

MEASUREMENT NO. 28-4 Standard Condition

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 160 C
	M_F: 2.42 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.45	
	T_C: 75 C	P_{amb}: 754 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12 %	C_8: 16 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 84 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

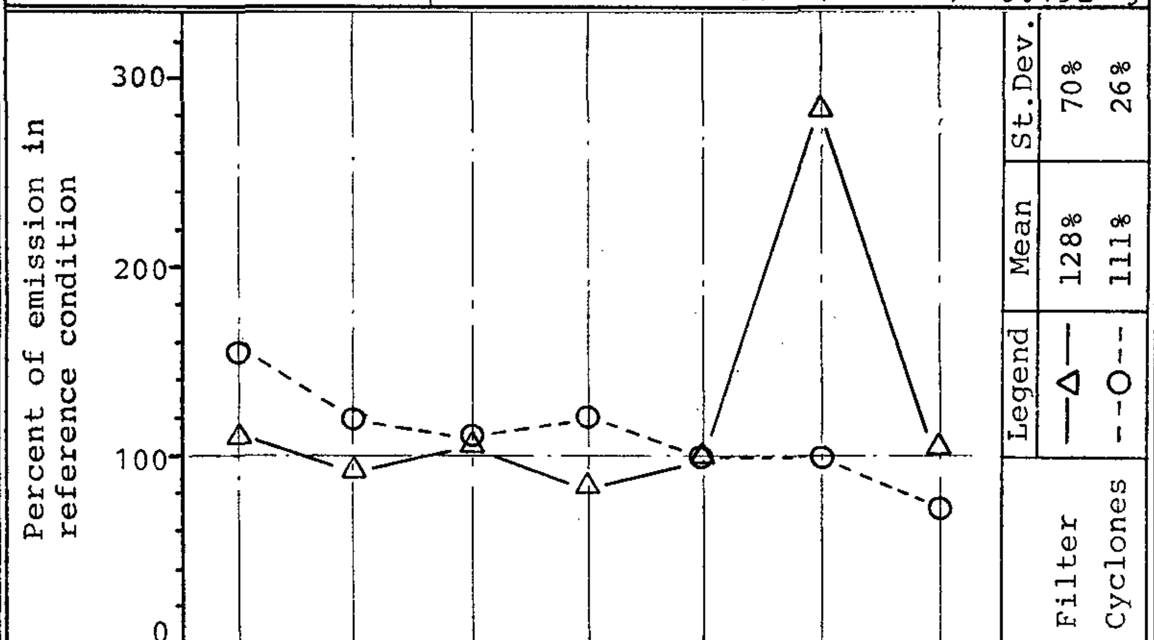
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.25 vol.%	HC(NDIR): 300 ppm C_6	NO_x: 1650 ppm
CO_2: 13.1 vol.%	HC(FID): 4600 ppm C_1	O_2: 1.40 vol.%
PNA (UV-reading): exhaust gas 2.4 mV. Reference 2.5 mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 32 C

Dilution ratio: 20 | Particulate matter (filter): 0.192 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	18.6	14.7	12.7	19.1	12.0	4.08	2.48	µg/test
Cyclones	2.16	2.39	1.16	2.98	1.49	0.072	0.11	µg/test
Sum	20.8	17.1	13.9	22.1	13.5	4.15	2.59	µg/test
%Filter	90	86	92	86	89	98	96	% of sum

MEASUREMENT NO. 19-5B Freeze trap experiment I

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 614 C	$T_{ex,t}$: 162 C
M_F: 2.47 kg/h	M_A: 35.14 kg/h	A/F-ratio: 14.23	
T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 25 C	Hum.: 28 % rel.

FUEL

Type: DTH Test Fuel Pb1 & Pb2 Mixture		0.4 g Pb/litre	
40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16 %
C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: -		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 85 C
BaP: - µg/ml. Analysis p.: -	Used 7 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

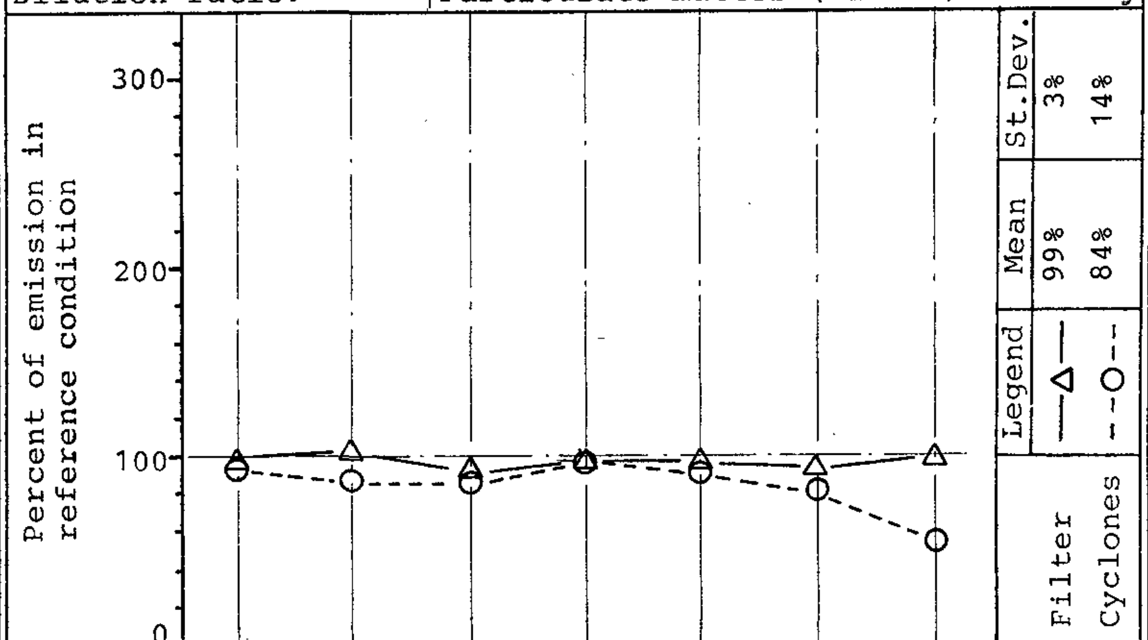
CO: 1.25 vol.%	HC(NDIR): 330 ppm C_6	NO_X: 1450 ppm
CO_2: 12.9 vol.%	HC(FID): 4700 ppm C_1	O_2: 1.35 vol.%

PNA (UV-reading): exhaust gas 1.1 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.199 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	16.4	16.2	11.6	21.7	11.8	1.37	2.36	µg/test
Cyclones	1.34	1.75	0.91	2.32	1.35	0.058	0.088	µg/test
Sum	17.7	18.0	12.5	24.0	13.2	1.43	2.44	µg/test
%Filter	92	90	93	90	88	96	97	% of sum

MEASUREMENT NO. 8-6 Freeze trap experiment II

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 158 C
	M_F: 2.48 kg/h	M_A: 35.26 kg/h	A/F-ratio: 14.22	
	T_C: 75 C	P_{amb}: 750.3 mmHg	T_{amb}: 26.5 C	Hum.: 46 % rel.
FUEL	Type: DTH Test Fuel Pb2			0.8 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 81 C	
	BaP: 0.70 µg/ml. Analysis p.: D.17		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

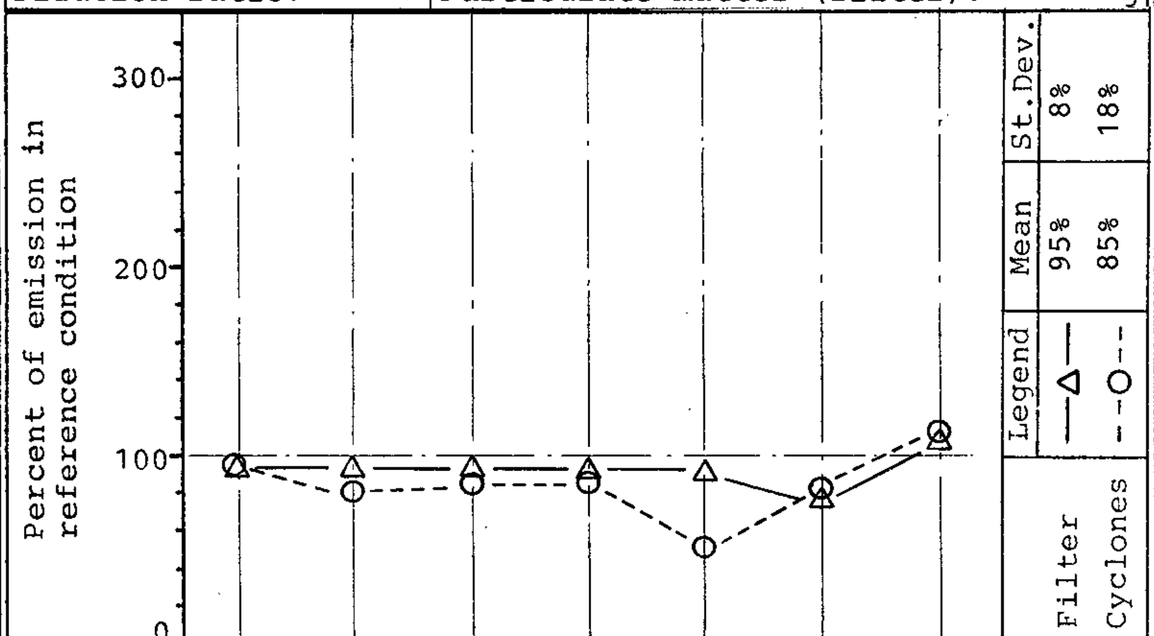
CO: 1.4 vol.%	HC(NDIR): 365 ppm C_6	NO_X: 1500 ppm
CO_2: 12.8 vol.%	HC(FID): 5400 ppm C_1	O_2: 1.3 vol.%

PNA (UV-reading): exhaust gas 4.5 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature - C

Dilution ratio: 20 | Particulate matter (filter): 0.217 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	16.1	14.9	11.4	20.8	11.0	1.15	2.58	µg/test
Cyclones	1.32	1.64	0.90	2.15	0.79	0.057	0.18	µg/test
Sum	17.4	16.5	12.3	23.0	11.8	1.21	2.76	µg/test
%Filter	92	90	93	91	93	95	93	% of sum

MEASUREMENT NO. 14-3A Reproducibility

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 600 C	$T_{ex,t}$: 160 C
	M_F: 2.42 kg/h	M_A: 34.4 kg/h	A/F-ratio: 14.19	
	T_c: 75 C	P_{amb}: 743 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			0.4 g Pb/litre
	40 vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: 2.54 µg/ml. Analysis p.: D17		Used 80 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

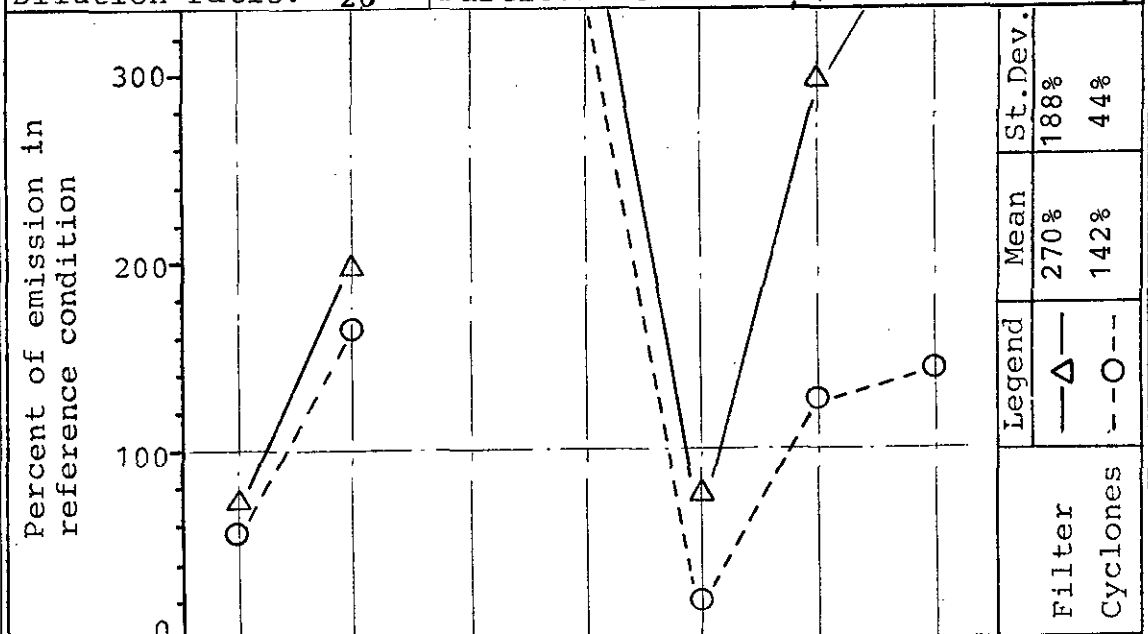
CO: - vol.%	HC(NDIR): - ppm C_6	NO_x: - ppm
CO_2: - vol.%	HC(FID): - ppm C_1	O_2: - vol.%

PNA (UV-reading): exhaust gas 23 mV. Reference 9.5 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 40 C

Dilution ratio: 20 | Particulate matter (filter): 0.224 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	12.6	30.5		96.9	9.30	4.24	12.3	µg/test
Cyclones	0.76	3.27		8.54	0.28	0.090	0.23	µg/test
Sum	13.4	33.8		105.4	9.58	4.33	12.5	µg/test
%Filter	94	90		92	97	98	98	% of sum

MEASUREMENT NO. 14-3B Reproducibility

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 604 C	$T_{ex,t}$: 161 C
	M_F: 2.46 kg/h	M_A: 34.5 kg/h	A/F-ratio: 14.00	
	T_c: 75 C	P_{amb}: 743 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			0.4 g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 82 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

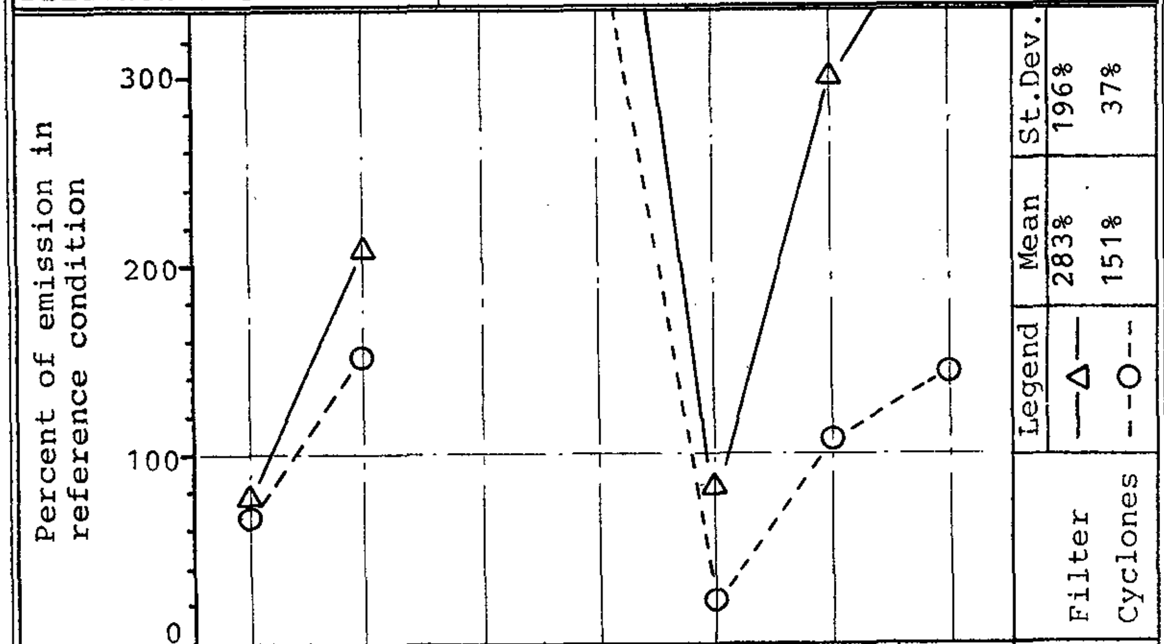
CO: - vol.%	HC(NDIR): - ppm C_6	NO_x: - ppm
CO_2: - vol.%	HC(FID): - ppm C_1	O_2: - vol.%

PNA (UV-reading): exhaust gas 21.5 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 40 C

Dilution ratio: 20 | Particulate matter (filter): 0.229 g



Amount of PAH collected	Anthracene	Fluoranthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	13.2	32.7		107.6	9.76	4.31	12.3	µg/test
Cyclones	0.95	3.05		10.2	0.38	0.076	0.23	µg/test
Sum	14.2	35.8		117.8	10.1	4.39	12.5	µg/test
%Filter	93	91		91	97	98	98	% of sum

MEASUREMENT NO. 17-3A Variation of dilution ratio

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 606 C	$T_{ex,t}$: 130 C
	M_F: 2.51 kg/h	M_A: 35.8 kg/h	A/F-ratio: 14.27	
	T_C: 75 C	P_{amb}: 743 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			0.4 g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 90 h before test	

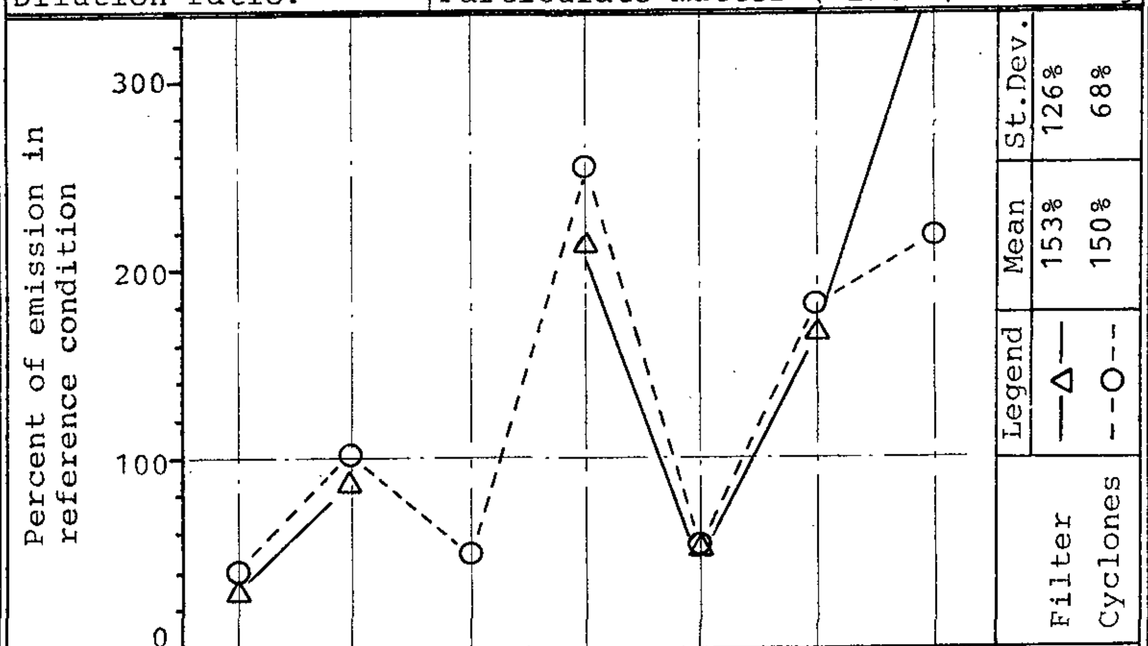
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.50 vol.%	HC (NDIR): 345 ppm C_6	NO_x: 1850 ppm
CO_2: 14.2 vol.%	HC (FID): 4400 ppm C_1	O_2: 1.38 vol.%
PNA (UV-reading): exhaust gas - mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 31 C

Dilution ratio: 25 | Particulate matter (filter): 0.113 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	5.11	13.3		45.9	6.37	2.40	8.71	µg/test
Cyclones	0.56	2.08	0.53	6.29	0.80	0.13	0.35	µg/test
Sum	5.67	15.4		52.2	7.17	2.53	9.06	µg/test
%Filter	90	86		88	89	95	96	% of sum

MEASUREMENT NO. 17-3B Variation of dilution ratio

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 130 C
	M_F: 2.51 kg/h	M_A: 35.8 kg/h	A/F-ratio: 14.27	
	T_C: 75 C	P_{amb}: 743 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			0.4 g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 93h before test	

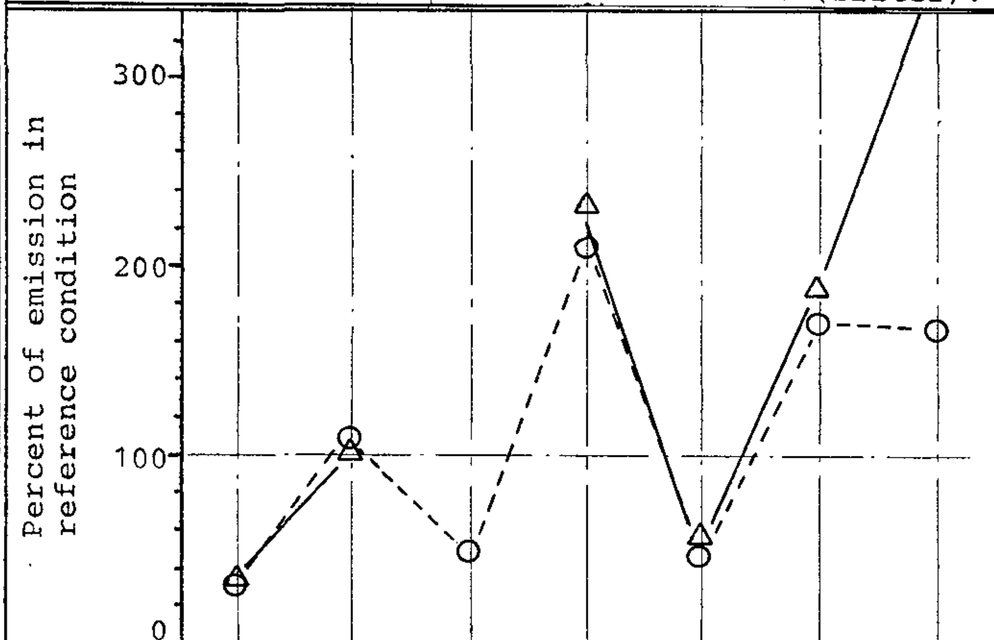
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.51 vol.%	HC(NDIR): 368 ppm C_6	NO_x: 1900 ppm
CO_2: 14.0 vol.%	HC(FID): 4600 ppm C_1	O_2: 1.38 vol.%
PNA (UV-reading): exhaust gas - mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 31 C

Dilution ratio: 25 | Particulate matter (filter): 0.109 g



	Filter	Cyclones
St.Dev.	142%	49%
Mean	172%	131%
Legend	—△—	--○--

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	5.89	15.7		50.6	6.74	2.70	9.83	µg/test
Cyclones	0.46	2.21	0.53	5.22	0.71	0.12	0.27	µg/test
Sum	6.35	17.9		55.8	7.45	2.82	10.1	µg/test
%Filter	93	88		91	90	96	97	% of sum

MEASUREMENT NO. 17-3C Variation of dilution ratio

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 130 C
	M_F: 2.51 kg/h	M_A: 35.8 kg/h	A/F-ratio: 14.27	
	T_C: 75 C	P_{amb}: 743 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			0.4 g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82C	
	BaP: - µg/ml. Analysis p.: -		Used 96 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

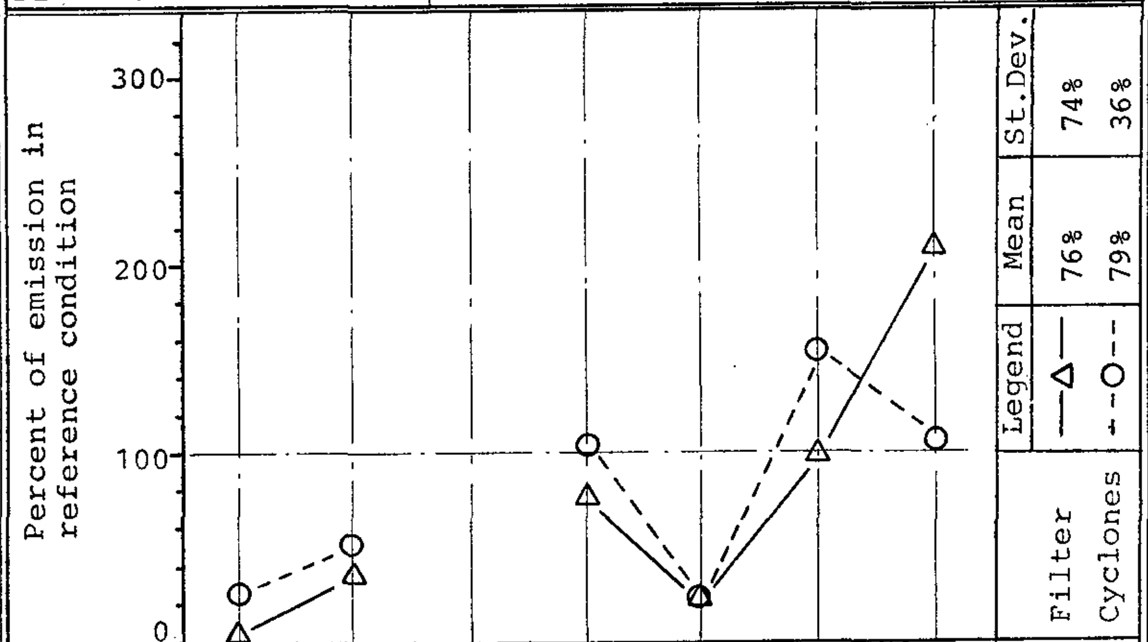
CO: 1.42 vol.%	HC(NDIR): 365 ppm C_6	NO_X: 1990 ppm
CO_2: 14.0 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.38 vol.%

