UH1

# EVALUATION OF FPC-1
# FUEL PERFORMANCE CATALYST

AT

**ANDHRA PRADESH STATE ROAD TRANSPORT CORPORATION, HYDRABAD NO 2 BUS DEPOT**

October, 1994


Report prepared by:

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# Appendices



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## EXECUTIVE SUMMARY

The basis of this study was to analyse the fuel efficiency effects of UHI Corporation's FPC-1 Fuel Performance Catalyst in a group of six (6) buses operated by the Andhra Pradesh State Road Transport Corporation at the Hydrabad No. 2 Bus Depot.

The study of the buses fuel consumption was conducted by an analytical method, namely Carbon Balance. The Carbon Balance tests conducted on a small sample of buses representative of the fleet showed an average reduction in fuel consumption of 5.8%. Smoke emissions reduced by 10%.

The purpose of this report is to review the test procedures and report the results achieved.

The Carbon Balance evaluation has been conducted and analysed by Fuel Technology Pty Ltd, the Australian subsidiary of the US based UHI Corporation.

## TEST METHOD - CARBON BALANCE (CB)

Carbon Balance (CB) measurement is a test procedure whereby the mass of carbon in the exhaust gas is calculated as a measure of fuel being burned. The elements measured in the test include the exhaust gas composition, its temperature and the gas flow rate calculated from the pressure and exhaust stack cross sectional area.

This is an engineering standard test (Australian Standard AS2077-1982, US - EPA).

The tests at Hydrabad involved adapting the exhaust pipe to a flexible trunkway straight for three meters which overcomes the potential for turbulent flow due to bends etc in the actual exhaust pipe.

## TEST PROCEDURE

The four (4) buses which made up the final test fleet (*refer Table I below*) were driven to the test centre in the workshop and the engines run up until the exhaust temperature stabilised. The engine rpm was set by the "snap on throttle control" and Shimpo tachometer taking the reading off the fan pulley. Buses run up under high idle condition.

The Horiba infra red analyser was calibrated with standard Horiba span gas prior to the tests commencing. The instrument probe inserted and centred into the flexible exhaust pipe and readings recorded for the gases, temperature and differential pressure.

Concurrent with this procedure the Bosch Smoke Sampling pump was used to extract a sample of exhaust gas and the smoke density determined.

**TABLE I**

**Summary of Engine RPM settings**

| Bus No. | Engine Type | Base RPM | Treated RPM |
|---|---|---|---|
| 723 | Leyland 370 | 2392 | 2329 |
| 3537 | Hino WD6 | 2488 | 2490 |
| 4229 | Hino WD6 | 2468 | 2445 |
| 6386 | Leyland 6-65 | 2419 | 2429 |

## CONCLUSION

The small sample of buses operating on FPC-1 treated fuel at Hydrabad No 2 Bus Depot showed a reduction in fuel consumption of 5.8% as measured by the exhaust emission Carbon Balance controlled test procedure.

Bosch Smoke measurements provided evidence of an average 10% reduction in smoke emissions.

The data work sheets and computer printouts are included in the Appendix. Also included is a description of the Carbon Balance procedure which includes the method of calculating the result.

*Annexure "A"*

# Fuel Technology Measurements using Carbon Balance Techniques

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# FUEL TECHNOLOGY MEASUREMENTS

# USING CARBON BALANCE TECHNIQUES

## CONTENTS

## INTRODUCTION

We are interested in measuring the amount of fuel used by an engine in doing a certain amount of work. This work is usually expressed as the distance covered by some equipment powered by the engine such as in a truck, or the amount of power produced over a certain time period for stationary equipment such as a generator. If all parameters are measured, expressions such as kilometres per litre (km/L) or kilowatt hours per litre (kW.h/L) can be calculated. In either case, the larger the number, the better the efficiency of the engine, i.e. the better the fuel consumption.

