THE INFLUENCE OF SURFACE ACTIVE ADDITIVES ON AIR FUEL MIXTURE BEHAVIOUR AND ENGINE EXHAUST POLLUTANTS LEVELS

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DEDICATED TO

THE AFFECTIONATE MEMORIES OF

MY MOTHER

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ABSTRACT

The research has been conducted in the field of control of air pollution as produced by an internal combustion - spark ignition engine. The studies involved the behaviour of air-fuel mixture and its effects on the amount of pollutants emitted. The pollutants studied are hydrocarbons and carbon monoxide. The research is based on the basic philosophy that the degree of homogeneity of air-fuel mixture determines the extent of combustion of fuel thus affecting the amounts of the pollutants emitted. To improve the air-fuel mixture homogeneity and its distribution among various cylinders four surface active fuel additives have been experimented with. The effects of such additives were observed and recorded both visually and in terms of the emitted concentrations of the pollutants concerned. A cine-film of mixture, flowing through two glass tubes mounted between the carburettors and inlet manifold of a twin carburettor engine, has been prepared to produce the visual records as to determine the change of flow patterns and the degree of fuel atomisation. Two kinds of fuel - Esso Plus and Reference Gasoline - have been used throughout the present work. The results thus obtained are correlated and discussed from the point of view of air-fuel mixture behaviour and the amounts of pollutants emitted. The research indicates the role of surface active fuel additives as a potential means of controlling air pollution from motor vehicle engines.

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Chapter 1

INTRODUCTION

INTRODUCTION

1:1

(a) The Problem of Air Pollution

During recent years environmental pollution has become one of the most threatening and urgent problems of the human race. The public and scientific concern shown towards the present state of our environment has resulted in a massive amount of research which alone would testify to the seriousness of this exceptionally difficult problem.

On this planet, there exist many kinds of environmental pollution, but perhaps the most important and widespread of them all is atmospheric pollution. The major sources for this pollution are industry and fuel operated engines. The present project is concerned with the air pollution produced by internal combustion, spark-ignition motor vehicle engines. It is estimated that nearly 60% of the total atmospheric pollution is attributed to this source. (1). The internal combustion engine produces pollutants like hydrocarbons, carbon monoxide, nitrogen oxides, lead, sulphur oxides, and particulate matter. The contribution of all these pollutants to the total amount of air pollution is given in Fig. 1:1 (2).

There has always existed a close relationship between man and his environment. This fact is being increasingly recognised by the world in present years. Inevitably this relationship is changing constantly and needs unceasing surveillance and control. The problem of air pollution has been compounded as new contaminants - by-products of expanding technology, population growth, urbanization, and

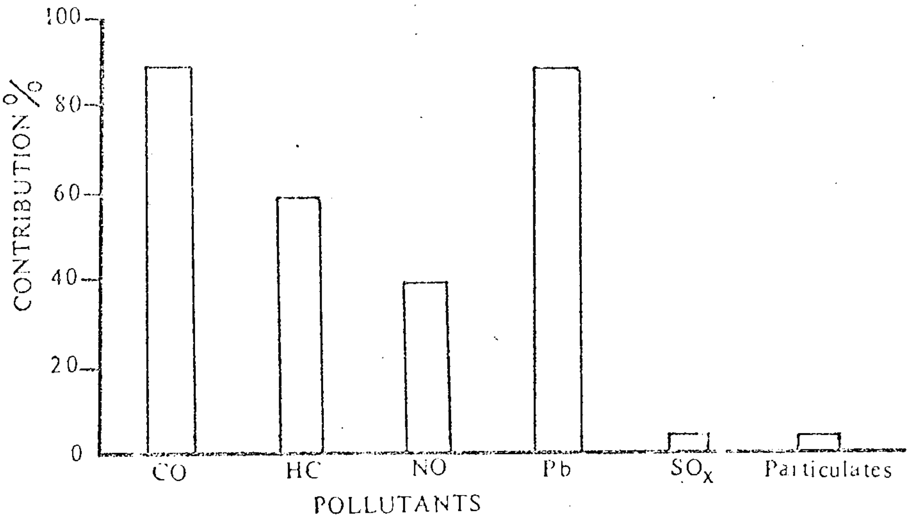


Fig.1:1 Contribution Of Motor Vehicles To Total Atmospheric Pollution

increasing demands as man's standard of living rises - are being added to the atmosphere in ever-increasing number and amounts. This has developed into the very acute problem of air pollution which demands an immediate effective remedy.

The efficiency with which people and the necessities of life can be transported from one place to another, over vast distances, determines progress on this industrialised planet. Motor vehicles are the major means of achieving this efficiency. These demands of progress have resulted in ever increasing need and number of motor vehicles, which clearly emphasise the urgency for finding a cure for this epidemic of air pollution. The publication "Research on

Road Traffic" forecasts the future number of fuel consuming vehicles in Great Britain as follows (3)

Year	Population Millions	Millions of Vehicles				
		Cars	Motor Cycles	Agri-Cultural Vehicles	Other Vehicles	All Motor Vehicles
1960	51	5.5	1.9	0.4	1.6	9.4
1965	53	8.7	2.6	0.5	2.0	13.8
1970	55	12.4	3.1	0.6	2.4	18.5
1980	59	19.2	3.5	0.6	3.3	26.6
1990	63	23.7	3.8	0.6	4.1	32.2
2000	69	27.0	4.1	0.7	5.0	36.8
2010	76	30.4	4.6	0.8	5.7	41.5

The forecast then made for possible increase in the number of vehicles up to 1980 was that the vehicles would generally increase nearly three-fold; motor cars would rise to 3½ times their present number, and the general goods carrying class vehicles would more than double in number. The number of vehicles operating in an area has a formidable effect on the amount of total air pollution. The route and time the car is driven for, its engine size and type, kind of fuel it uses are some of the many factors which determine the extent of vehicle emitted pollution. The estimates of the pollutants from road vehicles in Great Britain are given in Table 1-a

Table 1-a

Estimates of Pollutants from Road Vehicles in the United Kingdom in the Year 1970-71 in Million Tonnes

Consumption of Motor Spirit = 14.23 M. Tonnes

Consumption of Der. Spirit = 5.04 M. Tonnes

Pollutant	Petrol Engine	Diesel Engine
Carbon Monoxide	6.70	0.110
Hydrocarbons	0.34	0.021
Aldehydes	0.01	0.003
Oxides of Nitrogen	0.23	0.070
Oxides of Sulphur	0.025	0.040
Lead	6,000 Tonnes	

In the United States, the problem of air pollution is more severe than in Britain. The total number of motor vehicles given by The Automobile Industries Statistical Issue of 1961 was nearly 73 million (5). The latest figures show that the car population in America has now reached nearly a hundred million cars (6).

According to the studies conducted by the Air Pollution Control District of the county, as of January 1961, states that the gasoline driven vehicles in Los Angeles county emit 1,180 tons of hydrocarbons, 330 tons of nitrogen oxides, and 8,950 tons of carbon monoxide daily (7).

This amount of carbon monoxide is equivalent to a volume of 230,000,000 cubic feet, and is enough to pollute the air to a height of 400 ft. over an area of 681 sq. miles to concentration of 30 p.p.m. which is classified as "adverse" level according to the state of California Standards for Ambient Air.

The deductions made from the data supplied by the Nationwide Inventory of Air Emissions - a nationwide figure for discharge of pollutants - in 1968 are given as follows (8).

Pollutant	Quantity (millions of tons)
Carbon Monoxide	= 63.8
Hydrocarbons	= 16.6
Nitrogen Oxides	= 8.1
Sulphur Oxides	= 0.8
Particulates	= 1.2

(b) The Pollutants and their Effects on Human Health

Air pollution threatens the existence of man in more than one way. Most serious,of course, are the catastrophic effects on human health that can follow exposure to the pollutants during unusual meteorological conditions. The first of what has since become a growing list of such tragic episodes which have attracted world-wide concern, occurred in Belgium's Meuse River Valley in December 1930. There, some 60 people died, and 6,000 others became seriously ill from breathing abnormally high levels of particulates and gaseous pollutants present in the air, from various sources (9). Another calamity took place in the mill town of Donora, near Pittsburg, Pennsylvania in 1948. Almost half the population became ill, and 20 died (10). In December 1952, there occurred another calamity, this time in London which caused the death of about 4,000 people in one week, and another 8,000 over the next three months (11). Records also show a similar effect of air pollution in New York City, in 1953, when more than 200 excess deaths and numerous cases of increased illness were registered during a period when air pollution levels were high (12). This was followed by a "smog" in London in December 1962, which caused some 730 deaths (7).

The effects of the most important pollutants are now dealt with :

1. HYDROCARBONS :-

The fuel combusting inside a cylinder undergoes some cracking process which results in various kinds of unburned hydrocarbons, that are emitted in exhaust gases. Hoffman (13), Begeman (14), and Hoffmann and Wynder (15) were able to separate various polynuclear aromatic hydrocarbons and phenols. The benzene-soluble materials from the exhaust of a V-8 engine operated on a simulated city driving cycle were analysed for these compounds. The authors have given a long list of various polynuclear aromatic hydrocarbons (Table 1:b), but among these, the following are known to have carcinogenic characteristics.

Benz (a) anthracene, Benz (a) pyrene, Benz (e) pyrene, Benz (j) fluoranthene, 11 H - benz (b) fluoranthene, Dibenz (a-1) pyrene. In addition to these compounds, eight phenols were also

Table 1:b

Polynuclear Aromatics

Anthracene

Fluoranthene

Pyrene

Triphenylene

Alkylchrysene

Alkylbenz (a) anthracene

11 H - benz (b) fluorene

Benz (k) fluoranthene

Benz (j) fluoranthene *

11 H - benz (b) fluoranthene

Benz (g,h,i) fluoranthene

Benz (g,h,i) perylene

Indeno (1,2,3, c d) fluoranthene

Dibenz (a,l) naphthacene

Dibenz (a,l) pyrene *

Dibenz (b, pqr) perylene

Phenanthrene

Alkylfluoranthene

Alklpyrene

Chrysene *

Benz (a) anthracene *

Naphthacene

Benz (a) pyrene *

Perylene

Alkylbenz (a) pyrene

Dibenz (a,h) anthracene *

Dibenz (b,h) phenanthrene

Anthanthrene

Indeno (1, 2, 3, c d) pyrene

Dibenz (a, c) pyrene *

Coronene

Aliphatic Hydrocarbons

Hexadecane

Octadecane

Eicosane

Tetracosane

Heptadecane

Nonadecane

Docosane

* Indicates that compound is known to be carcinogenic.

identified. Five of these phenols are known to be tumour-promoting agents when applied to mouse epidermis. Among the polynuclear aromatic carcinogenic compounds contained in exhaust gas, only the Benz (a) pyrene is at present known to exist in relatively large amounts to be most effective. Hartwell (16) has proved in his work with Benz (a) pyrene and its effects on animals that this compound has a potent cancer-producing activity. Putting their findings together, Falk and his associate, postulated a disturbing sequence of events. (17) The lining of most of the respiratory tract is a mucous-secreting ciliated columnar epithelium. Fine particles of dust in the air are trapped by the mucous and swept away from the lungs by the beating of the cilia; this activity is inhibited by atmospheric pollution. The soot particles carrying hydrocarbons are abnormally deposited and retained in the lungs. These particles are engulfed by phagocytic cells, and intracellular proteins elute the absorbed hydrocarbons. Conceivably, a high local concentration of eluted aromatic hydrocarbon results, favouring the development of lung cancer.

The work conducted by Barnes, of the British Research Council, concludes that the exposure to small quantities of carcinogenic compounds is not very harmful, but an exposure to large quantities of these compounds could result in serious damage to human health (18).

Environmental Levels

Reported benzpyrene levels range in urban areas from 0.1 to 61 micrograms (ug) per 1,000 cubic metres of air and in non-urban areas from 0.01 to 1.9 ug 1,000 cubic metres of air. For comparison, 60 ug per 1,000 cubic metres is approximately equivalent to 5 parts per trillion, viz, 10^{12} by weight. However, it has been deduced that motor vehicles probably contribute as little as 2%, but no more than 10% of the total concentration of the benzpyrene contents (7). It is now generally agreed that the hydrocarbons, as found on street levels, do not of themselves pose a health hazard. Control of the emission of hydrocarbons is essential just the same, since their contribution towards the formation of photochemical smog makes them a dangerous pollutant. They also possess, in the partly oxidised stage, a very strong odour which is usually associated with the motor vehicles' exhaust.

2. CARBON MONOXIDE :-

Carbon monoxide (CO) a colourless, non-irritating gas, is generated by incomplete combustion. Because of the contribution by motor vehicles' exhaust, carbon monoxide is one of the most dangerous urban pollutants.

The major effect of carbon monoxide depends upon its abilities to impair oxygen transportation by blood, through two distinct mechanisms. First, since the affinity of human haemoglobin is 210 times greater for CO than it is for oxygen, a small quantity of CO can reversibly inactivate a substantial percentage of the oxygen-carrying capacity of blood. Second, CO-haemoglobin interferes with the release of the oxygen carried by the haemoglobin molecules.

New York Academy of Sciences sponsored a discussion of carbon monoxide effects, in January 1970, especially in the realm of heart diseases, in a conference in New York City (19). Evidence was found for atterogenic effects (fatty degeneration of blood vessels contributing to heart trouble) of exposure to even moderate quantities of carbon monoxide in animals. Kraut has established that moderate levels of carboxy-haemoglobin may reduce the capacity for physical exertion, even in the absence of obvious symptoms (20). At a 400 ppm level, headache, weakness, nausea, and dizziness appear; at 600 ppm tachcardia, i.e., rapid pulse rate with danger of collapse; at 800 ppm fainting; and at 1,000 ppm coma, convulsions, and death may occur. Nichols and Kinsey exposed volunteers during prolonged submarine submergence to 25 to 100 ppm of carbon monoxide for 22 days. The number of headaches at 100 ppm was significantly greater than the number occuring during 6 days immediately following the outboard ventilation (21).

The extent of carbon monoxide damage to health depends on the individual's physiological state, and smoking habits as well. In those with incompetent heart or lungs, oxygen-carbon dioxide exchange is impaired in the pulmonary alveoli and oxygen transport may be diminished. In anaemic people, the oxygen-carrying capacity of the blood is also decreased. Persons suffering from haemolytic diseases, in whose blood carbon monoxide is produced by break-down of haemoglobin, may have carboxy haemoglobin levels as high as 2% as compared to the normal of 0.5% (22). The new-born and those recovering from major surgery may also be especially sensitive (23). Smokers may have carboxy haemoglobin levels as high as 8-12%. Goldsmith found that 95% of the persons with carbon monoxide levels in excess of the previously established risk levels were smokers, where as only one third of those with the level below risk smoked. Of 4,200 ppm of carbon monoxide in cigarette smoke, all but 475 ppm was found to be retained in the body (24).

Summarising the known effects of carbon monoxide on health, Goldsmith stated that there is fragmentary evidence of effect on central nervous system from carbon monoxide as low as 10 ppm in the atmosphere. This level corresponds to the formation of about 2% carboxy-haemoglobin in blood after prolonged exposure (more than 8 hours). There is good evidence of adverse effect of carbon monoxide on oxygen transport in the blood when carboxy-haemoglobin level goes above 5% (from 30 ppm CO in the atmosphere) (19). Driving through London for three hours with the windows shut and the intake on, Lawther reported carbon monoxide concentration of 130 ppm in the vehicle; the passengers' haemoglobin doubling over their previous control value (25).

Henderson and co-workers have drawn a co-relationship between the time of exposure, concentrations of carbon monoxide present, and the degree of its injurious effects on health. According to their work, the relationship is given as : (26)

<u>Hours</u> <u>CO parts/10,000</u>

Time x Concentration = 3, no perceptible effect

Time x Concentration = 6, a just perceptible effect

Time x Concentration = 9, headache and nausea

Time x Concentration = 15, dangerous

Carbon monoxide also takes part in the reactions towards atmospheric smog.

Environmental Levels :

Bloomfield and Isbell examined the carbon monoxide contents in air of 14 United States Cities (27). The average street concentration was 80 ppm of carbon monoxide, with a range of 20 to 290 ppm, as compared with the motor repair shops average of 210 ppm and 10 - 1,100 ppm. Since then, the carbon monoxide concentrations in the atmosphere have decreased greatly due to the engineering advances which have resulted in better gasoline combustion. Wilkins did not find any striking increase in carbon monoxide levels over a period of 24 years, although the gasoline consumption has doubled, and the traffic in many streets had increased to the saturation point (28). At present, the high busy-street carbon monoxide concentrations are given as 15-25 ppm and can be compared with the threshold value of 50 ppm for an 8 hour exposure, as given by the publications of the Threshold Limit Values Table (T.L.V.) (29, 30)

3. ALDEHYDES :-

The low molecular weight aliphatic aldehydes formed during the engine combustion processes are the most irritating type of air pollutants. The accidental and suicidal ingestion of formaldehyde has resulted in dangerous effects on human health (31). The responses from non-fatal cutaneous and inhalation exposure include many serious internal and external disorders. Experiments conducted by Barnes and Speicher show that an exposure to 20 ppm of formaldehyde produced lachrymation in 15 to 30 seconds, irritation of the nose and throat in 30 seconds, and sneezing in 1 or 2 minutes (32). Melekina's work shows that 1.4 ppm delayed adaptation to darkness, and 0.056 to 0.088 ppm was determined to be threshold olfactory sensitivity (33). Sim and Pattle exposed 5 to 15 human volunteers to vapours of several aldehydes from 5 to 30 minutes

(34). Formaldehyde caused irritation of mucous membranes and lachrymation at 13.8 ppm; acrolein was violently irritating and lachyrmatory at 0.805 and 1.22 ppm; crotonaldehyde was irritant and lachyrmatoryat 4.1 ppm; acetaldehyde produced slight irritation to the upper respiratory tract at 134 ppm; propanaldehyde, butyraldehyde, and isobutyraldehyde were non-irritating at concentrations of 134 ppm, 230 ppm, and 207 ppm respectively. Isobutyraldehyde produced nausea and vomiting in one case.