PNA (UV-reading): exhaust gas - mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 28 C

Dilution ratio: 47 | Particulate matter (filter): 0.092 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	1.47	5.51		17.0	2.83	1.41	4.93	µg/test
Cyclones	0.38	1.04		2.69	0.43	0.11	0.17	µg/test
Sum	1.85	6.55		19.7	3.26	1.52	5.10	µg/test
%Filter	79	84		86	87	93	97	% of sum

MEASUREMENT NO. 28-2 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 602 C	$T_{ex,t}$: 162 C
	M_F: 2.49 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.11	
	T_C: 75 C	P_{amb}: 749 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: Commercial 99 RON			- g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.31 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82C	
	BaP: - µg/ml. Analysis p.: -		Used ½ h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

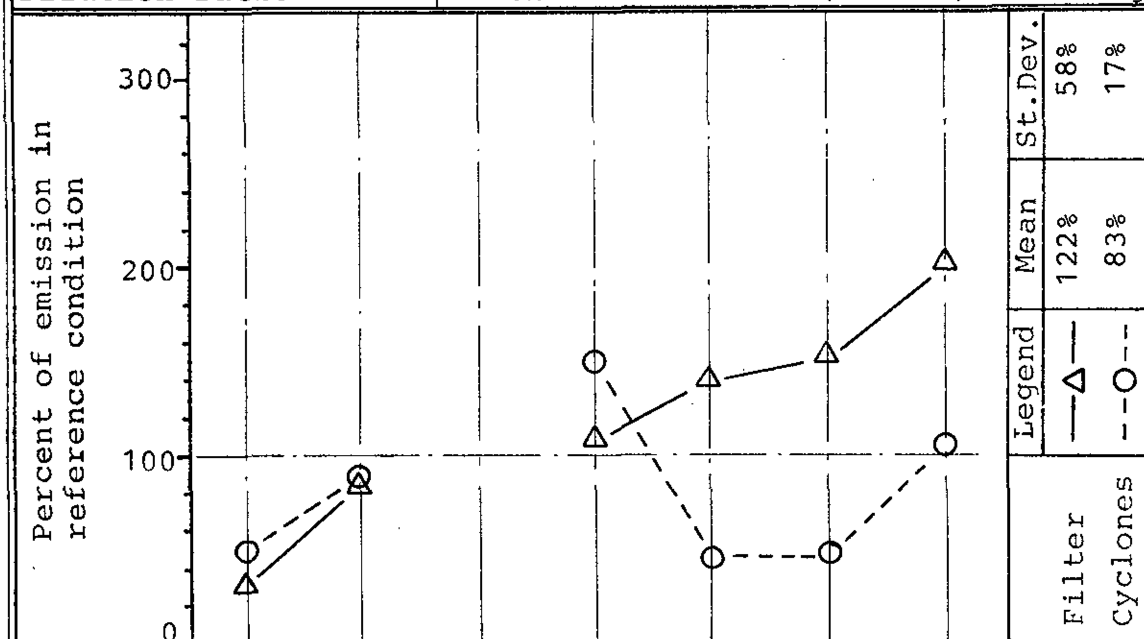
CO: 1.22 vol.%	HC(NDIR): 275 ppm C_6	NO_X: 1750 ppm
CO_2: 13.1 vol.%	HC(FID): 4200 ppm C_1	O_2: 1.45 vol.%

PNA (UV-reading): exhaust gas 7.4 mV. Reference 4 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 40 C

Dilution ratio: 20 Particulate matter (filter): 0.189 g



Amount of PAH collected	Anthracene	Fluoranthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	5.66	13.8		24.2	16.5	2.21	4.74	µg/test
Cyclones	0.71	1.85		3.73	0.72	0.034	0.17	µg/test
Sum	6.37	15.7		27.9	17.2	2.24	4.91	µg/test
%Filter	89	88		87	96	98	97	% of sum

MEASUREMENT NO. 2-3 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 603 C	$T_{ex,t}$: 161 C
	M_F: 2.46 kg/h	M_A: 35.17 kg/h	A/F-ratio: 14.3	
	T_C: 75 C	P_{amb}: 750.9 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: Commercial 99RON			- g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.31 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: 0.89 µg/ml. Analysis p.: D17		Used 20 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

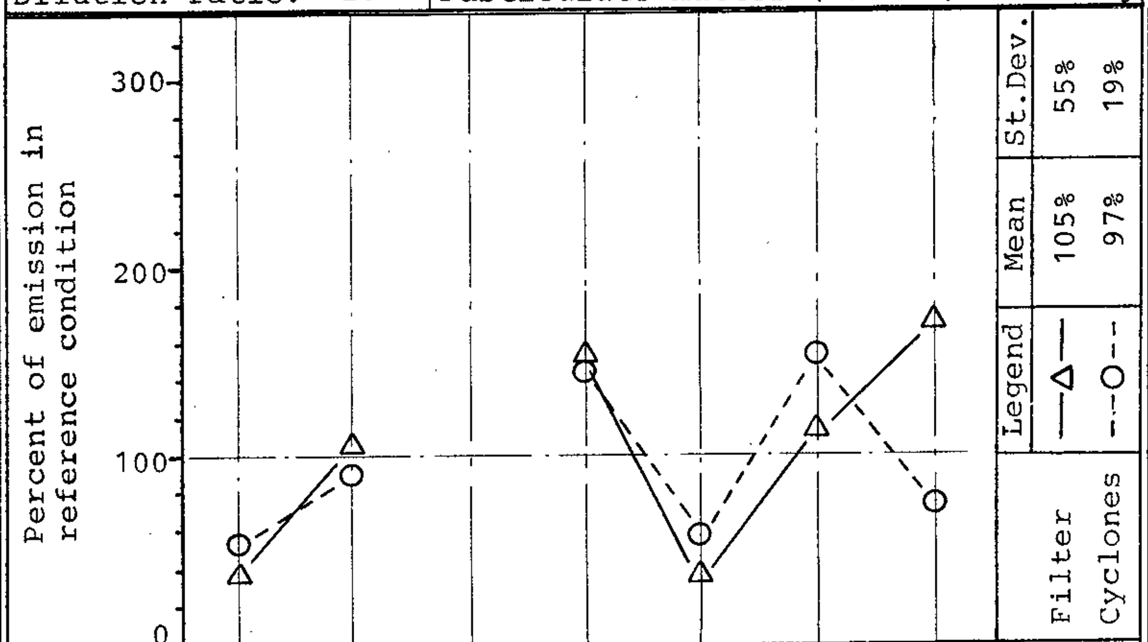
CO: 1.24 vol.%	HC(NDIR): 285 ppm C_6	NO_X: 1700 ppm
CO_2: 13.3 vol.%	HC(FID): 4250 ppm C_1	O_2: 1.45 vol.%

PNA (UV-reading): exhaust gas 12. mV. Reference 5. mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 40 C

Dilution ratio: 20 | Particulate matter (filter): 0.222 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	6.99	16.8		32.8	4.74	1.66	4.04	µg/test
Cyclones	0.78	1.85		3.63	0.86	0.11	0.12	µg/test
Sum	7.77	18.7		36.4	5.60	1.77	4.16	µg/test
%Filter	90	90		90	85	94	97	% of sum

MEASUREMENT NO. 3-3 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 603 C	$T_{ex,t}$: 160 C
	M_F: 2.48 kg/h	M_A: 35.2 kg/h	A/F-ratio: 14.20	
	T_C: 75 C	P_{amb}: 749 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			- g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82C	
	BaP: - µg/ml. Analysis p.: -		Used 22 h before test	

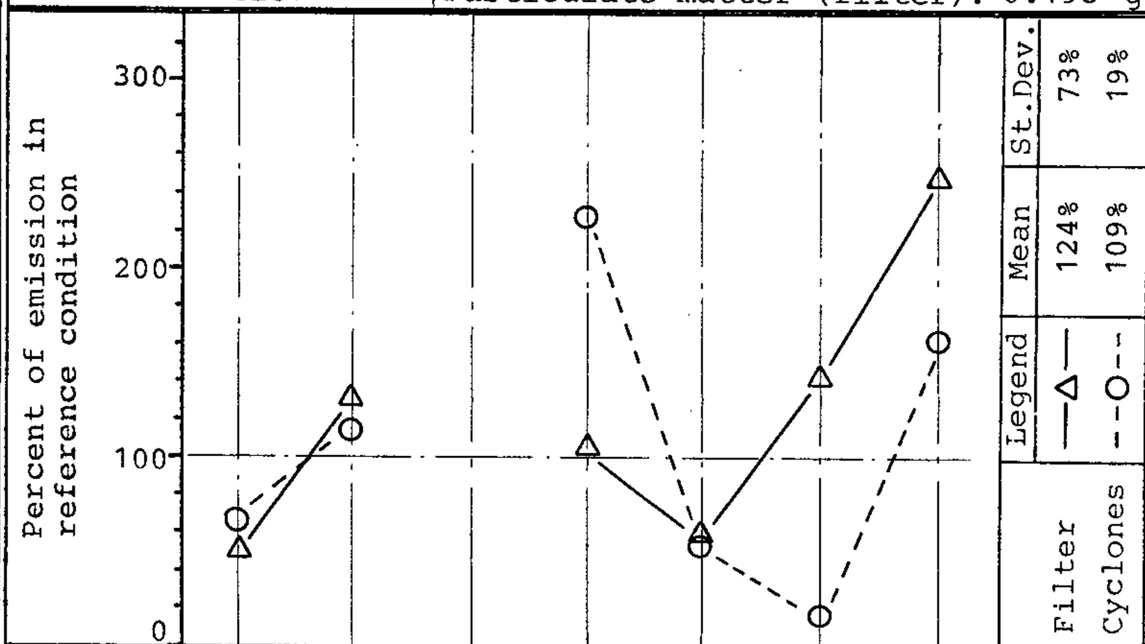
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.25 vol.%	HC(NDIR): 348 ppm C_6	NO_x: 1850 ppm
CO_2: 13.1 vol.%	HC(FID): 4700 ppm C_1	O_2: 1.55 vol.%
PNA (UV-reading): exhaust gas 14.4 mV. Reference 3.6 mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 39 C

Dilution ratio: 20 | Particulate matter (filter): 0.193 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	8.47	20.5		22.8	6.86	2.06	5.93	µg/test
Cyclones	0.97	2.34		5.73	0.80	0.015	0.26	µg/test
Sum	9.44	22.8		28.5	7.66	2.08	6.19	µg/test
%Filter	90	90		80	90	99	96	% of sum

MEASUREMENT NO. 6-3 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 604 C	$T_{ex,t}$: 158 C
	M_F: 2.49 kg/h	M_A: 34.7 kg/h	A/F-ratio: 13.93	
	T_C: 75 C	P_{amb}: 758 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			- g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: 1.24 µg/ml. Analysis p.: D17		Used 30 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

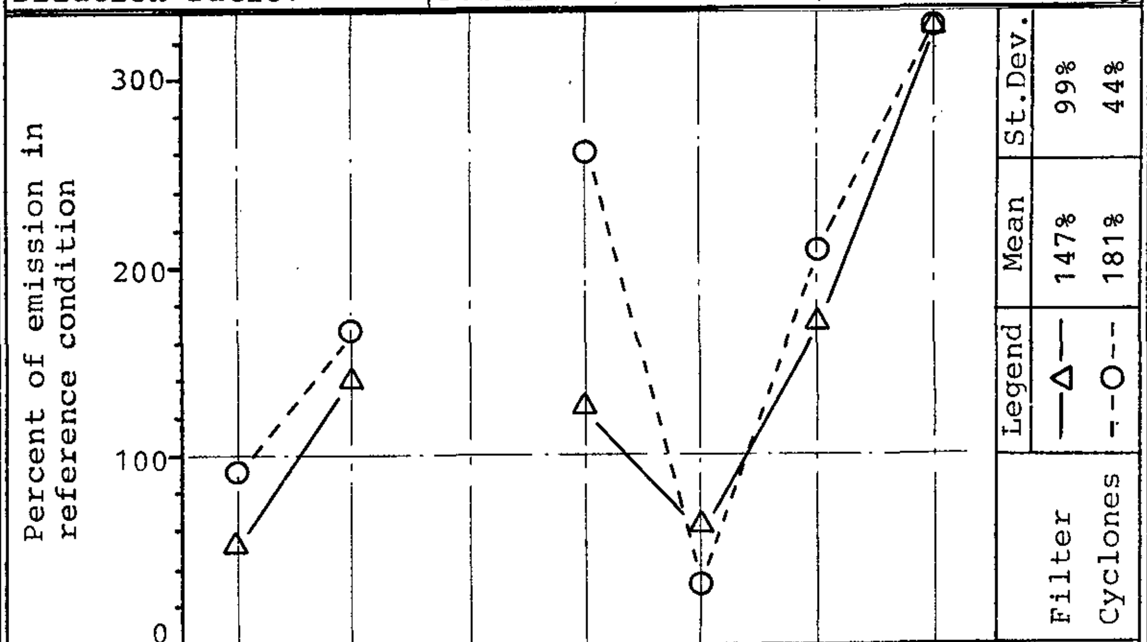
CO: 1.36 vol.%	HC(NDIR): 275 ppm C_6	NO_x: 1625 ppm
CO_2: 13.3 vol.%	HC(FID): 4400 ppm C_1	O_2: 1.65 vol.%

PNA (UV-reading): exhaust gas 26.5 mV, Reference 13 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 39 C

Dilution ratio: 20 | Particulate matter (filter): 0.191 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	9.20	21.3		27.0	7.54	2.43	7.75	µg/test
Cyclones	1.26	3.32		6.50	0.45	0.15	0.53	µg/test
Sum	10.5	24.6		33.5	8.00	2.58	8.28	µg/test
%Filter	88	86		81	94	94	94	% of sum

MEASUREMENT NO. 7-3 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 603 C	$T_{ex,t}$: 161 C
	M_F: 2.48 kg/h	M_A: 34.7 kg/h	A/F-ratio: 14.00	
	T_C: 75 C	P_{amb}: 757 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel			- g Pb/litre
	- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
	C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15W-50		Lubricant temp.: 82 C	
	BaP: 1.62 µg/ml. Analysis p.: D17		Used 40 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

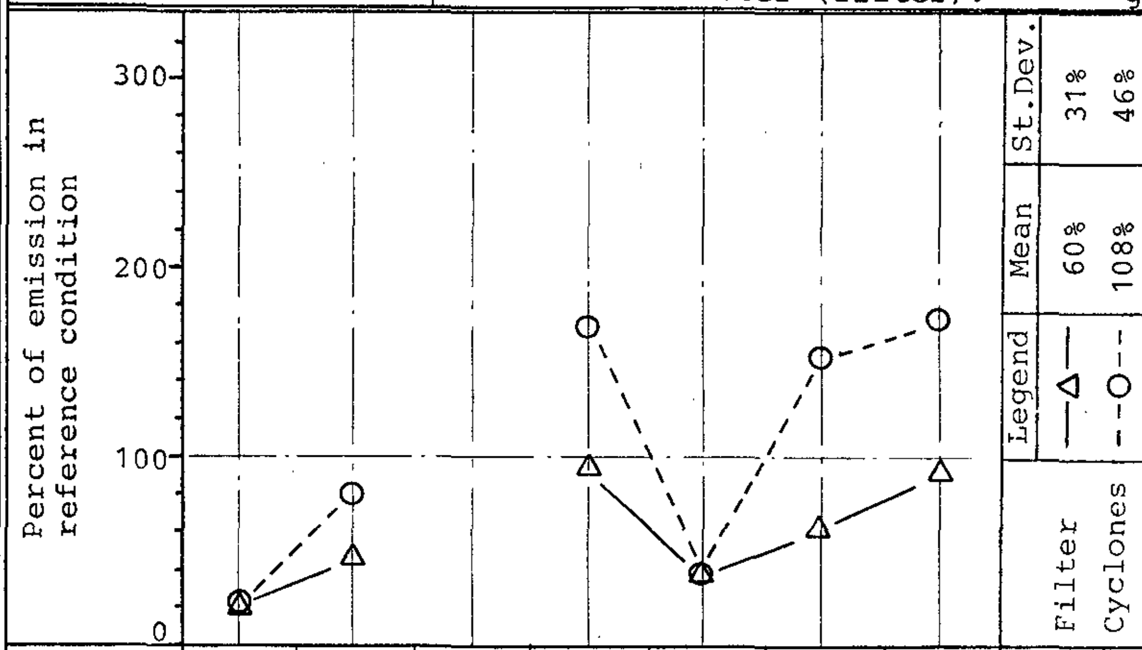
CO: 1.25 vol.%	HC(NDIR): 290 ppm C_6	NO_x: 1750 ppm
CO_2: 12.9 vol.%	HC(FID): 3700 ppm C_1	O_2: 1.5 vol.%

PNA (UV-reading): exhaust gas 26.0 mV, Reference 13.5 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 42 C

Dilution ratio: 20 | Particulate matter (filter): 0.227 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	3.05	7.35		20.8	4.59	0.91	2.24	µg/test
Cyclones	0.35	1.64		4.26	0.62	0.11	0.28	µg/test
Sum	3.40	9.00		25.1	5.21	1.02	2.52	µg/test
%Filter	90	82		83	88	89	89	% of sum

MEASUREMENT NO. 10-3 Engine stabilization test

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 601 C	$T_{ex,t}$: 160 C
M_F: 2.47 kg/h	M_A: 34.99 kg/h	A/F-ratio: 14.17	
T_C: 75 C	P_{amb}: 755 mmHg	T_{amb}: 23 C	Hum.: - % rel.

FUEL

Type: DTH Base Fuel			- g Pb/litre
- vol.% Aromates	C_6: - %	C_7: - %	C_8: - %
C_9+C_{10}: - %	BaP: 0.37 µg/ml. Analysis on page: D14		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 82 C
BaP: 2.73 µg/ml. Analysis p.: D17	Used 60 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

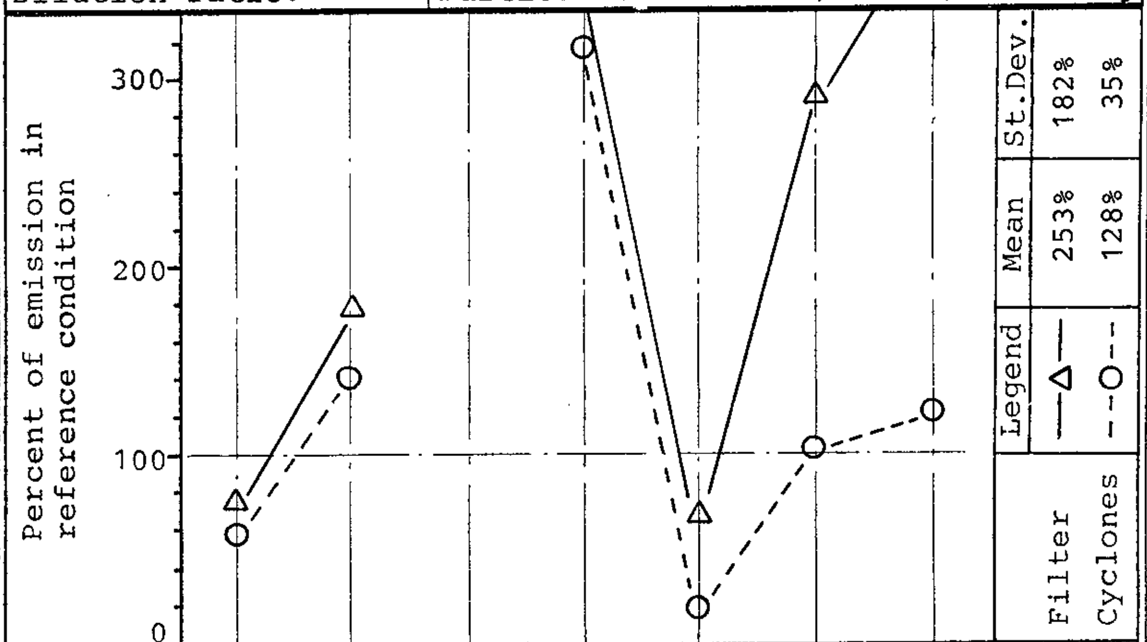
CO: 1.18 vol.%	HC(NDIR): 290 ppm C_6	NO_X: 1725 ppm
CO_2: 13.1 vol.%	HC(FID): 4300 ppm C_1	O_2: 1.48 vol.%

PNA (UV-reading): exhaust gas 27.5 mV. Reference 10 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 42 C

Dilution ratio: 20 | Particulate matter (filter): 0.200 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	12.6	27.5		81.1	8.00	4.12	12.5	µg/test
Cyclones	0.81	2.86		7.87	0.32	0.074	0.20	µg/test
Sum	13.4	30.4		89.0	8.32	4.19	12.7	µg/test
%Filter	94	91		91	96	98	98	% of sum

MEASUREMENT NO. 15-3 Engine stabilization test
No air injection into UV-cell

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 604 C		$T_{ex,t}$: 165 C		
	M_F: 2.48 kg/h	M_A: 34.99 kg/h	A/F-ratio: 14.11				
	T_C: 75 C	P_{amb}: 744.3 mmHg	T_{amb}: 23 C		Hum.: - % rel.		
FUEL	Type: DTH Base Fuel				0.4 g Pb/litre		
	- vol.% Aromates		C_6: - %	C_7: - %	C_8: - %		
	C_9+C_{10}: - %	BaP: 0.37 μg/ml. Analysis on page: D14					
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C			
	BaP: - μg/ml. Analysis p.: -			Used 85h before test			

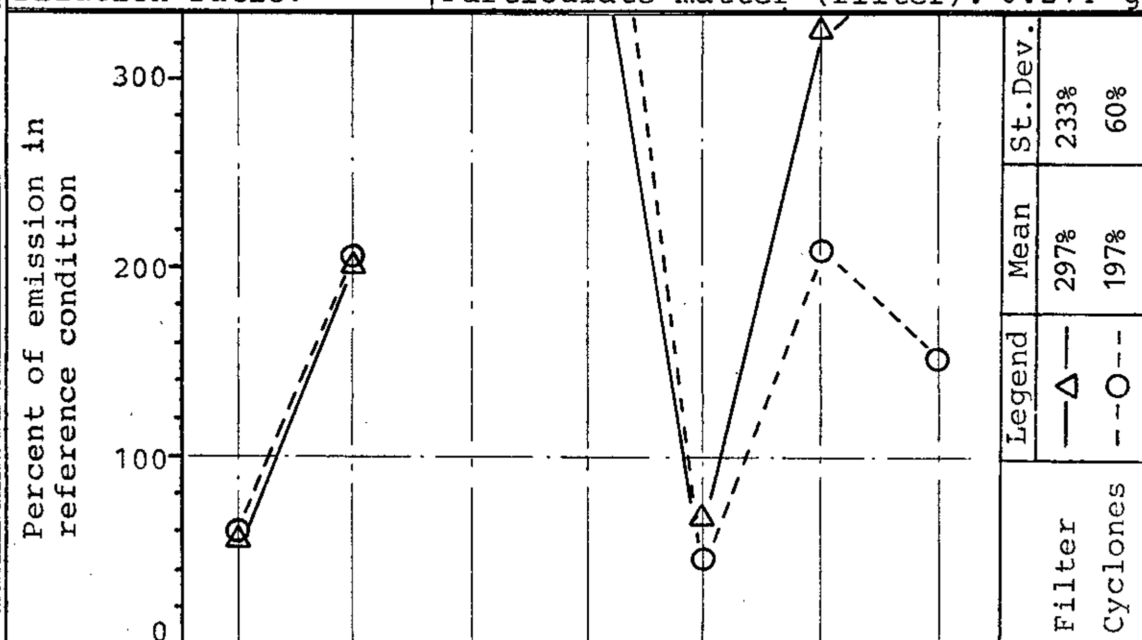
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.47 vol.%	HC(NDIR): 325 ppm C_6	NO_x: 1825 ppm
CO_2: 13.8 vol.%	HC(FID): 4650 ppm C_1	O_2: 1.63 vol.%
PNA (UV-reading): exhaust gas - mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 38 C

Dilution ratio: 20 | Particulate matter (filter): 0.214 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	9.93	31.3		102.8	8.27	4.70	15.2	μg/test
Cyclones	0.91	4.14		12.4	0.69	0.15	0.25	μg/test
Sum	10.8	35.4		115.2	8.96	4.85	15.5	μg/test
%Filter	92	88		89	92	97	98	% of sum

MEASUREMENT NO. 31-3 Engine stabilization test

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 161 C
	M_F: 2.47 kg/h	M_A: 35.45 kg/h	A/F-ratio: 14.35	
	T_C: 75 C	P_{amb}: 752.2 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page:		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 100 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