The measurement of distance covered or kilowatt hours is relatively easy to make in the field. However, determining the amount of fuel consumed is more difficult. A number of methods exist but often the practicability is not great. The amount of fuel may be measured volumetrically, i.e. measuring the volume of fuel used, or gravimetrically, i.e. weight of fuel consumed. It could also be calculated by measuring the flow of fuel through the fuel line. In all these cases existing equipment needs to be modified, often drastically, to produce acceptable accuracy. This is usually not desirable.

An alternative is to measure the fuel consumption indirectly by analysing what is leaving the engine, not what is going into it. This is the method used by Fuel Technology and is referred to as the **CARBON BALANCE** method. It is also the method used by the Standards Association of Australia (AS 2077-1982) although the techniques are slightly different.

The **CARBON BALANCE** method is based on the principle of conservation of matter. In this case it is assumed that what goes into an engine must come out again. The number of carbon atoms leaving the engine in the exhaust must exactly balance the number entering it. Hence the name "Carbon Balance". The only extra assumption which needs to be made is that there is no source of carbon other than from the fuel. This is the case with an engine in good condition, not burning a significant amount of oil.

Petroleum fuels are made up almost entirely from hydrogen and carbon. Combustion of the fuel with air in an internal combustion engine produces $H_2O$ (water), $CO_2$ (carbon dioxide), CO (carbon monoxide), HC (various partially-burned hydrocarbons), particulate carbon (soot) and various other minor components including nitrous oxides and sulphides. We are only interested in those products which contain carbon, i.e. $CO_2$, CO, HC and soot. If we can measure the amount of these components which leave the engine, then the equations developed in this paper can be used to calculate the amount of fuel used by an engine.

## PERFORMANCE FACTOR

In the field it is impossible to measure the total mass of carbon in the exhaust as we cannot capture all the exhaust gas. However, it is possible to measure the **rate** at which the exhaust gases are leaving the engine and to determine the composition of the exhaust, and thus determine the **rate** at which fuel is being consumed. This rate for a given load is known as the "Performance Factor". This is defined as:

$$PF = \dot{V}_F \qquad (6a)$$

$$= \dot{M}_{CE} \frac{(12x + y)}{\rho_F 12x} \qquad [\text{from } (5)] \qquad (6b)$$

Where PF = Performance Factor.

$\dot{V}_F$ = rate of change of $V_F$

$\dot{M}_{CE}$ = rate of change of $M_{CE}$

[Example: if 1 litre of fuel is used in 1 minute (60 seconds) then $\dot{V}_F$ = 1 litre/60 seconds = 1/60 litres per second.]

We also need the equation which relate the components of the exhaust gas to its mass. This is developed in the Appendix, giving:

$$\dot{M}_{CE} = \dot{Q}_E \frac{(V_P + 12P_E (XV_{HC} + V_{CO} + V_{CO_2}))}{RT_E} \qquad (7)$$

where:

| | | |
|---|---|---|
| $\dot{Q}_E$ | = | volumetric flow rate of exhaust $m^3$/sec |
| $P_E$ | = | exhaust pressure at sample point in pascals |
| $T_E$ | = | exhaust temperature at sample point in kelvin (kelvin = °C + 273.16) |
| $V_{CO_2}$ | = | volume fraction of $CO_2$ |
| $V_{CO}$ | = | volume fraction of CO |
| VHC | = | volume fraction of HC |
| $V_P$ | = | mass of soot in $kg/m^3$ |
| R | = | universal gas constant (=8.31 joule/mole K) |
| X | = | number of carbon atoms per molecule of hydrocarbon in exhaust (usually X = 6) |
| $\rho$ | = | density |

Thus if we can measure each of these variables, $\dot{M}_{CE}$ and hence the Performance Factor, PF can be calculated using equation (6).

FUEL CONSUMPTION

As stated in the introduction we are interested in measuring the amount of fuel used in doing a certain amount of work. Once we have measured the performance factor we can calculate the fuel consumption, FC:

$$FC = D/V_F = D/PF \times T \quad (11a)$$

or

$$FC = kW.h/V_F = kW.h/PF \times T \quad (11b)$$

where FC = fuel consumption
D = distance travelled
T = time of test
kW.h = kilowatt hours

Normally distance or kilowatt hours are easily measured.

