3.1 INTRODUCTION

The emission tests were conducted on an Izusu, four stroke, 4 cylinder petrol engine test-rig with hydraulic dynamometer loading system. The specifications of the engine are given in Table.3.1. The photographic view of the test engine is shown in Figure 3.1. AVL 444 Digas exhaust analyzer is used for measuring the emission of exhaust gas. The gas analyzer is capable of measuring CO, CO₂, HC, NOₓ and O₂ and is interfaced with RS232 cable. The temperature of the catalyst has been measured with K type thermocouple and the data are stored using data logger.

The experiments were conducted with two innovative catalytic converter systems namely Parallel Catalytic Converter System (PCCS) and Telescopic Catalytic Converter System (TCCS). The experimental setup have been designed using these two innovative approaches and the experimental procedure have been discussed in detail in this chapter with schematic diagrams.

Figure 3.1 Photographic View of IZUSU 4 Cylinder Petrol Engine Test Rig
Table 3.1 Specification of the Test Engine

<table>
<thead>
<tr>
<th>Make</th>
<th>Izusu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Inline four, SOHC with MPFI</td>
</tr>
<tr>
<td>Fuel</td>
<td>Petrol</td>
</tr>
<tr>
<td>Displacement Volume</td>
<td>1,817 cc</td>
</tr>
<tr>
<td>Bore / Stroke</td>
<td>84x 82 cc</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>8.5 : 1</td>
</tr>
<tr>
<td>Power</td>
<td>10 HP</td>
</tr>
<tr>
<td>Cooling</td>
<td>Water cooled</td>
</tr>
</tbody>
</table>

3.2 AVL DIGAS 444 EXHAUST GAS ANALYZER

AVL Digas 444 Exhaust gas analyzer is used to measure the relative volumes of certain gaseous constituents in the exhaust gases of automobile vehicles. These gases are Carbon monoxide(CO), Carbon dioxide(CO₂), Hydrocarbons(HC), Oxygen(O₂) and Oxides of Nitrogen(NOₓ). The air fuel ratio $\lambda$ can be calculated from the CO,CO₂,HC and O₂ constituents and displayed in the analyzer. The photographic view of the gas analyzer with test probe is shown in Figure 3.2.

![Photographic View of the AVL Exhaust Gas Analyzer with Test Probe](image)

3.3 K TYPE THERMOCOUPLE

A typical temperature measuring device is a thermocouple; however, it is important to choose the right type of thermocouple and to place it in the right location to obtain reliable data. Thermocouples vary in type and size with different temperature ranges and response characteristics. K-type thermocouples with a
diameter of 1/16 inch or 1/8 inch are commonly used for exhaust gas temperature measurements. This is the most common thermocouple type that provides the widest operating temperature range. Type K thermocouples generally will work in most applications because they are Nickel based and have good corrosion resistance. Following are some of the features of K type thermocouple:

1. Positive leg is non-magnetic (Yellow), negative leg is magnetic (Red).
2. Traditional base-metal choice for high temperature work.
3. Appropriate for use in oxidizing or inert atmospheres at temperatures up to 1260°C (2300°F).
4. Vulnerable to sulphur attack (refrain from exposing to sulphur-containing atmospheres).
5. Perform best in clean oxidizing atmospheres.

Thermocouple is composed of a positive leg, which is approximately 90% Nickel, 10% Chromium and a negative leg, which is approximately 95% Nickel, 2% Aluminum, 2% Manganese and 1% Silicon. Type K thermocouples are the most common general purpose thermocouple with a sensitivity of approximately 41µV/°C. It is inexpensive and a wide variety of probes are available in its -200°C to +1260°C / -328°F to +2300°F ranges.

Figure 3.3 DataLogger with 4 Channels and K type Thermocouple
3.3.1 DATA LOGGER

In some applications, the temperature may be measured at more than two points. The data logger provides the four channels thermometer and all the temperature data are shown on the LCD at the same time so that no extra step for the user to get the reading. Also, the temperature values are stored in the memory of the data logger. The photographic view of data logger and thermocouple is shown in Figure 3.3.