Environmental Levels :

Cholak has done some studies on the amount of the aldehydes present in the atmosphere (35). According to his studies conducted in various United States cities, sampled from 1946-1951, the concentration of aldehyde in the air ranged from 0 - 0.27 ppm. The average formaldehyde concentrations were 0.04 to 0.18 ppm. Thomas, Sanborn, Mukai, and Tebben's studies show that formaldehyde is the most prevalent of the series in urban air (36). According to the State of California, the maximal atmospheric level of formaldehyde is 1.87 ppm, and the average on a severe pollution day between 0.2 - 0.8 ppm (37). It must be understood that automobiles are not the only source of aldehyde pollution. Studies made by Chambers estimate that 36 pounds of aldehydes are emitted daily to the atmosphere for every 1,000 operating vehicles (38). Diesel engine exhausts are shown to contain a higher percentage of aldehydes than the gasoline engine (6 , 39). Undiluted auto-exhaust contains 8 ppm of acrolein.Aldehydes in high concentrations are toxic, but at present there is no evidence that concentrations found in the street air endanger health.

4. NITROGEN OXIDES

There are eleven different compounds of nitrogen which exist in the atmosphere. These are : nitrous and nitric acid (HNO_2, HNO_3), nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen peroxide or tetroxide (N_2O_4), nitrogen sesquioxide (N_2O_3), and the peroxy radicals $\overline{NO}_3$ and $\overline{NO}_4$. Of all these nitrogen compounds only nitrous oxide is dangerous in 90% concentration and even this has mainly anoxia effect. Nitric acid fumes are unbearable before they are lethal. Although the nitric oxide is rapidly oxidised to nitrogen dioxide in the air, on the other hand, nitrogen dioxide is reported to undergo photochemical dissosiation to nitric oxide (37). This is the reason why both nitrous and nitric oxide occur in Los Angeles smog.

In addition to having their own detrimental effects on health, the nitrogen oxides can give rise to peroxyacylnitrate, a lachrymator and a source of photochemical products of formaldehyde and acrolein.

Although nitric oxide does not have the irritating properties of nitrogen dioxide, it combines with haemoglobin to produce melhaemoglobin, leading to anoxia, central nervous system depression, asphyxial convulsions and sudden central paralysis, reversible if the subject is removed from the source (40). Nitric oxide is reported to have 300,000 times the affinity for haemoglobin that oxygen does (37).

The effects of nitrogen dioxide on human health were studied by Meyers and Hine (41). Normal subjects were exposed to 5 ppm of nitrogen dioxide for 5 minutes with pilocarpine to induce broncholar constriction. Asthmatic patients exposed to 5 ppm for 5 minutes showed no significant changes in the vital capacity. At 50 ppm, exposure was interrupted after one minute because about half the patients experienced respiratory discomfort and moderate nasal irritation.

Environmental Levels :

The data given by the State of California Department of Public Health states that the average 8 hours level of nitrogen oxides (NO_2, NO) on days of severe air pollution range from 0.1 - 0.2 ppm, and the maximum level recorded was 1.74 ppm (37). In another measurement, the Los Angeles County Air Pollution Control District, the first alert of 3 ppm occurred (42). The highest mean hourly concentration, as determined by Lawther and Commins, in London's Fleet Street, is given as 1.7 ppm of NO, and 0.2 ppm of NO_2 (43). The threshold value of these oxides of nitrogen is given at 5 ppm.

5. SULPHUR DIOXIDE :-

Sulphur dioxide is not considered a health hazard of air pollution at the present moment. This is because it is not emitted in appreciable quantities to be directly injurious to human health. Nevertheless, it is quite dangerous for bronchial sufferers. Air pollution, caused by sulphur dioxide, is taken more seriously in the United Kingdom as compared to other countries. Lawther subjected 18 healthy persons to mouth inhalation of 5 and 10 ppm of sulphur dioxide, six of the subjects were also treated to nasal inhalation. In two subjects - one of whom had been discomforted by sulphur dioxide in the past - bronchospasm developed at 10 ppm. He also indicated in his work that Londoners seem to be more immune to sulphur dioxide effects as compared to others living in less sulphonated conditions (44). Pattle and Cullumbine found out that although the quantities of sulphur dioxide present in the atmosphere (2 ppm or less) have no detectable effect on animals, it makes 1 per cent of the human beings suffer from bronchoconstriction when inhaling this concentration (45).

Sulphur dioxide has more dangerous effects on human health when it occurs as aerosol in smog. Amdur, Drinker, and their co-workers have shown that either a sulphuric acid mist of 0.35 to 5 ug/m^3 for five to fifteen minutes, or sulphur dioxide 1 to 8 ppm for ten minutes has marked respiratory effects of reflux nature, in the form of shallower more rapid breathing (46, 47).

Environmental Levels :-

Ellis analysed London air in 1931 and found out that in dense fog 0.53 ppm of sulphur dioxide and 2.5 ug/m^3 of sulphuric acid are present in the atmosphere (48). In 1958, Ivie found out that the sulphur compounds are distributed as 3-9% of sulphuric acid aerosol, 3 - 18% of neutralised sulphates, and 76 - 96% of sulphur dioxide. In a half hour estimation that was shown to be the maximum of 4 years of continuous sampling, it was found that there was 0.4 ug/m^3 of sulphuric acid and 2 ppm of sulphur dioxide. The monthly maxima of sulphuric acid averaged 0.12 ug/m^3, and the average concentration was 0.025 ug/m^3 (49).

6. LEAD :-

A universal substance in our civilisation, lead is a normal constituent of food and drink and is said to occur in small amounts in ambient air. Lead is continuously added to the atmosphere through industrial processing, lead bearing insecticides, the weathering of paint and solder, and the combustion of coal.

Lead carried in the motor vehicle exhaust is due to the lead alkyl compounds which are added to gasoline as antiknock additives to produce high octane fuels.

The toxicology of lead is very complex. Lead is a general metabolic poison and is cumulative in man. It inhibits enzyme action necessary for the formation of haemoglobin, through its strong interaction with - SH groups. It is said that lead interferes with practically any life process one chooses to study (50). Children and young people appear specially liable to suffer more or less permanent brain damage leading to mental retardation (51). Lead can replace calcium in bone, so it tends to accumulate there, and it can be remobilised long after absorption when the recipient is ill or old. Lead alkyls such as tetraethyl lead emitted through exhaust, are even more poisonous than lead ion itself, and are accumulated in the body quite differently (50). The main toxic agent appears to be the triethyl lead ion, formed from tetra ethyl lead in the liver. Lead in these organic forms has a special affinity for lipoid and nerve tissue, and crosses unbroken skin and the blood brain barrier much more readily than inorganic lead : indeed, the brain is one of the sites of greatest concentration.

Environmental Levels :-

Trott has shown that the general street levels of lead are usually below 5 ug/m^3 while 10 ug/m^3 is rarely exceeded in road tunnels (52). The threshold limit for lead is given as 200 ug/m^3. A safe limit, for a life time exposure, is given as 10-20 ug/m^3 (53, 54). A recent study has recorded 3.2 ug/m^3 of lead in Fleet

Street, London and 5.9 ug/m^3 in High Street, Warwick (44).

(c) Photochemical Smog

The pollutants that find their way into the air are fairly simple in themselves, but the reactions and the interactions that they go through when subjected to the physical conditions of the environment can be very complex. There is probably no better example of this than photochemical events that hang over Los Angeles and many of the metropolitan areas.Commonly referred to as a smog, it is formed through a series of complex photochemical initiated reactions. The word "smog" was coined to describe the combination of smoke and fog which was characteristic of London prior to the Clean Air Act. Although, there is a basic difference between these two kinds of smogs, they may be equally fatal and have very injurious effects on human and vegetational health. The London smogs were mainly due to sulphur dioxide in a humid atmosphere, and involved little or no photochemical reactions, and produced bronchial irritation in human beings, whereas, the Los Angeles smog is a result of a series of photochemical reactions between various pollutants and air, and cause eye irritation in man and damage to vegetation. London, after 1962, has not experienced any further crucial smog problems, but Los Angeles, more or less, is constantly suffering from this environmental affliction. Therefore, it is more essential to understand and control this latter kind of smog.

There are three major factors which result in the formation of photochemical smog. One is a mixture of nitrogen oxides, chiefly nitric oxide (NO) and nitrogen dioxide (NO_2). Nitric oxide is a primary pollutant from automobile exhaust and rises from the establishment of the equilibrium :

$$N_2 + O_2 \rightleftharpoons 2\ NO$$

at the high temperature of the internal combustion chamber and the freezing of the nitric oxide in the expansion cycle of the cylinder (55). When nitric oxide is emitted into the atmosphere, it immediately undergoes the reaction to produce nitrogen dioxide (NO_2). Second, is the hydrocarbons which are emitted through the tail-pipe, due to incomplete combustion and cracking processes in the internal combustion engine. The most significant of these hydrocarbons, from the stand point of being potential photochemical pollutants, are the unsaturated, olefinic double bond, substituted hydrocarbons, aldehydes, and ketones (56). The third factor, is the presence of sunlight which provides the necessary radiation energy to trigger off the complex chain of reactions. Haagen-Smit and Margaret Fox were the first to demonstrate that the laboratory irradiation of low concentrations of hydrocarbons and nitrogen dioxide in the air produces oxidants including ozone (57). The laboratory irradiation of the low concentration of car exhaust gases in air also resulted in ozone formation, eye irritation, plant damage, and aerosol formation. The most abundant secondary pollutants arising from the photo-oxidation reactions of primary air pollutants are : nitrogen dioxide, ozone, aldehydes, ketones, peroxyacyl nitrates and nitrites (PANS), and alkyl nitriles.

The basic work into the study of photochemical reactions, as they occur in smog, was started many years ago, but in 1961 Leighton came out with a very comprehensive guide to the chemistry of this environmental phenomenon (58). Caplan, working on the chemistry of

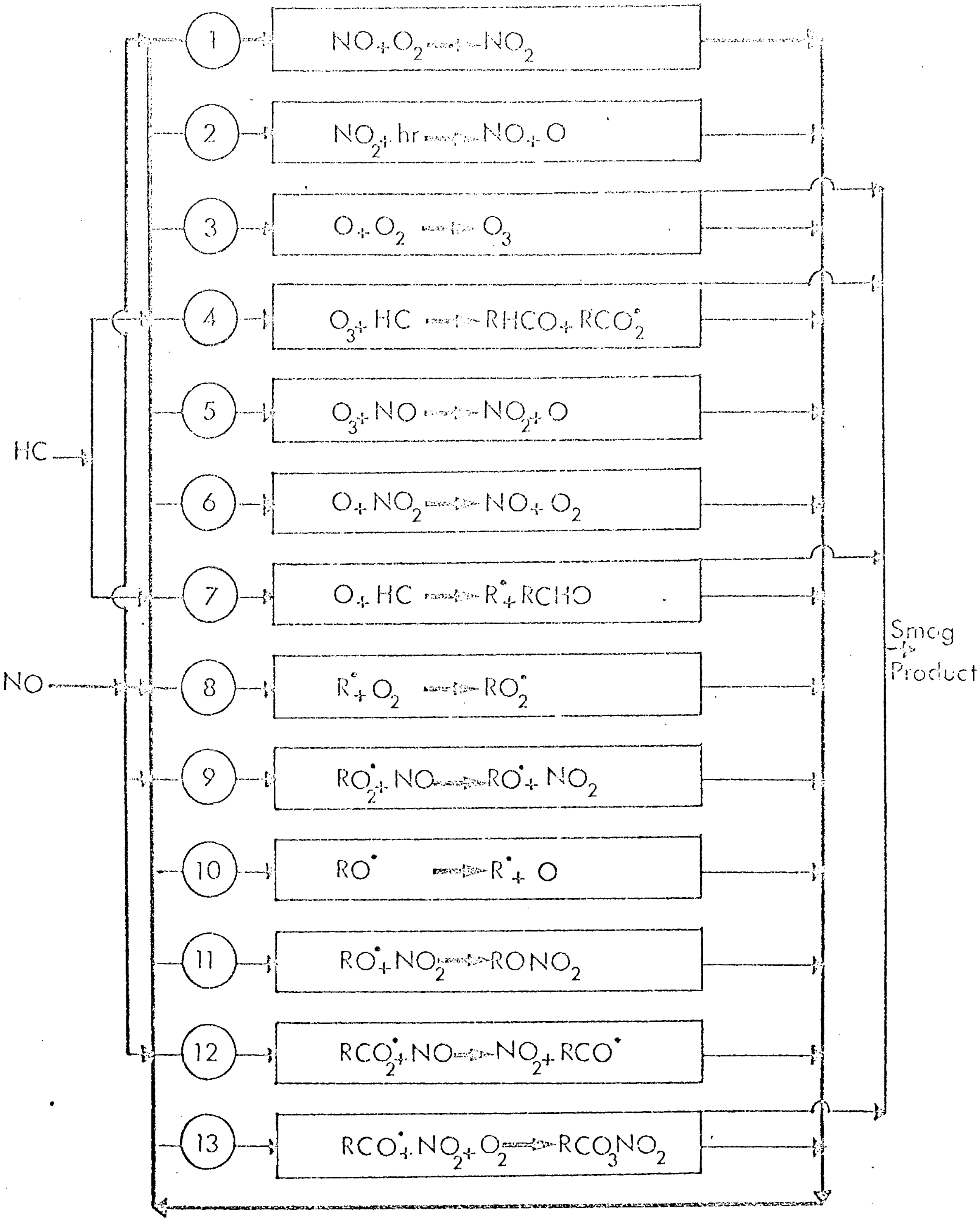


Fig.1:2 Routes To Photochemical Smog Formation

photochemical smog, gave above 13 equations to sum up the main reactions (59) (Fig. 1:2).

It will be noticed that the reactions are basically triggered off by conversion of nitric oxide (NO) into nitrogen dioxide (NO_2). Nitric oxide itself cannot absorb the ultra-violet radiation (wavelength 400-700 nm), and thus cannot initiate the chain of photochemical reactions. But nitric oxide is very rapidly oxidised to nitrogen dioxide which is capable of absorbing the solar ultra-violet radiation (wavelength $\leqslant$430 nm) and therefore can initiate the chain reaction according to the equation 2 in Fig. 1:2.

This rapid oxidation of nitric oxide into nitrogen dioxide has been puzzling scientists for some time. Dr. Pitts (11), who has been working on this reaction, commented : "Thermal oxidation would not be expected to occur sufficiently rapidly at the low concentrations (about 0.5 ppm) of nitric oxide in the air." This work led to the presence of "singlet oxygen" in the atmosphere. Singlet oxygen, an electronically excited species of molecular oxygen, with a greater than normal share of inherent energy, is an important oxidising agent produced in chemical smog. Dr. Pitts and his associates - Dr. Khan, Dr. Smith and Dr. Wyne (of Oxford University) have suggested that singlet oxygen plays a significant role in the rapid and complex oxidation of nitric oxide into nitrogen dioxide (60).

However, the photochemistry of smog results in two extremely harmful pollutants - ozone, and peroxyacyl nitrate (PAN). (equations 3 and 13 Fig. 1:2)

Ozone occurs in surprisingly high concentrations in the atmosphere. The data given by the Los Angeles Air Pollution Control District shows that an 8 hours value of ozone, for days with severe air pollution, is 0.15 to 0.2 ppm, and the maximum is 0.9 ppm.