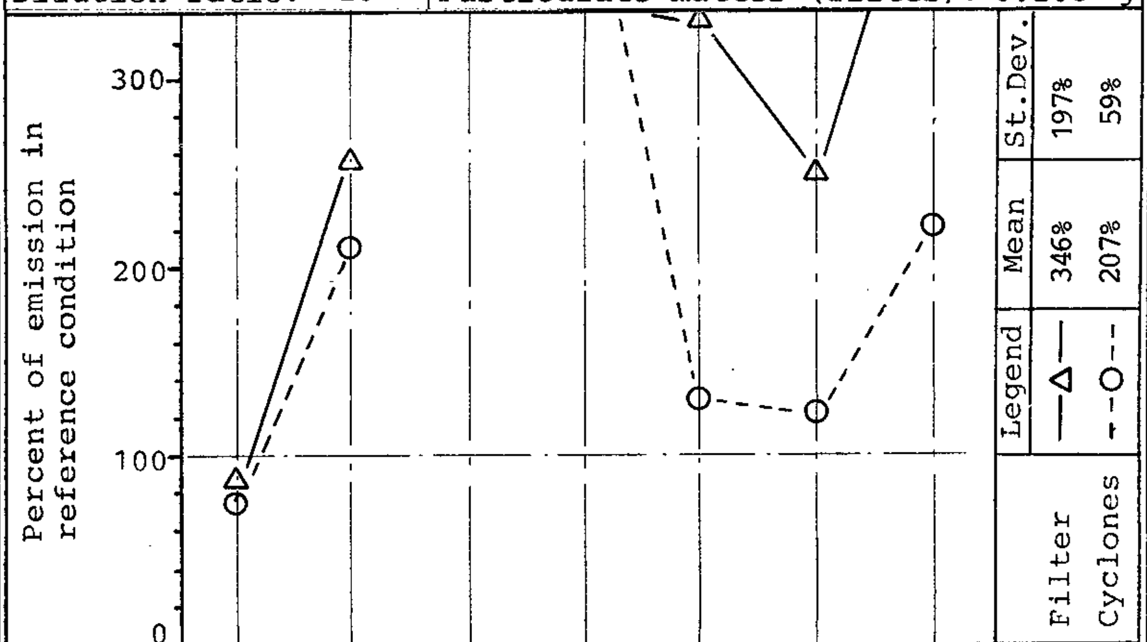
CO: 1.2 vol.%	HC(NDIR): 290 ppm C_6	NO_x: 1700 ppm
CO_2: 12.8 vol.%	HC(FID): 4350 ppm C_1	O_2: 1.5 vol.%

PNA (UV-reading): exhaust gas 19.2 mV. Reference 4.6 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 42 C

Dilution ratio: 20 | Particulate matter (filter): 0.203 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	14.4	40.0		134.2	39.3	3.56	12.4	µg/test
Cyclones	1.07	4.24		11.8	1.95	0.087	0.36	µg/test
Sum	15.4	44.2		146.0	41.2	3.65	12.8	µg/test
%Filter	93	90		92	95	98	97	% of sum

MEASUREMENT NO. 12-4 Air/Fuel-Ratio variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 577 C	$T_{ex,t}$: 154 C
	M_F: 2.87 kg/h	M_A: 35.1 kg/h	A/F-ratio: 12.23	
	T_C: 75 C	P_{amb}: 762 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 1 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

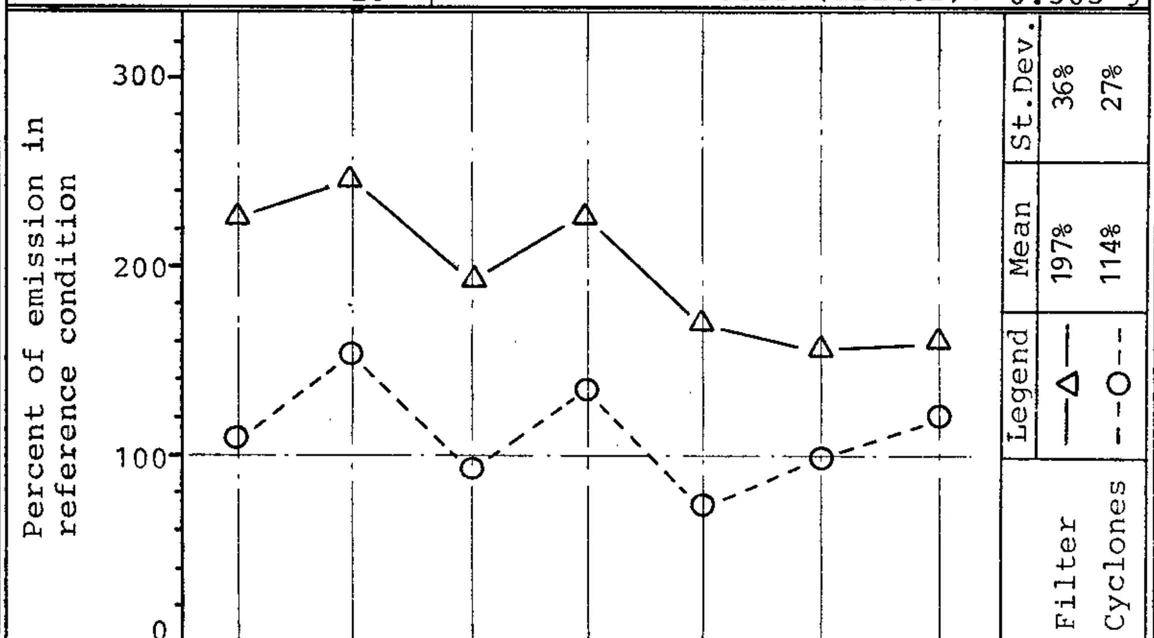
CO: 5.7 vol.%	HC(NDIR): 455 ppm C_6	NO_x: 510 ppm
CO_2: 10.8 vol.%	HC(FID): 6000 ppm C_1	O_2: 1.0 vol.%

PNA (UV-reading): exhaust gas 17.5 mV, Reference 2.0 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.363 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	38.1	38.3	23.4	48.3	19.7	2.25	3.85	µg/test
Cyclones	1.57	3.14	1.01	3.37	1.11	0.070	0.20	µg/test
Sum	39.7	41.4	24.4	51.7	20.8	2.32	4.05	µg/test
%Filter	96	92	96	93	95	97	95	% of sum

MEASUREMENT NO. 13-4A Air/Fuel-Ratio variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 605 C	$T_{ex,t}$: 158 C
	M_F: 2.60 kg/h	M_A: 34.5 kg/h	A/F-ratio: 13.25	
	T_C: 75 C	P_{amb}: 756 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C
	BaP: - µg/ml. Analysis p.: -			Used 1 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

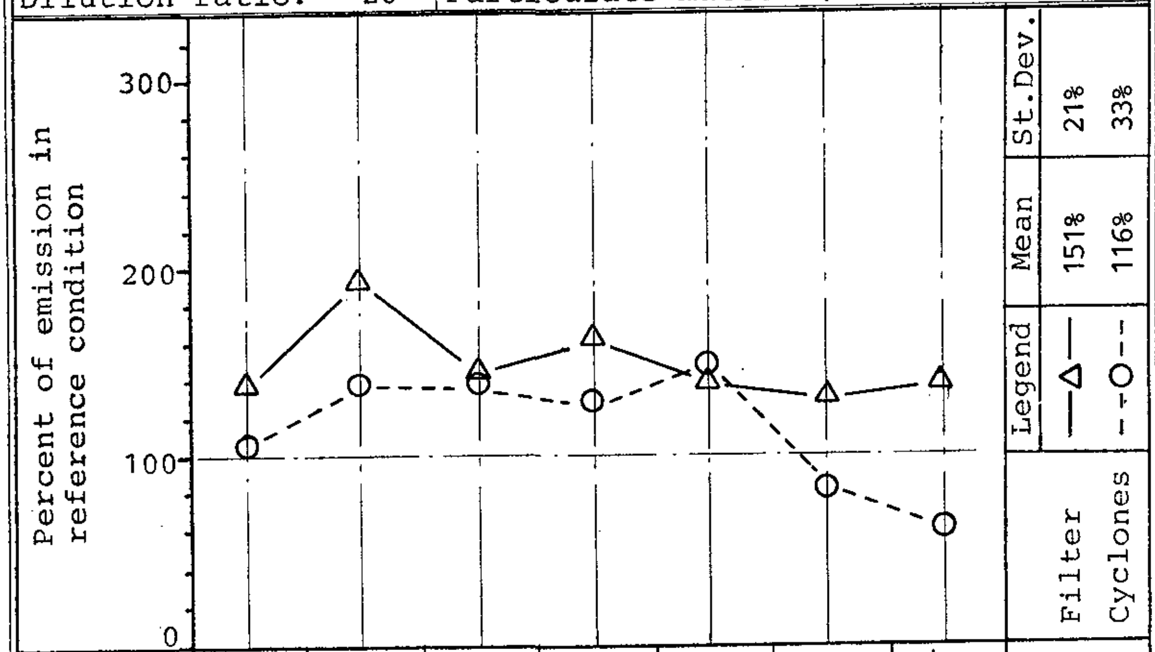
CO: 2.90 vol.%	HC (NDIR): 375 ppm C_6	NO_x: 1188 ppm
CO_2: 12.7 vol.%	HC (FID): 5100 ppm C_1	O_2: 1.05 vol.%

PNA (UV-reading): exhaust gas 0.58 mV. Reference 1.62 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.214 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	23.1	29.8	17.7	35.6	16.1	1.95	3.25	µg/test
Cyclones	1.50	2.79	1.47	3.22	2.22	0.060	0.10	µg/test
Sum	24.6	32.6	19.2	38.8	18.3	2.01	3.35	µg/test
%Filter	94	91	92	92	88	97	97	% of sum

MEASUREMENT NO. 13-4B Air/Fuel-Ratio variation

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 622 C	$T_{ex,t}$: 165 C
M_F: 2.41 kg/h	M_A: 37.95 kg/h	A/F-ratio: 15.75	
T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.

FUEL

Type: DTH Base Fuel A			0.4 g Pb/litre
40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 82 C
BaP: - µg/ml. Analysis p.: -	Used 0.5 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

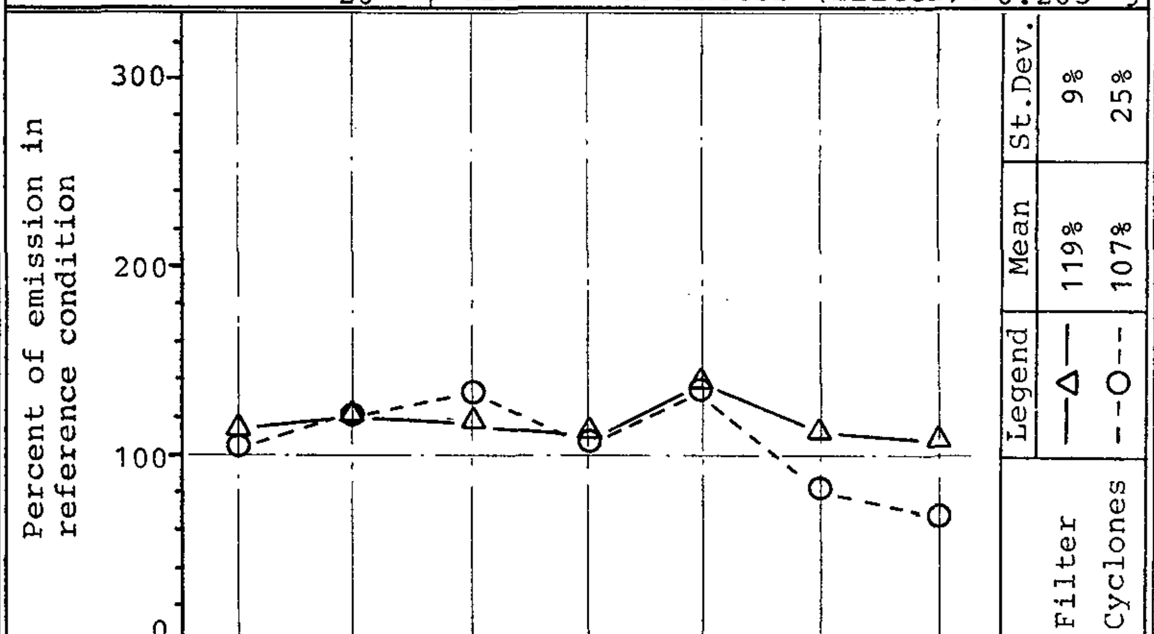
CO: 0.65 vol.%	HC(NDIR): 255 ppm C_6	NO_x: 1600 ppm
CO_2: 13.1 vol.%	HC(FID): 3800 ppm C_1	O_2: 2.4 vol.%

PNA (UV-reading): exhaust gas 0.4 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.203 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	19.5	18.9	14.1	24.4	16.1	1.66	2.61	µg/test
Cyclones	1.43	2.35	1.41	2.73	2.00	0.059	0.11	µg/test
Sum	20.9	21.3	15.5	27.1	18.1	1.72	2.72	µg/test
%Filter	93	89	91	90	89	97	96	% of sum

MEASUREMENT NO. 7-6B Air/Fuel-Ratio variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 628 C	$T_{ex,t}$: 171 C
	M_F: 2.39 kg/h	M_A: 38.44 kg/h	A/F-ratio: 16.08	
	T_C: 75 C	P_{amb}: 751.8mmHg	T_{amb}: 28 C	Hum.: 48 % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0%
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83C	
	BaP: - µg/ml. Analysis p.: -		Used 4.5h before test	

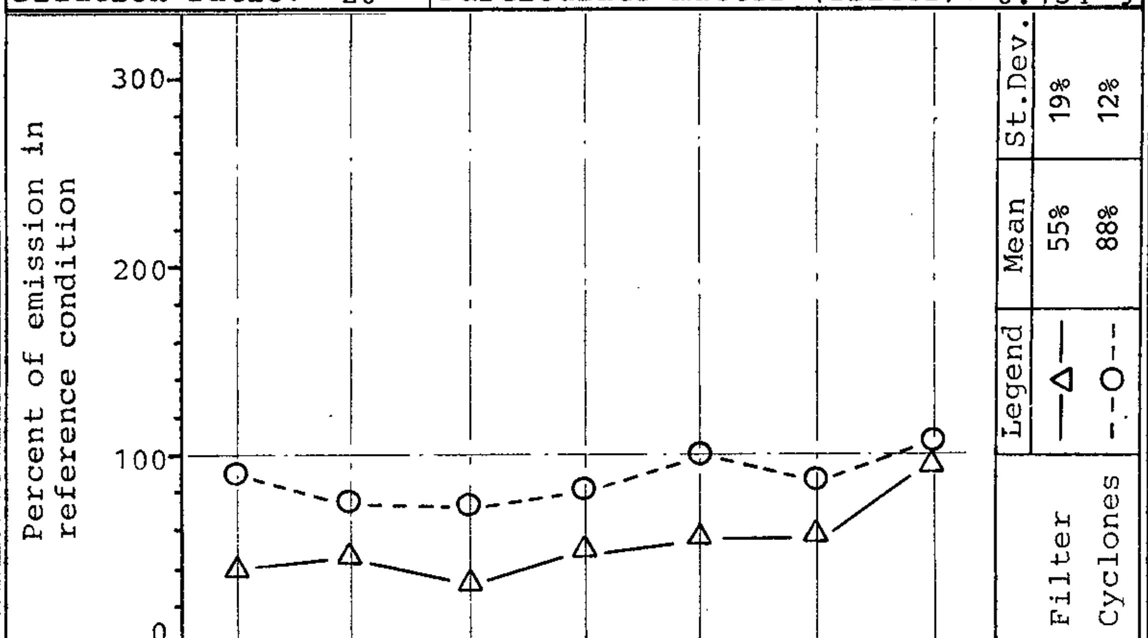
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 0.35 vol.%	HC(NDIR): 250 ppm C_6	NO_x: 1250 ppm
CO_2: 12.7 vol.%	HC(FID): 4000 ppm C_1	O_2: 3.0 vol.%
PNA (UV-reading): exhaust gas 7.5mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 37C

Dilution ratio: 20 | Particulate matter (filter): 0.134 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	6.63	7.38	4.46	10.7	6.97	0.87	2.20	µg/test
Cyclones	1.27	1.55	0.77	2.02	1.46	0.061	0.17	µg/test
Sum	7.90	8.93	5.23	12.7	8.43	0.93	2.37	µg/test
%Filter	84	83	85	84	83	93	93	% of sum

MEASUREMENT NO. 7-6A Air/Fuel-Ratio variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 637 C	$T_{ex,t}$: 182 C
	M_F: 2.46 kg/h	M_A: 42.95 kg/h	A/F-ratio: 17.46	
	T_C: 75 C	P_{amb}: 751.8mmHg	T_{amb}: 28 C	Hum.: 48 % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0%
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 2h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

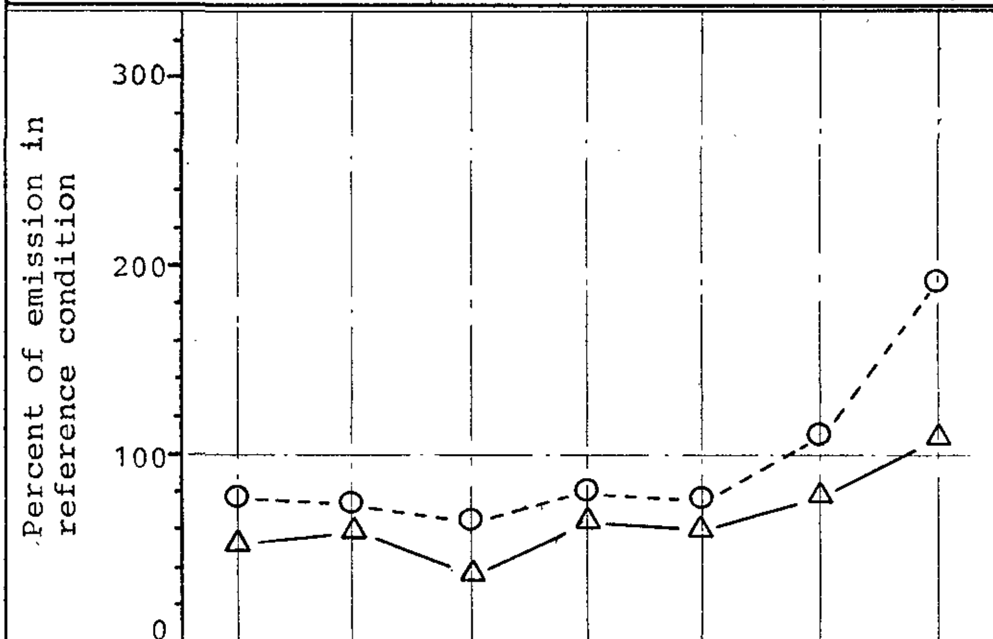
CO: 0.2 vol.%	HC(NDIR): 375 ppm C_6	NO_x: 900 ppm
CO_2: 11.2 vol.%	HC(FID): 5300 ppm C_1	O_2: 4.75 vol.%

PNA (UV-reading): exhaust gas 6.0 mV, Reference 3.0 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 38 C

Dilution ratio: 20 | Particulate matter (filter): 0.152 g



	Filter	Cyclones
St.Dev.	24%	44%
Mean	69%	98%
Legend	—△—	--○--

Amount of PAH collected	Anthracene	Fluoranthene	1-Methylanthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	8.93	9.22	4.92	14.8	7.62	1.15	2.70	µg/test
Cyclones	1.09	1.48	0.69	2.06	1.20	0.08	0.31	µg/test
Sum	10.0	10.7	5.61	16.9	8.82	1.23	3.01	µg/test
%Filter	89	86	88	88	86	93	90	% of sum

MEASUREMENT NO. 14-4 Air/Fuel-Ratio variation

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 634 C	$T_{ex,t}$: 185 C
M_F: 2.46 kg/h	M_A: 43.2 kg/h	A/F-ratio: 17.56	
T_C: 75 C	P_{amb}: 762 mmHg	T_{amb}: 24 C	Hum.: - % rel.

FUEL

Type: DTH Base Fuel A			0.4 g Pb/litre
40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
C_9+C_{10}: 8.8 %	BaP: 0.12 μg/ml. Analysis on page: D.14		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 82 C
BaP: - μg/ml. Analysis p.: -	Used 1 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

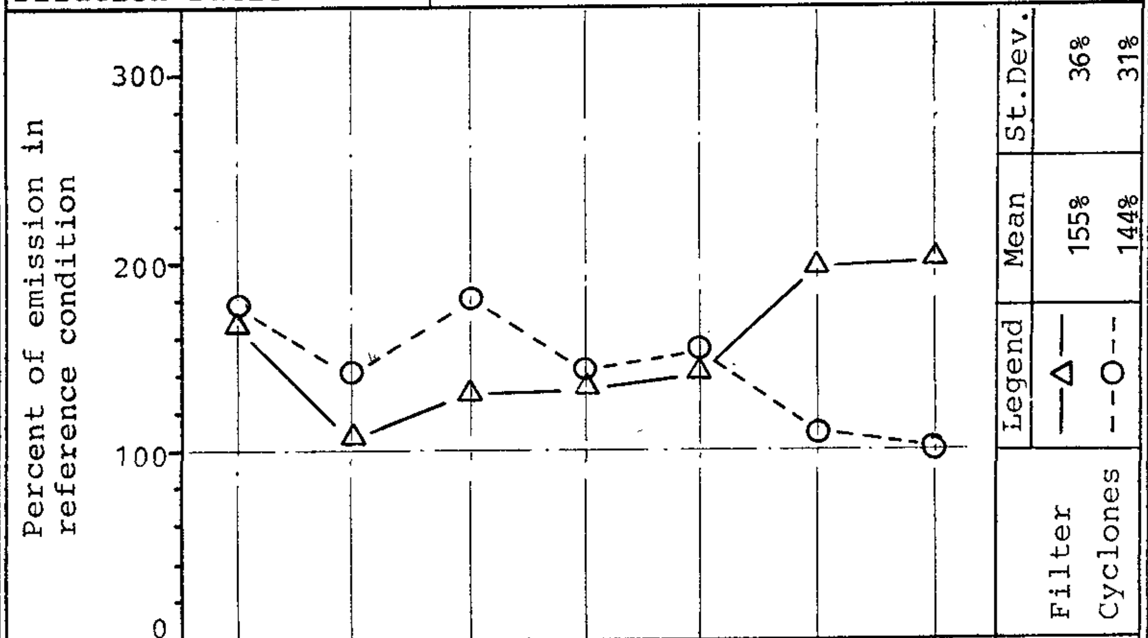
CO: 0.19 vol.%	HC(NDIR): 450 ppm C_6	NO_x: 800 ppm
CO_2: 10.3 vol.%	HC(FID): 5600 ppm C_1	O_2: 5.85 vol.%

PNA (UV-reading): exhaust gas 5.25 mV. Reference 1.44 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 36 C

Dilution ratio: 20 | Particulate matter (filter): 0.386 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	28.3	16.6	15.7	28.9	16.7	2.83	4.80	μg/test
Cyclones	2.46	2.83	1.91	3.58	2.28	0.078	0.16	μg/test
Sum	30.8	19.4	17.6	32.5	19.0	2.91	4.96	μg/test
%Filter	92	85	89	89	88	97	97	% of sum

MEASUREMENT NO. 10-4A Engine load variation

ENGINE	P: 7.15kW	N: 2490 RPM	$T_{ex,m}$: 638 C	$T_{ex,t}$: 180 C
	M_F: 2.80 kg/h	M_A: 40.7 kg/h	A/F-ratio: 14.53	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 2 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

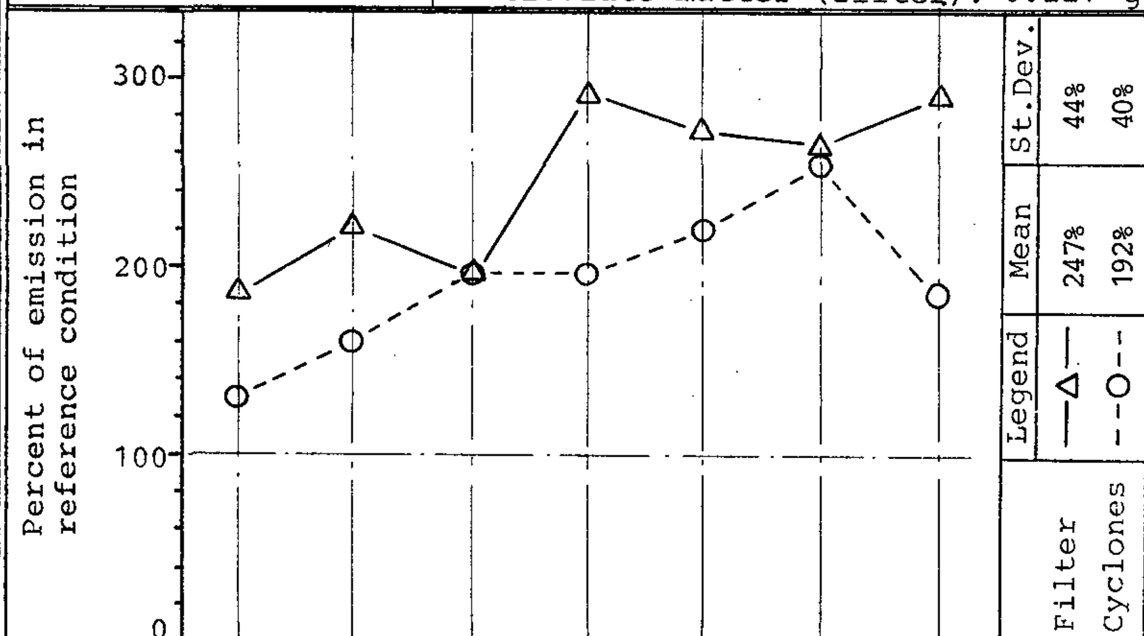
CO: 1.04 vol.%	HC(NDIR): 340 ppm C_6	NO_X: 1925 ppm
CO_2: 12.9 vol.%	HC(FID): 4600 ppm C_1	O_2: 1.9 vol.%

PNA (UV-reading): exhaust gas 12 mV. Reference 2.0 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 35 C