CONCLUSION

Equation (7) gives the mass of carbon used per unit time; equation (10) gives the % change in fuel consumption and equation (6b) yields the volume of fuel used per unit time. All these quantities require the measurement of $M_{CE}$.

Once the volume of fuel used has been determined, equation (11a) or (11b) can be used to calculate the fuel consumption of the engine.

APPENDIX

**Development of the relationship between the density of carbon in the fuel to the density of the fuel.**

$\rho_{CF}$ = mass of carbon/litre of fuel.

If the fuel used has the hydrocarbon formula $C_xH_y$, then the fraction of the mass of fuel which is carbon is equal to:

$$\frac{\text{Mass of carbon in fuel}}{\text{Mass of fuel}} \qquad \text{(i)}$$

$$= \frac{\text{Molecular weight of carbon x number of carbon atoms per molecule}}{\text{Molecular weight of the fuel}}$$

$$= \frac{MWc \times Nc}{(MWc \times Nc) + (MWh \times Nh)} \qquad \text{(ii)}$$

Where
Nc = Number of carbon atoms per molecule of fuel = x
MWc = Molecular weight of carbon = 12.0
Nh = Number of hydrogen atoms per molecule of fuel = y
MWh = Molecular weight of hydrogen = 1.0

This means that (ii) becomes:

$$\frac{12x}{12x + y} = \text{fraction of mass of fuel which is carbon}$$

Now since this mass of carbon occupies the same volume as the fuel the ratios of the masses of carbon and fuel must be equal to the ratio of their densities. This means that:

$$\frac{\rho_{CF}}{\rho_F} = \frac{12x}{12x + y} \qquad \text{(iii)}$$

which may be expressed equivalently as

$$\rho_{CF} = \rho_F \times \frac{12x}{12x + y} \qquad \text{(iv) = (3)}$$

**Derivation of the equation for mass of carbon in the exhaust**

The mass of carbon in the exhaust
= the sum of the masses of carbon in each of the carbon-bearing exhaust components
= mass of carbon as soot + mass of carbon in hydrocarbons + mass of carbon in carbon monoxide + mass of carbon in carbon dioxide.

This can be expressed as:

$$M_{CE} = M_C\text{ (soot)} + M_{C(HC)} + M_{C(CO)} + M_{C(CO_2)} \qquad \text{(a)}$$

It is important to note that the pressure, temperature, and volume must be measured at the same place otherwise the equation does not hold.

The pressure and temperature of all the gases is equal.

The volume of each of the components of the exhaust is equal to the total volume x the volume of fraction of that component. That is:

$$\text{Volume of hydrocarbons} = V_{HC} \times Q_Z \qquad (f)$$

Where $V_{HC}$ is the volume fraction of the hydrocarbon gas component.

Then substituting (f) into (e) the expression for the number of moles of hydrocarbons is obtained:

$$u_{HC} = \frac{PV_{HC}}{RT} \times Q_Z \qquad (g)$$

Then substituting (g) into (c) the expression for the mass of carbon in the exhaust due to the hydrocarbons is obtained:

$$M_{C(HC)} = MW_C \times N_{C(HC)} \times \frac{PV_{HC}}{RT} \times Q_E \qquad (h)$$

Equivalent equations are obtained for CO and $CO_2$; these are:

$$M_{C(CO)} = MW_C \times N_{C(CO)} \times \frac{PV_{CO}}{RT} \times Q_E \qquad (i)$$

and

$$M_{C(CO_2)} = MW_C \times N_{CO(CO_2)} \times \frac{PV_{CO_2}}{RT} \times Q_E \qquad (j)$$