The toxic effects of ozone on human health were studied by Thorp who showed, in a graph of pure ozone toxic limits, that 1 ppm by weight is easily detected by anyone because of the odour. With exposure to 2 ppm for 5 hours, a decrease in metabolism of 10% to 20% occurs, the pulse rate is lowered by about 5%, and hypersensitives experience a fall in blood pressure (61). The presence of oxidants (chiefly ozone) has resulted in a complaint of eye irritation, plant damage, poor visibility and rubber cracking. The most important effects of ozone is the damage to vegetation. Studies conducted by the United States Department of Agriculture, the California Agriculture Station at Riverside, the Connecticut Tobacco Station at Windsor, and the United States Public Health Service show that ozone is the probable cause of tobacco disease known as Weather Fleck (62, 63). Possibly some of the effects of ozone are produced by its direct action upon cell enzymes in plants. The damage by ozone caused to the vegetation in regions from Washington D.C. to Boston are now confirmed (64)

Peroxyacyl nitrates and nitrites - PANS as they are called, are produced in the smog during the photochemical oxidation of nitrogen dioxide and olefinic hydrocarbons. Stephens and his co-workers demonstrated that the accumulation of ozone was accompanied by unstable nitrogen compounds which were later identified as PANS (65). Their studies suggested a reaction in which the olefin molecule splits at the double bond - one end forms a carbonyl compound and the other end yields a variety of products. Among these other products are PANS. These exist in a homologous series of compounds ,the other members may be more or less active than peroxyacyl nitrate in eye irritation and plant damage.

Taylor compared the various mixtures of chemicals to produce chemical pollutants to establish their damage to the vegetation (66). His studies have led to the conclusion that although both ozone and PANS are detrimental towards plants, there exists a basic difference between their choice of plants. Ozone causes damage to the older plants, while PANS attack the younger plants. PANS are very dangerous pollutants which are capable of causing visible damage to crops even when present in parts per hundred million concentration range. Pitts has proved in his latest work that PANS, in combination with acrolein and formaldehyde, constitute the eye-irritating portion of smog (11).

Put together, these two pollutants, ozone and PANS, are causing damage to crops estimated in the region of millions of dollars. In 1961, the loss, due to damage to agricultural crops in the North-Eastern coastal States, was estimated to be $18,000,000 (67).

1:2

LEGISLATION AND LAWS CONTROLLING AIR POLLUTION BY AUTOMOTIVE ENGINES :-

Operation of an automobile engine to produce desired mobility is a complex process. The performance of the internal combustion engine depends on various factors such as the type of engine, its age, the type of fuel used, and mode of driving among many others. These factors, together or individually have considerable effects on the concentrations of the pollutants emitted. When it comes to drawing up legislation to control air pollution from this source, all such factors are to be considered. People tend to use their cars according to their temperaments and needs, and this results in varying driving habits, which in turn result in various driving modes, causing different extents of air pollutant concentrations. To put down any controlling laws, it thus becomes essential that a standard mode of driving should be prescribed. To establish such a standard mode of driving, various countries have come out with driving cycles depending on the traffic conditions existing in their cities and climates. Invariably these test cycles describe the starting of an automotive engine from cold conditions and, under specified average speed and time, go through four major stages of driving, i.e. idle, cruise, acceleration, and deceleration. The concentrations of various pollutants emitted through the tail-pipe are recorded, and then the legislative limits drawn up accordingly.

The legislation already existing, or proposed in future, are discussed here under two separate sections according to the severity of air pollution existing at the present moment.

SECTION 1 : American Legislation

America, containing half the world population of cars and having severe smog problems in the Los Angeles Basin, was first to recognise the necessity for control of air pollution from motor vehicle engines. The earliest control for air pollution in California was enacted in 1947 (68). These laws authorised the formation of air pollution control districts encompassing various counties or groups of counties . These districts were given the authority to make and enforce such orders, rules, and regulations as will reduce the amount of air contaminants released within the district. Thereafter, a significant progress was made, and in 1959 the Californian Legislature required the State Department of Public Health to develop and publish by February, 1960, standards controlling the quality of air and the emissions of exhaust contaminants from motor vehicles. This in turn resulted in the 13 men California Motor Vehicle Pollution Control Board (C.M.V.P.C.B.), and the work after that in the field of car air pollution control, is the efforts of this organisation. The first thing this Control Board did was to establish three different levels of air quality, which were defined as :-

1. "Adverse" Level - level at which there will be sensory irritation, damage to vegetation, reduction in visibility, or similar effects.
2. "Serious" Level - level at which there will be significant alteration of bodily functions, or which is likely to lead to a chronic disease.

3. "Emergency" Level - level at which it is likely that acute sickness or death in sensitive groups of persons will occur.

Two of the motor vehicle pollutants fell under these categories :

1. At the "adverse" level - "Oxidants Index" 0.15 ppm for 1 hour exposure, and

2. At the "serious" level - carbon monoxide 30 ppm for 8 hours exposure

The later work resulted in a standard test driving cycle, which is representative of modes of operation in typical urban driving. The cycle is described as follows :

Condition	Rate of Speed Change mph/sec	Per Cent of Total Time	Per Cent of Total Sample Volume
Idle	-	15.0	4.2
Cruise			
20 mph	-	6.9	5.2
30 mph	-	5.7	6.1
40 mph	-	2.7	4.2
50 mph	-	0.7	1.5
Acceleration			
0-60 mph	3.0	1.1	5.9
0-25 mph	2.2	10.6	18.5
15 - 30 mph	1.2	25.0	45.5
Deceleration			
50 - 20 mph	1.2	10.2	2.9
30 - 15 mph	1.4	11.8	3.3
30 - 0 mph	2.5	10.3	2.9
		100.0	100.0

The column headed "Per Cent of total time " derives from the Los Angeles Traffic Pattern Survey by the Traffic Survey Panel of the Automobile Manufacturers' Association. The column headed

"Per Cent of total sample volume" combines the time factor with an average exhaust flow for each condition.

The quantities of various pollutants were specified according to the driving test cycle. It was then possible to set maximum limits for the concentrations of various pollutants. The prescribed exhaust control standards for the California driving cycles were introduced in 1966. It was followed by the United States driving cycle in 1968. Under these controls, the current and future standards for various pollutants are given in Table 1:C (1). It is noteworthy that from 1970 onwards, emission limits are specified in g/mile.

For comparison :

1.5 % CO = 32g/mile (approximately)

275 ppm HC = 3.1 g/mile (approximately)

Table 1:C

Pollutant	1968/69	1970	1971	1972/73	1974
CO	1.5%	23g/mile	23g/mile	23g/mile	23g/mile
HC	275 ppm	2.2g/mile	2.2g/mile	1.5g/mile	1.5g/mile
NO	-	-	4.0g/mile	3.0g/mile	1.3g/mile
Evap	-	6g/Test	6g/Test	6g/Test	6g/Test

Need for a more integrated approach to the Nation's environmental problem was recognised by the passing of the National Environmental Act of 1969 (Public Law 91-190 January, 1970). It sets forth the Nation's environmental policy to create a better atmosphere. It also provides for the establishment of a Council of Environmental Quality, in the Executive Office of the President to assist in the carrying out of that policy. The working of this Council has resulted in a new test procedure, which is known as the U.S. Federal Driving Cycle. This test procedure has come into practice since 1972. A comparison of both California Test Cycle and U.S. Federal Cycle is shown in Fig. 1:3 (69)

The current data shows that the future cycle is on average 1.6 times more severe for hydrocarbons, 1.9 times more severe for carbon monoxide, and 1.4 times more severe for nitrogen oxides than the California Test Cycle. The control of air pollution from vehicles is specified as far as the 1980s, as illustrated in Fig. 1:4 and the corresponding figures given in Table 1:D (70).

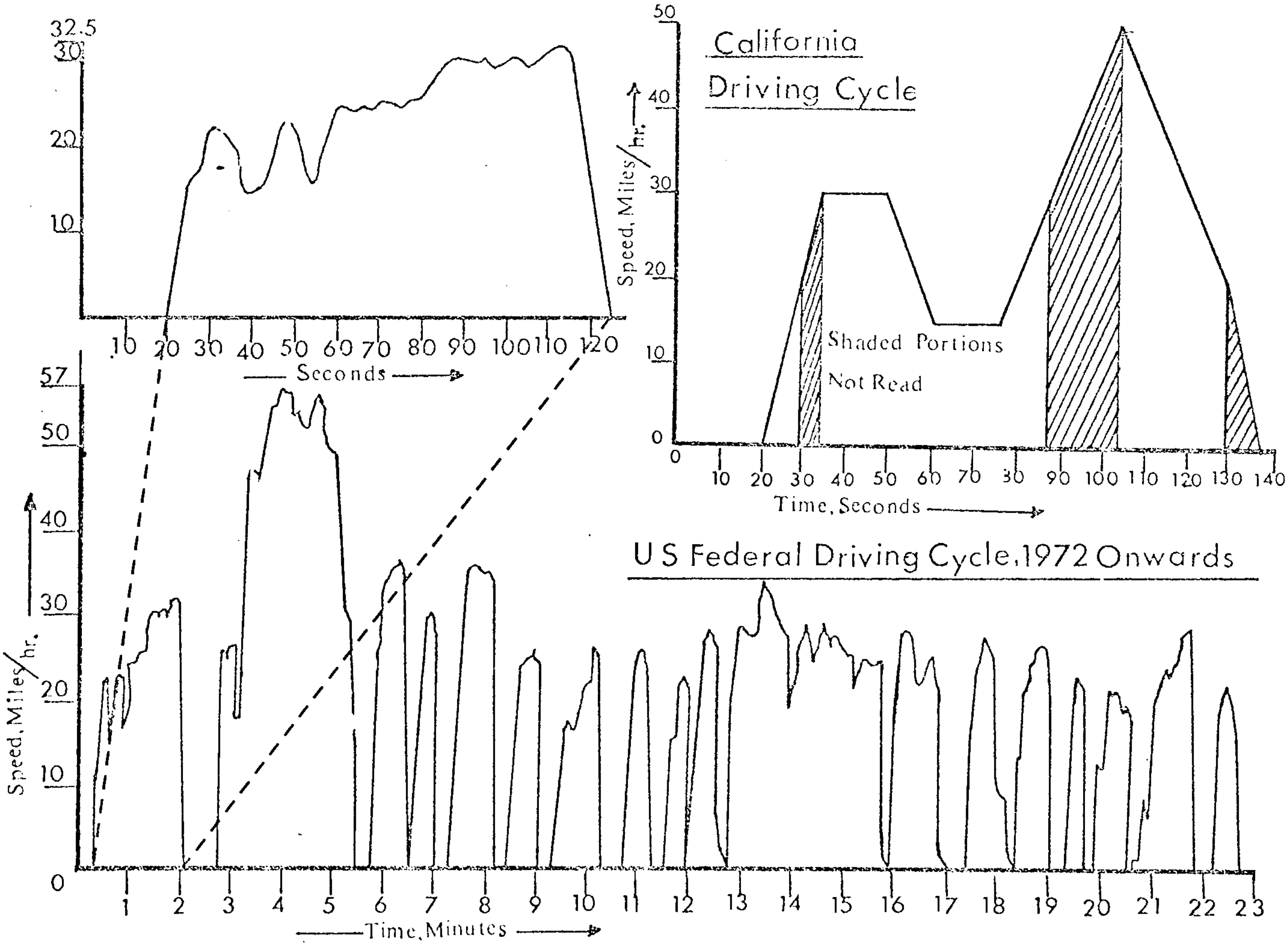


Fig. 1:3 Comparision Between U S Federal Driving Cycles

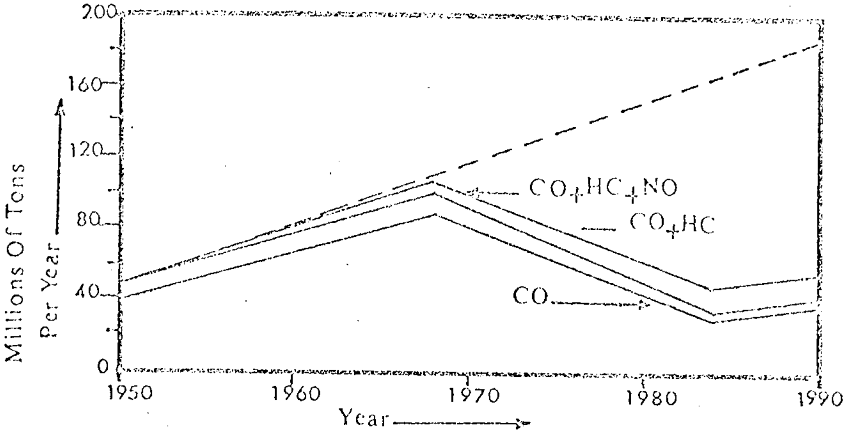


Fig.1:4 Automobile Emissions In USA

Table 1:D

Trends in U.S. Legislation

Year	Grams/Mile				Grams/Test
	CO	HC	NO_x	Partic	Evap.
1970	23	2.2	-	-	-
1971	23	2.2	-	-	6
1972 +	39	3.4	-*	-	2
1973	39	3.4	3.0	-	2
1975	11	0.5	0.9	0.1	2
1980	4.7	0.25	0.4	0.03	2

\+ Incorporated new test procedure (U.S. Federal Cycle)

* 4.0 grams/mile NO_x applies only to California.

Table 1:E shows the variations in emission standards, both current and projected for light duty automotive vehicles and engines for the years 1968-1977 inclusive. (71)

Current and Projected emission Standards for Automobile and light duty trucks (6,000 lbs. G.V.W. or less) 1968-1977

Table 1:E

Model Year	Exhaust Emissions, grams/mile				Evaporative g/Test
	Test Procedure +	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides	
1968-69 + +	F.T.P.	(275 ppm)	(1.5%)	NR	(-)
1970	F.T.P.	2.2	23	NR	NR
1971	F.T.P.	2.2	23	NR	6
1972	C.V.S.	3.4 *	39	NR	2
1973	C.V.S.	3.4	39	3.0	2
1974	C.V.S.	3.4	39	3.0	2
1975	C.V.S.	0.41 ++	3.4 ++	3.0	2
1976-77	C.V.S.	0.41	3.4	0.4 + +	2

NR = No requirement

\+ = Federal Test Procedure (F.T.P.) measures exhaust concentration, uses a 7-mode-7 driving cycle

(-) = Constant volume sampler (C.V.S.) measures true exhaust mass, uses non-repeating 1372 sec. driving cycle (Closed, self weighting).

\+ + = The 1968-9 standards are expressed as portion of exhaust gas, parts per million (ppm) or volume per cent.

* = The larger number for hydrocarbons and carbon monoxide standards beginning 1972 are due to the fact that the C.V.S. procedure gives larger reading than F.T.P. On a test procedure 1972 standards are more stringent than 1971 requirements.

++ = 1975-1977 hydrocarbons and carbon monoxide requirements and 1976-77 NO_x requirements based on Clean Air Amendments of 1970.

An American government agency, the Environmental Protection Agency (E.P.A.), is charged with the responsibility for controlling air pollution of the atmosphere and implication of the above mentioned control standards. Increasing severity is demanded until, in 1975/6, emissions should contain only $\frac{1}{10}$ of the three major pollutants as compared with the average figure in 1970/1. It has been said that vehicle exhausts meeting these standards would eject from their exhausts, cleaner 'air' than they consumed, although with very little oxygen and a large quantity of carbon dioxide.

Without exception, vehicle manufacturers and other bodies have protested that these standards go beyond what is possible in the state of technical and scientific knowledge today, at least in the ability to mass-produce such engine systems and to ensure that they continue to maintain their emission control performance throughout their useful life. Despite all this protest, Congress in 1970 passed the Clean Air Act amendments which require the above stringent standards (72).

The only amelioration provided for this is one year suspension of these laws for manufacturers who can show that despite bona fide efforts to develop complying systems; they have been unable to do so. Only in extreme cases was such suspension possible under the terms of the Act. All the American automobile companies and the Swedish Volvo Company have applied for this suspension period. The National Academy of Science has pronounced a verdict against the feasibility of the standards, at least in the time scale proposed.

A recent study sponsored by the White House concludes that the cost of meeting the 1975 safety and emission standards will exceed the social benefit expected to result. The excess of the cost over benefit for emission control alone is put at \$6,300 million per year from 1976 onwards. Included in this cost is an average price increase of \$350 per car at 1971 prices. The 1976 safety requirements would add an estimated \$523 to this at a total of \$873 at 1971 prices (72).

SUMMARY OF LEGISLATION , PROJECTIONS, AND GOAL FOR PASSENGER.- CAR EXHAUST EMISSIONS

(Volume given in g/mile)

	Prior to Control	First Control 1966	1968 California Pure Air Act (AB357) Requirements				Morse[a]	IIEC[b]	AB 35.6[c]	TAC[d]
			1970	1971	1972	1974				
HC	11.0	3.4	2.2	2.2	1.5	1.5	0.6	0.86	0.5	0.5
CO	80.0	34.0	23.0	23.0	23.0	23.0	12.0	7.1	11.1	12.0
NO_x	4.0	-	-	4.0	3.0	1.3	1.00	0.68	0.75	1.0

a) 1967 Morse report gives these values as technically feasible for Spark - ignition engine by 1975.

b) Standard objective of Inter industry Control Progress.

c) Act of California State legislation in 1968 that relates to a 'low emission motor vehicle'.

d) Recommendations of Technical Advisory Committee of California Air Resources Board for 1975 model vehicles sold new in California.

SECTION 2 : Legislation for the Rest of the World

As the world's biggest car market, the U.S.A. has been a prime target for the world's exporters who have been energetically ensuring that this market remains open to them, despite the non-tariff barrier built from safety and emission legislations. This consideration has influenced some legislation laid down by various European countries for protection of their own atmosphere.

