APPENDICES
**APPENDIX-A-1.1**

**SPECIFICATION OF ENGINE USED IN THE INVESTIGATION**

Engine: Kirloskar make, Four-stroke, vertical, single-cylinder, constant speed, water-cooled diesel engine.

<table>
<thead>
<tr>
<th>1. Bore</th>
<th>:</th>
<th>80 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Stroke</td>
<td>:</td>
<td>110 mm</td>
</tr>
<tr>
<td>3. Rated output</td>
<td>:</td>
<td>3.68 kW</td>
</tr>
<tr>
<td>4. Rated speed</td>
<td>:</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>5. Fuel injection timing</td>
<td>:</td>
<td>27° b TDC</td>
</tr>
<tr>
<td>6. Fuel injection pressure</td>
<td>:</td>
<td>190 bar</td>
</tr>
<tr>
<td>7. Injector</td>
<td>:</td>
<td>MICO BOSCH MAKE</td>
</tr>
<tr>
<td>8. Compression ratio</td>
<td>:</td>
<td>16:1</td>
</tr>
<tr>
<td>9. Combustion system</td>
<td>:</td>
<td>Open chamber</td>
</tr>
<tr>
<td>11. Fuel injection pump</td>
<td>:</td>
<td>Make: BOSCH: NO- 8085587/1</td>
</tr>
</tbody>
</table>
APPENDIX A-1.2

DETAILS OF SMOKE METER

A-1.2.1 BASIC OPERATING PRINCIPLE

The smoke of the engine exhaust is a visible indicator of the combustion in the engine. Smoke is due to incomplete combustion. Smoke measurements can be broadly classified into two groups viz. comparison method and obscuration method. The obscuration method is further classified as light extinction type, continuous filtering type, and spot filtering type. The Hartridge Smokemeter is very commonly used instrument based on the principle of Light extinction. In this method of testing, the intensity of a light beam is reduced by smoke, which is a measure of smoke intensity. A continuously taken exhaust sample is passed through a tube of about 0.43 m length, which has light source at one end and photocell at the other end. The amount of the light passed through this column is used as indication of smoke levels or smoke density. The smoke level or smoke density is defined as the ratio of electric output from photocell when the sample is passed through the column to the electric output when clean air is passed through it.

Fig.A.1 represents the flow schematic diagram, while Plate A-1 shows the photographic view of the AVL Hartridge Smokemeter. The AVL Smokemeter measures the opacity of polluted air; in particular diesel exhaust gases. The opacity is the extinction of light between light source and receiver. The gas to be measured is fed into a chamber with non-reflective inner surface. The effective length of the light absorption track is determined by taking into consideration possible influences of devices used to protect the light source and the photocell. The effective length is 0.430 m. Light scatter on the photocell from reflections or diffused light inside the chamber is reduced to a minimum by the use of matt black light traps. The light source is an incandescent bulb, with a color temperature between 2800 K and 3250 K. The receiver is a photocell with spectral sensitivity tuned to the sensitivity curve of the human eye. The entire electric circuitry, including the display, is designed so that the current delivered from the photocell is a linear function of the intensity of the received light within the operating temperature range. The absorption coefficient is calculated in accordance with ECE-R 24 ISO, with an absorption coefficient of 1.7 m⁻¹.

The response time of the electrical circuit, specified as the time within which the indicator reaches 90% of the full scale when a completely opaque plate is placed in front of the photocell is between 0.9 and 1.1 seconds. The exhaust gas pressure in the measurement chamber does not deviate from the surrounding pressure by more than 75
mm water. The opacity measurement equipment possesses a suitable pressure sensor for measuring the pressure in the chamber. The permissible tolerance limits for the gases and purging air in the measurement chamber are 75 mm of water. The temperature of the gases to be measured shall be between 70 and 130° C at each point in the measuring chamber. An appropriate temperature sensor connected to a regulator ensures that temperature in the measurement chamber is maintained at 100° C. The equipment has a microprocessor-controlled program sequence to check the measurement process and to store such values as pressure, temperature, opacity, absorption and engine speed.