3.4 EXPERIMENTAL SETUPS

The experimental investigations were carried out with the following experimental setups.

1. Parallel Catalytic Converter System (PCCS).
2. Telescopic Catalytic converter System (TCCS) at different positions of catalyst.
3. TCCS at different positions of catalyst with pre-catalyst (40%vol).
4. TCCS at different positions of catalyst with pre-catalyst(20%vol).
5. TCCS at different positions of catalyst with hot air injection gun.

In the real time driving cycle of a vehicle, the load on the engine increases as it starts from idling to maximum speed. Hence the investigation was conducted at different load condition to study the effect of loading on light-off time of the catalyst.

3.5 PARALLEL CATALYTIC CONVERTERSYSTEM (PCCS)

Conventional underfloor catalytic convertors are normally placed at a distance of around 1m from the exhaust manifold, which takes 2 to 3 minutes to reach the light-off temperature. Close coupled catalyst is a good solution to reduce the light-off time. However, close proximity of the catalyst from the engine added with high temperature of exhaust gases creates thermal degradation of the catalyst and accelerates catalyst ageing. Parallel catalytic convertor is a solution to reduce the light-off time and at the same time protects the catalyst from early ageing.
In PCCS, two catalysts namely Close coupled catalyst (CCC) and a main catalyst (MC) are arranged in parallel. CCC is located very close to the exhaust manifold and MC is kept far away from the engine to keep the temperature down to levels that will not harm the catalyst. The schematic representation of PCCS is shown in Figure 3.4.

V1, V2: Butterfly valves, V3, V4: Non return valves, ECS: Electronic control system

**Figure 3.4 Schematic of Parallel Catalytic Converter System**

In the present work the CCC is attached at a distance of 15cm from exhaust manifold and the MC parallel to the CCC is kept at a distance of 90cm from the exhaust manifold. The study has been conducted at various engine load conditions. Since the CCC is close to the exhaust manifold, the light-off temperature is achieved very quickly. The exhaust entering the CCC undergoes exothermic oxidation and passes through the main catalyst. The exothermic heat carried away by the exhaust gas heats the MC quickly and hence it attains earlier light-off. When the MC reaches the light-off, the flow of exhaust gas through CCC is cut off and the exhaust is directed to flow directly through the MC.
The butterfly valves V1, V2 and non return valves V3 & V4 are mounted at appropriate positions to control the flow of exhaust gas through CCC and MC. The temperatures are measured using K type thermocouples, stored in data logger and sent to ECS for actuating the motor shafts to open and close the valves. The flow diagram for ECS controlled PCCS is shown in Figure 3.5.

Figure 3.5 Flow Diagram for ECS controlled Parallel Catalytic Converter System

3.5.1 Experimental Procedure for PCCS

Emission test has been conducted with parallel catalytic converter system at different loading conditions namely no load, half load and full load conditions. Light-off temperature of MC is programmed in the ECS system. Initially the Valve
V1 will be kept opened and the valve V4 will be kept closed and exhaust is allowed to flow through CCC and then through MC to the tail pipe.

Once the MC reached the light-off, the temperature sensor would send the signal to the ECS and accordingly the valve V1 would close and the valve V2 would open. The exhaust gas would directly flow through the MC till the engine stops. During the subsequent start of the engine the temperature of MC would have dropped below the light-off temperature and accordingly the temperature sensor sends signal to ECS to open the valve V1 and to close the valve V2. This enables the exhaust to flow through the CCC and then to MC till MC reaches light-off. This process will be repeated during every fresh start. Thus during every cold start the exhaust first flows through the CCC for first few seconds until MC reaches light-off temperature and then directed to flow directly through the MC for the remaining period of engine operation. Hence CCC acts as a bypass catalyst for the first few seconds only and thus prevented from thermal damage and early ageing. Following parameters are measured in the investigation.

The temperature of the catalyst was measured at the following points using K type thermocouple and data logger. The test was conducted at an ambient temperature of 36°C.