The majority of the European countries mainly revised the old days steam - propelled vehicles legislations to fit into present day demand for pollution control. Although the governments have been more concerned with the density of smoke emitted from diesel-driven vehicles, rather than the concentration of various pollutants, various motor industries have adapted to controlled pollutants emission. The reason may lie in their export potential to the U.S.A. as the one major market. As early as 1961, some laws dealing with the smoke emission from motor vehicles were passed by the French Government (74), and lately limits over carbon monoxide emission have also been set. In Belgium, a similar attitude is taken towards air pollution.

Contamination of the atmosphere by various pollutants in Great Britain was recognised as early as 1273 (75), when the use of coal was prohibited in London as being "prejudicial to health". The pollution caused by industry was brought under some control by the Alkali etc. Works Regulation Act in 1863 (75). These regulations are still in force and are revised, when need be, to adjust to new environmental protection requirements. In 1956 the Clean Air Act was formulated, passed in 1968, and brought into effect in 1969 (76). This Act is concerned mainly with soot and smoke regulations to protect the environment.

Motor vehicles and their emissions were being considered several years before the Clean Air Act. Regulations were made in 1966 (77), and were mainly directed at diesel engine emissions. The extracts from the regulations affecting the present day state of pollution are given as follows :-

Extract from the United Kingdom Motor Vehicles (Construction and Use) Regulations, 1966.

Use Regulations Part III

Use of Vehicles so as not to emit smoke etc.

83. No person shall use or cause or permit to be used on a road, any motor vehicle from which any smoke, visible vapour, grit, sparks, ashes, cinders, or oily substance is emitted, if the emission thereof causes or is likely to cause damage to any property or injury to any person who is actually at the time, or who reasonably may be expected on the road, or is likely to cause danger to any such person as aforesaid.

84. Where a motor vehicle, being a vehicle propelled by a compression ignition engine, is fitted with a device designed to facilitate the starting of the engine by causing it to be supplied with excess fuel :

a) The device shall be maintained in such a condition that it does not cause the engine to be supplied with excess fuel while the vehicle is in motion on a road, and

b) No person shall use the device, or cause, or permit it to be used, so as to cause it to supply the engine with excess fuel while the vehicle is in motion on the road.

Meanwhile the rest of Europe was also developing various legislations in motor vehicle emission control. In 1968/9 France and West Germany imposed an exhaust emission limit on carbon monoxide at 4.5% when idle, while Spain put it down to 5.0%. The Co-ordination Europe Council (C.E.C.) and the Economic Commission of Europe (E.C.E.), along with the co-operation of the United Kingdom, have worked together to establish a measure of control of motor vehicle pollution (78). France and Germany were working under different, but similar, test procedures. Co-ordination of standards is now being further encouraged by the United Nations, while Europe's Economic Community (E.E.C.) has issued a directive that all countries in the Community conform to the "European" standards by 1972. This directive also establishes the French test cycle as the standard "European Test Cycle". (79) Inclusion of the United Kingdom in E.E.C. resulted in a vigorous surge of efforts to put more control on motor vehicle emissions. In Summer, 1972, the Department of the Environment, along with other interested organisations in Great Britain, put forward a proposal that the British standards should be amended to comply with E.C.E. Regulation No. 15 which concerns emissions of carbon monoxide and hydrocarbons concentrations from a motor vehicle.(80). This resulted in the most recent amendment in the British Legislation. This regulation The Motor Vehicles (Construction and Use) (Amendment) (No.5)

Regulations 1972, (81) which came into force on 7th December, 1972, requires that petrol engines (spark ignition) vehicles (except small three-wheeled cars) first used on or after 10th November, 1973, but not manufactured before 20th September, 1973, shall comply with the limits for the emission of carbon monoxide and hydrocarbons laid down by E.C.E. Regulation No. 15, and that such vehicles should carry a designated, approved mark. It is claimed that this will reduce emissions of carbon monoxide by up to 30% and of hydrocarbons by up to 10%. This will be achieved by better carburration and spark timing devices. It should be noted that the regulation that all new cars are required to be fitted with a device for re-cycling crank-case emissions has already been passed (1st January 1970). A comparison of the California Test Cycle and the European Test Cycle is given in Fig. 1:5 (82).

In Japan, having its own smog problems, a stricter line of action has been taken. Japan has introduced domestic regulations

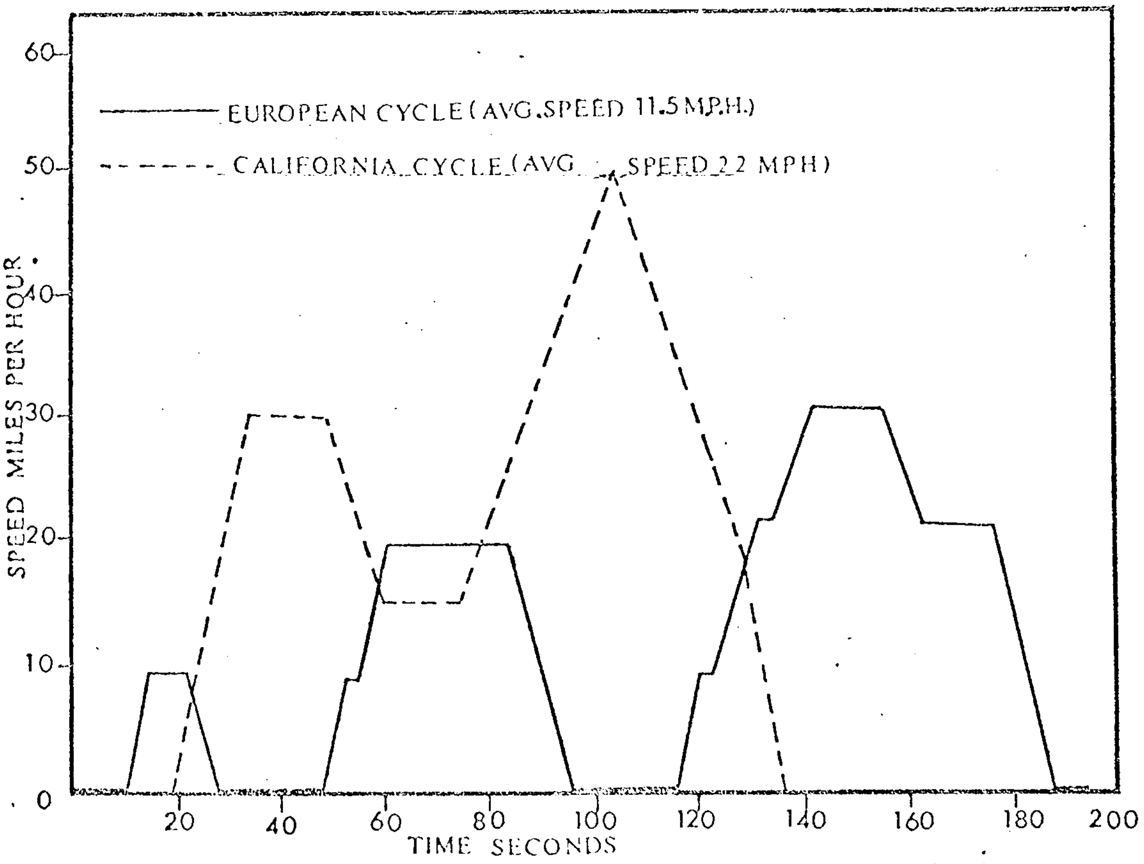


Fig.1:5 Comparison Between U S And European Driving Cycles

affecting emission of carbon monoxide only (3% by volume). The Japanese Test Cycle is simpler than that of the United States, and is a 4-mode cycle. It consists of periods of idling, acceleration from idle to 20 km/hr (12.427 m.p.h.), constant speed at 40 km/hr (24.85 m.p.h.), and deceleration (83).
In 1970 the concentration limit for carbon monoxide was reduced to 2.5% In August 1972, the additional requirements for idle for new cars (4.5%) and used cars (5.5%) was imposed.

Canada (Ontario) has adopted the same legislation for air pollution control as the U.S.A., while Australia (Victoria) has controlled only the crank-case emissions.

Table 1:F shows a tabulated form of all these legislation indicating the dates and limits imposed (78).

Table 1:F

SUMMARY OF EMISSION LEGISLATION

	MAXIMUM PERMITTED LEVELS							
	1966-67	1968-69	1970	1971	1972	1973	1974	1975	1976
FRANCE EXHAUST CO Ex. HCE CRANK CASE		4.5 % at Idle	4.5 % at Idle	New vehicle design to meet 1972 standards from Sept. 1971		100 g/test for 1650 vehicles varying up to 220 g/test for 4730 lb. vehicle		These conditions represent the European Test procedure.	
				Not to exceed 0.15% of fuel consumed by engine					
WEST GERMANY EXHAUST CO EXHAUST HCE CRANK CASE		4.5 % at Idle	25 g/100 gm fuel used (1.8%) 1.5g/ 100 g fuel used (385ppm)		European test procedure as shown above for France. These conditions are slightly less severe than the ones in the preceeding years.				
				Not to exceed 1.5% by weight of fuel consumed.					
JAPAN EXHAUST CO		3.0 % (Japanese Test Cycle)	2.5% (J.T.C.)		From 1970 additional requirement for idle 4.5% CO new cars 5.5% CO used cars				
SPAIN EXHAUST CO		5.0 % at Idle							
SWEDEN EXHAUST CO EXHAUST HCE		4.5 % at Idle	4.5 % at Idle	(F) (G)					

Chapter 2

THEORETICAL

2:1

ENGINE COMBUSTION PROCESSES

The combustion processes which take place inside an internal combustion, spark-ignition engine, are of a highly complicated nature. A detailed discussion of such processes is beyond the scope of the present work. However, a general background of these processes throws some light on the present study of inlet manifold distribution effects.

The two main aspects, directly related to this project, are the distribution of the air-fuel mixture to various cylinders and the combustion of this mixture inside these cylinders in relation to the various pollutants emitted. The air/fuel mixture ratios are controlled by the carburettors and the distribution, depending on the physio-chemical nature of this mixture, is effected by the inlet manifold. The hydraulic principles of the carburettor and the details of inlet manifold design are thus of prime importance.

1. Carburettor :-

Fig. 2:1 shows an elementary carburettor consisting of a fuel reservoir (the float chamber) in which the level of the fuel is kept constant by a float-actuated needle valve. The fuel from this chamber supplies a small orifice jet situated in the narrowest part, or throat, of a venturi in the choke tube. During an intake stroke of a cylinder, a vacuum is created inside the inlet manifold drawing air through the venturi. The pressure drop thus created produces the atomized spray. The degree of the atomization of the fuel naturally depends upon the relative velocity of the air and the fuel stream, the density of the fuel and its surface tension. Knowing the designed dimensions of the carburettor and the intake system, it is possible to calculate the amounts of air and fuel and therefore the air/fuel ratio

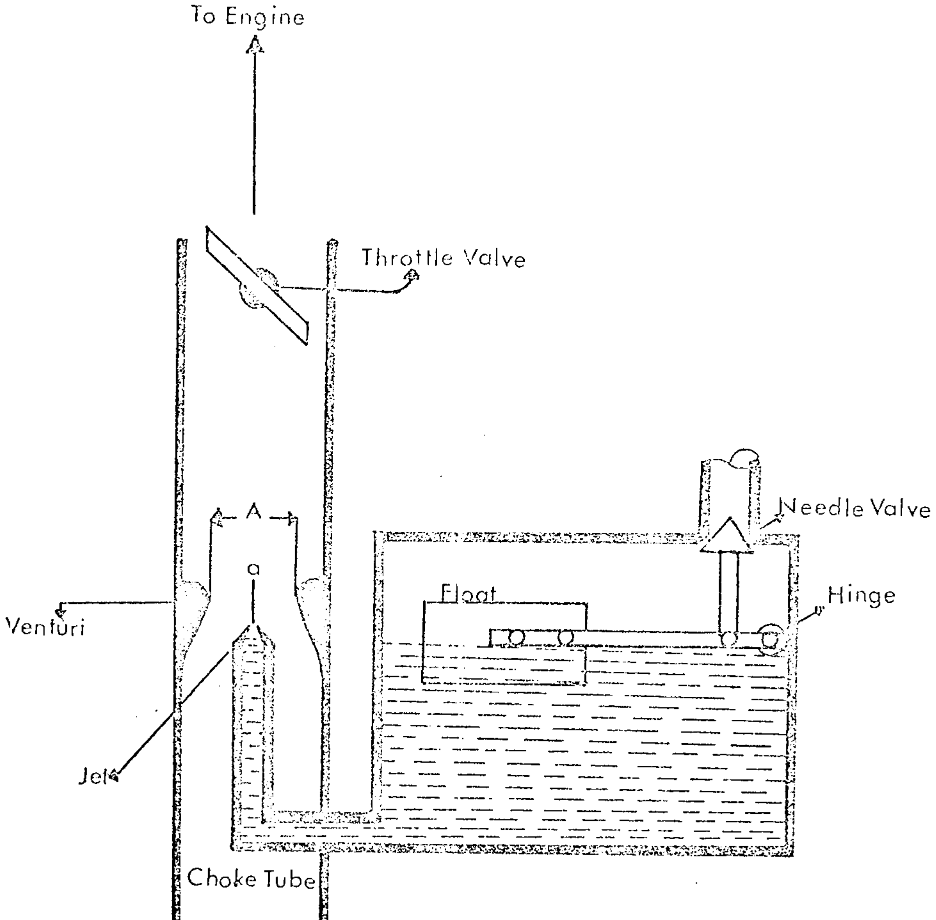


Fig 2:1 The Elementary Carburettor

of the mixture entering the inlet manifold.

Expressions for the fuel flow :-

Rate of the fuel flow, inside the choke tube, is calculated by Bernouilli's Equation

$$\frac{p}{\rho} + \frac{v^2}{2g} + H = \text{constant} \quad \text{———————} (1)$$

where

p = pressure per m area

ρ = density of the fuel

v = velocity in ft/sec.

g = acceleration due to gravity

H = potential energy - measured above an arbitrary datum level.

If the pressure head (h) created inside the choke tube equals the potential energy H, then by equating the pressure head (h) in the venturi to its kinetic energy $\frac{v^2}{2g}$ the following expression is obtained:

$$\frac{v^2}{2g} = h$$

Neglecting the energy losses, the theoretical velocity of flow (v) is given :

$$v = \sqrt{2g}\, h \quad \text{———————} (2)$$

Since there are losses due to the friction between the liquid fuel and its surrounding, this velocity of jet will be higher than actual jet velocity. To obtain a correct value for jet velocity, a velocity coefficient is introduced. This coefficient is defined as :

$$C_v = \text{velocity coefficient} = \frac{\text{actual velocity of jet}}{\text{theoretical velocity of jet}}$$

or

$$C_v = \frac{v}{\sqrt{2gh}}$$

If the area of the orifice is taken as A, then theoretical rate of fuel discharge, under a pressure head h, should be given as :

$$m = \rho A \times \sqrt{2g}\, h$$

But practically it does not happen because of the Vena Contracta effect. The ratio of the area of the Vena Contracta (a) to the actual orifice (A) is termed as the coefficient of contraction and is defined as :

$$C_c = \text{coefficient of contraction} \quad \frac{a}{A}$$

or $$a = C_c A \text{ \_\_\_\_\_\_\_\_\_\_\_\_ } (4)$$

To define the actual rate of flow, a coefficient of discharge is introduced which is defined as :

$$C_d = \text{coefficient of discharge} = \frac{\text{actual discharge}}{\text{theoretical discharge}}$$

$$= \frac{m'}{m} = \frac{m'}{\rho A \sqrt{2gh}}$$

or $$m' = C_d \rho A \sqrt{2gh} \text{ \_\_\_\_\_\_\_\_\_\_\_\_ } (5)$$

The actual discharge of the fuel is given by the actual area of the jet (a) and the actual velocity of the jet (ν)

i.e. $$m' = a \times \nu$$

From equations (4) and (5) it follows that : actual quantity of fuel flow = $m' = C_d \rho A \sqrt{2gh}$

$$= C_c \rho A \sqrt{2gh} \text{ \_\_\_\_\_\_\_\_\_\_\_\_ } (6)$$

where A is the area of the orifice, and density ρ is expressed in terms of specific weight of the fuel lbs/ft^3.