**FIG.A.1 FLOW SCHEMATIC DIAGRAM OF HARTRIDGE SMOKE METER**

**A-1.2.2 SPECIFICATIONS**

- **Measuring range:** 0----100% opacity in %, 0----∞ absorption m⁻¹.
- **Measuring chamber:** Effective length 0.430 m
- **Heating time:** 220 V ----approx.20 min.
- **Light source:** Halogen bulb 12 V/ 5 W.
- **Color temperature:** 3000 K.
- **Detector:** Selenium photocell diameter- 45 mm, maximum sensitivity in light, Frequency range:550- 570 mm
  Below 430 mm and above 680 mm sensitivity is less than 4% related to maximum sensitivity.
- **Measurement value indicator:** Processor-controlled ,LED, display 4 × 15 mm.
- **Maximum gas temperature at entrance:** 250° C.
- **Temperature gauge:** Electric temperature measuring instrument for displaying exhaust gas temperature in the measurement chamber on the LED display.
Power consumption:
Overall equipment: 600 W.
Measurement chamber heating: 500 W at 220 V.
Weight: Approx. 50 kg net.
Printer: Thermal matrix printer 7 5.24 characters
Paper: Width: 58 mm,
Type: Jujo paper TP 50 KS -A
Honshu paper FH65BX-14N or similar.

PLATE A-1 PHOTOGRAPHIC VIEW OF THE AVL SMOKE METER

A.1.2.3 APPLICATIONS

i. The AVL 437 Smoke meter is used to measure the emission of air-polluting substances, from the engine as per 1ECE - R24. It meets the requirement for the smoke measurement (opacity measurement equipment) as stipulated in ECE- R24
and ISOR 3173. It is used to check and approve emissions of auto ignition combustion engine and measures the opacity and absorption of the vehicle being tested for approval. The integral printer documents the measurement results.

ii. Periodic measurement of the opacity of exhaust gases from diesel engines of passenger cars, trucks, buses, agriculture and construction plant etc. in accordance with the legal requirements.

iii. For checking exhaust gas opacity in diesel vehicles and for approval by authorities.

iv. For diagnostics directly on the vehicle.

v. For treating directly on the vehicle. For testing during engine development and type approval.

vi. Exhaust gas opacity measurement on chassis dynamometers where the smoke density is assessed with engine under constant load by the wheels.

vii. Measurement of peak opacity during free acceleration.

A-1.2.4 ADDRESS OF THE EQUIPMENT SUPPLIER:

AVL INDIA (P) LIMITED:
HEAD OFFICE: 22/48, DHARAM MARG, CHANAKYAPURI,
NEW DELHI- 1100021
PHONE NUMBERS- 2301 2762, 2379 2965, 2379 2966.
FACTORY: 376-377 PHASE- IV, UDYOG VIHAR, GURGAON- 122015
APPENDIX A-1.3

DETAILS OF NETEL CHROMATOGRAPH NOx ANALYZER

A-1.3.1. PRINCIPLE OF OPERATION

Oxides of nitrogen (NOx), which occur only in the engine exhaust, are a combination of nitric oxide (NO) and nitrogen dioxide (NO2). Internationally accepted method for measuring oxides of nitrogen is by chemiluminescence analyzer. The heart of the NETEL’s chemiluminescent analyzer is the chemiluminescent gas phase reaction between ozone and nitric oxide

\[
\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \quad (1.3.1)
\]

\[
\text{NO} + \text{O}_3 \rightarrow \text{NO}_2^* + \text{O}_2 \quad (1.3.2)
\]

A small proportion of the nitrogen oxide generated by the reaction (2) is in an electronically excited state.

\[
\text{NO}_2^* \rightarrow \text{NO}_2 + \text{light} \quad (1.3.3)
\]

This excited NO2 molecules may lose energy by emitting light (Reaction 1.3.3). The light produced has its spectrum in the wavelength region of 0.6 and 3.0 μm. The light is viewed through a selective optical filter by a photomultiplier tube. The light measured by photomultiplier tube varies linearly with nitric oxide concentration; hence a direct reading of nitric oxide concentration is obtained. It is important to note that only a very small proportion of excited NO2 molecules lose energy by emitting light, the major proportion losing energy by collision with other molecule. This is due to the fact that the mean lifetime of the exited molecule (assuming no collisions) is more than the time between the collisions when at atmospheric pressure. Since the number of collisions per second varies linearly with pressure, a low pressure favors loss of energy by light emission. The model NPM-N1 operates at low pressure in order to maximize the light output and minimize the effect of other interfering gases, which are known to be very efficient at deactivating excited NO2 molecule.