Dilution ratio: 17.3 | Particulate matter (filter): 0.227 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	31.6	34.4	23.9	63.4	31.9	3.79	6.81	µg/test
Cyclones	1.82	3.21	2.06	4.94	3.27	0.18	0.30	µg/test
Sum	33.4	37.6	26.0	68.3	35.2	3.97	7.11	µg/test
%Filter	95	91	92	93	91	95	96	% of sum

MEASUREMENT NO. 10-4B Engine load variation

ENGINE	P: 3.85 kW	N: 2490 RPM	$T_{ex,m}$: 592 C	$T_{ex,t}$: 140 C
	M_F: 2.14 kg/h	M_A: 29.3 kg/h	A/F-ratio: 13.71	
	T_C: 75 C	P_{amb}: 753 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

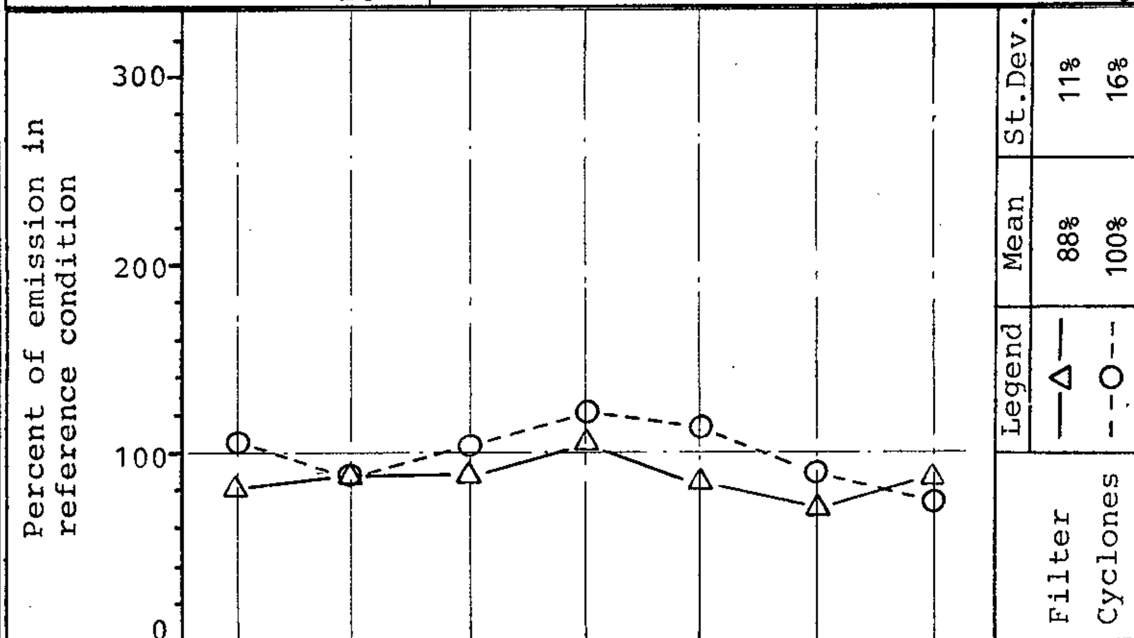
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.72 vol.%	HC(NDIR): 328 ppm C_6	NO_X: 788 ppm
CO_2: 12.8 vol.%	HC(FID): 4550 ppm C_1	O_2: 1.58 vol.%
PNA (UV-reading): exhaust gas 15.5 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 32 C

Dilution ratio: 24 | Particulate matter (filter): 0.149 g



Amount of PAH collected	Anthracene	Fluoranthene	1-Methylanthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	13.8	14.2	10.7	23.2	10.2	1.03	2.05	µg/test
Cyclones	1.47	1.84	1.09	3.02	1.70	0.065	0.12	µg/test
Sum	15.3	16.0	11.8	26.2	11.9	1.10	2.17	µg/test
%Filter	90	88	91	88	86	94	94	% of sum

MEASUREMENT NO. 17-4B Coolant temperature variation

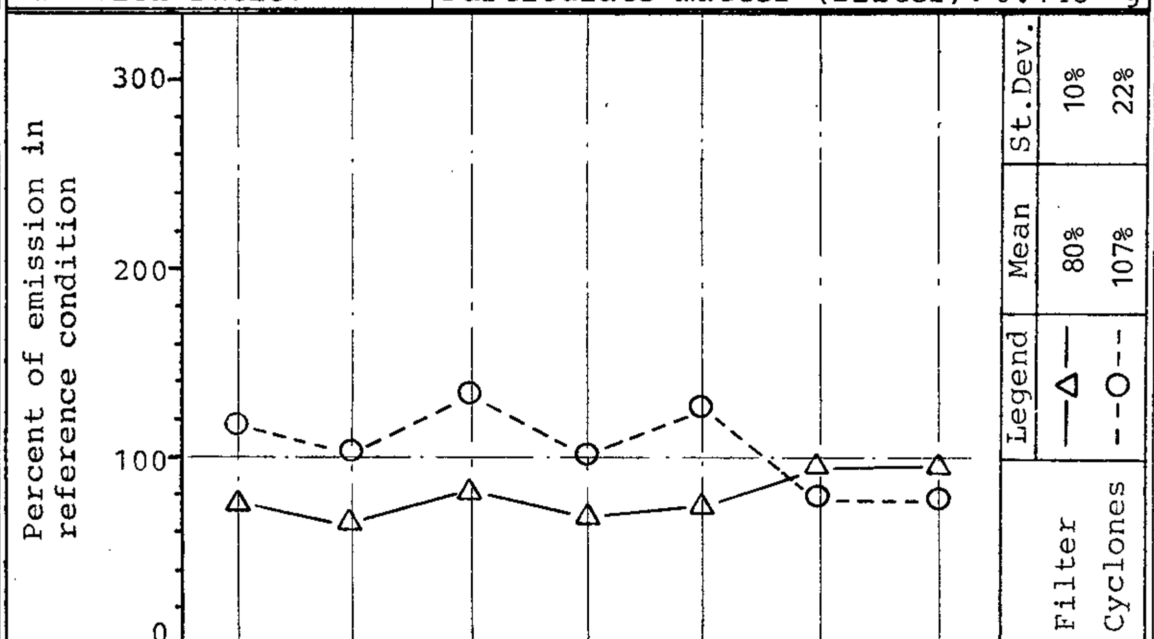
ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 613 C	$T_{ex,t}$: 168 C
	M_F: 2.46 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.28	
	T_C: 50 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4.5 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.1 vol.%	HC(NDIR): 325 ppm C_6	NO_x: 1500 ppm
CO_2: 12.9 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.55 vol.%
PNA (UV-reading): exhaust gas 8.0 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 33 C	
Dilution ratio: 20	Particulate matter (filter): 0.148 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	12.6	10.7	9.80	15.5	8.85	1.34	2.24	µg/test
Cyclones	1.68	2.10	1.42	2.53	1.87	0.057	0.13	µg/test
Sum	14.4	12.8	11.2	19.0	10.7	1.40	2.37	µg/test
%Filter	88	84	87	86	83	96	95	% of sum

MEASUREMENT NO. 17-4A Coolant temperature variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 614 C	$T_{ex,t}$: 161 C
	M_F: 2.45 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.28	
	T_C: 85 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 2 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

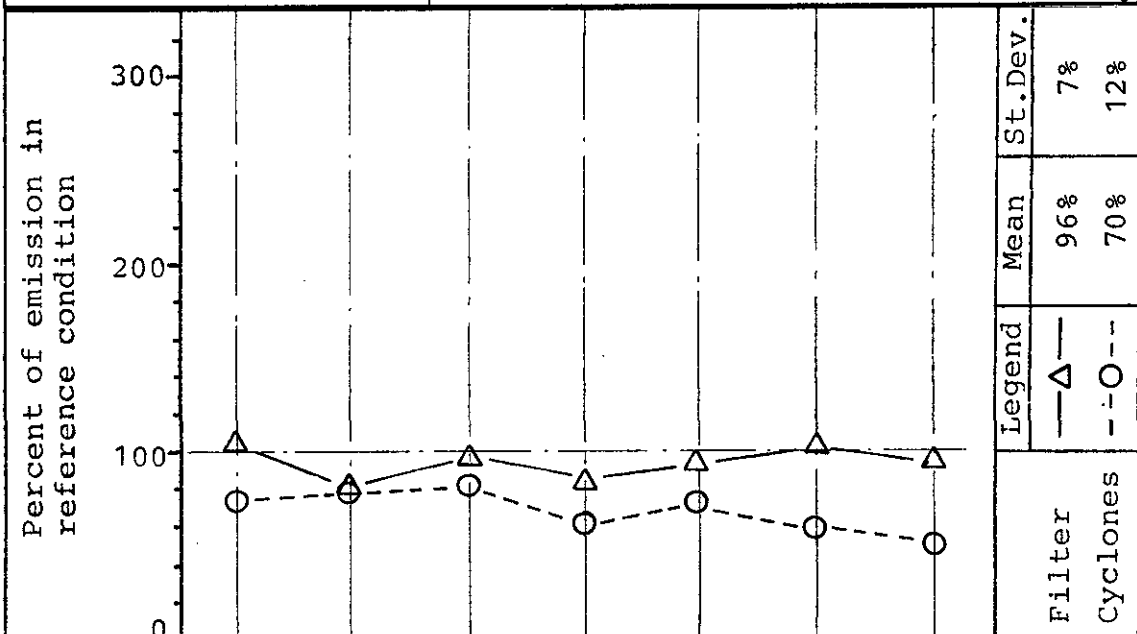
CO: 1.10 vol.%	HC(NDIR): 310 ppm C_6	NO_x: 1500 ppm
CO_2: 12.9 vol.%	HC(FID): 4400 ppm C_1	O_2: 1.55 vol.%

PNA (UV-reading): exhaust gas 10.4 mV, Reference 2.2 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.176 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	17.5	13.0	12.1	19.0	11.1	1.47	2.27	µg/test
Cyclones	1.06	1.56	0.89	1.59	1.10	0.043	0.080	µg/test
Sum	18.6	14.6	13.0	20.6	12.2	1.51	2.35	µg/test
%Filter	94	89	93	92	91	97	97	% of sum

MEASUREMENT NO. 19-4A Low oil temperature

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 161 C
M_F: 2.48 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.16	
T_C: 75 C	P_{amb}: 762 mmHg	T_{amb}: 24 C	Hum.: - % rel.

FUEL

Type: DTH Base Fuel A			0.4 g Pb/litre
40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 70 C
BaP: - µg/ml. Analysis p.: -	Used 2 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

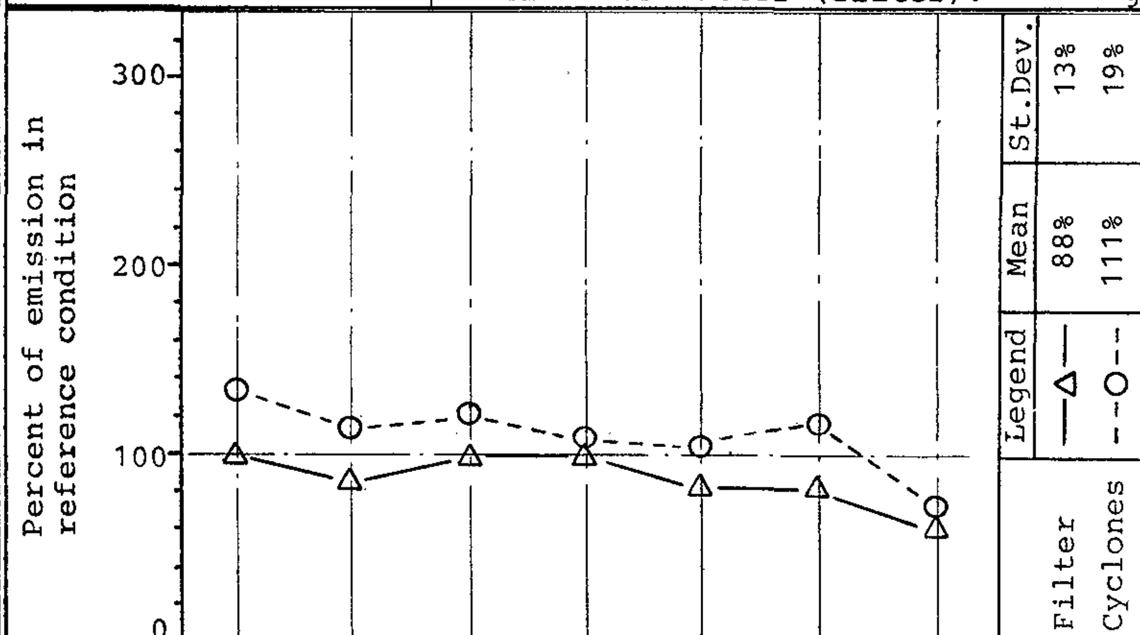
CO: 1.10 vol.%	HC(NDIR): 300 ppm C_6	NO_x: 1600 ppm
CO_2: 13.1 vol.%	HC(FID): 4300 ppm C_1	O_2: 1.55 vol.%

PNA (UV-reading): exhaust gas 14.4 mV. Reference 2.3 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.182 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	16.7	13.8	12.0	20.9	9.91	1.17	1.46	µg/test
Cyclones	1.88	2.27	1.28	2.77	1.54	0.085	0.12	µg/test
Sum	18.6	16.1	13.3	23.7	11.5	1.26	1.58	µg/test
%Filter	90	86	90	88	87	93	92	% of sum

MEASUREMENT NO. 19-4B High oil temperature

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 165 C
	M_F: 2.40 kg/h	M_A: 34.2 kg/h	A/F-ratio: 14.23	
	T_C: 75 C	P_{amb}: 762 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 100 C	
	BaP: - µg/ml. Analysis p.: -		Used 4.5 h before test	

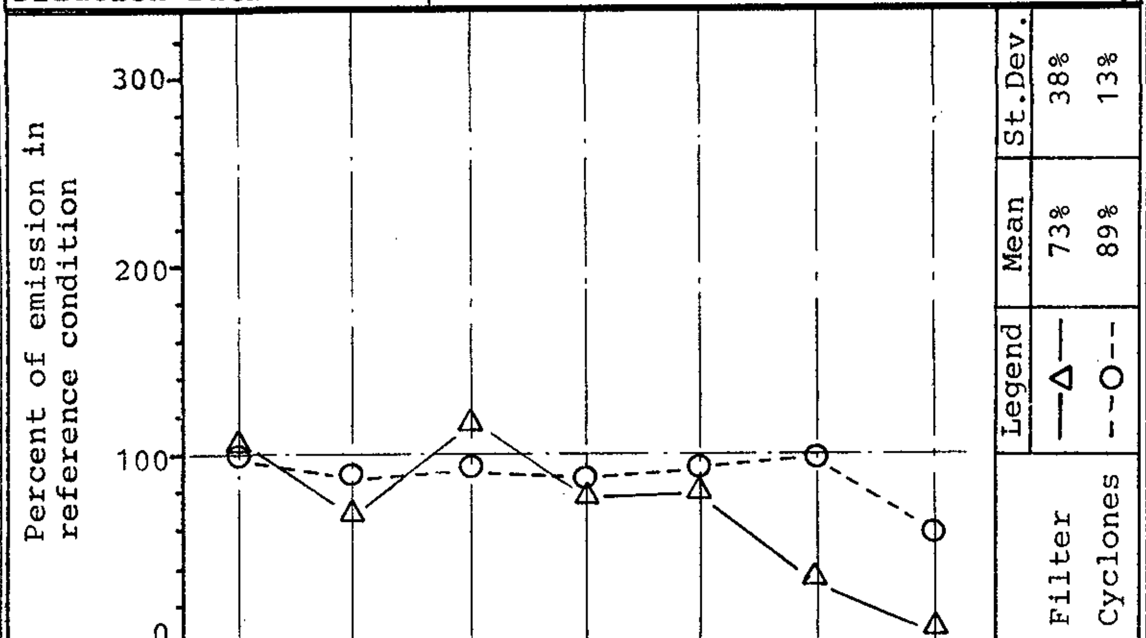
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.22 vol.%	HC(NDIR): 295 ppm C_6	NO_X: 1350 ppm
CO_2: 13.1 vol.%	HC(FID): 4150 ppm C_1	O_2: 1.45 vol.%
PNA (UV-reading): exhaust gas 15.2 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 34 C

Dilution ratio: 20 Particulate matter (filter): 0.185 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	18.2	11.3	14.3	17.2	9.67	0.49	0.31	µg/test
Cyclones	1.36	1.80	0.98	2.26	1.40	0.069	0.098	µg/test
Sum	19.6	13.1	15.3	19.5	11.1	0.56	0.41	µg/test
%Filter	93	86	94	88	87	88	76	% of sum

MEASUREMENT NO. 7-6C High oil temperature

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 611 C	$T_{ex,t}$: 164 C
	M_F: 2.43 kg/h	M_A: 34.70 kg/h	A/F-ratio: 14.28	
	T_C: 75 C	P_{amb}: 751.8mmHg	T_{amb}: 28 C	Hum.: 48 % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0%
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 100C	
	BaP: - µg/ml. Analysis p.: -		Used 1h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

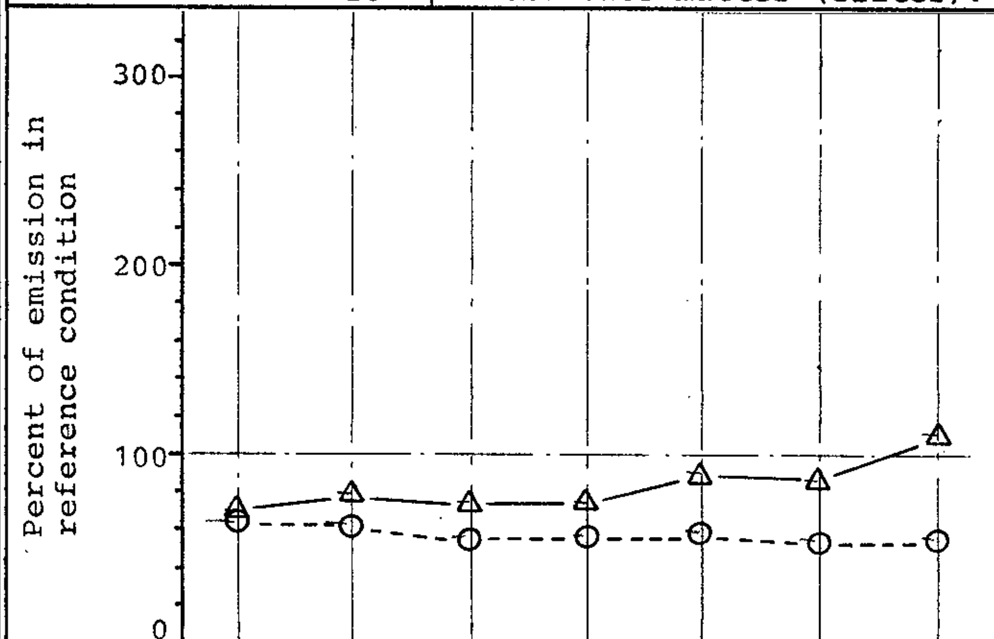
CO: 1.0 vol.%	HC(NDIR): 325 ppm C_6	NO_x: 1325 ppm
CO_2: 12.9 vol.%	HC(FID): 5000 ppm C_1	O_2: 1.4 vol.%

PNA (UV-reading): exhaust gas 15.0 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 36 C

Dilution ratio: 20 | Particulate matter (filter): 0.203 g



	Legend	Mean	St.Dev.
Filter	—△—	84%	15%
Cyclones	- -O- -	59%	3%

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	11.9	12.1	9.02	15.8	10.6	1.22	2.66	µg/test
Cyclones	0.89	1.24	0.62	1.51	0.89	0.038	0.092	µg/test
Sum	12.8	13.3	9.64	17.3	11.5	1.26	2.75	µg/test
%Filter	93	91	94	91	92	97	97	% of sum

MEASUREMENT NO. 18-4C Low oil temperature, without PCV

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 163 C
	M_F: 2.48 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.13	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 70 C	
	BaP: - µg/ml. Analysis p.: -		Used 7 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

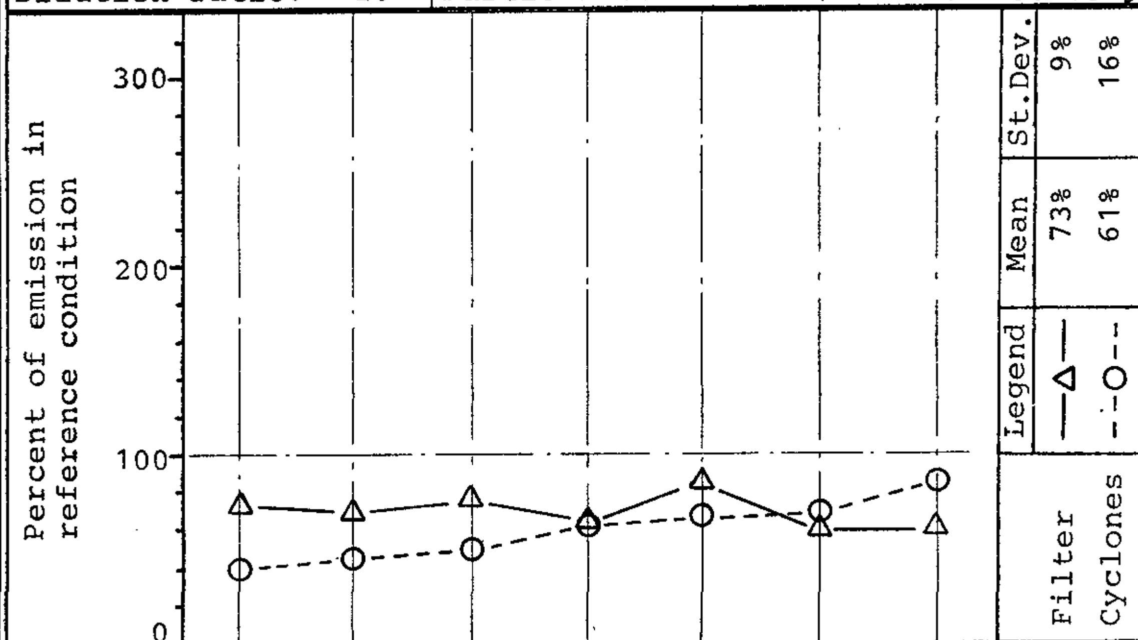
CO: 0.9 vol.%	HC(NDIR): - ppm C_6	NO_x: 1775 ppm
CO_2: 13.1 vol.%	HC(FID): 4150 ppm C_1	O_2: 1.70 vol.%

PNA (UV-reading): exhaust gas 8.0 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 Particulate matter (filter): 0.179 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	12.9	11.0	9.35	14.8	10.3	0.92	1.50	µg/test
Cyclones	0.57	0.99	0.54	1.55	0.98	0.052	0.14	µg/test
Sum	13.5	12.0	9.89	16.4	11.3	0.97	1.64	µg/test
%Filter	96	92	95	91	91	95	91	% of sum

MEASUREMENT NO. 18-4A Normal oil temp., without PCV

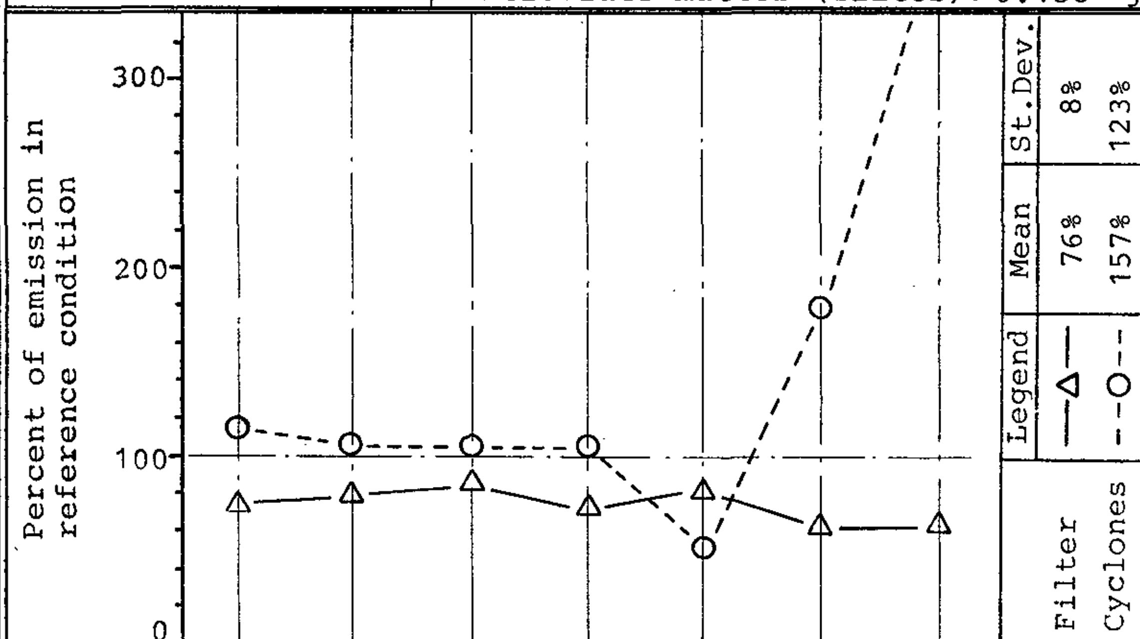
ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 609 C	$T_{ex,t}$: 161 C
	M_F: 2.46 kg/h	M_A: 35.2 kg/h	A/F-ratio: 14.29	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C
	BaP: - µg/ml. Analysis p.: -			Used 2 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.04 vol.%	HC(NDIR): 308 ppm C_6	NO_x: 1625 ppm
CO_2: 13.1 vol.%	HC(FID): 4200 ppm C_1	O_2: 1.65 vol.%
PNA (UV-reading): exhaust gas 7.9 mV. Reference 1.4 mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 34 C	
Dilution ratio: 20	Particulate matter (filter): 0.158 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	12.9	12.5	10.3	16.0	9.56	0.90	1.58	µg/test
Cyclones	1.61	2.13	1.13	2.63	0.84	0.13	0.68	µg/test
Sum	14.5	14.6	11.4	18.6	10.40	1.03	2.26	µg/test
%Filter	89	85	90	86	92	87	70	% of sum