These may be simplified by noting that:

$$N_{C(HC)} = 6 \quad \text{(since HCs are measured as hexane)}$$

$$N_{C(CO)} = 1$$

$$N_{C(CO_2)} = 1$$

and

$$MW_C = 12.0$$

to obtain:

$$M_{C(HC)} = 12 \times 6 \times \frac{PV_{HC}}{RT} \times Q_E \qquad (k)$$

$$M_{C(C)} = 12 \times 1 \times \frac{PV_{CO}}{RT} \times Q_E \qquad (l)$$

and

$$M_{C(CO_2)} = 12 \times 1 \times \frac{PV_{CO_2}}{RT} \times Q_E \qquad (m)$$

*Annexure "B"*

# Raw Data Sheets

# Emission Data Work Sheet

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Fuel Technology

Baseline Test Date 4/6/94 Treated Test Date 23/10/94

Company APSRTC Hydrabad 2

Engine Description: Pre-Comb ☐ A/Cooled ☐ I/Cooled ☐ Turbo ☐ N/Asp. ☑

Type of equipment Bus Fleet/Unit Number 723

Engine Make Leyland Model 370 Rating

Type of Fuel: Baseline Treated

Engine Hours ☐ Miles ☐ Kms ☑ Baseline 21623 Treated 62998

Engine Test Mode: Baseline Treated 28/3/94 O/H Engine. new pistons cranked pistons 30 thou undersize

## ANALYSIS DATA

### BASELINE

Barometric (Mb) 948 Fuel Density (Kg/1)

Ambient Temp. °C 34 Engine RPM 2392

Stack Dia. mm 100 Engine Load Hi idle

| | | | | | |
|---|---|---|---|---|---|
| Pressure Diff. (Pa) | 60 | 60 | 60 | 60 | 60 |
| Exhaust Temp. °C | 124 | 124 | 124 | 124 | 125 |
| HC (ppm) | 10 | 10 | 10 | 10 | 10. |
| CO (%) | 0·05 | 0·05 | 0·05 | 0·05 | 0·05 |
| $CO_2$ (%) | 2·38 | 2·37 | 2·38 | 2·37 | 2·38 |
| $O_2$ (%) | 13·11 | 13·10 | 13·11 | 13·10 | 13·10· |

### TREATED

Barometric (Mb) 960 Fuel Density (Kg/1)

Ambient Temp. °C 29 Engine RPM 2324–2334.

Stack Dia. mm 100 Engine Load Hi Idle

| | | | | | |
|---|---|---|---|---|---|
| Pressure Diff. (Pa) | 62 | 65 | 65 | 65 | 65 |
| Exhaust Temp. °C | 119 | 120 | 120 | 121 | 121 |
| HC (ppm) | 30 | 30 | 30 | 30 | 30 |
| CO (%) | 0·05 | 0·05 | 0·05 | 0·05 | 0·05 |
| $CO_2$ (%) | 2·03 | 2·03 | 2·03 | 2·03 | 2·03 |
| $O_2$ (%) | 18·17 | 18·17 | 18·14 | 18·16 | 18·16 |

REMARKS

Test conducted by [signature] Supervised by

# EMISSION DATA WORK SHEET

ft Fuel Technology

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Baseline Test Date 4/6/94 Treated Test Date 23/10/94.

Company APSRTC Hydrasad Z

Engine Description: Pre-Comb ☐ A/Cooled ☐ I/Cooled ☐ Turbo ☐ N/Asp. ☑

Type of equipment Bus Fleet/Unit Number 4229

Engine Make Hino Model ~~Hino~~ WD6 Rating

Type of Fuel: Baseline Treated

13/5/92 Commissioned

Engine Hours ☐ Miles ☐ Kms ☑ Baseline 340709 Treated

Engine Test Mode: Baseline Treated Inj changed 12/5/94

Total Kms ~~409~~ 56. 679055.