If the head causing the flow is expressed as inches of water it can be shown that

$$m_f = \text{Fuel Flow rate} = 18.3\, A_f C_f \sqrt{h_w}\, \rho_f \text{ \_\_\_\_\_\_\_\_\_\_\_\_ } (7)$$

Calculations for the air flow :-

A similar mathematical method can be used for the calculations of the air flow. However in this case, the area of the venturi inside the choke tube is considered for air velocity. The air passing this area (A_a) causes a pressure drop. Therefore the velocity of air can be given as :

$$V_a = \rho_a A_a C_a \sqrt{2gh}$$

As the head causing the air flow is the same as the one causing fuel flow, the air flow rate can be given by an equation similar to equation (7)

$$m_a = \text{air flow rate} = 18.3\, A_a C_a \sqrt{hw}\, \rho_a \qquad (8)$$

where ρ_a is the specific weight of air in lbs/ft^3. The air/fuel ratio is thus obtained from equations (7) and (8) as :

$$\text{air/fuel ratio} = \frac{m_a}{m_f} = \frac{A_a}{A_f} \times \frac{C_a}{C_f} \times \sqrt{\frac{\rho_a}{\rho_f}} \qquad (9)$$

where : C_a = coefficient of discharge for air

and C_f = coefficient of discharge for fuel

Air-fuel mixture behaviour inside the manifold :

The distribution of the air-fuel mixture to various cylinders depends on the condition of the mixture and the design of the inlet manifold. Function of a manifold is to conduct the air-fuel mixture to the individual cylinder ports evenly. However, in practice this is rarely achieved.

The fuel starts vapourizing as soon as it joins the air stream. Complete vaporization of the fuel is not required as this will lead to loss of charge density and displacement of required oxygen. It has been observed that good power output is obtained when 65% of the fuel is vaporized (84). The condition of the air-fuel mixture is influenced by the pressure drop effect of the venturi tube (choke tube), its temperature, velocity, and the surrounding walls along which it moves towards the cylinders.

The fuel which spurts out of the fuel jet orifice of the carburettor is carried down to the inlet manifold as a spray consisting of multisized droplets. Droplet size depends on the conditions prevailing inside the choke tube, the viscosity and density of the fuel, and the size and shape of the jet orifice. When air begins to flow past the jet in the choke tube, the fuel begins to rise because of the pressure difference. The surface tension and the viscosity of the fuel tend to prevent the flow from the jet. Thus for the actual case of fuel flow, equation (7) becomes :

$$m_f = 18.3\, A_f\, C_f \sqrt{(h_w - h'w)}\, \rho_f$$

where : h'w is the head, in inches of water required to cause the fuel to begin to flow (about 0.5"). Therefore the equation for air/fuel ratio (equation (9)) becomes :

$$\text{air/fuel ratio} = \frac{m_a}{m_f} = \frac{A_a}{A_f} \cdot \frac{C_a}{C_f} \cdot \sqrt{\frac{\rho_a}{\rho_f}} \quad \frac{hw}{(hw - hw's)}$$

The air-fuel mixture experiences an appreciable rise of temperature due to the hot manifold walls particularly when passing through the cylinder ports. There exists a critical limit for the temperature rise for the mixture for optimum performance. A substantial rise in mixture temperature results in a loss of volumetric efficiency due to expansion of the charge which in turn affects the engine power output. It has been estimated that an increase of 10^{0}F (5.5^{0}C) in the mixture temperature results in about one per cent power drop due to the lowered charge density and mass flow. Further, due to the high temperature of the mixture, a tendency to knock develops in the charge. This requires a slight reduction in the throttle opening, which increases the power loss for the above mentioned temperature to about 2 per cent. However, if the temperature is lower than its optimum value, the fuel vapours tend to condense and hence form bigger droplets causing maldistribution of the mixture.

The speed of the incoming mixture also has a marked effect on the mixture distribution. If the mixture speed is low, it tends to drop its heavier fraction to the adjacent manifold surface which produces a film of liquid fuel running alongside the manifold walls. On the other hand, a mixture speed of 150 ft/sec. results in loss of engine torque, where at a speed of 250 ft/sec. the inertia effect of the droplets becomes very marked (85). The deposition of the heavy fractions of the fuel mixture is restricted if the manifold pressure is reduced. A momentary maximum deposition is caused at the instant of throttle opening due to the combination of the suddenly increased pressure and low mixture velocity. With stabilized manifold pressure, it is probable that part-throttle opening allows greater vaporization. The inlet manifold vacuum has a marked effect on the emission of hydrocarbons. Volumetric concentration of the exhaust gas hydrocarbons remains relatively low as the manifold vacuum range is varied from the heavy load condition of severe acceleration (0-6" of Hg) to the light load conditions of idle (18-20" Hg). Further increase in the manifold vacuum, beyond 18-20" of Hg range through the light to heavy load deceleration conditions, is associated with a sharp continuing increase in the exhaust hydrocarbons.

Design of the inlet manifold produces a marked effect on the behaviour of the mixture. The velocity of the mixture in the inlet manifold, during open throttle conditons, depends on the engine displacement, revolution of the engine, volumetric efficiency, and the size of inlet manifold.

The velocity of the air-fuel mixture is given as :

$$\text{manifold velocity} = \frac{\text{engine displacement} \times \text{vol. efficiency} \times \text{r.p. m}/2}{\text{manifold cross sectional area}}$$

The relationship shows that the velocity of the air-fuel mixture is inversely proportional to the manifold cross sectional area. Therefore to obtain the most suitable velocity of the mixture necessary for best distribution, it becomes essential to have an appropriate size manifold. The optimum speed of the mixture required for best results is 50 ft./sec. at 1,000 r.p.m.

A small cross sectional manifold will give high mixture velocity throughout the engine performance. This will be suitable at low speed, when heavier droplets will be carried to the cylinders. At high speed, when the throttle is fully opened and less fuel is required, the engine power output will be restricted because of the throttling effect of the small manifold. Similarly, a large manifold will produce a desirable result at high speed, but at low speed will produce maldistribution and the air-fuel mixture will be leaner as compared to the optimum. So a compromise is reached, depending on other engine characteristics, to obtain maximum power output throughout the engine performance.

The heavier liquid fuel droplets tend to drop out of the mixture stream, depending on the velocity of the mixture.Therefore the inlet manifold should be of such a design as to encourage this liquid fuel back into the mixture stream. The liquid fuel tends to run in the form of a film along the manifold walls. If the manifold is of circular type, it will provide a channel for this liquid fuel film. However, if the manifold floor is kept flat the liquid film will spread out thus providing a greater chance of vaporization and re-entrainment. The roughness of the manifold walls is another factor which produces maldistribution of the air-fuel mixture. A rougher surface will resist the flow of the liquid film causing accumulation of the fuel into puddles. These will find their way to enter various cylinders causing misfiring, resulting in increased pollutant concentrations. A smooth surface keeps the liquid film flowing and prevents the large accumulation of fuel while keeping the film thin with a greater chance of vaporization.

Usually to evaporate the deposited fuel, it is necessary to provide extra heat. If the manifold is heated as a whole, it results in unwanted temperature rise of the mixture. To achieve a limited desired evaporation a hot spot is provided in the riser. This is the section between the carburettor and the manifold distributor section. It is surrounded by a circular jacket in which high temperature exhaust gas circulates to raise the mixture temperature. The design of the manifold tees and elbows also have a marked effect on the formation of the fuel deposits. A stream-lined tee will allow the liquid fuel film to run around the curved wall, while a sharp edged tee will tend to throw it back into the up-coming mixture stream. The experiments conducted at the elbows of the manifolds show that eddies exist over most of the cross sectional area but a steady flow is regained at a distance of about four or five diameters from the elbow. Streamline flow in the mixture encourages the heavier fractions of the fuel to drop out of the stream. It is found in practise that the sharp elbows by creating turbulence give better uniformity of the mixture stream than bends with large radii of curvature. With the latter, deposition of the heavy fractions takes place on the outer portion of the curve due to the centrifugal forces, and may also occur on the inside of the curve due to the slowing down of the mixture stream. On the other hand, the liquid fuel reaching the inside edge of a comparatively sharp elbow, tends to be thrown off as droplets which are carried away by the mixture stream.

Combustion inside the cylinders :-

Under operating conditions of an engine, due to various factors involved, combustion is never complete. This results in unburned hydro-carbons, carbon monoxide and various other pollutants in the exhaust gases. However, an understanding of the combustion processes and the influencing factors is necessary to comprehend the nature of exhaust pollution.

Under ideal conditions, the hydrocarbons will burn and be oxidised by a required amount of oxygen and produce expected chemical products. It follows from the chemical analysis of combustion processes that to achieve complete combustion, a specific air/fuel mixture ratio is required - the stoichiometric ratio. The range of air/fuel mixture upon which the petrol engine will actually operate, extends from a rich mixture - about 9:1, to a very weak - about 20:1, air/fuel ratio by weight. Depending upon the chemical nature of the fuel, the stoichiometric ratio lies between 14.5:1 to 15.1:1.In practice it is found that an engine's power output is maximum when air/fuel mixture is 15-20 per cent richer in fuel.

The basic function of the internal combustion engine is to utilize the combustion processes and convert the heat energy thus produced into mechanical energy to perform work. A true combustion engine should be efficient and capable of producing the power expected of it. There are various factors which govern the efficiency and power output of an engine.

When the compression stroke of a piston is completed, the spark initiates combustion which spreads to the air-fuel mixture surrounding it. The rate of combustion depends primarily upon the temperature of the flame front and secondly upon both the temperature and the richness of the mixture surrounding it. If the air-fuel mixture were at rest, the combustion would start from the spark plug and spread outwards, but in an engine the development is not so simple. The mixture has a high degree of turbulence, the extent of which depends on the speed of incoming mixture charge and design of the cylinder and piston heads. This turbulence speeds up the combustion processes by breaking up the flame into many other small flames thus providing new ignition centres. Experiments have shown that although turbulence speeds up the combustion process in later stages, it does not affect the ignition in the early stages. This phenomenon has been explained as due to a delay period commonly known as ignition lag, which is the time required by the air-fuel mixture to attain a temperature where autoignition occurs. This usually lies in the range of 0.6 and 0.8 seconds from the moment of the spark. During the second stage of the combustion which follows the ignition lag, the flame is propagated thermally i.e. as result of conduction and radiation from the flame front of the unburnt gases. Flame photographs have shown that the flame front is not smooth but irregular, so that its area is increased, hence the combustion of the gases in its vicinity is enhanced. The completion of the combustion hence after, depends on the speed of the reaction and flame front velocity. Various parameters of the engine operation such as speed, throttle opening, mixture strength, spark advance, inlet manifold temperature and compression ratio then determine the course of further combustion.

The pressure generated by the combustion depends on the air/fuel ratios, calorific value of the fuel, thermal efficiency and the compression ratio. The theoretical value for the I.M.E.P. (indicated mean effective pressure) is given by :

$$\left.\begin{matrix}\text{maximum theoretical}\\ \text{I.M.E.P.}\end{matrix}\right\} = \frac{V \quad C_F \times J}{R \times 1728 \times 12.4} \times 12 \text{ lb/ins.}^2$$

where V = working volume of the cylinder i.e. cylinder area x stroke, in cubic ins.

C_f = calorific value for the fuel in B.T.U. per pound

R = air/fuel ratio for complete combustion

J = Joule's Equivalent.

This maximum I.M.E.P. can only be obtained under ideal engine conditions and its actual value is decreased in practice as various losses are taken into consideration. The two main factors influencing I.M.E.P. are thermal and volumetric efficiencies.

Thermal efficiency of the engine depends mainly on the compression ratio.

$$\text{Thermal efficiency} = 1 - \left(\frac{1}{r}\right)^n$$

where r = compression ratio

n = a constant value depending upon the mixture ratio and certain other design factors.

Volumetric efficiency is defined as the ratio between the volume of the air-fuel mixture actually entering the cylinder under ideal conditions. This is greatly influenced by the engine speed. If the total volume of air entering the cylinder at N.T.P. be V ft^3/hr., and the total piston-swept volume of the cylinder be denoted by V_c, then:

$$\text{volumetric efficiency} = \frac{30\ N.Vc}{V}$$

where N = engine's r.p.m.

To obtain the correct value for I.M.E.P., which is possible in practice (known as brake mean effective pressure - B.M.E.P.), the theoretical value should be multiplied by the thermal and volumetric efficiency. Thus :

$$B.M.E.P. = \frac{V\ C_F \times J}{R \times 1728 \times 12.4} \times \left[1-\left(\frac{1}{r}\right)^n\right] \times \frac{30\ NVc}{V} \times 12$$

A co-relation diagram of B.M.E.P., mixture strength, thermal efficiency and compression ratio is given in Fig. 2:2

Engine power - indicated horse power (I.H.P.)of a multicylinder engine is given as follows :

$$I.H.P. = \frac{p \times \frac{l}{12} \times \frac{\pi d^2}{4} \times \frac{N}{2} \times n}{33{,}000}$$

$$= 9.9166 \times 10^{-7}\ pld^2Nm$$

where p = I.M.E.P.

l = stroke of piston (inches)

d = diameter of the cylinder (inches)

N = r.p.m.

n = number of cylinders

or, in terms of cylinder volume capacity :

$$I.H.P. = \frac{p}{33{,}000} \times \frac{N}{24}\ \left(\frac{\pi\ d^2 l n}{4}\right) = \frac{PNV}{792{,}000}$$

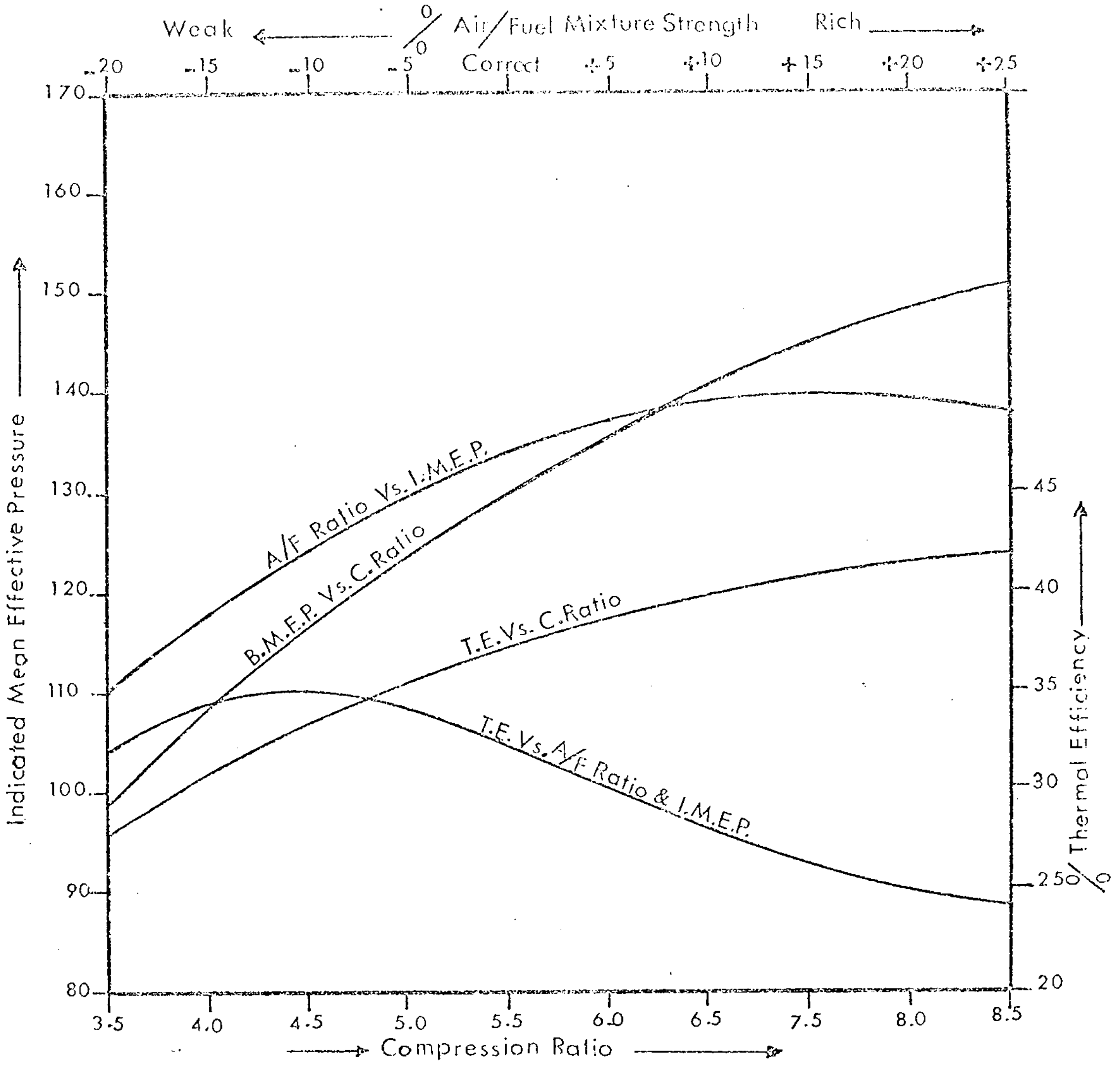


Fig.2:2 Co-relation among I.M.E.P., Thermal Efficiency, Air/Fuel Strength, & Compression Ratio

The indicated horse power (I.H.P.) is again a theoretical value and does not include the losses due to the various factors involved. For practical purposes, the actually developed horse power is measured as brake horse power (B.H.P.) which is the indicated horse power minus the power losses during practical operation.

The ratio of the brake horse power to the indicated horse power of course gives the mechanical efficiency of the engine.