MEASUREMENT NO. 18-4B High oil temperature, without PCV

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 606 C	$T_{ex,t}$: 162 C
	M_F: 2.41 kg/h	M_A: 34.1 kg/h	A/F-ratio: 14.15	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 100 C	
	BaP: - µg/ml. Analysis p.: -		Used 5 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

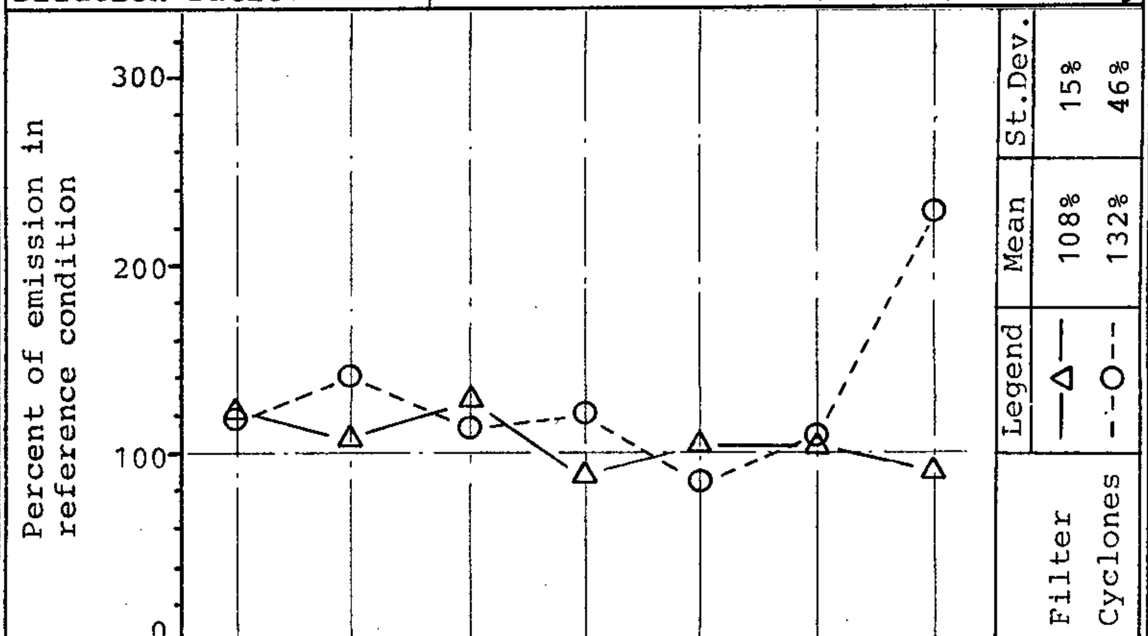
CO: 1.08 vol.%	HC(NDIR): 320 ppm C_6	NO_x: 1550 ppm
CO_2: 13.1 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.60 vol.%

PNA (UV-reading): exhaust gas 9.15 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.182 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	20.5	16.9	15.9	20.0	12.4	1.51	2.14	µg/test
Cyclones	1.67	2.87	1.20	3.00	1.28	0.079	0.37	µg/test
Sum	22.2	19.8	17.1	23.0	13.7	1.59	2.51	µg/test
%Filter	92	85	93	87	91	95	85	% of sum

MEASUREMENT NO. 24-4 Doped lubricant

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 168 C
	M_F: 2.45 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.40	
	T_C: 75 C	P_{amb}: 749 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 84 C	
	BaP: 2.02 µg/ml. Analysis p.: D17		Used 4 h before test	

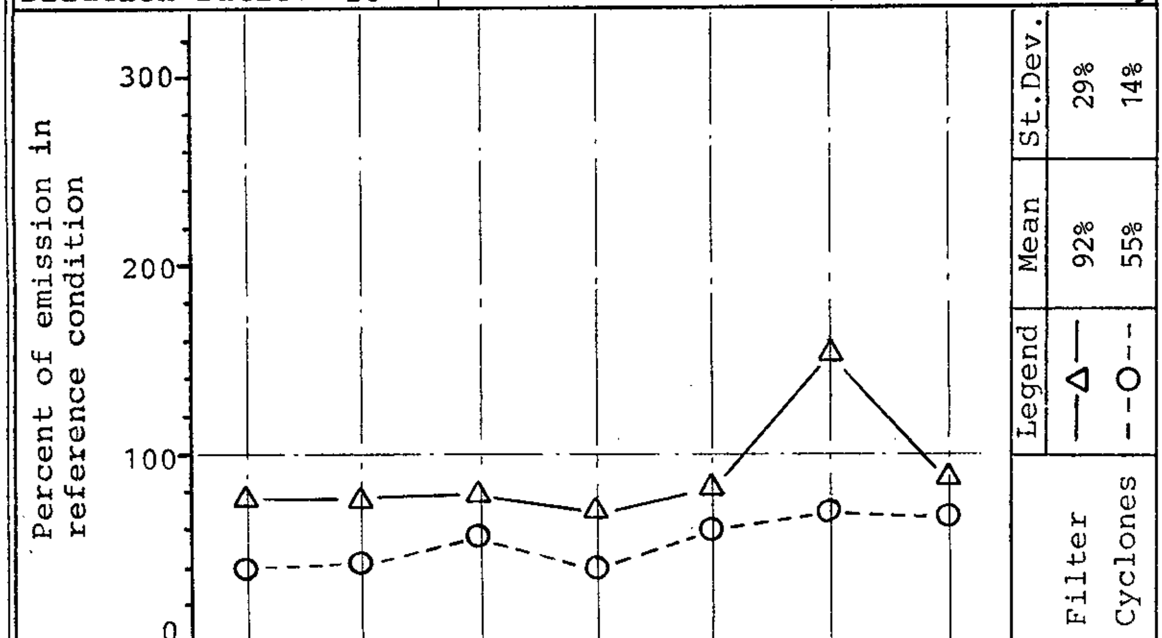
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.32 vol.%	HC(NDIR): 313 ppm C_6	NO_x: 1450 ppm
CO_2: 13.3 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.45 vol.%
PNA (UV-reading): exhaust gas 9.0 mV. Reference 1.8 mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.179 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	13.6	12.5	10.1	15.3	9.63	2.23	2.16	µg/test
Cyclones	0.54	0.91	0.61	0.98	0.89	0.051	0.11	µg/test
Sum	14.1	13.4	11.0	16.3	10.5	2.28	2.27	µg/test
%Filter	96	93	94	94	92	98	95	% of sum

MEASUREMENT NO. 25-4A Doped lubricant, without PCV.

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 162 C
	M_F: 2.46 kg/h	M_A: 36.3 kg/h	A/F-ratio: 14.77	
	T_C: 75 C	P_{amb}: 751 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C
	BaP: 2.02 µg/ml. Analysis p.: D17			Used 4 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

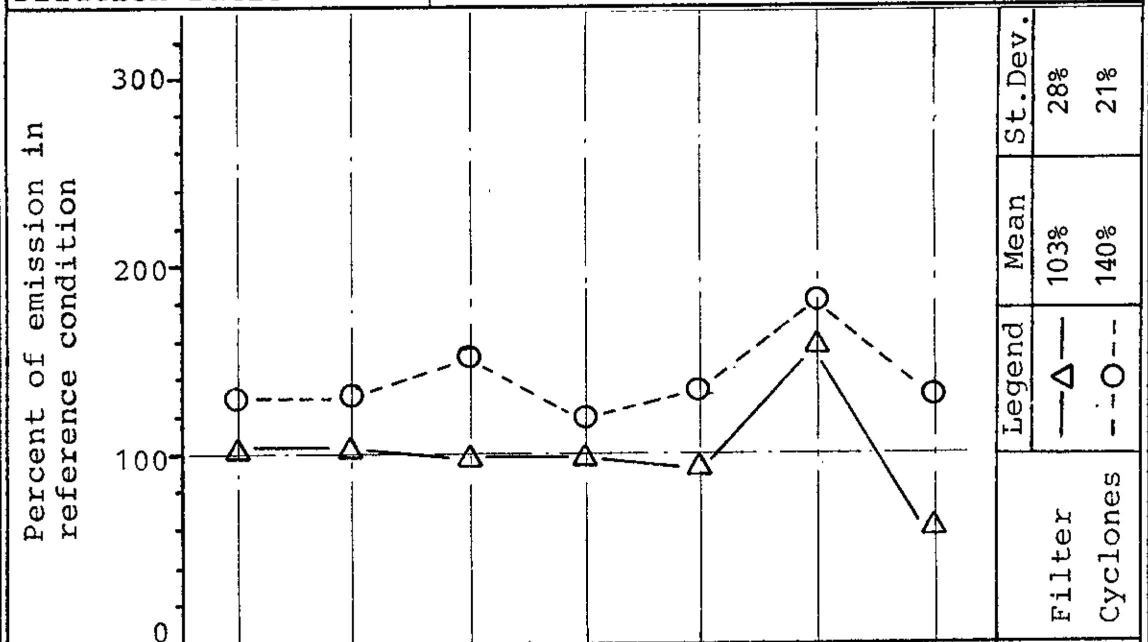
CO: 1.38 vol.%	HC(NDIR): 320 ppm C_6	NO_x: 1575 ppm
CO_2: 13.1 vol.%	HC(FID): 4600 ppm C_1	O_2: 1.40 vol.%

PNA (UV-reading): exhaust gas 10.0 mV. Reference 3.4 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 33 C

Dilution ratio: 20 Particulate matter (filter): 0.202 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	17.5	16.0	12.1	20.9	10.9	2.27	1.50	µg/test
Cyclones	1.81	2.66	1.60	2.98	2.00	0.13	0.21	µg/test
Sum	19.3	18.7	13.7	23.9	12.9	2.40	1.71	µg/test
%Filter	91	86	88	88	85	95	88	% of sum

MEASUREMENT NO. 25-4B Doped lubricant

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 611 C	$T_{ex,t}$: 160 C
	M_F: 2.44 kg/h	M_A: 34.9 kg/h	A/F-ratio: 14.31	
	T_C: 75 C	P_{amb}: 751 mmHg	T_{amb}: 24 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: 2.02 µg/ml. Analysis p.: D17		Used 6 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

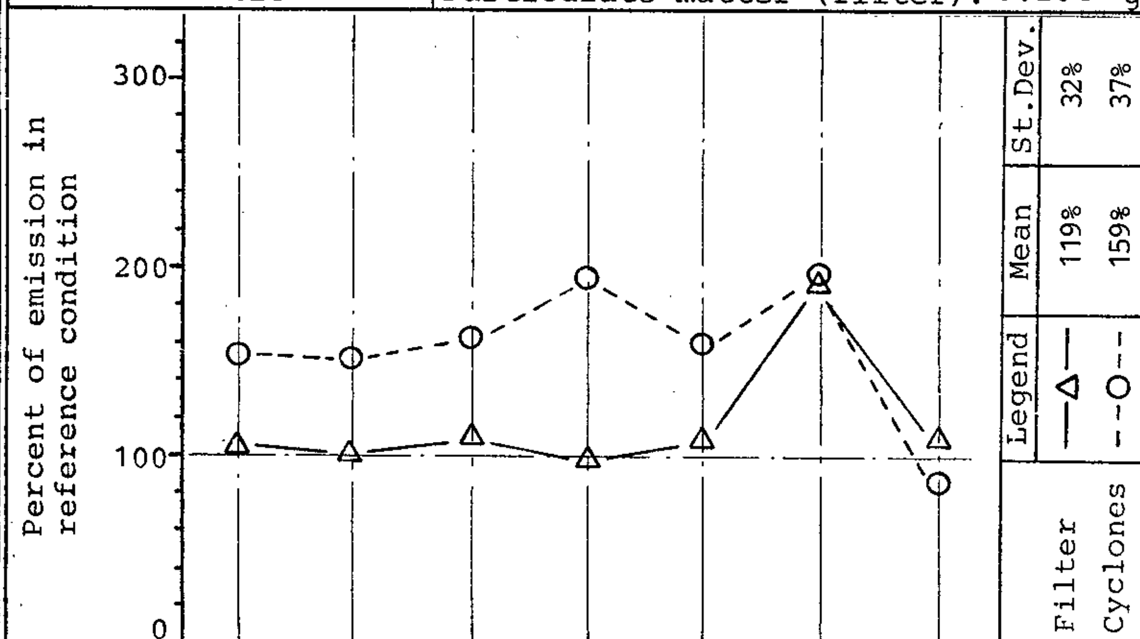
CO: 1.38 vol.%	HC(NDIR): 318 ppm C_6	NO_x: 1575 ppm
CO_2: 13.3 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.30 vol.%

PNA (UV-reading): exhaust gas 10.8 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.204 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	18.4	16.2	13.4	21.4	12.8	2.72	2.61	µg/test
Cyclones	2.16	3.00	1.72	4.84	2.43	0.14	0.14	µg/test
Sum	20.6	19.2	15.1	26.2	15.2	2.86	2.75	µg/test
%Filter	89	84	87	82	84	95	95	% of sum

MEASUREMENT NO. 9-6 Synthetic lubricant

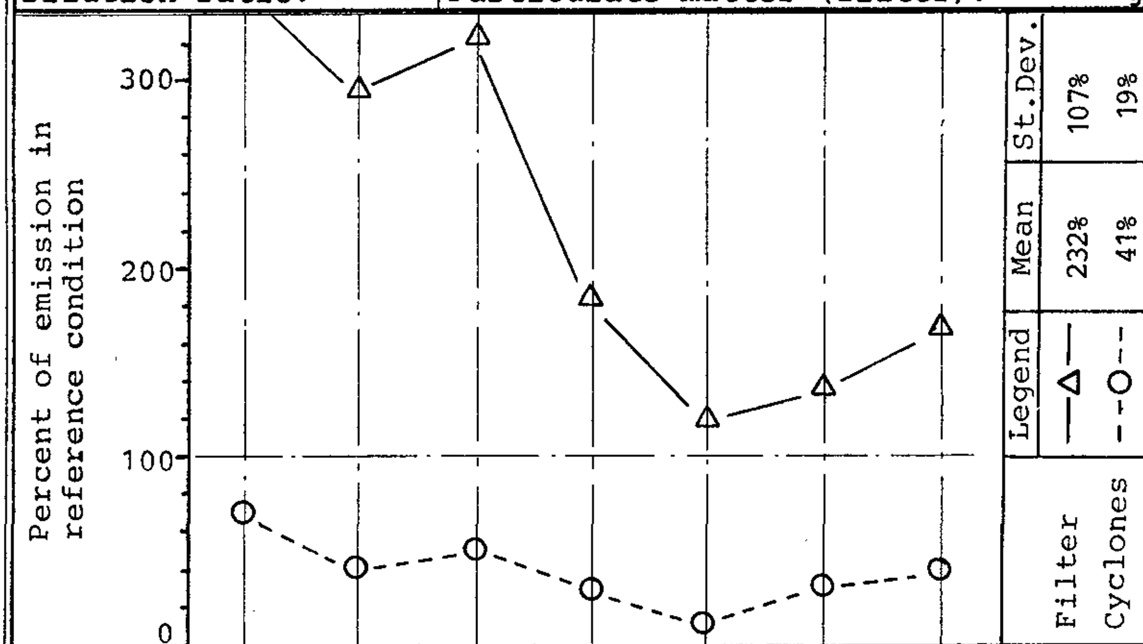
ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 598 C	$T_{ex,t}$: 153 C
	M_F: 2.34 kg/h	M_A: 32.97 kg/h	A/F-ratio: 14.09	
	T_C: 75 C	P_{amb}: 749.9mmHg	T_{amb}: 26 C	Hum.: 38 % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0%
	C_9+C_{10}: 8.8 %	BaP: 0.12 µg/ml. Analysis on page: D.14		
OIL	Type: Enerjet 523		Lubricant temp.: 81C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.7 vol.%	HC(NDIR): 390 ppm C_6	NO_x: 1150 ppm
CO_2: 12.8 vol.%	HC(FID): 5700 ppm C_1	O_2: 1.3 vol.%
PNA (UV-reading): exhaust gas 2.75mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 33 C	
Dilution ratio: 20	Particulate matter (filter): 0.591 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	67.4	46.0	38.8	39.6	14.1	1.98	3.89	µg/test
Cyclones	1.02	0.91	0.55	0.77	0.20	0.023	0.063	µg/test
Sum	68.4	46.9	39.4	40.4	14.3	2.00	3.95	µg/test
%Filter	99	98	99	98	99	99	98	% of sum

MEASUREMENT NO. 12-6 Synthetic lubricant

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 594 C	$T_{ex,t}$: 153 C
	M_F: 2.23 kg/h	M_A: 33.15 kg/h	A/F-ratio: 14.87	
	T_C: 75 C	P_{amb}: 746.8mmHg	T_{amb}: 24.5C	Hum.: 47 % rel.
FUEL	Type: DTH Test Fuel A2			0.4 g Pb/litre
	0 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 0%	BaP: 0.003 µg/ml. Analysis on page: D.14		
OIL	Type: Enerjet 523		Lubricant temp.: 82 C	
	BaP: 0.38 µg/ml. Analysis p.: D17		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

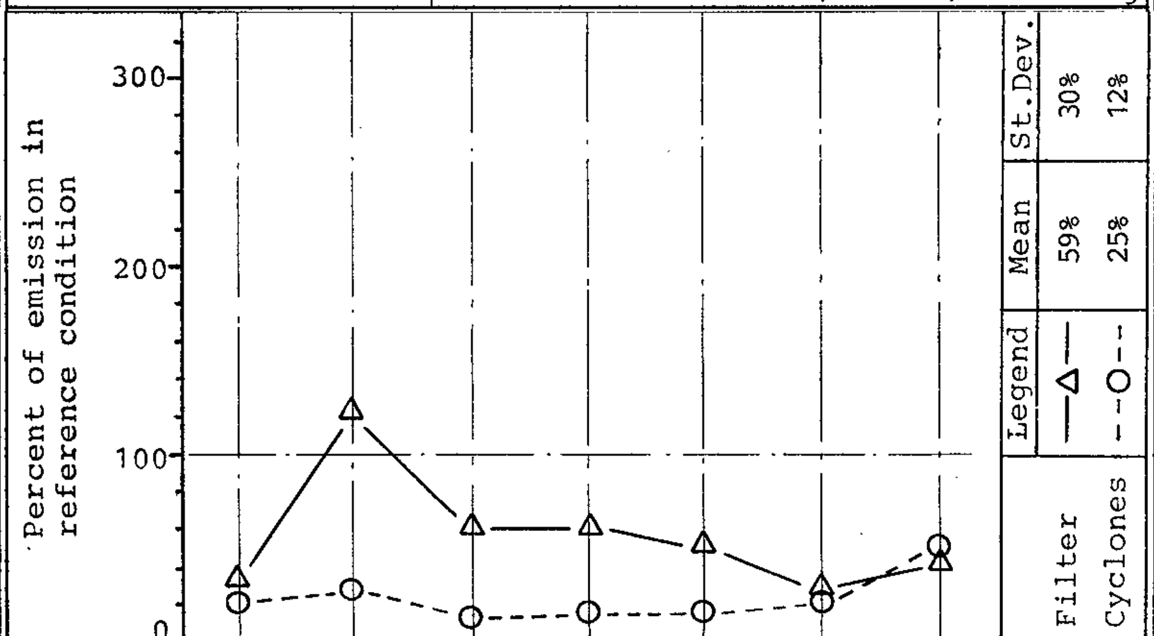
CO: 1.7 vol.%	HC(NDIR): 540 ppm C_6	NO_x: 775 ppm
CO_2: 12.0 vol.%	HC(FID): 5600 ppm C_1	O_2: 1.4 vol.%

PNA (UV-reading): exhaust gas 0.65mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 32 C

Dilution ratio: 20 Particulate matter (filter): 0.497 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	5.87	18.8	7.41	13.2	6.58	0.45	1.01	µg/test
Cyclones	0.34	0.58	0.18	0.40	0.21	0.018	0.080	µg/test
Sum	6.21	19.4	7.59	13.6	6.79	0.047	1.09	µg/test
%Filter	95	97	98	97	97	96	93	% of sum

MEASUREMENT NO. 2-5 Aromatic content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 602 C	$T_{ex,t}$: 165 C
	M_F: 2.34 kg/h	M_A: 34.46 kg/h	A/F-ratio: 14.73	
	T_C: 75 C	P_{amb}: 751 mmHg	T_{amb}: 24 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel A2			0.4 g Pb/litre
	0 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 0 %	BaP: 0.003 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C
	BaP: - µg/ml. Analysis p.: -			Used 4 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

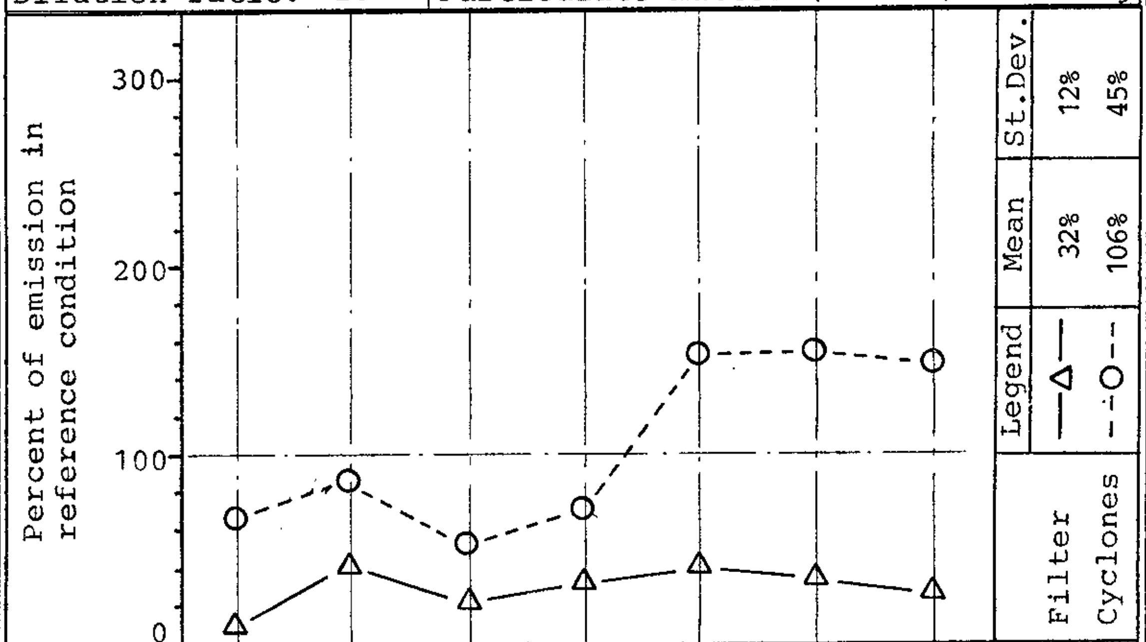
CO: 1.36 vol.%	HC(NDIR): 485 ppm C_6	NO_x: 1125 ppm
CO_2: 11.9 vol.%	HC(FID): 4850 ppm C_1	O_2: 1.4 vol.%

PNA (UV-reading): exhaust gas 2.75 mV. Reference 4.3 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 31 C

Dilution ratio: 20 Particulate matter (filter): 0.187 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	2.01	6.97	2.96	8.05	4.98	0.49	0.65	µg/test
Cyclones	0.96	1.74	0.60	1.74	2.26	0.11	0.24	µg/test
Sum	2.97	8.71	3.56	9.79	7.24	0.60	0.89	µg/test
%Filter	68	77	83	82	69	82	73	% of sum

MEASUREMENT NO. 5-5 Aromatic content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 606 C	$T_{ex,t}$: 165 C
	M_F: 2.37 kg/h	M_A: 34.8 kg/h	A/F-ratio: 14.67	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 24 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel A1 & A2 Mixture			0.4 g Pb/litre
	15 vol.% Aromates	C_6: 1.2 %	C_7: 4.5 %	C_8: 6.0 %
	C_9+C_{10}: 3.3 %	BaP: 0.04 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