The collision mode deactivation reaction is represented in equation-4

\[
\text{NO}_2^* + \text{M} \rightarrow \text{NO}_2 + \text{M} \quad (1.3.4)
\]

The collision deactivation process is commonly referred to as quenching and the efficiency with which a molecular species ‘M’ may quench a chemiluminescent reaction is measured by the quenching coefficient. It is fortunate that the quenching effects of nitrogen and oxygen are very similar and no errors are involved by the use of nitric oxide.
balance nitrogen calibration standards for the analysis of NOx in air. It should be noted that if the measurements are to be made of gas mixture containing neither oxygen or nitrogen (example nitric oxide in argon) then calibration standards containing the balance gas in the same matrix as sample gas are necessary to avoid errors from the different quenching and viscosity characteristics of the balance gas.

It is obvious from the reactions 1 & 2, the chemiluminescent reaction takes place only with NO gas and not with other oxides of nitrogen. To measure NOx concentrations, the sample gas flow is passed through a converter, which converts NOx to NO. The chemiluminescent intensity of the reaction now becomes linearly proportional to NOx. Thereby, the light intensity can be taken to be proportional to the oxides of nitrogen concentration in the sample.

A-1.3.2 SPECIFICATIONS

**Display**: 3-digit display  
**Range**: 0-9999 ppm  
**Noise**: ± 1 ppm  
**Minimum detectable level**: 2 ppm.  
**Response time**: 10 seconds.  
**Reproducibility**: ± 0.2% FS.  
**Recorder output**: options of 0-100 mV, 0-1 V or 4-20 mA.  
**Power requirement**: 600 Watts, 240 VAC, 50 Hz.  
**Weight**: 30 kg (excluding pump)

A-1.3.3 TECHNICAL DESCRIPTION

Fig.A.2 represents the flow schematic diagram, while Plate A-2 shows the photographic view of the Netel Chromatograph NOx analyzer. A modular approach has been made in the assembly of the analyzer and the system may be described by referring to the various modules and sub-system. The analyzer can be divided into the following sub systems. i) Controls, ii) Flow systems, iii) Ozonator, iv) Converter, v) Reaction chamber & Photomultiplier assembly, vi) Electronics.

A-1.3.3.1 CONTROLS: Glowing LEDs show the different switches in operation.  
A-1.3.3.1.1 Switches: Operation of ZERO/SPAN/SAMPLE/REMOTE selector interlocked switches opens gas solenoid valves within the analyzer directing zero, span or sample gas to the reaction chamber. Selection of 'REMOTE' allows remote selection of zero, sample and sample via the 'EXT' connector on the back panel.
Operation of NO/NOx mode switches decides the mode of selection of analyzer for NO & NOx. In the NOx mode, a three-way solenoid valve is energized directing the gas through the converter. In the NO mode, the converter is bypassed.


FIG. A.2- FLOW SCHEMATIC DIAGRAM OF NOx ANALYZER

PLATE A.2 PHOTOGRAPHIC VIEW OF THE NETEL CHROMATOGRAPH NOx ANALYZER
'Converter temperature-set/actual' switches are momentary 'ON' switches. When 'SET' is pressed, the set temperature of the converter is displayed on the digital meter. In 'ACTUAL' mode, the real time information about converter temperature is displayed on DPM.

Power switches provide power to the analyzer, photomultiplier tube assembly units, solenoid valves, cooling fan, NOx converter and ozonizer etc.

A-1.3.3.1.2 Control Potentiometers: Adjustment of 'ZERO' control backs off any background current in the photomultiplier tube. The instrument should be adjusted to give a zero reading while in NO mode, with zero and dry air/oxygen gas flowing and ozone 'ON'.

Adjustment of 'SPAN' control, allows the analyzer to be calibrated while in 'span' mode with NO calibration gas.

Adjustment of 'HEATER' control, allows the set temperature of the converter to be varied while observing it on DPM with SET switch is pressed.