## ANALYSIS DATA

### BASELINE

| | | | | | |
|---|---|---|---|---|---|
| Barometric (Mb) | 948 | | Fuel Density (Kg/l) | | |
| Ambient Temp. °C | 35 | | Engine RPM | 2468 | |
| Stack Dia. mm | 100 | | Engine Load | Hi Idle. | |
| Pressure Diff. (Pa) | 110 | 111 | 111 | 110 | 111 |
| Exhaust Temp. °C | 127 | 128 | 129 | 129 | 129 |
| HC (ppm) | 30 | 30 | 30 | 30 | 30 |
| CO (%) | 0.04 | 0.04 | 0.04 | 0.035 | 0.03 |
| $CO_2$ (%) | 2.25 | 2.25 | 2.25 | 2.23 | 2.23 |
| $O_2$ (%) | 13.16 | 13.17 | 13.15 | 13.15 | 13.16 |

### TREATED

| | | | | | |
|---|---|---|---|---|---|
| Barometric (Mb) | 960 | | Fuel Density (Kg/l) | | |
| Ambient Temp. °C | 28 | | Engine RPM | 2448 - 2450 | |
| Stack Dia. mm | 100 | | Engine Load | Hi Idle | |
| Pressure Diff. (Pa) | 100 | 100 | 99 | 100 | 99 |
| Exhaust Temp. °C | 130 | 131 | 131 | 131 | 131 |
| HC (ppm) | 30 | 30 | 30 | 30 | 30 |
| CO (%) | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| $CO_2$ (%) | 2.17 | 2.17 | 2.18 | 2.18 | 2.18 |
| $O_2$ (%) | 17.81 | 17.81 | 17.80 | 17.81 | 17.82 |

REMARKS

Test conducted by [signature] Supervised by

*Annexure "C"*

**Computer printouts - results**

## FUEL TECHNOLOGY PTY LTD CARBON BALANCE RESULTS

| | | | |
|---|---|---|---|
| COMPANY : | APSRTC | LOCATIO | HYDRABAD 2 DEPOT |
| EQUIPMENT : | BUS | UNIT NR. : | 723 |
| ENG. TYPE : | LEYLAND | MODEL : | 370 |
| RATING : | | FUEL : | |

### BASELINE TEST

**DATE : 4/6/94**

| | | | |
|---|---|---|---|
| ENG. HOURS : | 21623 | ENG. RPM | 2392 |
| AMB. TEMP (C) : | 34 | STACK(m | 100 |
| BAROMETRIC(mb): | 948 | LOAD: | Hi Idle |

| | *TEST 1* | *TEST 2* | *TEST 3* | *TEST 4* | *TEST 5* | AVERAGE | % ST.DEV |
|---|---|---|---|---|---|---|---|
| PRES DIFF (Pa): | 60 | 60 | 60 | 60 | 60 | 60 | 0.00 |
| EXHST TEMP (C): | 124 | 124 | 124 | 124 | 125 | 124 | 0.36 |
| HC (ppm) : | 10 | 10 | 10 | 10 | 10 | 10.0 | 0.00 |
| CO (%) : | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.050 | 0.00 |
| CO2 (%) : | 2.38 | 2.37 | 2.38 | 2.37 | 2.38 | 2.38 | 0.23 |
| O2 (%) : | 13.11 | 13.10 | 13.11 | 13.10 | 13.10 | 13.10 | 0.04 |
| CARB FLOW(g/s): | 0.645 | 0.643 | 0.645 | 0.643 | 0.644 | 0.644 | 0.21 |

REYNOLDS NR. : 3.39E+04

### TREATED TEST

**DATE : 23/10/94**

| | | | |
|---|---|---|---|
| ENG. HOURS : | 62998 | ENG. RPM | 2324-2334 |
| AMB. TEMP (C) : | 29 | STACK(m | 100 |
| BAROMETRIC(mb): | 960 | LOAD: | Hi Idle |