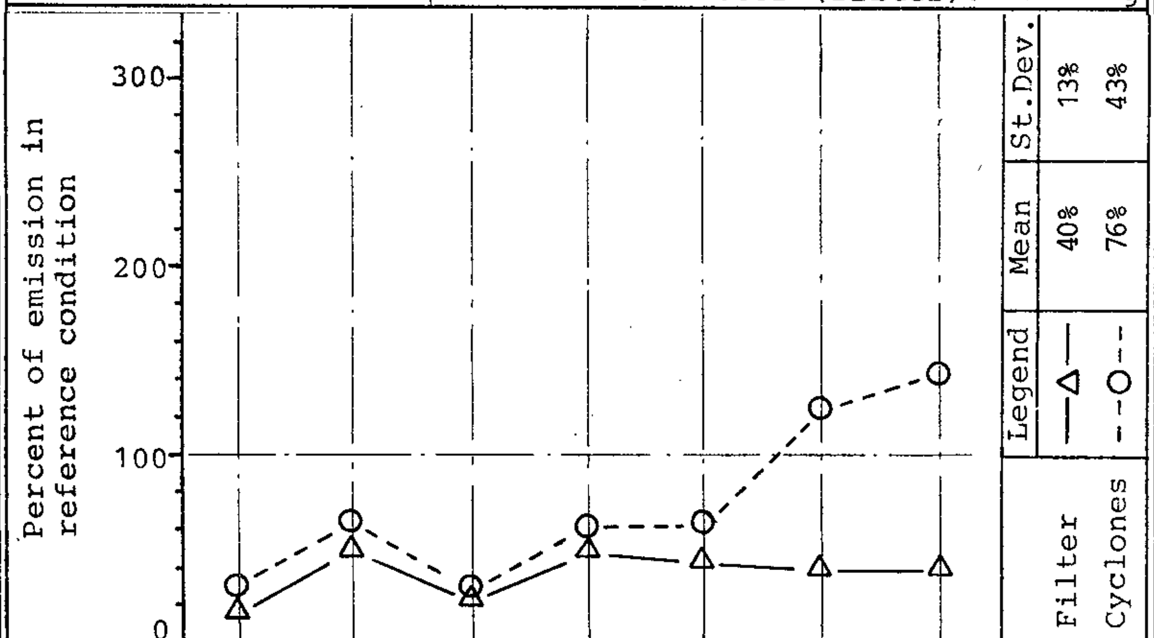
CO: 1.38 vol.%	HC(NDIR): 420 ppm C_6	NO_x: 1250 ppm
CO_2: 12.6 vol.%	HC(FID): 4700 ppm C_1	O_2: 1.4 vol.%

PNA (UV-reading): exhaust gas 2.25 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 32 C

Dilution ratio: 20 | Particulate matter (filter): 0.173 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	3.26	7.98	3.06	11.2	5.34	0.60	1.06	µg/test
Cyclones	0.44	1.38	0.34	1.60	0.99	0.089	0.23	µg/test
Sum	3.70	9.36	3.40	12.8	6.33	0.69	1.29	µg/test
%Filter	88	85	90	88	84	87	82	% of sum

MEASUREMENT NO. 3-5 Aromatic content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 608 C	$T_{ex,t}$: 164 C
	M_F: 2.43 kg/h	M_A: 34.9 kg/h	A/F-ratio: 14.36	
	T_C: 75 C	P_{amb}: 757 mmHg	T_{amb}: 24 C	Hum.: 25 % rel.
FUEL	Type: DTH Test Fuel A1 & A2 Mixture			0.4 g Pb/litre
	30 vol.% Aromates	C_6: 2.4 %	C_7: 9.0 %	C_8: 12.0 %
	C_9+C_{10}: 6.6 %	BaP: 0.08 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

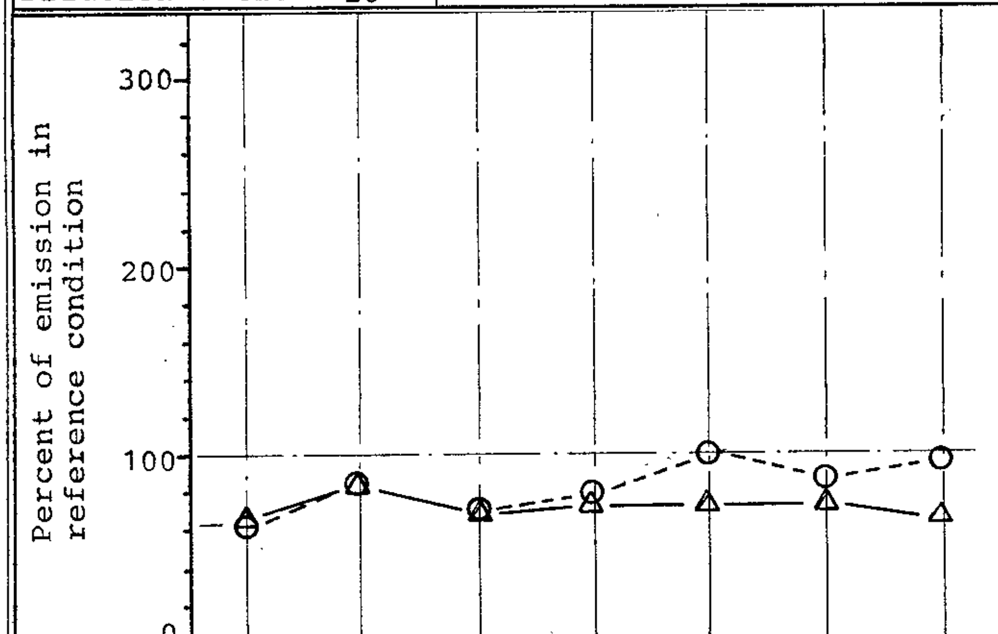
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.36 vol.%	HC(NDIR): 373 ppm C_6	NO_X: 1375 ppm
CO_2: 12.8 vol.%	HC(FID): 4800 ppm C_1	O_2: 1.4 vol.%
PNA (UV-reading): exhaust gas 5.5 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 32 C

Dilution ratio: 20 Particulate matter (filter): 0.198 g



	Filter	Cyclones
Legend	—△—	--○--
Mean	73%	84%
St.Dev.	6%	13%

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	11.3	12.9	8.47	15.8	8.94	1.08	1.60	µg/test
Cyclones	0.90	1.79	0.73	2.01	1.46	0.065	0.15	µg/test
Sum	12.2	14.7	9.20	17.8	10.4	1.15	1.75	µg/test
%Filter	93	88	92	89	86	94	91	% of sum

MEASUREMENT NO. 1-5 Aromatic content variation

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 612 C	$T_{ex,t}$: 162 C
M_F: 2.47 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.27	
T_C: 75 C	P_{amb}: 752 mmHg	T_{amb}: 23 C	Hum.: - % rel.

FUEL

Type: DTH Test Fuel A1			0.4 g Pb/litre
60 vol.% Aromates	C_6: 4.8 %	C_7: 18.0 %	C_8: 24.0 %
C_9+C_{10}: 13.2 %	BaP: 0.16 µg/ml. Analysis on page: -		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 82 C
BaP: - µg/ml. Analysis p.: -	Used 4 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

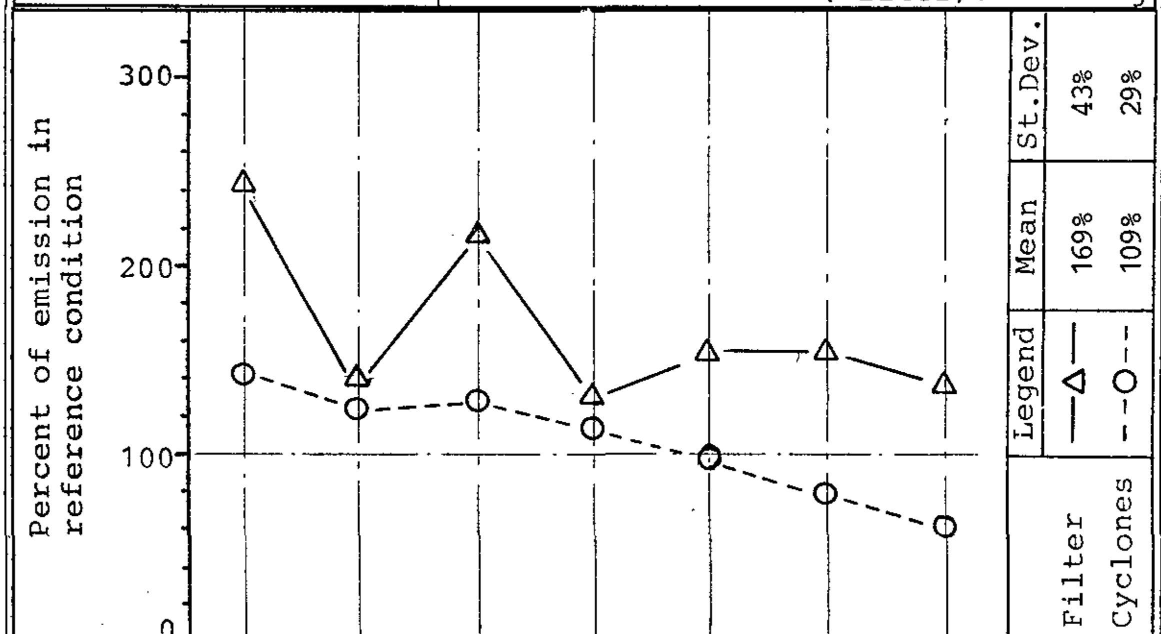
CO: 1.19 vol.%	HC(NDIR): 265 ppm C_6	NO_x: 1700 ppm
CO_2: 13.7 vol.%	HC(FID): 4400 ppm C_1	O_2: 1.40 vol.%

PNA (UV-reading): exhaust gas 3.1 mV. Reference 0.8 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 32 C

Dilution ratio: 20 | Particulate matter (filter): 0.190 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	40.8	21.9	26.2	29.3	17.9	2.23	3.29	µg/test
Cyclones	2.01	2.53	1.37	2.89	1.45	0.060	0.10	µg/test
Sum	42.8	24.4	27.6	32.2	19.4	2.29	3.39	µg/test
%Filter	95	90	95	91	93	97	97	% of sum

MEASUREMENT NO. 8-5A C_6 aromat only

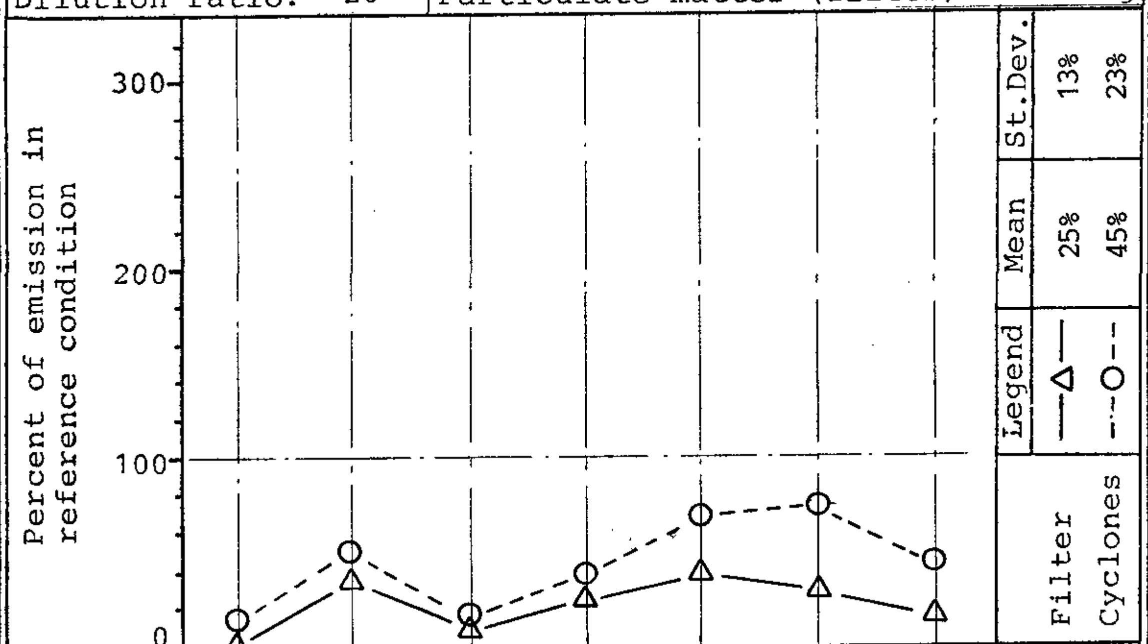
ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 606 C	$T_{ex,t}$: 168 C
	M_F: 2.44 kg/h	M_A: 35.5 kg/h	A/F-ratio: 14.57	
	T_C: 75 C	P_{amb}: 753 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel A3			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 40 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 0 %	BaP: 0.004 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 84 C	
	BaP: - µg/ml. Analysis p.:		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.10 vol.%	HC (NDIR): 235 ppm C_6	NO_x: 1825 ppm
CO_2: 13.6 vol.%	HC (FID): 4300 ppm C_1	O_2: 1.45 vol.%
PNA (UV reading): exhaust gas 1.25 mV. Reference - mV		

PARTICULATE/PAH EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 33 C	
Dilution ratio: 20	Particulate matter (filter): 0.154 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	0.81	5.62	1.25	5.77	4.73	0.47	0.51	µg/test
Cyclones	0.21	1.00	0.20	0.99	1.07	0.053	0.070	µg/test
Sum	1.02	6.62	1.45	6.76	5.80	0.52	0.58	µg/test
%Filter	79	85	86	85	82	90	88	% of sum

MEASUREMENT NO. 8-5B C_6 aromat only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 606 C	$T_{ex,t}$: 167 C
	M_F: 2.44 kg/h	M_A: 35.2 kg/h	A/F-ratio: 14.44	
	T_C: 75 C	P_{amb}: 753 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel A3			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 40 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 0 %	BaP: 0.004 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 6 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

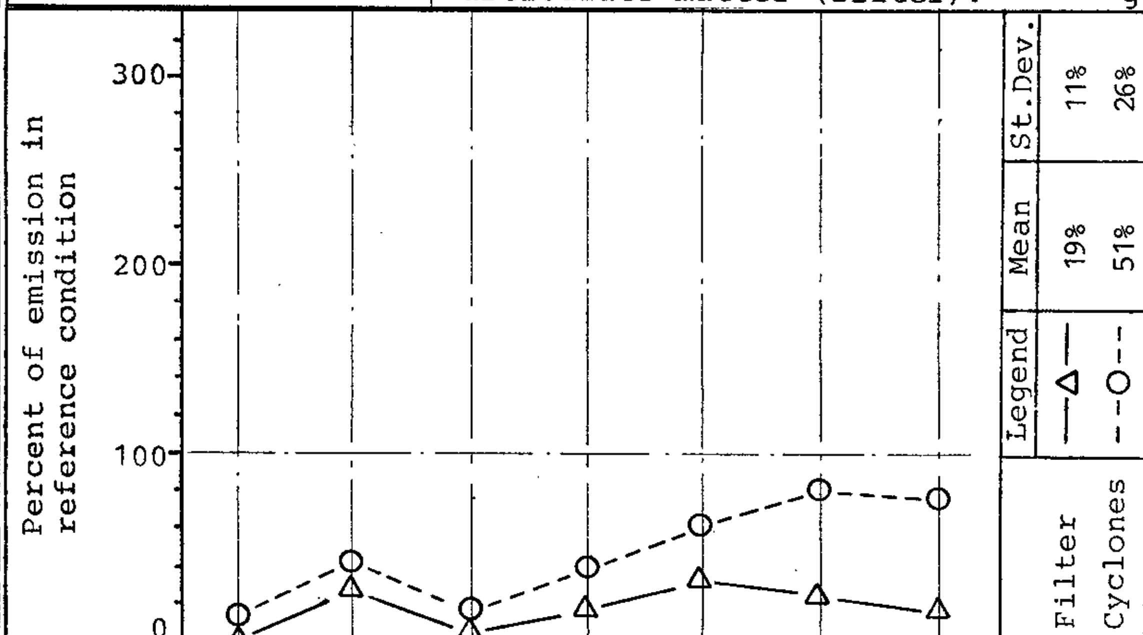
CO: 1.10 vol.%	HC (NDIR): 235 ppm C_6	NO_x: 1900 ppm
CO_2: 13.6 vol.%	HC (FID): 4200 ppm C_1	O_2: 1.45 vol.%

PNA (UV-reading): exhaust gas 1.25 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.134 g



Amount of PAH collected	Anthracene	Fluoranthene	1-Methylanthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	0.60	4.02	0.83	3.91	3.99	0.38	0.44	µg/test
Cyclones	0.24	0.99	0.21	1.08	0.94	0.058	0.13	µg/test
Sum	0.84	5.01	1.04	4.99	4.93	0.44	0.57	µg/test
%Filter	71	80	80	78	81	87	77	% of sum

MEASUREMENT NO. 10-5A C_7 aromat only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 612 C	$T_{ex,t}$: 164 C
	M_F: 2.47 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.30	
	T_C: 75 C	P_{amb}: 766 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A4			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 40 %	C_8: 0 %
	C_9+C_{10}: 0 %	BaP: 0.010 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

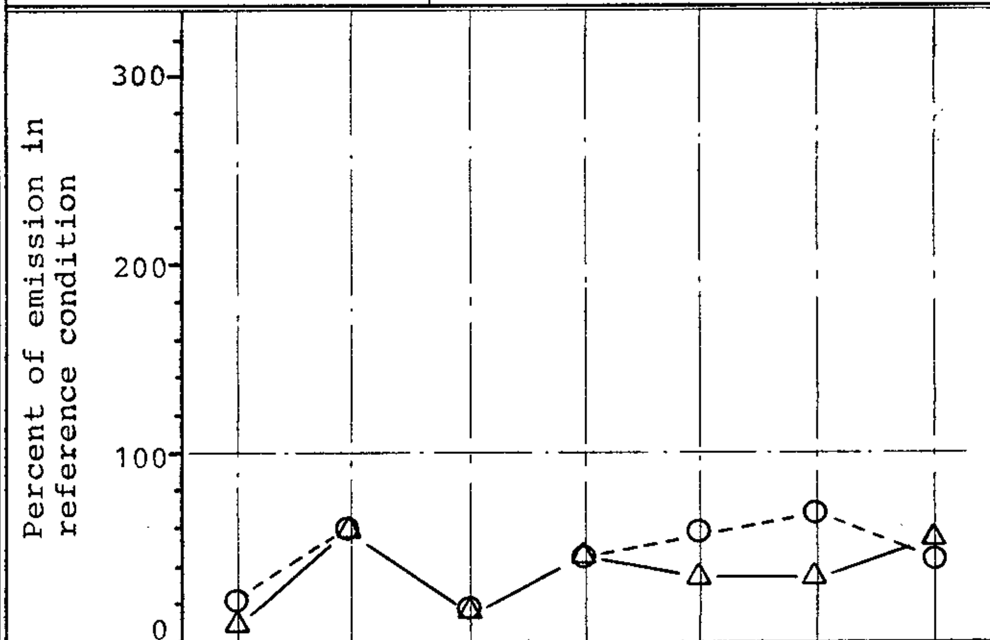
CO: 1.36 vol.%	HC(NDIR): 295 ppm C_6	NO_x: 1575 ppm
CO_2: 13.1 vol.%	HC(FID): 4350 ppm C_1	O_2: 1.2 vol.%

PNA (UV-reading): exhaust gas 0.24 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature - C

Dilution ratio: 20 Particulate matter (filter): 0.163 g



	St.Dev.	Mean	Legend
Filter	18%	41%	—△—
Cyclones	19%	47%	--○--

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	2.00	8.99	2.18	10.6	5.21	0.65	1.35	µg/test
Cyclones	0.31	1.24	0.22	1.13	0.87	0.051	0.075	µg/test
Sum	2.31	10.2	2.40	11.7	6.08	0.70	1.43	µg/test
%Filter	87	88	91	90	86	93	95	% of sum

MEASUREMENT NO. 10-5B C_7 aromat only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 611 C	$T_{ex,t}$: 164 C
	M_F: 2.47 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.30	
	T_C: 75 C	P_{amb}: 766 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A4			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 40 %	C_8: 0 %
	C_9+C_{10}: 0 %	BaP: 0.010 µg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 82 C
	BaP: - µg/ml. Analysis p.: -			Used 6 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

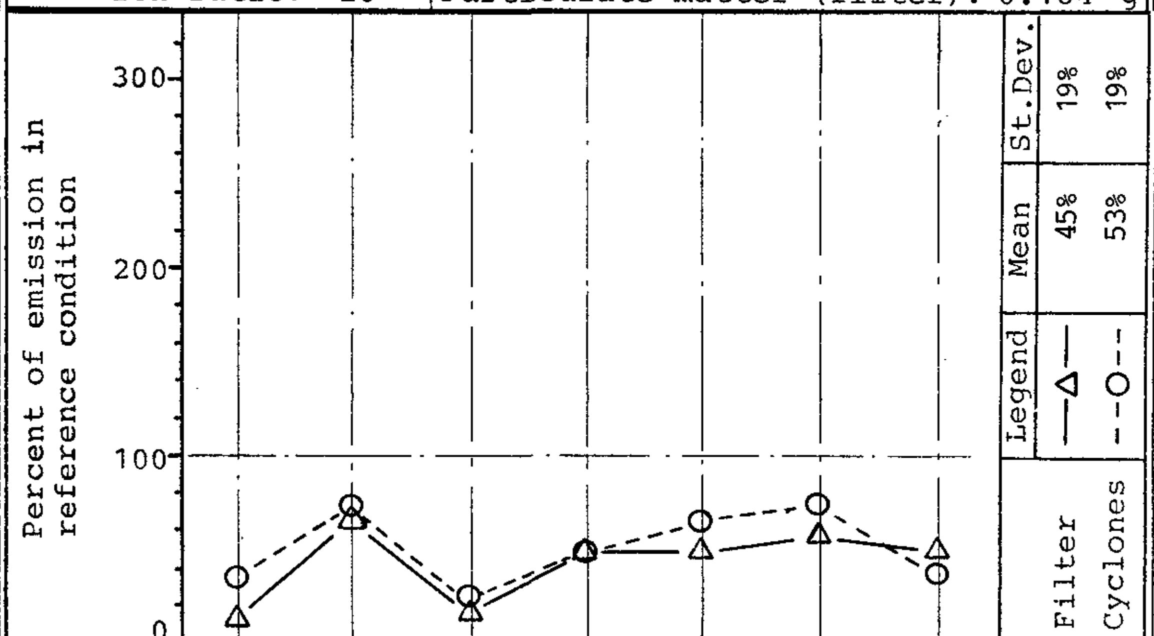
CO: 1.42 vol.%	HC(NDIR): 318 ppm C_6	NO_x: 1650 ppm
CO_2: 13.1 vol.%	HC(FID): 4150 ppm C_1	O_2: 1.2 vol.%

PNA (UV-reading): exhaust gas 0.30 mV. Reference 0.3 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.184 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	2.66	10.4	2.40	10.7	6.18	0.83	1.17	µg/test
Cyclones	0.48	1.48	0.31	1.31	0.99	0.053	0.065	µg/test
Sum	3.14	11.9	2.71	12.0	7.17	0.88	1.24	µg/test
%Filter	85	88	89	89	86	94	95	% of sum

MEASUREMENT NO. 11-5A C_8 aromats only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 613 C	$T_{ex,t}$: 163 C
	M_F: 2.44 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.48	
	T_C: 75 C	P_{amb}: 765 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A5			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 40 %
	C_9+C_{10}: 0 %	BaP: 0.0008 μg/ml. Analysis on page: D.14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - μg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

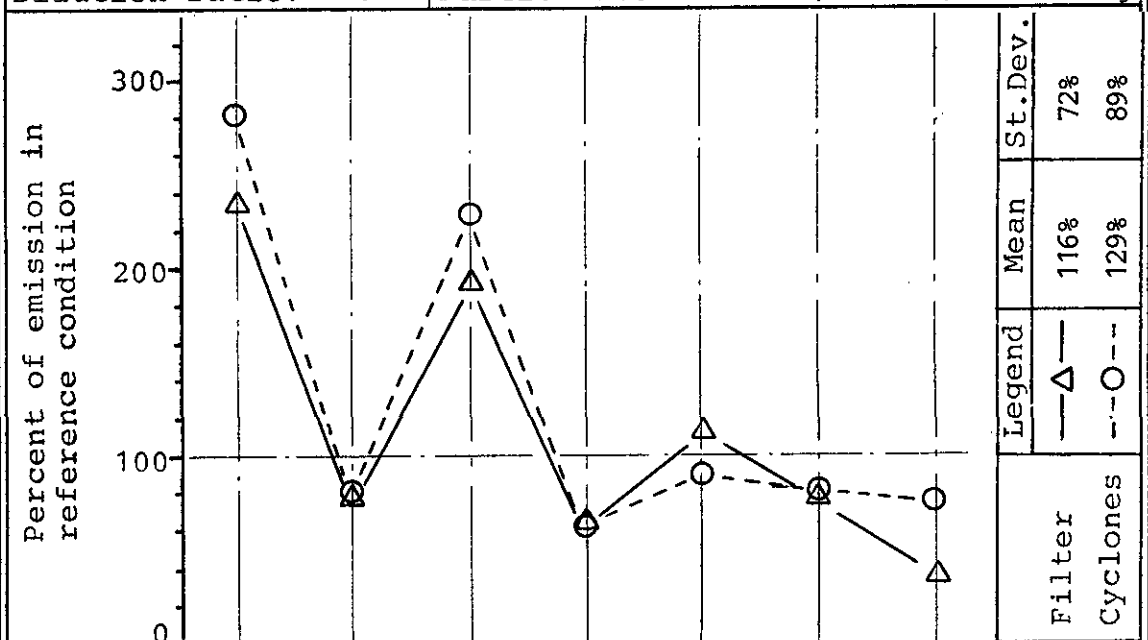
CO: 1.10 vol.%	HC (NDIR): 315 ppm C_6	NO_x: 1450 ppm
CO_2: 13.1 vol.%	HC (FID): 4300 ppm C_1	O_2: 1.25 vol.%

PNA (UV-reading): exhaust gas 11.6 mV. Reference 3.2 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.174 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	39.8	12.0	23.5	14.6	13.6	1.12	0.97	μg/test
Cyclones	3.96	1.67	2.42	1.54	1.34	0.058	0.12	μg/test
Sum	43.7	14.1	25.9	16.1	14.9	1.17	1.09	μg/test
%Filter	91	88	91	90	91	95	89	% of sum