1. Temperature of exhaust gas at exhaust manifold represented as “Base value”
2. Temperature of CCC, T1 represented as “CCC”
3. Temperature of MC, T2 represented as “MC”

Emission values of CO and HC were measured using AVL Digas analyzer at no load, half load and full load conditions at the following points.

1. Emission at exhaust manifold without catalyst represented as “Base value”
2. Emission at CCC, represented as “CCC”
3. Emission at MC, represented as “MC”.

The tests were conducted with the experimental set up of PCCS at different load conditions namely no load, half load (5Kgf) and full load (10Kgf) at 1500 rpm. The time was recorded using a stop clock.

3.6 TELESCOPIC CATALYTIC CONVERTER SYSTEM (TCCS)

A telescopic catalytic converter system consists of number of pipes of increasing diameter which can be stacked one inside the other so that the length of the pipe can be extended or shortened. One end of the telescopic pipe is attached to the exhaust manifold of the engine and the other end is attached to the catalytic converter. In the present work the telescopic pipe consists of 6 pipes each measuring 150mm length. The maximum diameter of the pipe being 60mm and the succeeding pipes have the diameters 50 mm, 40 mm, 30 mm, 25 mm and 20 mm. To prevent the leakage of exhaust gases rubber sealing (Garlock 9850-carbon fibre with Nitrile binder) is provided in between the pipes. The TCCS moves on the rails provided on the frame as shown in Figure 3.6. The photographic view of Experimental setup with TCCS is shown in Figure 3.7.

The telescopic catalytic converter system(TCCS) is connected to the lead screw arrangement coupled to the DC motor. The temperature of TCCS is measured with the help of K-Type thermocouple and the signal is sent to ECS. When the engine is cold started the TCCS will be at minimum distance of 150mm from exhaust manifold. The temperature sensor senses the temperature continuously and once it reaches light-off, ECS actuates the DC motor to move the TCCS to next position. At each position of TCCS once light-off temperature is sensed it moves to the next position and reaches the maximum distance at 900mm from the exhaust manifold. The catalyst will be positioned at the maximum distance till the engine is stopped. Thus the catalyst remains safe under thermal degradation and prevented from early ageing.
3.7 **TCCS WITH PRE-CATALYST**

In this technique the pre-catalyst (PC) is usually placed in the vicinity of the exhaust manifold. PC should be carefully designed regarding their formulation and volume. A pre-catalyst with high precious metal loading (Pd) and 10%-40% of a main converter volume allows easy installation close to the exhaust manifold.
Konstantinidis et al. (1997). It also favors exothermic oxidation and consequently the heat is utilized to heat-up the main catalyst.

3.7.1 TCCS with Pre-Catalyst (40% vol)

PC (40% vol) is directly connected to the exhaust manifold and TCCS is connected to the PC. Emission test has been conducted with TCCS attached to PC (40%) at different positions starting from minimum position to maximum position and at different loading conditions—namely, no load, half load and at full load conditions. TCCS with PC (40% vol) is schematically represented in Figure 3.8.

![Figure 3.8 Telescopic Catalytic Converter System with PC (40% vol)](image)

3.7.2 TCCS with Pre-Catalyst (20% vol)

PC (20% vol) is directly connected to the exhaust manifold and TCCS is connected to the PC. Emission test has been conducted with TCCS attached to PC (20% vol) at different positions starting from minimum position to maximum position and at different loading conditions—namely, no load, half load and at full load conditions. TCCS with PC (20% vol) is schematically represented in Figure 3.9.
3.8 **TCCS WITH HOT AIR INJECTOR**

Hot air gun is used to supply air at 400°C and at 200 lpm (1KW) at the instant when the engine was started. Hot air was supplied at exhaust manifold prior to the catalyst for the first 20 seconds. The hot air increases the temperature of exhaust gas and enables for quick light-off of the catalyst. Also the additional air has supplied more oxygen for faster oxidation CO and HC. TCCS with hot air injector gun is schematically represented in Figure 3.10.