A-1.3.3.1.3. Flow & Vacuum Indicators: Flow of dry air/oxygen to the ozonator is indicated on the rotameter for OZONE while the SAMPLE gas rotameter indicates the total flow (sample + ozone). This reaction chamber vacuum is displayed on the vacuum gauge.

A-1.3.3.1.4. Alarm: The alarm can be set with the help of this ten turn potentiometers. A ten-turn dial with 100 graduations for each turn provides direct setting of alarm at any value from 0 to 9999. The potential free contacts the alarm relay are provided on three-way connector. A buzzer on the front panel gets ON when the concentration exceeds the alarm setting.

A-1.3.3.1.5. Recorder O/P: Two analogue outputs 0-1000 mv and 4-20 mA are provided as standard through BNC connectors. Both these outputs correspond to full scale of reading in range. The maximum load for current output can be 500 ohms.

A-1.3. 3.1.6. Fuses: Two fuses are provided. The analyzer fuse has a rating of 2 Amps while that of ozonator is 250 mA.

A-1.3.3.2. FLOW SYSTEM: An externally connected vacuum pump evacuates the reaction chamber, this lowering of pressure causes gas to flow via capillary restrictors to the reaction chamber. The flow rate through these restrictors is sufficient to maintain the chamber pressure at less than 10 torr. Two teflon filters before the capillaries ensure removal of fine particles thereby reducing the probability of blockage of fine capillaries. Solenoid valves SV2 admits zero gas, SV3 span gas and sample gas enters when none of these valves are energized. The solenoid valves are controlled by the mode selector

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switch and associated circuit switch. Solenoid valve SV1 allows the gas to be fed through the converter or direct NOx or NO mode.

A-1.3.3.3 OZONATOR: The ozonator system is housed within stainless steel tube enclosure to minimize the electrical interference, which may otherwise cause noise in electronic circuits within the analyzer. The ozonator system comprises of ozoniser, high voltage transformers, inline teflon filter and capillary restrictor to control the flow of ozone to the reaction chamber. It is powered by a 10 kV transformer.

A-1.3.3.4 CONVERTER: Nitrogen dioxide does not react with ozone in the same way as nitric oxide and no light is emitted. To measure nitrogen dioxide it is therefore necessary to convert nitrogen dioxide to nitric oxide prior to the reaction with ozone. Conversion of nitrogen dioxide to nitric oxide is carried out by passing the gas through the heated stainless steel tube containing a catalyst. The conversion of NO2 to NO is accomplished thermally

\[ 2\text{NO}_2 + \text{Heat} \xrightarrow{\text{catalyst}} 2\text{NO} + \text{O}_2 \]

A-1.3.3.5. Reaction chamber & Photomultiplier tube assembly: The reaction chamber consists of a stainless steel body mounted on photomultiplier housing by a flange and gaskets. The gas inlets pass through to the inside of the chamber and terminate as jets close to the Photomultiplier tube. The photomultiplier views the chamber via on optical filter chosen so as to cut out chemiluminescent emissions from olefinic hydrocarbons. Access to the Photomultiplier socket is via a plate mounted inside on the opposite end of the photomultiplier tube assembly to the reaction chamber. The photomultiplier diode resistors are soldered to the photomultiplier socket.

A-1.3.3.6 ELECTRONICS: The electronics of the analyzer consists of four major and five minor printed circuit boards (PCB). The power supply to PCB provides a regulated supply for all integrated chips and has relays for operation of solenoid valves. The high voltage card has circuit for generating negative power supply required for the operation of photomultiplier tube. The temperature controller card houses the converter heater controller circuitry. The signal amplifier card contains the current to the voltage amplifier along with alarm and recorder output circuits. The minor PCB contain circuits for mode switches and for digital display.

A-1.3.4 APPLICATIONS

Netel Chromatograph NOx analyzer Model NPM- N1 is used for measuring oxides of nitrogen in the exhaust of diesel engines varying from passenger cars to heavy-duty trucks.
A-1.3.5 ADDRESS OF THE EQUIPMENT SUPPLIER

M/S NETEL CHROMATOGRAPHS
S.V. ROAD, MANPADA, THANE- 400 607.
TELEPHONE: 2595361, 2508107.