MEASUREMENT NO. 11-5B C_8 aromats only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 614 C	$T_{ex,t}$: 164 C
	M_F: 2.43 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.53	
	T_C: 75 C	P_{amb}: 765 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A5			0.4g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 40 %
	C_9+C_{10}: 0 %	BaP: 0.0008 µg/ml.	Analysis on page: D.14	
OIL	Type: BP Visco 2000 Sport 15w-50			Lubricant temp.: 83 C
	BaP: - µg/ml. Analysis p.: -			Used 6 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

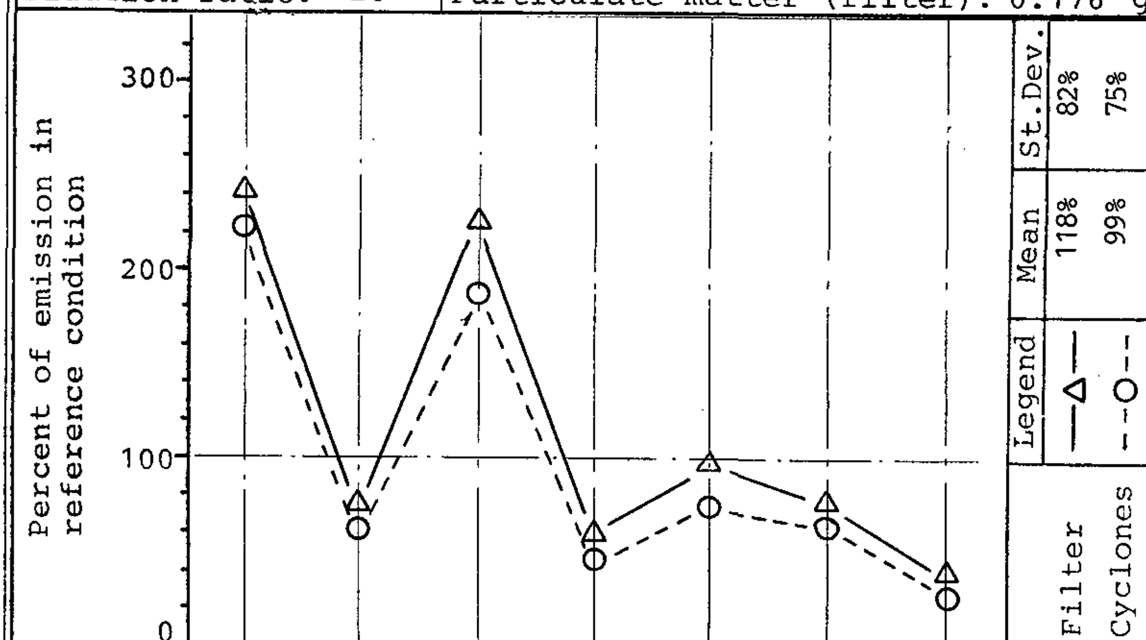
CO: 1.10 vol.%	HC(NDIR): 330 ppm C_6	NO_x: 1450 ppm
CO_2: 13.1 vol.%	HC(FID): 4550 ppm C_1	O_2: 1.23 vol.%

PNA (UV-reading): exhaust gas 12.2 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.176 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	40.8	12.1	27.3	13.3	11.8	1.12	0.96	µg/test
Cyclones	3.13	1.26	1.97	1.22	1.13	0.047	0.043	µg/test
Sum	43.9	13.4	29.3	14.5	12.9	1.17	1.00	µg/test
%Filter	93	91	93	92	91	96	96	% of sum

MEASUREMENT NO. 9-5A $C_9 + C_{10}$ aromats only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 614 C	$T_{ex,t}$: 167 C
	M_F: 2.42 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.46	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A6			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 40 %	BaP: 0.48 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

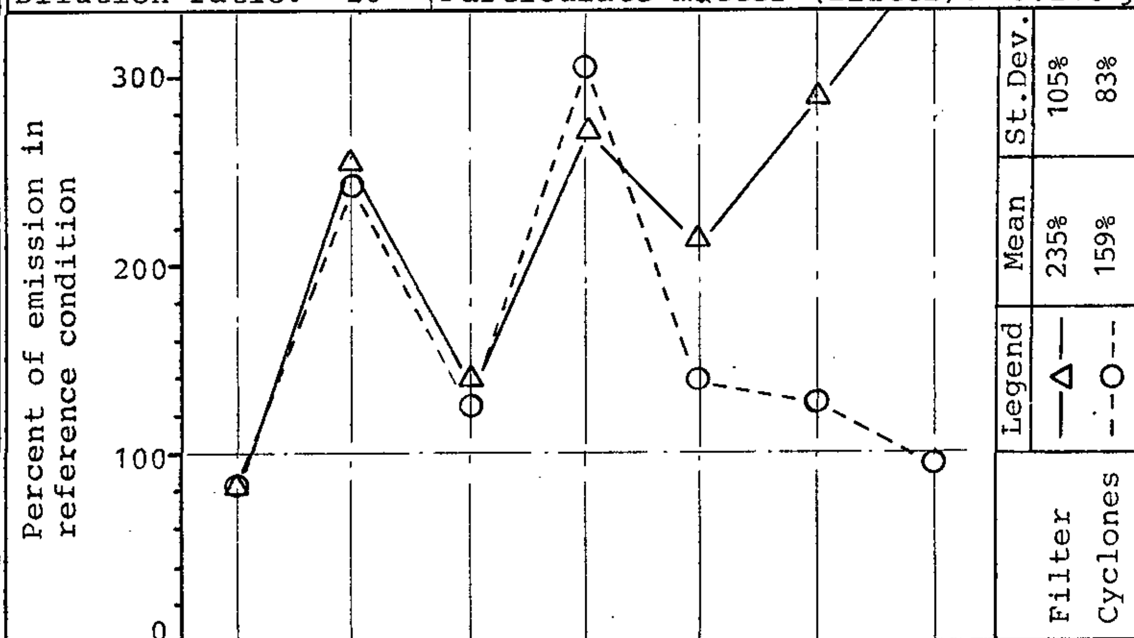
CO: 1.00 vol.%	HC(NDIR): 245 ppm C_6	NO_x: 1575 ppm
CO_2: 13.6 vol.%	HC(FID): 4400 ppm C_1	O_2: 1.15 vol.%

PNA (UV-reading): exhaust gas 6.5 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.216 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	13.8	39.3	16.4	58.0	25.2	4.12	9.49	µg/test
Cyclones	1.17	4.86	1.32	7.57	2.08	.089	0.15	µg/test
Sum	15.0	44.2	17.7	65.6	27.3	4.21	9.64	µg/test
%Filter	92	89	93	88	88	98	98	% of sum

MEASUREMENT NO. 9-5B $C_9 + C_{10}$ aromats only

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 614 C	$T_{ex,t}$: 168 C
	M_F: 2.42 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.46	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 25 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel A6			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 0 %	C_7: 0 %	C_8: 0 %
	C_9+C_{10}: 40 %	BaP: 0.48 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 82 C	
	BaP: - µg/ml. Analysis p.: -		Used 6 h before test	

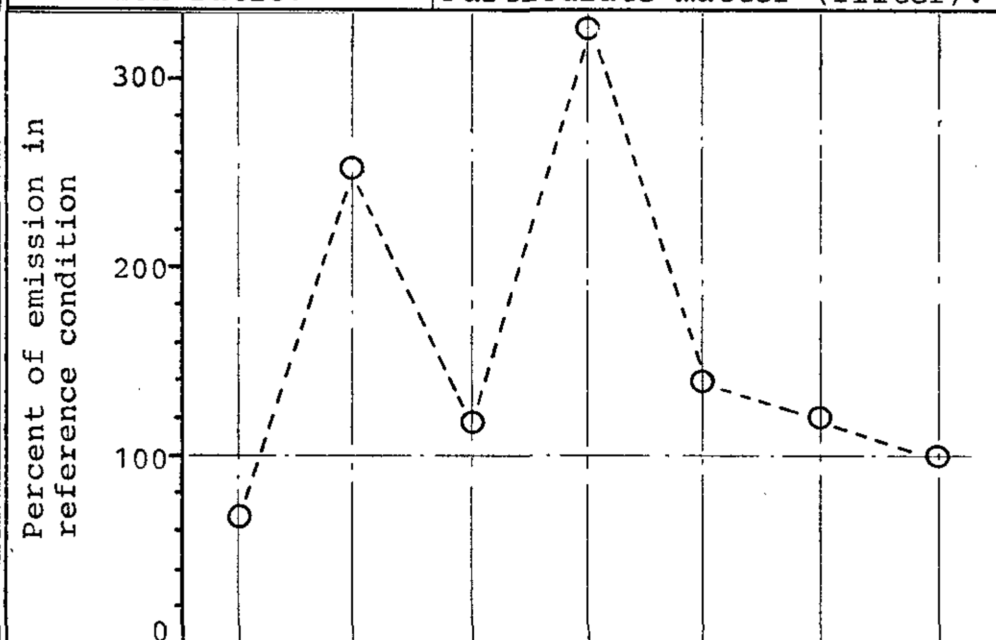
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.04 vol.%	HC(NDIR): 355 ppm C_6	NO_x: 1700 ppm
CO_2: 13.6 vol.%	HC(FID): 4500 ppm C_1	O_2: 1.20 vol.%
PNA (UV-reading): exhaust gas 4.3 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.225 g



St.Dev. 93%

Mean 161%

Legend: —△— Filter; --○-- Cyclones

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter			Test sample lost					µg/test
Cyclones	1.00	5.02	1.24	8.14	2.04	0.086	0.16	µg/test
Sum								µg/test
%Filter								% of sum

MEASUREMENT NO. 27-4A Doped fuel

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 163 C
	M_F: 2.42 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.47	
	T_C: 75 C	P_{amb}: 756 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 2.81 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

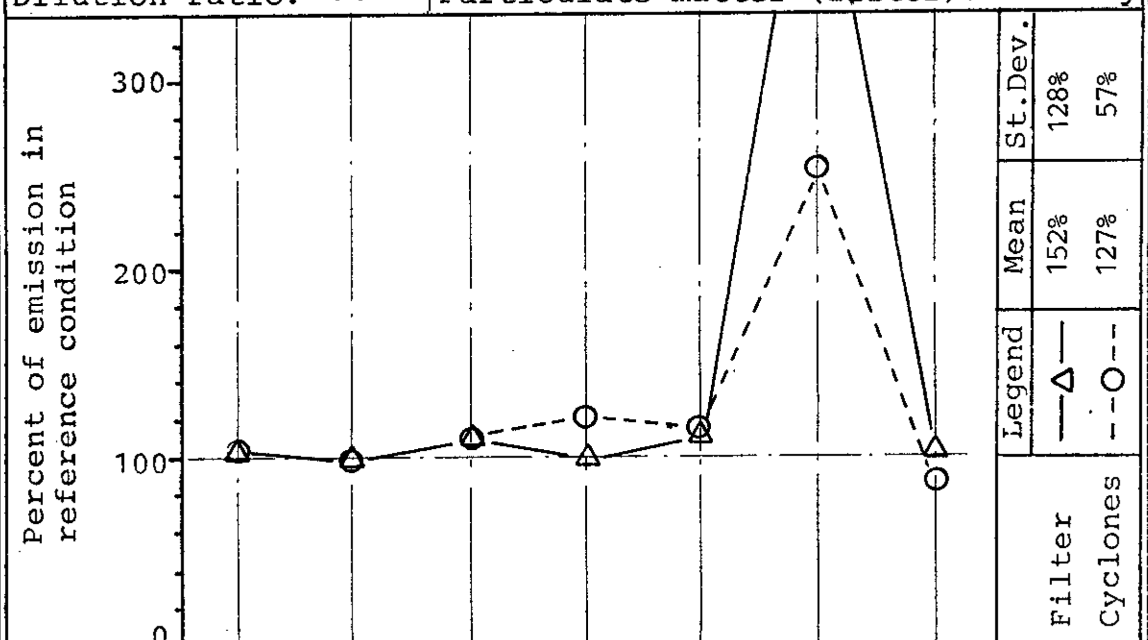
CO: 1.25 vol.%	HC(NDIR): 295 ppm C_6	NO_x: 1600 ppm
CO_2: 13.3 vol.%	HC(FID): 4350 ppm C_1	O_2: 1.50 vol.%

PNA (UV-reading): exhaust gas 3.8 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.178 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	17.7	15.6	12.6	21.0	13.1	6.31	2.43	µg/test
Cyclones	1.44	1.98	1.16	3.02	1.68	0.18	0.14	µg/test
Sum	19.1	17.8	13.8	24.0	14.8	6.49	2.57	µg/test
%Filter	92	89	92	87	89	97	95	% of sum

MEASUREMENT NO. 27-4B Doped fuel

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 611 C	$T_{ex,t}$: 161 C
	M_F: 2.43 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.41	
	T_C: 75 C	P_{amb}: 756 mmHg	T_{amb}: 23 C	Hum.: - % rel.
FUEL	Type: DTH Base Fuel A			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 2.81 µg/ml. Analysis on page: D14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 6 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

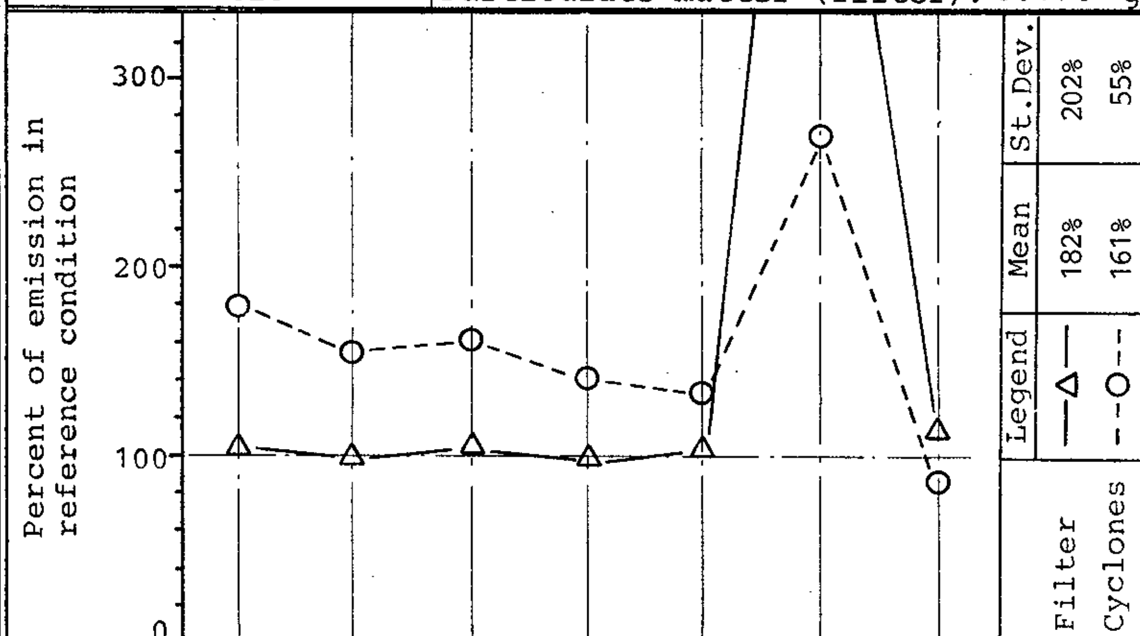
CO: 1.22 vol.%	HC(NDIR): 293 ppm C_6	NO_x: 1560 ppm
CO_2: 13.3 vol.%	HC(FID): 4350 ppm C_1	O_2: 1.45 vol.%

PNA (UV-reading): exhaust gas 3.7 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 33 C

Dilution ratio: 20 | Particulate matter (filter): 0.174 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	17.8	15.5	12.9	20.9	12.7	9.15	2.67	µg/test
Cyclones	2.50	3.09	1.72	3.56	2.00	0.19	0.14	µg/test
Sum	20.3	18.6	14.6	24.5	14.7	9.34	2.81	µg/test
%Filter	88	83	88	85	86	98	95	% of sum

MEASUREMENT NO. 18-5B Lead content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 615 C	$T_{ex,t}$: 162 C
	M_F: 2.47 kg/h	M_A: 35.14 kg/h	A/F-ratio: 14.23	
	T_C: 75 C	P_{amb}: 760 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel Pb1			0 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 85 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

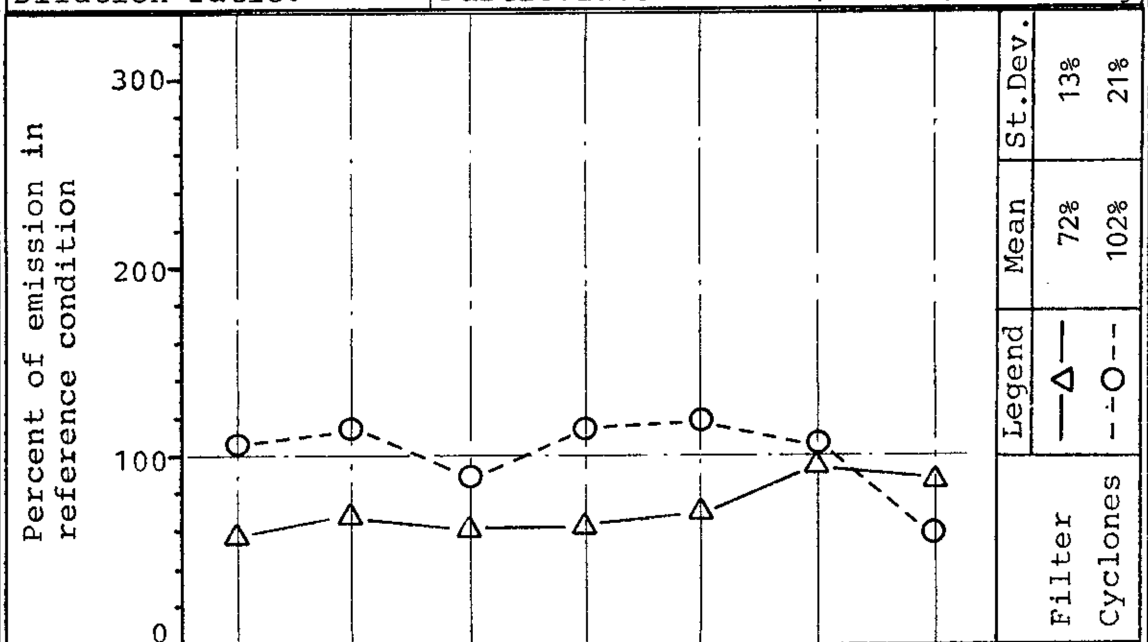
CO: 1.25 vol.%	HC (NDIR): 325 ppm C_6	NO_X: 1500 ppm
CO_2: 12.9 vol.%	HC (FID): 4200 ppm C_1	O_2: 1.25 vol.%

PNA (UV-reading): exhaust gas 1 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.092 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	10.2	10.7	7.45	13.6	8.28	1.34	2.07	µg/test
Cyclones	1.49	2.29	0.97	2.89	1.76	0.076	0.094	µg/test
Sum	11.7	13.0	8.42	16.5	10.0	1.42	2.16	µg/test
%Filter	87	82	88	83	82	95	96	% of sum

MEASUREMENT NO. 12-5B Lead content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 613 C	$T_{ex,t}$: 165 C
	M_F: 2.46 kg/h	M_A: 35.0 kg/h	A/F-ratio: 14.22	
	T_C: 75 C	P_{amb}: 754 mmHg	T_{amb}: 24 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel Pb1 &Pb2 Mixture			0.2 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 4h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

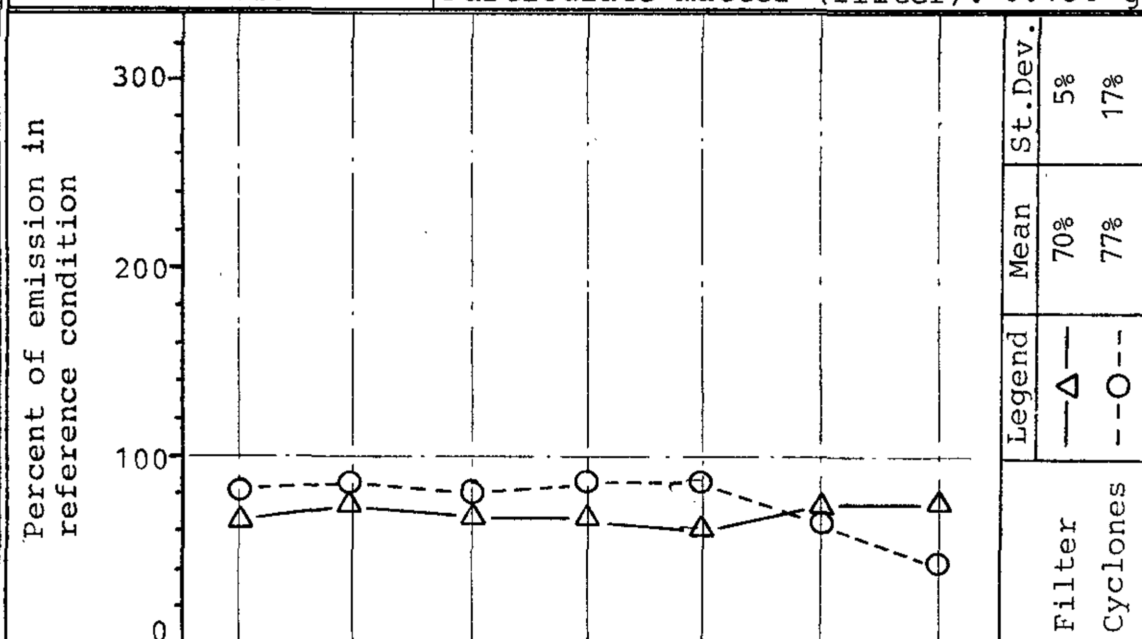
CO: 1.30 vol.%	HC(NDIR): 315 ppm C_6	NO_x: 1525 ppm
CO_2: 13.1 vol.%	HC(FID): 4300 ppm C_1	O_2: 1.48 vol.%

PNA (UV-reading): exhaust gas 4.4 mV. Reference 1.2 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.154 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	11.2	11.6	8.33	14.2	7.36	1.07	1.74	µg/test
Cyclones	1.14	1.77	0.86	2.18	1.27	0.049	0.068	µg/test
Sum	12.3	13.4	9.19	16.4	9.13	1.12	1.81	µg/test
%Filter	91	87	91	87	86	96	96	% of sum

MEASUREMENT NO. 19-5A Lead content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 161 C
	M_F: 2.47 kg/h	M_A: 35.14 kg/h	A/F-ratio: 14.23	
	T_C: 75 C	P_{amb}: 759 mmHg	T_{amb}: 25 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel Pb1 & Pb2 Mixture			0.4 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page:		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 85 C	
	BaP: - µg/ml. Analysis p.: -		Used 4h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

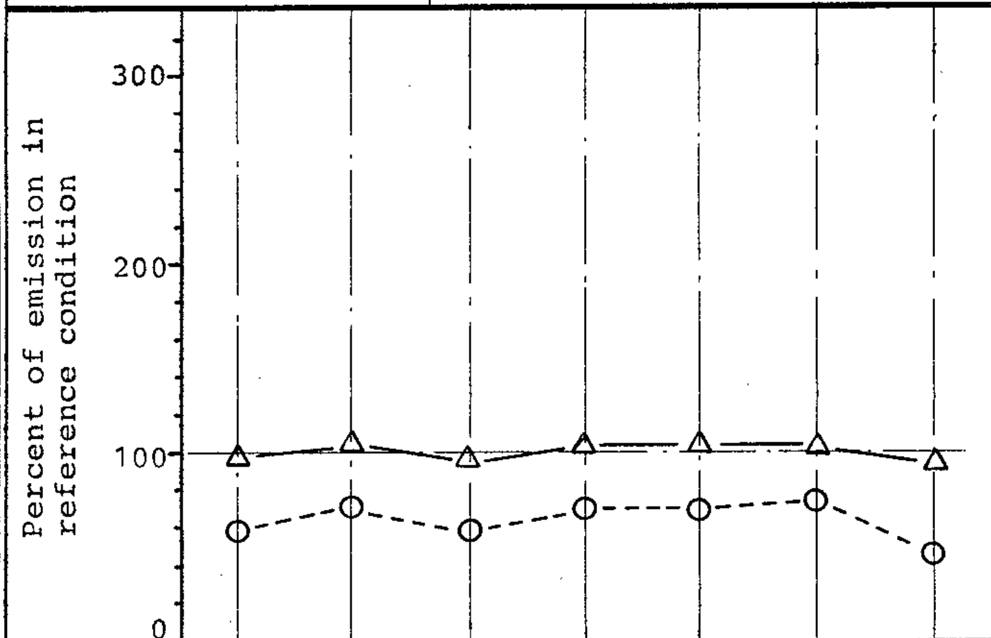
CO: 1.25 vol.%	HC(NDIR): 330 ppm C_6	NO_X: 1500 ppm
CO_2: 12.9 vol.%	HC(FID): 4700 ppm C_1	O_2: 1.4 vol.%

PNA (UV-reading): exhaust gas 1.1 mV. Reference 0.36 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.200 g



Legend	Mean	St.Dev.	
—Δ—	101%	3%	Filter
--O--	66%	11%	Cyclones

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	16.6	16.2	12.0	21.9	11.9	1.49	2.26	µg/test
Cyclones	0.85	1.43	0.64	1.77	1.08	.054	.074	µg/test
Sum	17.8	17.6	12.6	23.7	13.0	1.54	2.34	µg/test
%Filter	95	92	95	93	92	97	97	% of sum

MEASUREMENT NO. 12-5A Lead content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 612 C	$T_{ex,t}$: 164 C
	M_F: 2.45 kg/h	M_A: 34.9 kg/h	A/F-ratio: 14.26	
	T_C: 75 C	P_{amb}: 754 mmHg	T_{amb}: 24 C	Hum.: 26 % rel.
FUEL	Type: DTH Test Fuel Pb1 & Pb2 Mixture			0.6 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 84 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