| | *TEST 1* | *TEST 2* | *TEST 3* | *TEST 4* | *TEST 5* | AVERAGE | % ST.DEV |
|---|---|---|---|---|---|---|---|
| PRES DIFF (Pa): | 62 | 65 | 65 | 65 | 65 | 64 | 2.08 |
| EXHST TEMP (C): | 119 | 120 | 120 | 121 | 121 | 120 | 0.70 |
| HC (ppm) : | 30 | 30 | 30 | 30 | 30 | 30.0 | 0.00 |
| CO (%) : | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.050 | 0.00 |
| CO2 (%) : | 2.03 | 2.03 | 2.03 | 2.03 | 2.03 | 2.03 | 0.00 |
| O2 (%) : | 18.17 | 18.17 | 18.14 | 18.16 | 18.16 | 18.16 | 0.07 |
| CARB FLOW(g/s): | 0.570 | 0.583 | 0.583 | 0.582 | 0.582 | 0.580 | 0.97 |

REYNOLDS NR. : 3.55E+04 TOTAL HOURS ON TREATED 41375

PERCENTAGE CHANGE IN FUEL CONSUMPTION ((TREATED-BASE)/ **-9.9 %**

REMARKS:

## FUEL TECHNOLOGY PTY LTD CARBON BALANCE RESULTS

COMPANY : APSRTC LOCATIO HYDRABAD 2 DEPOT

EQUIPMENT : BUS UNIT NR. : 4229
ENG. TYPE : HINO MODEL : WD6
RATING : FUEL :

**BASELINE TEST** **DATE : 4/6/94**

ENG. HOURS : 340709 ENG. RPM 2468
AMB. TEMP (C) : 35 STACK(m 100
BAROMETRIC(mb): 948 LOAD: Hi Idle

| | *TEST 1* | *TEST 2* | *TEST 3* | *TEST 4* | *TEST 5* | AVERAGE | % ST.DEV |
|---|---|---|---|---|---|---|---|
| PRES DIFF (Pa): | 110 | 111 | 111 | 110 | 111 | 111 | 0.50 |
| EXHST TEMP (C): | 127 | 128 | 129 | 129 | 129 | 128 | 0.70 |
| HC (ppm) : | 30 | 30 | 30 | 30 | 30 | 30.0 | 0.00 |
| CO (%) : | 0.04 | 0.04 | 0.04 | 0.035 | 0.03 | 0.037 | 12.09 |
| CO2 (%) : | 2.25 | 2.25 | 2.25 | 2.23 | 2.23 | 2.24 | 0.49 |
| O2 (%) : | 13.16 | 13.17 | 13.15 | 13.15 | 13.16 | 13.16 | 0.06 |
| CARB FLOW(g/s): | 0.825 | 0.827 | 0.826 | 0.814 | 0.816 | 0.821 | 0.78 |

REYNOLDS NR. : 4.58E+04

**TREATED TEST** **DATE : 23/10/94**

ENG. HOURS : 67905 ENG. RPM 2440-2450
AMB. TEMP (C) : 28 STACK(m 100
BAROMETRIC(mb): 960 LOAD: Hi Idle

| | *TEST 1* | *TEST 2* | *TEST 3* | *TEST 4* | *TEST 5* | AVERAGE | % ST.DEV |
|---|---|---|---|---|---|---|---|
| PRES DIFF (Pa): | 100 | 100 | 99 | 100 | 99 | 100 | 0.55 |
| EXHST TEMP (C): | 130 | 131 | 131 | 131 | 131 | 131 | 0.34 |
| HC (ppm) : | 30 | 30 | 30 | 30 | 30 | 30.0 | 0.00 |
| CO (%) : | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.040 | 0.00 |
| CO2 (%) : | 2.17 | 2.17 | 2.18 | 2.18 | 2.18 | 2.18 | 0.25 |
| O2 (%) : | 17.81 | 17.81 | 17.80 | 17.81 | 17.82 | 17.81 | 0.04 |
| CARB FLOW(g/s): | 0.758 | 0.758 | 0.757 | 0.761 | 0.757 | 0.758 | 0.21 |