2:2

CONTROL OF AIR POLLUTION FROM MOTOR VEHICLES.

There are three ways in which a motor vehicle may add to the atmospheric pollution. All these three sources are under legislative control in the U.S.A. and certain other countries, and various control devices are used to comply with the standard limits. These sources can be classified as follows :-

1. The crankcase emissions (blow-by gases).
2. The evaporative losses from the fuel system, i.e., carburettors and fuel tank.
3. The major and most important the exhaust emissions.

The combined contribution of crankcase and evaporative emissions is 35-45 per cent while exhaust is responsible for 65 percent of the total pollution caused by the vehicle.

1. CRANKCASE EMISSIONS :-

This source of emission constitutes the gases which blow pass the piston rings ('blow-by' gases) while an engine is under operation. The blow-by emissions consist of a mixture of approximately 85 per cent unburned air-fuel mixture and the remainder as the exhaust products, such as carbon monoxide, nitrogen oxides etc. (7, 86). The chemical nature of the hydrocarbons thus emitted, is of prime importance as regards their contribution towards photochemical smog formation (87). 'Blow-by' hydrocarbons, as expected, are of similar nature to the fuel used. These hydrocarbons differ significantly in their reactivity potential towards smog formation from exhaust hydrocarbons which undergo various chemical changes during their passage through the engine. The increased capability of the 'blow-by' hydrocarbons in smog formation is attributed to their olefinic contents. Bennett and co-workers (88) have shown that the blow-by gases contain a higher percentage of olefines which are chemically more active to produce smog.

The'blow-by' gases also contain acids and abrasive compounds which result from sulphur in the fuel, chlorine and bromine in lead scavangers, the water from combustion, and moisture from the air (89). These compounds contaminate the engine crankcase and the lubricating system resulting in sludge formation in engine oil. This in turn results in an increase in corrosion and wear rate of the engine parts.

It is obvious that the control of such emissions is essential from the point of view of air pollution as well as the engine's operational life.

Control of Crankcase Emissions :

In 1960, in America, the State Board of Public Health adopted the first California Standards for Ambient Air and Motor Vehicle Exhaust.

Up to October 1964, the maximum limit for crankcase emissions was 0.15 per cent by weight of fuel used and was later reduced to 0.1 per cent. France and West Germany put a limit of 0.15 per cent in 1971 and Sweden, of 1.5 g/km, while none was allowed in Switzerland.

No crankcase emission was allowed in Australia (Victoria) from 1970 onwards (78).

Control Devices :-

The work on the positive crankcase ventilation (P.C.V.) devices was started as early as the 1940's. The purpose of such devices was the removal of blow-by gases from stationary or slow moving engines (90)

These devices are now being used to prevent the crankcase emission from escaping to the atmosphere. The California Motor Vehicle Pollution Control Board (C.M.V.P.C.B.) has approved about fifty different devices for new vehicles and about six for used cars.

All the PCV devices which are mostly in use can be generalised in the four following types :-

Type 1 : Ventilation to the Intake Manifold :-

The 'blow-by' gases are fed to the intake manifold through a variable orifice valve (91). The opening of this valve is actuated by manifold vacuum. This valve is designed to produce a synchronised flow rate of the 'blow-by' gases, and also acts as an antibackfire valve isolating the crankcase when a pressure wave arises. This device is quite competent for most cars operating under low load conditions. At high load conditions the intake manifold vacuum is not strong enough to produce the required flow of crankcase emissions. Under these conditions some of the crankcase emission is released in the engine compartment which produces an undesirable odour. This device also fails in producing high enough flow rates for engines having unusually high 'blow-by' emissions.

Type 2 : Metering Valve Actuated by Crankcase Vacuum :-

The metering of the 'blow-by' gases is controlled by a similar valve as in type 1. The ventilation tube is connected to the intake manifold but the opening of the variable orifice valve is controlled by the crankcase vacuum (92). Ventilating air is admitted to the crankcase through a controlled orifice in the oil filler cap. This device is more successful as the flow rate adjusts to the 'blow-by' rate of the vehicle. Some 'blow-by' outflow may occur at wide open throttle.

Type 3 : Tube-to-air Cleaner Device :-

This device involves a simple ventilation of crankcase emissions into the carburettor air cleaner (93). The flow is induced by using a single tube which is projected into the air cleaner snorkel at right angles. The end of this tube is inclined at 45^0 facing the downstream thus creating pressure differential. A small orifice in the filler cap or breather prevents the oil being carried to the induction system at high engine speed.

Type 4 : Combination Ventilation Systems :-

These are also known as 'split-flow' systems (94). The 'blow-by' gases are returned to the intake manifold and to the air cleaner by combining type 1 or type 2 with type 3 device. A fixed orifice controls the flow to the intake manifold. These systems have been found to be adequate over all engine operational conditions. At low 'blow-by' flow rates, all of the 'blow-by' gases are returned to the intake manifold, while at higher rates, the excess gases are returned to the air cleaner. One of such devices is shown in Fig. 2:3

2. EVAPORATIVE EMISSIONS :

Evaporative losses of fuel from the carburettor and fuel tank constitute a further source of volatile hydrocarbons. The vapours from motor gasoline contained in these two parts of a motor vehicle contain hydrocarbons chiefly in the range of iso-butane, n-butane, n-pentane, and hexane - with butane and pentane as major components. These vapours also contain some olefinic hydrocarbons, the potential photochemical smog generators (95-96). The extent, and therefore the composition of the evaporative emissions depends on the carburettor's location and venting procedures adopted, fuel volatility, and the climatic

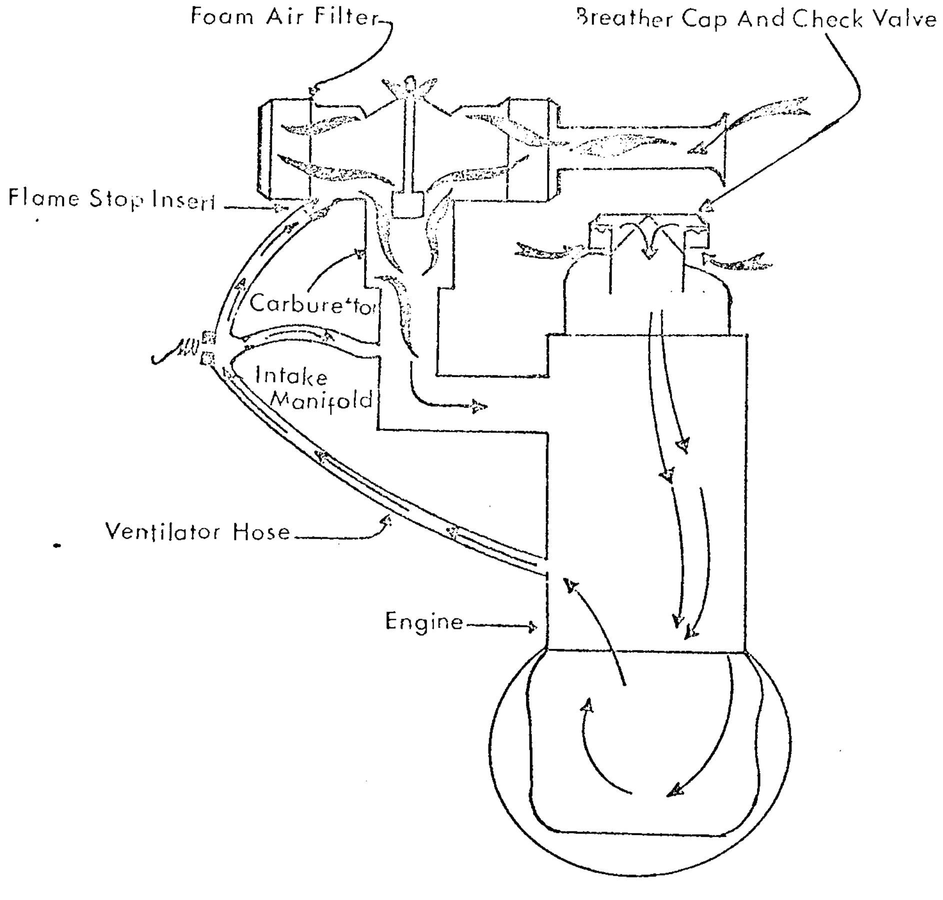


Fig. 2:3 Split-flow Crankcase Ventilation System

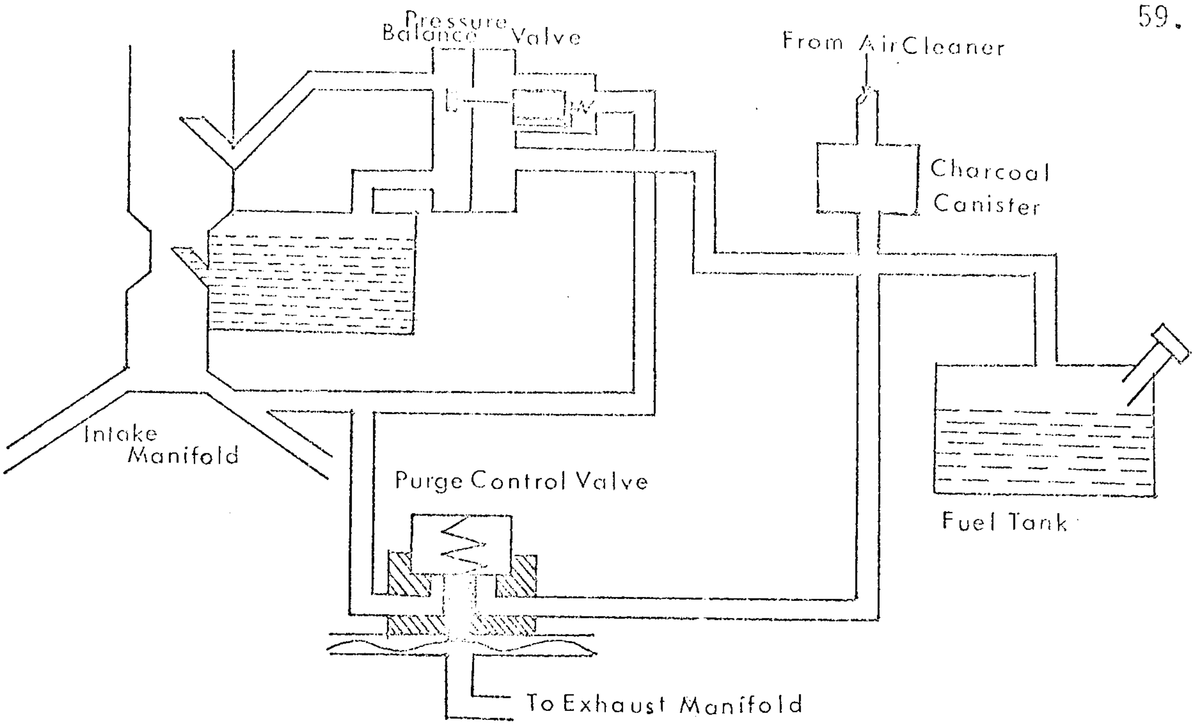
temperature. Slow speed driving in the city traffic tends to increase the carburettor bowl temperature and consequently the varpour losses. The hydrocarbons emission from this source amounts to 15 per cent of the total car emissions (1).

Control of Evaporative Emissions :

A maximum limit of 6 grams of hydrocarbons per test was put down by the California State Department of Public Health in 1964. The test was described as driving over an urban route on a warm day with temperatures 60-70°F, with maximum at 90°F. After parking, the carburettor losses (hot-soak) were put down to 2 grams of evaporative for an hour at a minimum cooling temperature of 180°F and climatic temperature of 85-95°F (97). This compares with 50 gms of evaporative losses without any control device, for the same test procedure.

Control Devices :

The basic principle behind Evaporative Loss Control Devices (E.L.C.D.) is to trap the fuel vapours chemically or physically and then feeding into the intake system of the engine. Fig. 2:4 shows one of these devices which is currently in use (98). All the fuel vapours are carried to the canister containing a charcoal bed, and are retained there until fed into the intake system. The pressure balancing valve actuated by the intake manifold vacuum, maintains the metering pressure in the carburettor while engine is operating. It also shuts down all external vents and allows the vapours to be absorbed in the charcoal canister when the engine is stopped. The purge control valve is actuated by exhaust back pressure. When open it allows the air to be drawn through the canister thus re-entraining the fuel vapours.



ESSO'S CHARCOAL SYSTEM

Fig 2:4 Basic Evaporative Loss Control System

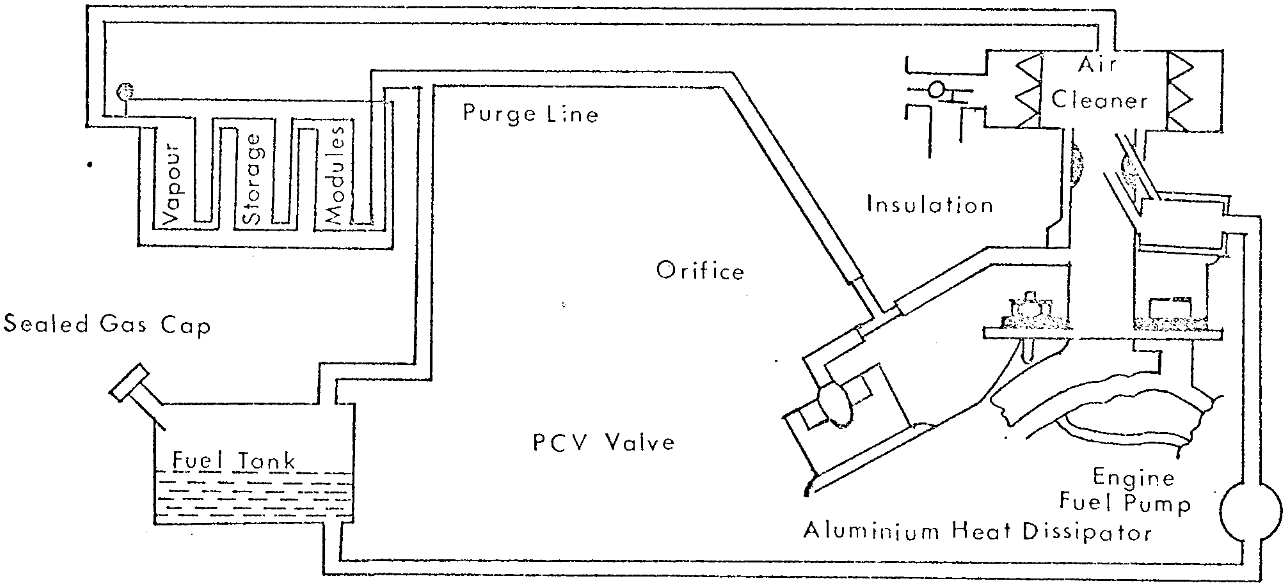


Fig 2:5 Chevrolet Evaporative Control

Carburettor evaporative losses are vented via a throttle actuated poppet to the charcoal canister.

Another device, shown in Fig. 2:5, is also currently being used on quite a few cars. This device stores the fuel vapours in the storage modules in the engine crankcase (78). These vapours are then fed into the intake system with other crankcase emissions. This device also incorporates heat barriers which prevent the carburettor from getting hot, thus reducing the carburettor evaporative losses.

The fuel tank ventilation is achieved by providing vents at all four corners of the fuel tank, and expansion volume inside the tank, in combination with a vapour-liquid separator to prevent syphon possibilities between tank and carburettor bowl.

3. EXHAUST EMISSIONS :-

The exhaust emissions are the most important and major source of air pollution caused by an internal combustion engine. A brief idea about the origin, composition, their harmful effects, and the legislative situation of these emissions has already been given in the prior pages of this treatise. The following paragraphs contain a general account of various methods and devices used to control the exhaust emissions.

Control of Exhaust Emissions :-

During the past two decades, considerable efforts and resources with more or less success,have been put towards developing devices which could efficiently control the exhaust air pollution. The initial requirement made of these devices was that they should maintain the pollution control standards over a distance of 12,000 miles (99,100). This was changed in September 1965 to a satisfactory performance over 50,000 miles, with only one servicing permitted at 25,000 or over miles. Such a device should also have the following attributes : effectiveness, durability, simplicity, low initial cost, and little, if any, operational expenses. None of the devices developed in the past have complied with all of these requirements although quite a few have been successful in reducing the amounts of air pollutants to the legislative levels. Such devices have been able to achieve approval in the U.S.A. and are currently in use on various air pollution controlled vehicles.

Understandably, the first attempt to control exhaust emissions lay in the treatment of exhaust gases to cut down the pollutant concentrations. This approach mainly involved physio-chemical reactions accompanied by the continuation of combustion processes inside the exhaust manifold. The devices used were mainly directed towards carbon monoxide and hydrocarbon reductions and were of the following three types :

1. Catalytic reactors
2. Direct flame after-burners
3. Exhaust manifold air oxidation reactors.

1. Catalytic Reactors :-

These reactors rely mainly on catalysis to further the oxidation of the combustibles in the exhaust manifold. They also require introduction of extra air inside the exhaust manifold. Although these are very efficient they suffer from some basic disadvantages. A successful device will require a large quantity of relatively expensive catalyst for reasonable reduction of the pollutants. The high temperatures of the exhaust also affect the life and working of the catalyst. Repeated exposure of the catalyst to high temperature of exhaust gases makes the location of the catalyst muffler at some distance from the exhaust ports also mandatory. This results in a loss of an appreciable porportion of useful heat. One of the major hazards jeopardising the success of these devices is the lead poisoning of the catalyst.