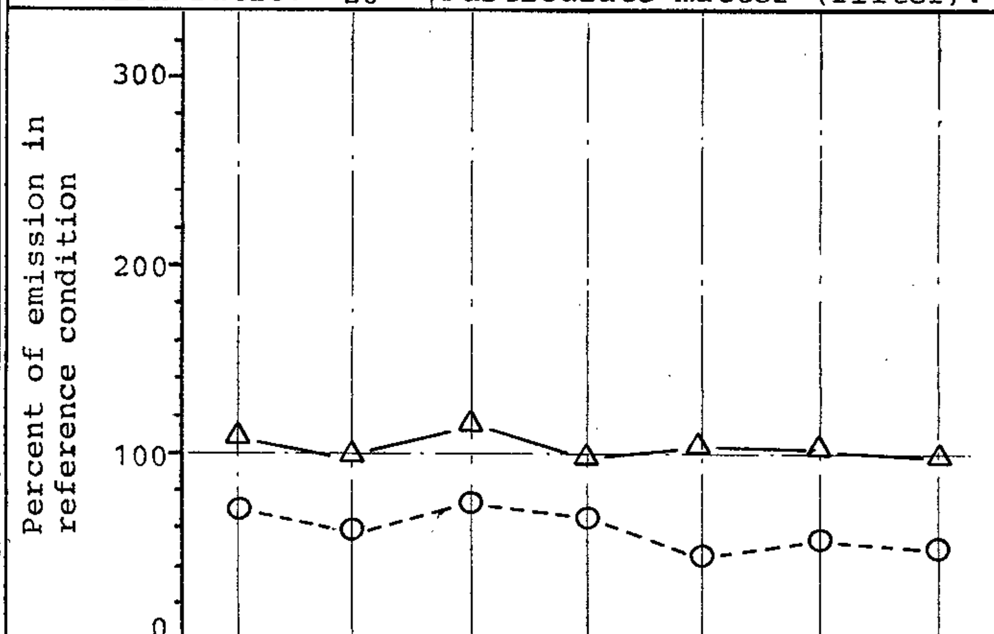
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.36 vol.%	HC(NDIR): 335 ppm C_6	NO_X: 1500 ppm
CO_2: 13.1 vol.%	HC(FID): 4550 ppm C_1	O_2: 1.50 vol.%
PNA (UV-reading): exhaust gas 4.9 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.223 g



	Legend	Mean	St.Dev.
Filter	—△—	106%	8%
Cyclones	--○--	61%	11%

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	18.9	15.3	14.2	21.7	12.7	1.50	2.31	µg/test
Cyclones	1.02	1.16	0.77	1.68	0.69	0.040	0.080	µg/test
Sum	19.9	16.5	15.0	23.4	13.4	1.54	2.39	µg/test
%Filter	95	93	95	93	95	97	97	% of sum

MEASUREMENT NO. 18-5A Lead content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 613 C	$T_{ex,t}$: 160 C
	M_F: 2.46 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.28	
	T_C: 75 C	P_{amb}: 760 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel Pb2			0.8 g Pb/litre
	40 vol.% Aromates	C_6: 3.2 %	C_7: 12.0 %	C_8: 16.0 %
	C_9+C_{10}: 8.8 %	BaP: 0.11 µg/ml. Analysis on page: D. 14		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 85 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

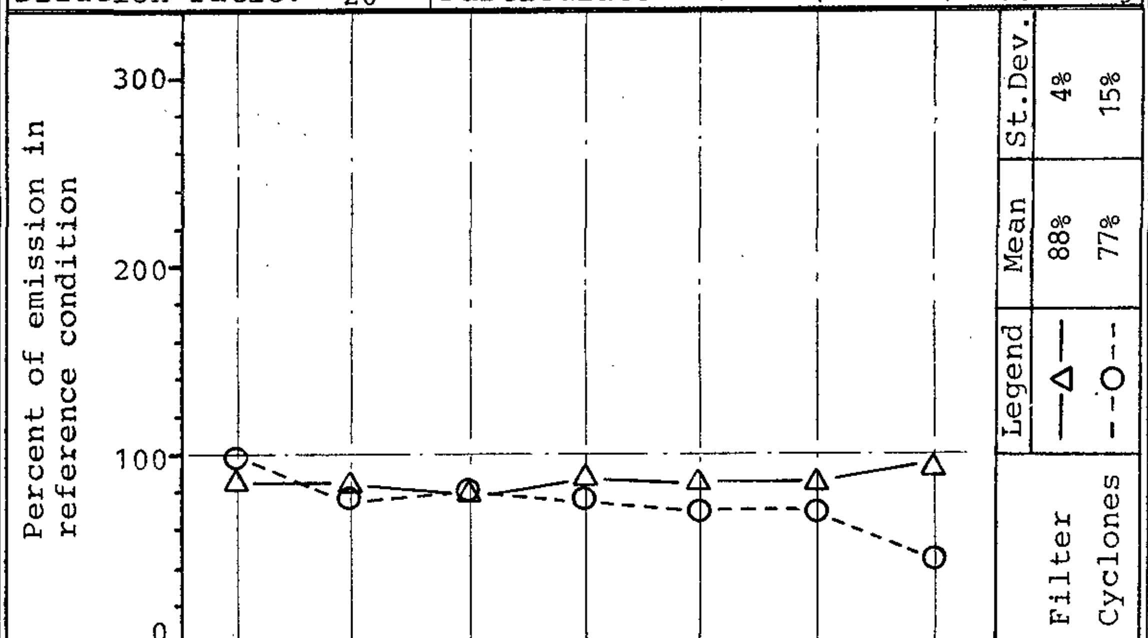
CO: 1.25 vol.%	HC(NDIR): 330 ppm C_6	NO_X: 1560 ppm
CO_2: 13.1 vol.%	HC(FID): 4700 ppm C_1	O_2: 1.45 vol.%

PNA (UV-reading): exhaust gas 1.24 mV. Reference 0.45 mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.261 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	14.5	13.3	9.96	19.6	10.1	1.25	2.23	µg/test
Cyclones	1.36	1.61	0.89	1.98	1.08	0.052	0.078	µg/test
Sum	15.9	14.9	10.9	21.6	11.2	1.30	2.31	µg/test
%Filter	91	89	92	91	90	96	97	% of sum

MEASUREMENT NO. 16-5B Lead/Aromatic content variation

ENGINE

P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 605 C	$T_{ex,t}$: 162 C
M_F: 2.43 kg/h	M_A: 35.2 kg/h	A/F-ratio: 14.47	
T_C: 75 C	P_{amb}: 756 mmHg	T_{amb}: 25 C	Hum.: 28 % rel.

FUEL

Type: DTH Test Fuel C2			0.8 g Pb/litre
20 vol.% Aromates	C_6: 1.6 %	C_7: 6.0 %	C_8: 8.0 %
C_9+C_{10}: 4.4 %	BaP: 0.046 µg/ml. Analysis on page: D.14		

OIL

Type: BP Visco 2000 Sport 15w-50	Lubricant temp.: 86 C
BaP: - µg/ml. Analysis p.: -	Used 4 h before test

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

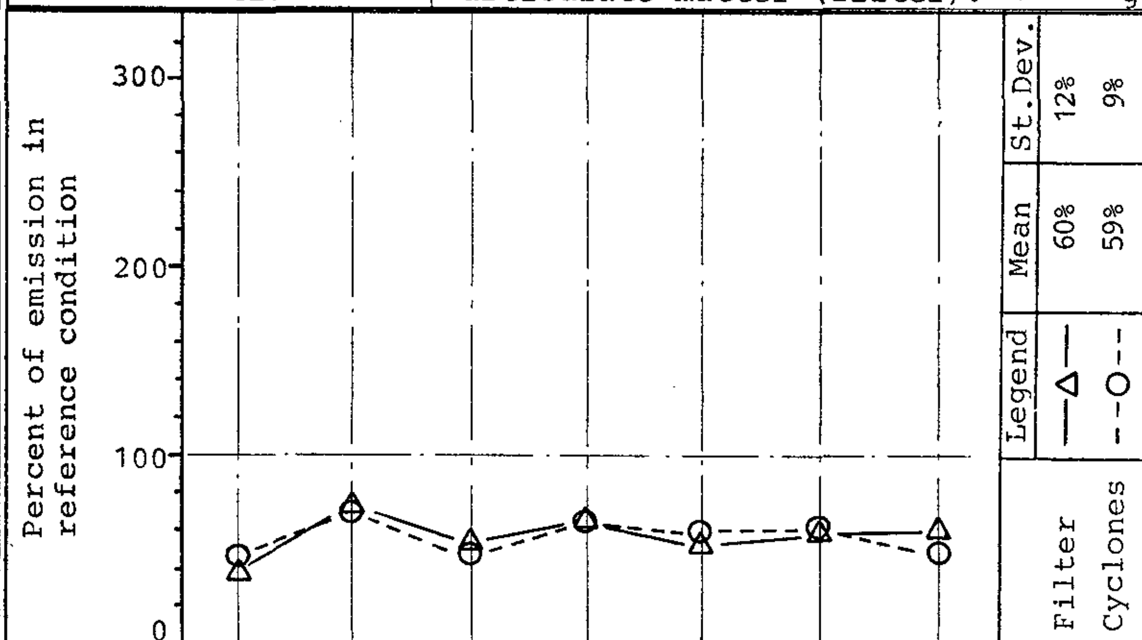
CO: 1.47 vol.%	HC(NDIR): 430 ppm C_6	NO_x: 1375 ppm
CO_2: 12.6 vol.%	HC(FID): 5000 ppm C_1	O_2: 1.35 vol.%

PNA (UV-reading): exhaust gas 1.7 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 34 C

Dilution ratio: 20 | Particulate matter (filter): 0.277 g



Amount of PAH collected	Anthra- cene	Fluor- anthene	1-Methyl- anthracene	Pyrene	Benzo(a)- anthracene	Benzo(a)- pyrene	Benzo(ghi)- perylene	Unit
Filter	6.63	11.9	6.68	14.7	6.57	0.83	1.50	µg/test
Cyclones	0.68	1.45	0.52	1.68	0.93	0.045	0.084	µg/test
Sum	7.31	13.4	7.20	16.4	7.50	0.88	1.58	µg/test
%Filter	91	89	93	90	88	95	95	% of sum

MEASUREMENT NO. 17-5A Lead/Aromatic content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 610 C	$T_{ex,t}$: 162 C
	M_F: 2.45 kg/h	M_A: 35.1 kg/h	A/F-ratio: 14.32	
	T_C: 75 C	P_{amb}: 758 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel C1 & C2 Mixture			0.53 g Pb/litre
	33.3 vol.% Aromates	C_6: 2.7 %	C_7: 10.0 %	C_8: 13.3 %
	C_9+C_{10}: 7.3 %	BaP: 0.09 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
	BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

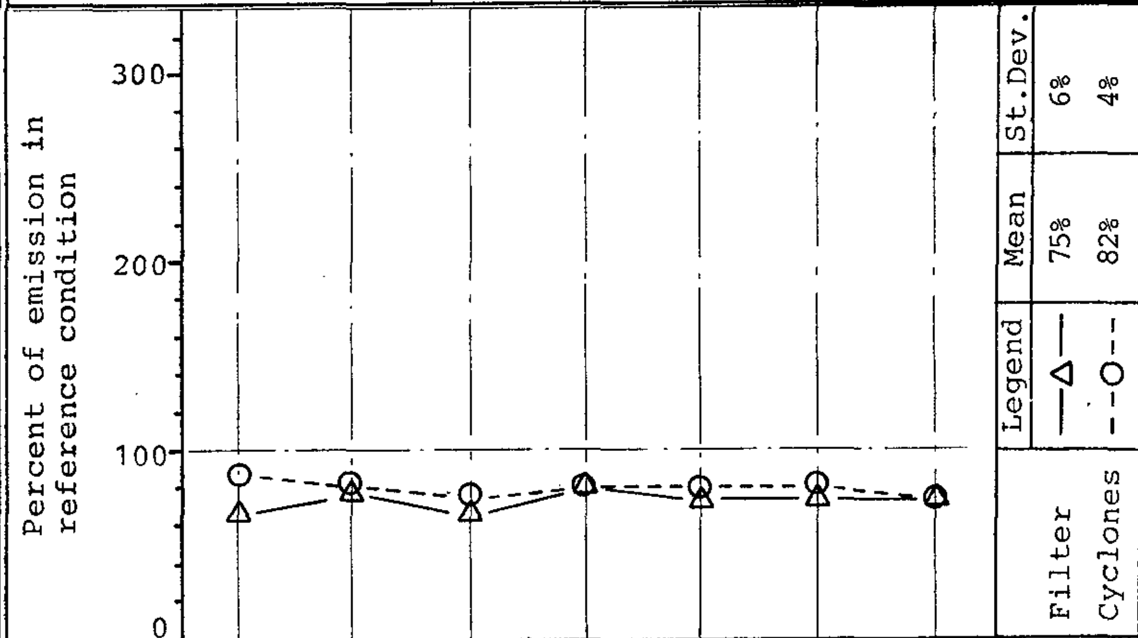
CO: 1.38 vol.%	HC(NDIR): 343 ppm C_6	NO_x: 1440 ppm
CO_2: 12.9 vol.%	HC(FID): 4650 ppm C_1	O_2: 1.50 vol.%

PNA (UV-reading): exhaust gas 1.7 mV. Reference - mV

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.209 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	11.5	12.4	8.07	17.7	9.00	1.07	1.82	µg/test
Cyclones	1.20	1.70	0.82	2.09	1.25	0.060	0.12	µg/test
Sum	12.7	14.1	8.89	19.8	10.3	1.13	1.94	µg/test
%Filter	91	88	91	89	88	95	94	% of sum

MEASUREMENT NO. 17-5B Lead/Aromatic content variation

ENGINE	P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 615 C	$T_{ex,t}$: 162 C
	M_F: 2.49 kg/h	M_A: 35.3 kg/h	A/F-ratio: 14.17	
	T_C: 75 C	P_{amb}: 758 mmHg	T_{amb}: 26 C	Hum.: 28 % rel.
FUEL	Type: DTH Test Fuel C1 & C2 Mixture			0.27g Pb/litre
	46.7vol.% Aromates	C_6: 3.7 %	C_7: 14.0 %	C_8: 18.7%
	C_9+C_{10}: 10.3 %	BaP: 0.12 µg/ml. Analysis on page: -		
OIL	Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 84 C	
	BaP: - µg/ml. Analysis p.: -		Used 4h before test	

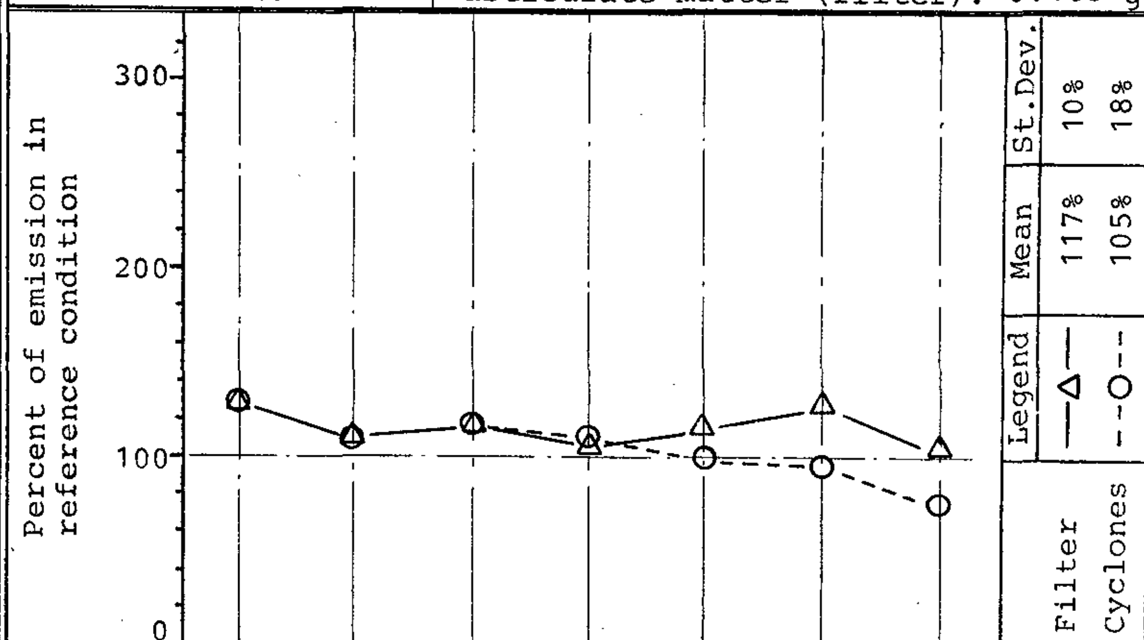
GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

CO: 1.25vol.%	HC(NDIR): 318 ppm C_6	NO_x: 1600 ppm
CO_2: 13.6 vol.%	HC(FID): 4600 ppm C_1	O_2: 1.35 vol.%
PNA (UV-reading): exhaust gas 2.18 mV. Reference - mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 35 C

Dilution ratio: 20 | Particulate matter (filter): 0.163 g

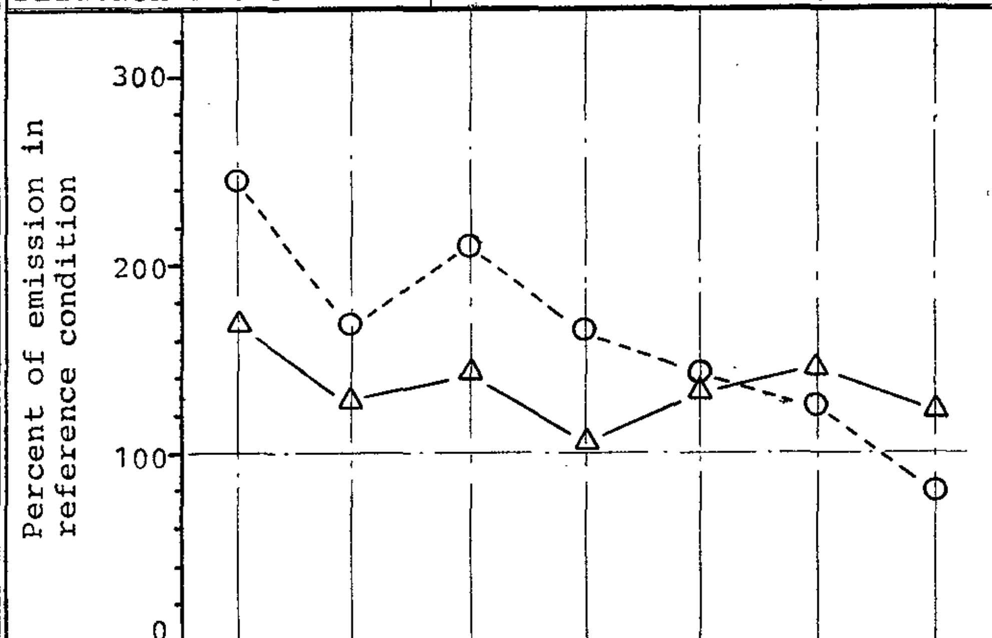


Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	22.0	17.3	14.3	22.6	13.8	1.85	2.55	µg/test
Cyclones	1.85	2.21	1.23	2.71	1.44	0.068	0.12	µg/test
Sum	23.9	19.5	15.5	25.3	15.2	1.92	2.67	µg/test
%Filter	92	89	92	89	91	96	96	% of sum

MEASUREMENT NO. 16-5A Lead/Aromatic content variation			
ENGINE			
P: 5.5 kW	N: 2490 RPM	$T_{ex,m}$: 613 C	$T_{ex,t}$: 163 C
M_F: 2.49 kg/h	M_A: 34.9 kg/h	A/F-ratio: 14.03	
T_C: 75 C	P_{amb}: 756 mmHg	T_{amb}: 25 C	Hum.: 28 % rel.
FUEL			
Type: DTH Test Fuel C1			0 g Pb/litre
60 vol.% Aromates	C_6: 4.8 %	C_7: 18.0 %	C_8: 24.0 %
C_9+C_{10}: 13.2 %	BaP: 0.16 µg/ml. Analysis on page: -		
OIL			
Type: BP Visco 2000 Sport 15w-50		Lubricant temp.: 83 C	
BaP: - µg/ml. Analysis p.: -		Used 4 h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):		
CO: 1.22 vol.%	HC(NDIR): 258 ppm C_6	NO_X: 1575 ppm
CO_2: 13.8 vol.%	HC(FID): 4200 ppm C_1	O_2: 1.40 vol.%
PNA (UV-reading): exhaust gas 5.8 mV. Reference 0.78 mV		

PARTICULATE/PAH-EMISSIONS (FILTER AND CYCLONE SAMPLES):	
Sampling data: Rate 45 m³/h Volume 90 m³ Temperature 34 C	
Dilution ratio: 20	Particulate matter (filter): 0.112 g



	Filter	Cyclones
St.Dev.	20%	54%
Mean	137%	163%
Legend	—△—	--○--

Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	28.6	20.3	17.8	23.4	15.8	2.11	2.88	µg/test
Cyclones	3.41	3.40	2.22	4.13	2.12	0.090	0.13	µg/test
Sum	32.0	23.7	20.0	27.7	17.9	2.20	3.01	µg/test
%Filter	89	86	89	85	88	96	96	% of sum

MEASUREMENT NO. 13-6 Dilution tube back-ground

ENGINE	P: kW	N: RPM	$T_{ex,m}$: C	$T_{ex,t}$: C
	M_F: kg/h	M_A: kg/h	A/F-ratio:	
	T_c: C	P_{amb}: mmHg	T_{amb}: C	Hum.: % rel.
FUEL	Type:			g Pb/litre
	vol.% Aromates	C_6: %	C_7: %	C_8: %
	C_9+C_{10}: %	BaP: µg/ml. Analysis on page:		
OIL	Type:		Lubricant temp.: C	
	BaP: µg/ml. Analysis p.:		Used h before test	

GASEOUS EMISSIONS (SAMPLED AT ENGINE EXHAUST MANIFOLD):

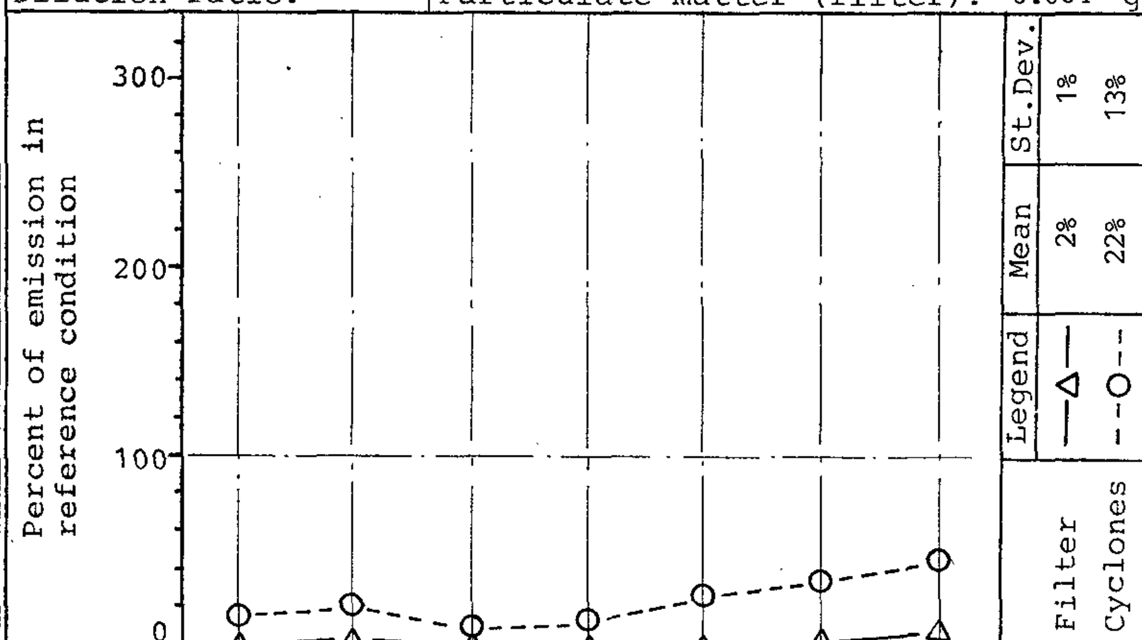
CO: vol.%	HC(NDIR): ppm C_6	NO_x: ppm
CO_2: vol.%	HC(FID): ppm C_1	O_2: vol.%

PNA (UV reading): exhaust gas mV. Reference mV

PARTICULATE/PAH EMISSIONS (FILTER AND CYCLONE SAMPLES):

Sampling data: Rate 45 m^3/h Volume 90 m^3 Temperature 25^o C

Dilution ratio: —— Particulate matter (filter): 0.004 g



Amount of PAH collected	Anthra-cene	Fluor-anthene	1-Methyl-anthracene	Pyrene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(ghi)-perylene	Unit
Filter	0.13	0.33	0.08	0.24	0.14	.022	.092	µg/test
Cyclones	0.20	0.41	0.08	0.37	0.34	.022	.073	µg/test
Sum	0.33	0.74	0.16	0.61	0.48	0.044	.165	µg/test
%Filter	39	45	50	39	29	50	56	% of sum

ISSN 0105-3094
ISBN 87-503-2771-2
ISBN 87-503-2773-9

Fu 00-91

SCANTRYK, KBHVN
TELEFON 01-30 06 01