M/S NETEL CHROMATOGRAPHS
EAST COAST CENTRE, 5th FLOOR, 553, MOUNT ROAD, TEYNAMPET, CHENNAI- 600 018.
TELEPHONE: 2450160,

M/S NETEL CHROMATOGRAPHS
CHITRAKOOT, 8th FLOOR, 9th FLAT, 230A-AJC BOSE ROAD, CALCUTTA-, 700 020.
TELEPHONE: 2441911,434699,
APPENDIX A-1.4

PRESSURE-CRANK ANGLE ANALYZER

A-1.4.1 BASIC OPERATING PRINCIPLE

The device, which measures the variation of the pressure in the cylinder over a part or full cycle, is called an indicator and plot of such information obtained is called an indicator diagram. Thus an indicator diagram gives very good indication of the process of combustion and in the associated factors by its analysis.

Cylinder pressure changes with crank angle as a result of cylinder volume changes, combustion, heat transfer to the chamber walls, flow into and out of crevice regions and leakage. The first two of these effects are the largest. The effect of volume change on the pressure can readily be accounted for; thus, combustion rate information can be obtained from accurate pressure data provided models for the remaining phenomena could be developed at an appropriate level of approximation.

The major components used for obtaining pressure-crank angle diagrams are piezoelectric pressure transducer, TDC encoder, consol or charge amplifier, Personal computer and printer. Fig.A.3 shows the flow schematic diagram of pressure-crank angle indicator, while Plate.A.3 represents the photographic views of piezoelectric pressure transducer, consol and TDC encoder.

Cylinder pressure is usually measured with piezoelectric pressure transducers. The transducer is fitted in the cylinder head, without projecting into the combustion space and it contains a quartz crystal. One end of the crystal is exposed through a diaphragm to the cylinder pressure; as the cylinder pressure increases, the crystal is compressed and generates an electric charge, which is proportional to the pressure. A charge-amplifier or consol is then used to produce an output voltage proportional to this charge. The consol is then connected to Pentium Personal Computer. The diaphragm is made very stiff in order to reduce the displacement and hence the inertial effects are reduced to minimum.

The pick-up used for measuring the cylinder pressure must have linear output and a good frequency response. Its temperature behavior should also be satisfactory. Also it must have low acceleration sensitivity. The quartz transducer, which has natural frequency greater than 50 kHz, has sensitivity of about one tenth of other types of transducers in which inductive, capacitive or strain gauge principles are applied. The temperature effect is about 0.005 per cent per degree centigrade change in the temperature of the crystal. The uses of electrical pressure pickups avoid almost all the difficulties of a mechanical indicator and gives inertia free operation.
TDC encoder is provided at the extended shaft of the dynamometer and is connected to the consol to measure the crank angle of the engine. This typical time base unit consists of permanent magnet with the coil and V-shaped pole piece and a rotating disc having slots in which magnet material is fixed. When the disc rotates and a slot passes the permanent magnet it generates voltage according to its depth and produces peak on the diagram. Usually slots are 1° apart with deeper slots 10° intervals and still deeper at 90° interval so that a complete degree-timing diagram is produced. The disc is so adjusted on the dynamometer shaft that when the deepest slot is against magnet poles it shows the top dead centre. This type of time base device does not work below 150 rpm because of weak impulse signal. Hence triggering circuit is used.

A special P-0 software package evaluates the combustion characteristics such as peak pressure (PP), time of occurrence of peak pressure (TOPP), maximum rate of pressure rise (MRPR), time of occurrence of maximum rate of pressure rise (TOMRPR), brake mean effective pressure (BMEP), indicate mean effective pressure (IMEP), speed of the engine, from the signals of pressure and crank angle. Pressure-crank angle and pressure-volume diagrams are obtained on the screen of the personal computer.
APPENDIX A-1.5

LIST OF PUBLICATIONS OF THE AUTHOR

A. INTERNATIONAL JOURNALS
3. “Investigations on low heat rejection diesel engine with crude pongamia oil as alternate fuel “, Transactions of ASME International Journal of Energy Resources and Utilization (Accepted for publication)

B. NATIONAL JOURNALS

C. PAPERS PRESENTED AT INTERNATIONAL CONFERENCES

D. PAPERS PRESENTED AT NATIONAL CONFERENCES


E. PAPERS PRESENTED AT NATIONAL SEMINARS