![Figure 3.9 Telescopic Catalytic Converter Systems with PC (20% vol)](image)

![Figure 3.10 Telescopic Catalytic Converter with Hot Air Injector Gun](image)
3.9 EXPERIMENTAL PROCEDURE

The CO and HC emission values were recorded using AVL Digas exhaust gas analyzer, temperature of the exhaust gas and catalyst were recorded using K type thermocouple and data logger. Since the investigation under study is cold start emission, the emission values have to be recorded during the first few minutes only, at close interval of time say every 5 seconds. 3 sets of readings were taken for the measurement of temperature and emission for each configuration of the catalyst and average value is taken as the final value.

The present investigation is restricted to CO and HC emission only. Generally, NO\textsubscript{x} is not considered during cold start due to the following reasons.

1. During cold start, the engine will run with rich fuel and hence the concentration of CO and HC will be maximum and the concentration of NO\textsubscript{x} will be minimum.

2. NO\textsubscript{x} concentration starts increasing when the air fuel ratio changes from rich to stochiometric and will be maximum at slightly leaner than stochiometric.

3. Also NO\textsubscript{x} will be formed only at high combustion temperature and hence not considered during cold start.

Tests were conducted with the following experimental setups.

1. TCCS (Telescopic catalytic converter system) at different locations of the catalyst (15cm, 30cm, 45cm, 60cm, 75cm and 90cm from exhaust manifold represented as Position 1 to Position 6 respectively). The different configurations of TCCS using which the tests were conducted are shown in Figure 3.11(a) to 3.11(f).

2. Pre-catalysts (40%vol) connected to the TCCS at different positions of the catalyst (Position 1 to Position 6)
3. Pre-catalysts (20%vol) connected to the TCCS at different positions of the catalyst. (Position 1 to Position 6)

4. TCCS with hot air injector gun, at exhaust manifold capable supplying hot air at 400° C and 200 lpm and test conducted at different positions of the catalyst (Position 1 to Position 6).

All the above tests were conducted at different loading conditions namely, no load, half load (5Kgf) and full load (10Kgf) conditions at an engine speed of 1500 rpm.

Following parameters are measured in the present work.

- Temperature of exhaust gas at the exhaust manifold without catalyst(Base value)
- Temperature of the catalyst(TCCS) at different positions
- CO(%vol.)
- HC(ppm)
- Time (seconds)
Table 3.2 TEST MATRIX

<table>
<thead>
<tr>
<th>S. No</th>
<th>Experimental setup</th>
<th>Emission measured at</th>
<th>Loading Condition</th>
<th>Temperature measured at</th>
<th>Measured parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PCCS</td>
<td>CCC</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold, at CCC and MC</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
<tr>
<td>2</td>
<td>PCCS</td>
<td>MC</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold, at CCC and MC</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
<tr>
<td>3</td>
<td>TCCS</td>
<td>Position 1 to Position 6</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold and TCCS</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
<tr>
<td>4</td>
<td>TCCS with Pre catalyst(40% vol.)</td>
<td>Position 1 to Position 6</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold and TCCS</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
<tr>
<td>5</td>
<td>TCCS with Pre catalyst(20% vol.)</td>
<td>Position 1 to Position 6</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold and TCCS</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
<tr>
<td>6</td>
<td>TCCS with hot air injector gun</td>
<td>Position 1 to Position 6</td>
<td>No load, half load and Full load condition</td>
<td>Exhaust manifold and TCCS</td>
<td>Temperature(°C), Time(s), CO (%vol.) and HC(ppm)</td>
</tr>
</tbody>
</table>
Figure 3.11(a) TCCS at Position 1

Figure 3.11(b) TCCS at Position 2

Figure 3.11(c) TCCS at Position 3
Figure 3.11(d) TCCS at Position 4

Figure 3.11(e) TCCS at Position 5

Figure 3.11(f) TCCS at Position 6
The movement of Telescopic catalytic converter from Position 1 to Position 6 has been explained by a flow diagram as shown in Figure 3.12.

Figure 3.12 Flow Diagram of ECS Controlled Telescopic Catalytic Converter System