REYNOLDS NR. : 4.36E+04 TOTAL HOURS ON TREATED -272804

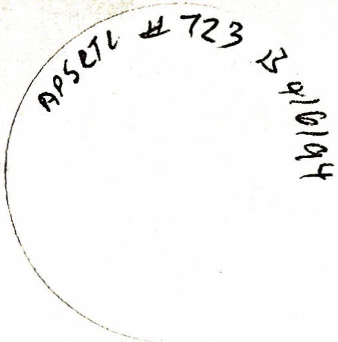
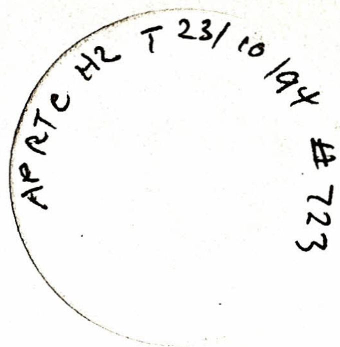
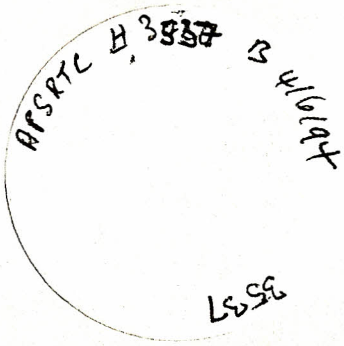
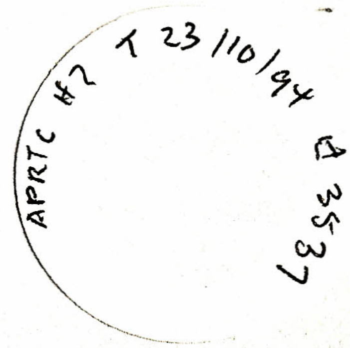
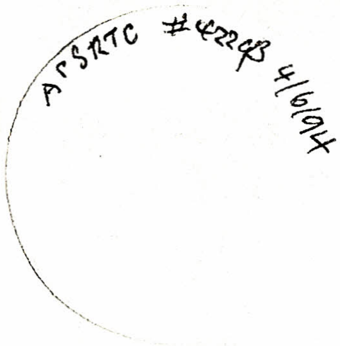
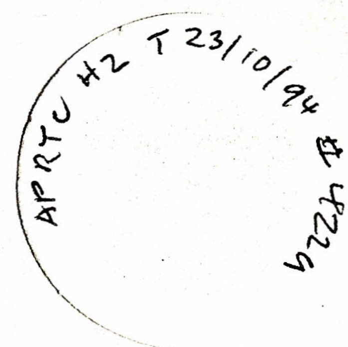
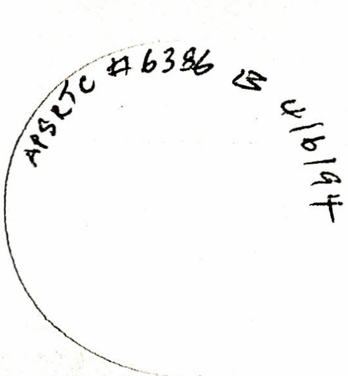
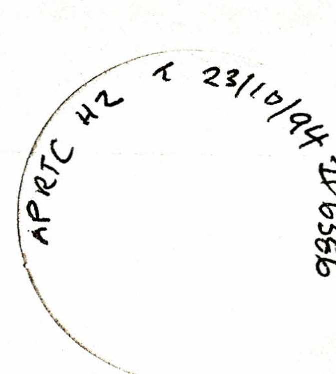
PERCENTAGE CHANGE IN FUEL CONSUMPTION ((TREATED-BASE)/ **-7.7 %**

REMARKS:

*Annexure "D"*

**Bosch Smoke Patches**

# BOSCH SMOKE METER FILTER TEST RESULTS

| Unit No. | Baseline 4/6/94 | *Bosch No.* | Treated 23/10/94 | *Bosch No.* |
|---|---|---|---|---|
| 723 |   | 0.2 |   | 0.1 |
| 3537 |   | 0.3 |   | 0.4 |
| 4229 |   | 0.3 |   | 0.3 |
| 6386 |   | 0.2 |   | 0.1 |