However in 1962, W.R. Calvert described the rejuvenation of the catalyst purifier by using a mechanical method for removing the catalyst particles and accumulated solid lead components in the form of dust (101). The catalyst bed was then treated with a solution of catalyst material. Such a system is shown in Fig. 2:6.

The catalyst bed is carried between two porous grids and provision is made for air inspiration, catalyst discharge, and vibration by attachment to the automobile chassis. This system seems to act quite efficiently for the revival of the catalyst but does not provide any means for prolonging the effectiveness of the catalyst for long distances.

Research is still in progress to perfect this system. Cheap and longer-lasting catalysts with improved effectiveness under varied conditions of temperature are being developed (102, 103).

2. Non-catalytic after-burners :-

Depending upon the concentrations of combustible pollutants in the exhaust gases, it is possible to combust a high percentage of the harmful pollutants by introducing additional air inside the exhaust manifold. In case of low concentrations of combustible contents, it will be necessary that the exhaust gases must be heated to a relatively high temperature (in the order of 1123^{0}K) before the combustion can take place. Since the exhaust gases' combustible

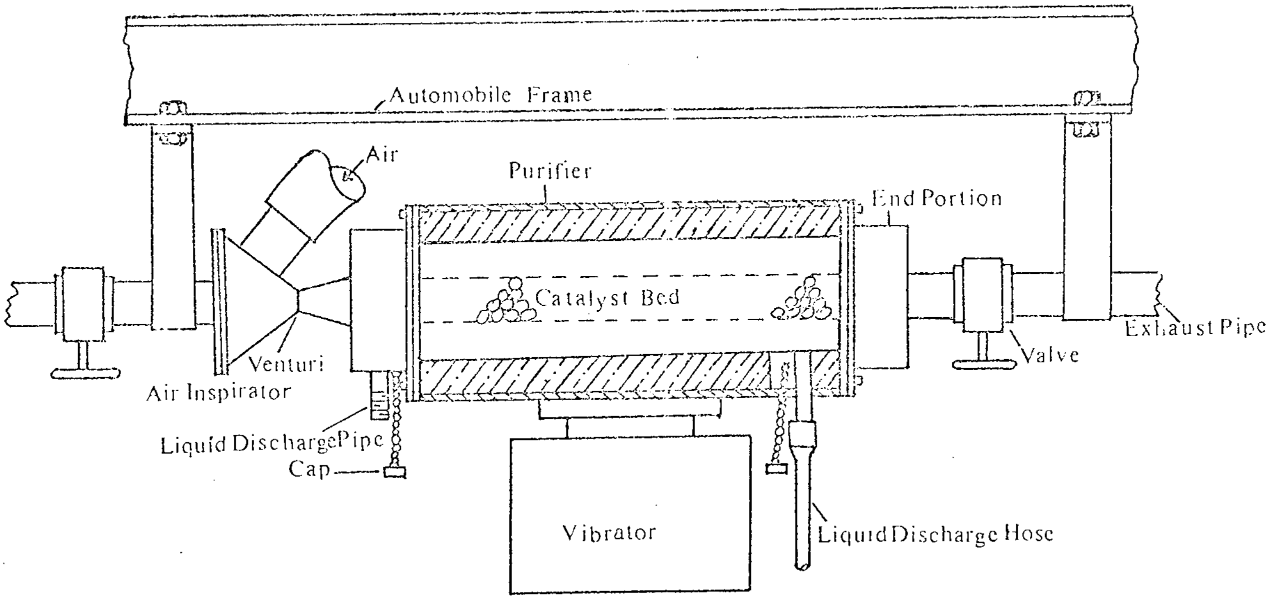


Fig 2:6 Catalytic Exhaust Purifier And Regeneration Means For Mechanical Removal Of Accumulated Lead Dust

contents are usually low, the combustion cannot be achieved at normal exhaust temperatures (from about 523^{0}K to 823^{0}K). Various devices have been developed using the above principle. The major reason for failure of such devices is due to the variations of the combustible contents of exhaust gases over various engines' operational modes. During cruising,

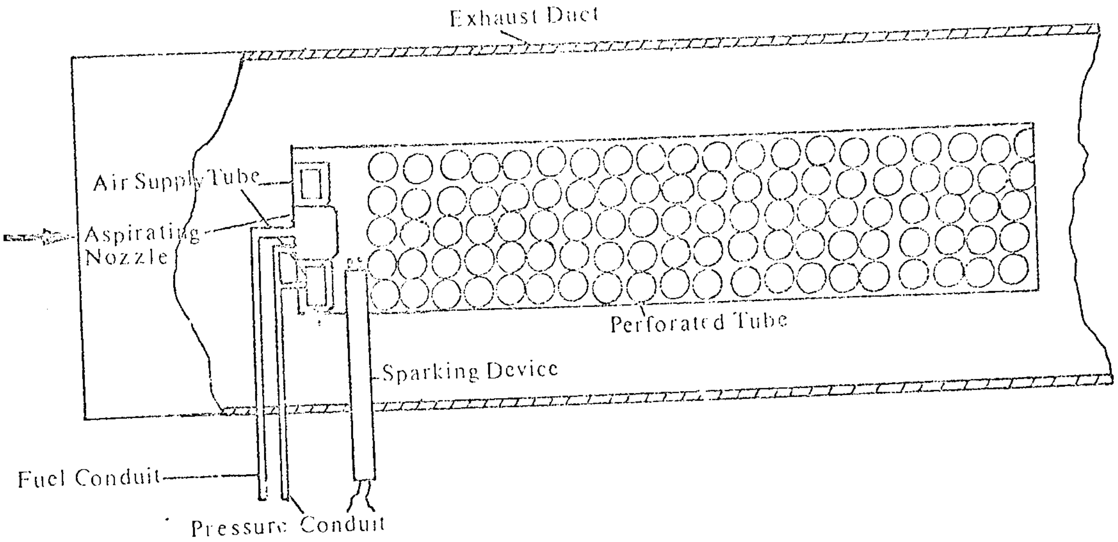


Fig 2:7 One Type Of Non_Catalytic Afterburner

mild acceleration and sometimes idling, the exhaust will not burn without preheating, whereas during deceleration or malfunctioning of the engine, such as spark plug misfiring, the preheating will result in temperatures high enough to damage the device itself.

One of the successful devices is shown in Fig. 2:7 (104). The exhaust gases are introduced into an exhaust duct containing a perforated tube. This perforated tube is supplied with nozzles projecting inside the tube. Air is introduced, at a pressure of about 2 pounds per square inch into the air-inspirating nozzle resulting in aspiration in the fuel nozzle connected to the fuel tank. A spray of air-fuel mixture is introduced into the perforated tube and ignited by a spark device actuated by the ignition system of the engine.

The flame from the nozzle spray is confined within the perforated tube and in its transit past the perforation, creates an aspirating effect. It tends to draw inwardly, through the perforations, the exhaust gases passing on the outside of the perforated tube, co-currently with the flame. Such devices are now being used in combination with heat exchangers to reduce the temperature variations and produce, more or less, proper conditions for combustion over all modes of engine operations.

3. Exhaust Manifold Air Oxidation Reactors :-

These devices simply provide the continuation of the exhaust gas oxidation of hydrocarbons and carbon monoxide. The air is introduced into the very hot region of the exhaust system i.e. close to the exhaust valves. The oxidation of the exhaust gases leaving the cylinders at a high temperature is maintained by the additional oxygen and is completed inside the exhaust pipe.

General Motors Air Injection Reactor (A.I.R.) system is based on the above principle (105). In addition to the injection of air into exhaust ports, this system is accompanied by other engine modifications as required by individual engine design. A positive displacement, non-lubricated pump, belt-driven from the engine crankcase is used to supply the necessary amount of air. The effectiveness and safe performance of this system requires special carburettors, calibrated for optimum air injection as well as vehicle performance and fuel economy. Ignition distributors are supplied with ported vacuum spark advance units. The port is situated above the throttle valve thus controlling the ignition retardation as no vacuum is signalled to the distributor. On opening the throttle, the open vacuum port provides a spark advance for normal open throttle operation. At idle speed, due to retarded ignition, this system experiences an extra heat rejection by the engine. Modifications in the engine cooling system are made to compensate such increases in engine working temperatures. An anti-backfire valve is supplied to stop the exhaust system from exploding on sudden throttle closure, and a check valve to prevent exhaust gas backflow into the air injection lines. For high speed and high load operation, an air-pump relief valve is supplied to prevent excessively high exhaust system temperatures. This system has been certified to reduce exhaust hydrocarbons and carbon monoxide to the limits set by the C.M.V.P.C.B., and is typical of many systems fitted to U.S. cars. One of such is the Ford Thermactor (105).

For some engines, modifications to distributors and carburettors are also required. As the efficiency of manifold air oxidation systems depends on the enrichment of the exhaust mixture to sustain oxidation of the pollutants, certain adjustments are required of the carburettors and ignition tuning to create such essential conditions in the exhaust systems.

4. <u>The Zenith Duplex Induction System</u> :-

This system is mainly concerned with the air-fuel composition and its induction to the inlet manifold (107, 108). The main components are a primary and a secondary manifold, and a Stromberg Constant Depression carburettor. The primary and secondary throttle valves can be arranged at various positions to suit various vehicles. The main system and alternative positions of throttle valves are shown in Figs. 2:8 and 2:9. The air-fuel mixture is conducted through the heated primary manifold during idling, acceleration and deceleration. The secondary throttle valve is brought into operation during the high speed and load running of the engine to prevent any limitation of power as a consequence of head loss or heating in the primary manifold.

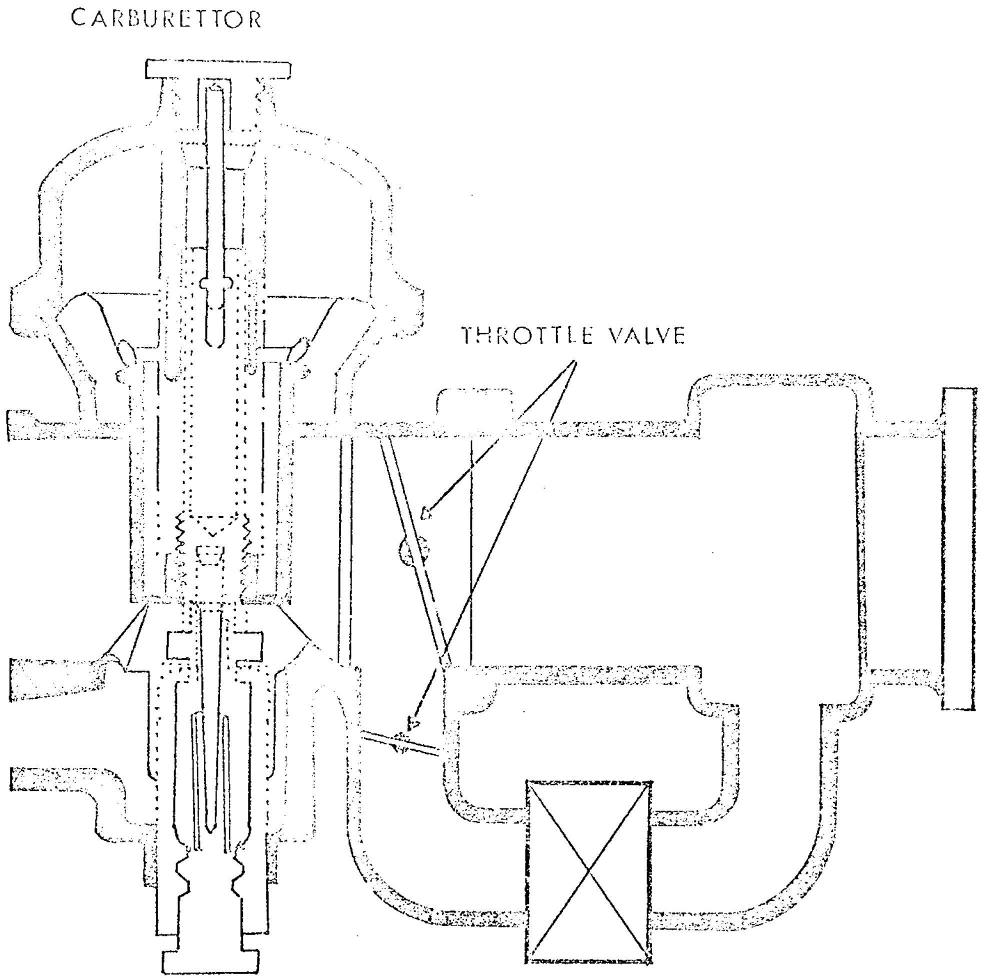


Fig 2:8 Zenith Duplex Induction System

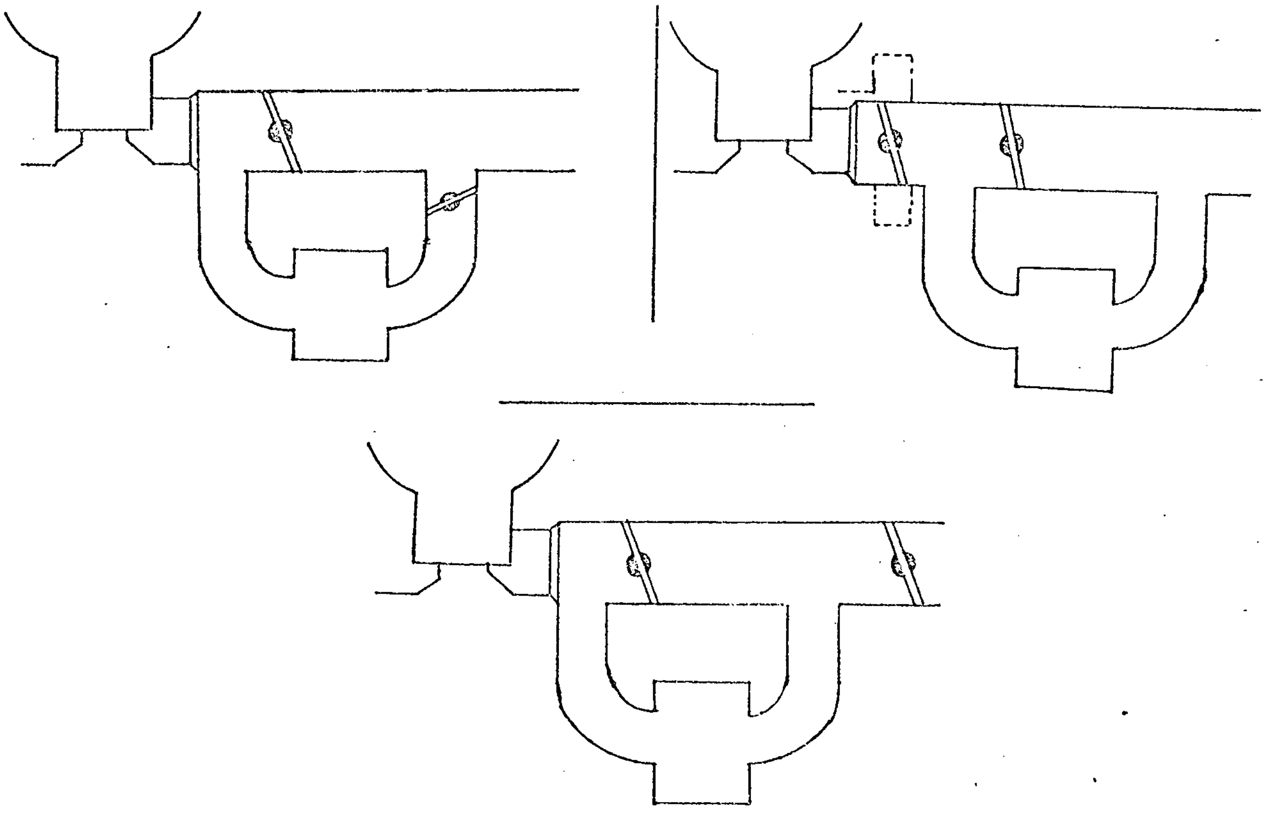


Fig 2:9 Alternative Throttle Arrangements In Zenith Duplex System

To overcome the fuel enrichening effect, during the engine warm-up period, the Stromberg Constant Depression carburettor plays a significant part, maintaining a lean air-fuel mixture, and lowering the manifold depression which results in extra mixture to enhance combustion. Emission control during idling and deceleration is achieved by a small valve operated by means of lost motion on the accelerator linkage, so that after closure of the throttle, vacuum is fed to a retard capsule situated on the distributor resulting in extra retardation.

This system by improving mixture distribution allows a higher air/fuel ratio to be used thus reducing the exhaust emissions.

5. The Chrysler 'Clean Air Package' :-

This was the first device involving engine modifications which was approved by C.M.V.P.C.B. in 1964 (109). It provides for alterations to reduce the air pollutants levels in the several modes of engine operation. These alterations mainly involve the modifications to the ignition and induction system. The basic layout of this system is shown in Fig. 2:10. The highest concentrations of pollutants are emitted at idle and deceleration modes, while comparatively less contribution is made during acceleration. The reductions in emissions at idle speed is achieved by simply increasing the friction load which requires the raising of engine speed at idle. The ignition tuning for idle is also retarded to reduce the efficiency at which the friction loads are carried. A combination of these modifications results in making the air-fuel mixture leaner at idle with a decrease in the amount of pollutants emitted.

During deceleration the higher manifold vacuum sucks the incoming air-fuel mixture into the cylinders before the exhaust valve is fully closed, and some of this charge is mixed with the escaping exhaust gases resulting in increased emissions. In the C.A.P. system, such emissions are controlled by increasing the air flow. A small hole drilled in the throttle valve provides increased air flow and also reduces the manifold vacuum. In addition, a vacuum control sensing valve is brought into operation directly connecting the manifold vacuum to the spark advance unit resulting in an advanced spark timing which improves the combustion during deceleration.

Acceleration is accompanied by leaning of the air-fuel mixture, therefore the exhaust emissions are low. "Modified choke calibration" deals with the rich air-fuel mixture when the engine is being started from the cold conditions. Modified cylinder distribution and manifold heat exchange permits the choke calibration to open sooner than in un-modified engines.

6. Volvo Dual Manifold Emission Control System :-

This system, shown in Fig. 2:11, includes a centrally heated turbulence chamber, a cross-flow pipe,and two manifold throttles (110). In addition, a retarded spark timing at idle and increasing idle speed is also used. During idle or moderate power operations the manifold throttles are kept shut. This allows the air-fuel mixture coming from both carburettors, to the turbulence chamber where fuel is vaporised and mixed with air to produce a more homogeneous mixture. A spark timing of 50^0 before T.D.C. is used to avoid 'running on', and prevents the cooling system from getting overheated. With power increase, the throttle valve, synchronised by means of the crank-shaft, starts opening and allows some of the mixture to by-pass the turbulence chamber. At full throttle-opening all the mixture by-passes the turbulence chamber. This system has the advantages of providing near perfect distribution due to the heated

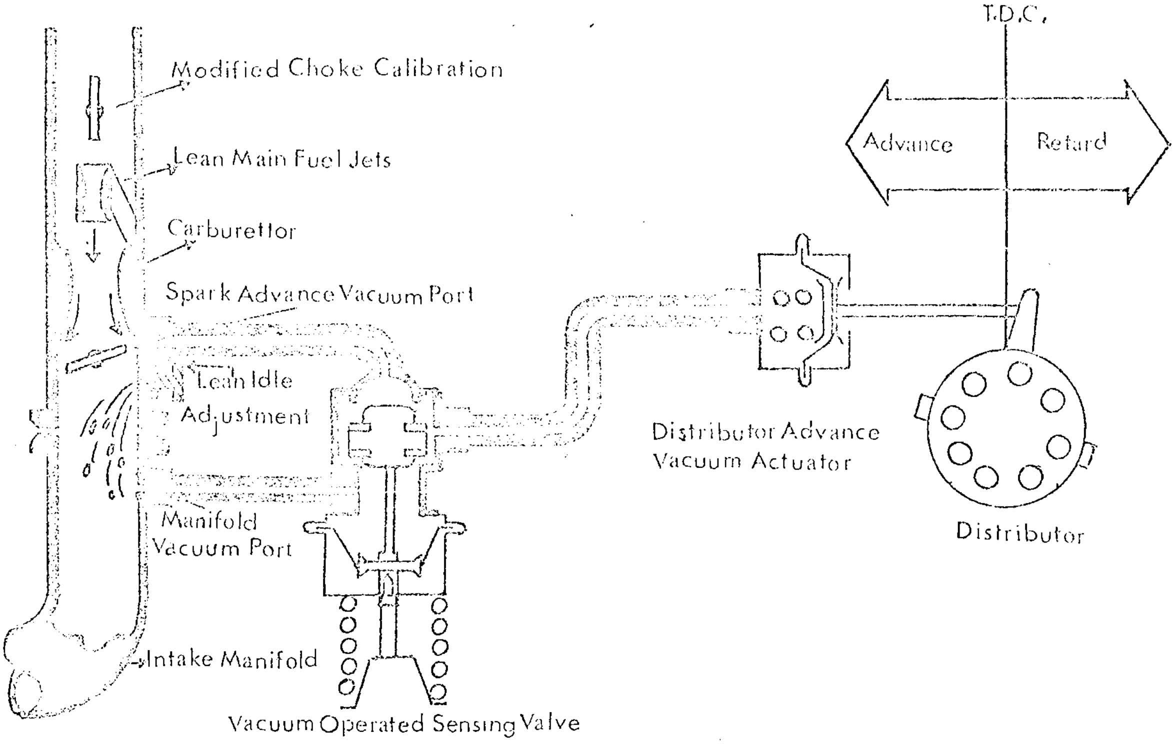


Fig.2:10 Chrysler Clean Air Package System

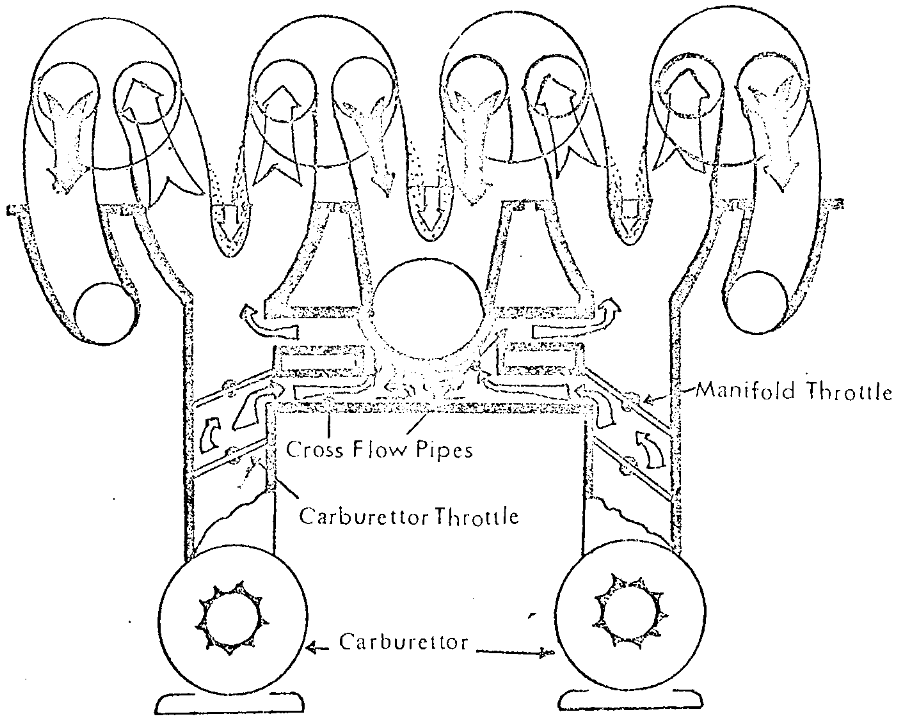


Fig 2:11 Induction System For Volvo Emission Control Engine

turbulence chamber, and reduces the exhaust emissions by working on the lean side of the mixture ratios.

Miscellaneous Control Systems :-

Although various devices have been developed to reduce hydrocarbons and carbon monoxide emissions, less work has been done as yet to reduce nitrogen oxides emissions. These emissions are mainly governed by the peak flame temperature and the amount of oxygen available for combustion. Work conducted by Newhall (111) shows an appreciable reduction in nitrogen oxides by recycling a portion of exhaust gases into the inlet manifold. Deeter and co-workers (112) and Benson (113) have been able to achieve 70 per cent reduction in nitrogen oxides by recycling only 15 per cent of exhaust gases (114). The addition of inert gases lowers the peak temperature by dilution, while reducing the amount of oxygen available at the same time. Although recycling results in horse power loss and rough engine operation, it has been claimed that these problems can be solved by spark advance and by raising the air/fuel ratio by carburetion modifications.

Many American motor firms have combined control systems with little or no additional modifications. Usually these have an air pump and air distribution manifold accompanied by improved carburretion and ignition timing modifications.

During deceleration, (a driving mode characterised by excessive exhaust emissions) numerous devices, including shut-off and vacuum limiting systems, are in use. Shut-off devices are quite effective but suffer from lag time i.e. the manifold is wet enough to supply gasoline for some time even after shut off, and the engine requires some time to recover when the shut-off opens. Vacuum limiting devices produce less combustibles in the exhaust gases, but they add to braking requirements. This can be overcome by spark retardation during deceleration.

2:3

LITERATURE SURVEY :-

Since Professor Haagen-Smit's work showing the connection between photochemical smog and automobile exhaust gases, an enormous amount of research has been conducted in the field of air pollution control (57). An ever increasing number of scientific publications resulting from various research efforts, makes it impossible to give a complete account of the many engine parameters controlling the air polluting emissions. This survey is mainly concerned with work involving air-fuel mixture condition and distribution and their influence on automobile emissions. However, a concise account of the formation of important pollutants is given, and where possible, various other relevant factors are also briefly described.

Early work by Shinn and Olson (115) indicated that hydrocarbon emissions arose due to the phenomena of flame quenching and fuel condensation on the cylinder walls due to temperature variations. The exhaust products near the cylinder walls are not completely removed and thus the residual gases contain a high percentage of hydrocarbons. These in turn may play a significant role in the formation of cylinder deposits affecting the further inhibition of combustion of the new charge. In their studies, these authors also took into consideration factors such as manifold pressure, engine speed, and type of fuel used. Their findings agreed with the work conducted by Rounds, Bennet, and Nebel (116) who studied the fuel and engine variables and their effects on hydrocarbon emissions. These authors concluded that at a manifold vacuum above 21 ins. of Hg, the hydrocarbon concentrations increased considerably and suggested that none of engine-fuel variables like mixture ratio, compression ratio, fuel type, coolant temperature, engine type and speed, and engine load had such a significant effect on exhaust hydrocarbon concentrations. This work was followed by Wentworth and Daniel (117) who looked more deeply into the cause of high hydrocarbon concentrations at high manifold vacuum. With the help of flame photographs, these authors proved the existence of wall quenching and concluded that the dilution of residual gas was the major factor inhibiting complete combustion of the air-fuel mixture. In 1957, Potter and Berland (118) conducted research to establish the effect of fuel type on the quenching of the combustion. The quench distance was found to decrease in the following order : iso-octane > n-heptane > propane > benzene, which is also in order of burning velocities of these compounds. Mathematically it has been proved by Simon and Belles (119) and Tanford (120) that the quench distance is inversely proportional to the flame speed. The mass of unburned hydrocarbons is therefore inversely related to the flame speed. Begeman (121) agreed with the above findings but his main interest lay in the emission of carcinogenic hydrocarbons. His work was mainly concerned with Benz-a-pyrene and showed that the concentrations of this carcinogenic compound from di-isobutylene and iso-octane were significantly lower than from gasoline. In contrast, the benz-a-pyrene emission rate with 50 per cent oxy-xylene and 50 percent benzene was 2.7 times the rate with gasoline, 37 times that of di-isobutylene fuel, and 10 times higher than iso-octane fuel.

The phenomenon of quenching and production of hydrocarbons during combustion processes was studied in some detail by El-Mawla and Mirsky (122). Wall quenching in an internal combustion engine naturally occurs within a very short period of time and in a very thin layer (0.005 ins.) along the combustion chamber wall. Flame travelling towards the chamber wall experiences a reduction in speed mainly because of the thermal influence of the wall until it is completely quenched. Between the region where the free flame exists and the point where quenching is complete, exists the region in which 'partial' quenching is assumed to exist. These studies are concerned with the measurement of the amount of unburnt hydrocarbon in the 'partial quench zone'. Minimum mass for a given plate (wall) temperature occured at an equivalent ratio of 1.105 and increased for both lean and rich air-fuel mixtures. The mixture producing minimum mass also produced the maximum equilibrium flame temperature, and therefore maximum flame speed. Maximum burning velocity decreased with increased equivalence ratio. A higher wall temperature will reduce the rate of heat transfer from flame to wall and would result in an increase in reaction rate, reducing the unburnt hydrocarbons. From photochemical smog point of view, olefines amount to an average of 25 per cent of total mass of unburnt hydrocarbons.

In 1972, Panduranga (123) studied the effects of turbulence on the amount of hydrocarbons emitted from automotive engines (turbulence naturally interferes with wall quenching phenomenon). This author has worked with a spherical bomb combustion chamber with central ignition achieved by extending the electrodes of a Bosch spark plug. Quartz windows in combination with a photocell were used to observe the flame. The results show that it is possible to substantially reduce unburnt hydrocarbons (due to wall quenching) by generating suitable turbulence.

The position of the spark plug is important in relation to the combustion chamber walls where the motion of the air-fuel mixture decides the quench zone thickness. It was noticed that the mass of unburnt hydrocarbons decreased first, and then gradually increased with increase in turbulence. It is suggested that this may be partly due to the homogeneous quenching and partly due to thorough mixing of the quenched layer and burning gases.

A most recent publication by Heywood and Keck (124) has given a very comprehensive account of the formation of hydrocarbons and nitrogen oxides in automobile engines. This paper asserts that the hydrocarbons are produced alongside the combustion chamber walls due to quenching, and in crevices above the piston rings between the piston and cylinder walls. During the 'power stroke', the piston recedes depositing the unburnt hydrocarbons above the piston rings and along the combustion chamber walls. Due to the reducing temperature of the walls (freezing), the further oxidation of the nitrogen oxide and carbon monoxide is slowed down stet increases the concentrations of these pollutants as compared to the expected values under these conditions. During the 'exhaust stroke', the piston while moving up scrapes the thin layer of quenched hydrocarbons from the cylinder walls and from the crevice and a vortex of the fuel film is created. Tabaczynski et al (125) have shown that the area of this vortex divided by the square of the stroke correlates with Reynold's number. These authors were also able to show the concentrations of the exhaust hydrocarbon concentrations in terms of the time taken by an 'exhaust stroke'. They also related their results to crank angle showing that the hydrocarbon concentrations at the end of the 'exhaust stroke' were much higher than at the beginning, which establishes the theory of vortex formation above the piston head.

In 1960-61, J. S. Clarke (126) published a paper discussing the effect of engine parameters on internal combustion engine processes in great detail. The fuel dispersion in the inlet manifold was observed through a 'perspex' manifold and analysed on high-speed film records. The fuel was shown to form a film along the manifold walls. Sharp edges in the inlet manifold were shown to be beneficial in promoting good mixing but may cause undue restriction to the air-flow at high engine speed. During bad mixing the combustion only takes place in more favourable regions. The effects of initial air and fuel temperatures are shown to have significant effects on combustion especially during cold start conditions. A detailed section on the chemical kinetics proves that the heat loss and volumetric efficiency are correlated, e.g. if 25 per cent heat loss is associated with 75 per cent volumetric efficiency, then the reaction rate is reduced by a factor as much as 14. Jackson et al (127) studied the influence of air/fuel ratio, spark-timing, and combustion chamber deposits on hydrocarbon emissions. Air/fuel ratio was shown to have appreciable effects, an air/fuel ratio of 16-18 producing minimum exhaust hydrocarbons and best fuel economy. However, the problem of power 'surge' was found to be a handicap. Retarding spark ignition by 10 degrees from the optimum economy value, produced a 7-13 per cent reduction in hydrocarbon emissions. A combination of both leaner air-fuel mixture and retarded spark ignition timing resulted in off-setting the fuel economy effects and produced lower pollutants emissions. Build-up of combustion chamber deposits inside the cylinders showed an increase in hydrocarbon emissions. This work was followed by Hagen and Holiday (128) who limited the alteration of various engine variables to those which produced reasonably good engine operation.

Their findings also showed that leaner air/fuel ratio resulted in reduction of hydrocarbons. Increase in the air/fuel ratio beyond 14.7:1 (theoretical ratio for complete combustion) did not produce extra reductions due to insufficient air supply. However, an increase in air supply beyond the carburettor at above ratio, resulted in further reductions in both hydrocarbons and carbon monoxide. Engine speed or power out-put changes operated to have no effect on carbon monoxide emission concentrations, although, engine power out-put increased hydrocarbon due to increased engine air-flow required to produce high power. Increased engine speed reduced hydrocarbon emission concentrations but again depending on engine air-flow. Retarding the spark timing had a marked effect on hydrocarbon emission whereas carbon monoxide emission remained more or less unchanged and there was power loss. During part-throttle opening, 10 per cent power loss occurs at about 19^{O}B.T.D.C., whereas at wide-open throttle the same amount of power loss is observed at around 6^{O} B.T.D.C. Exhaust back pressure was shown to be ineffective in influencing both type of emissions. The valve over-lap decreased the exhaust gas dilution of the fresh charge resulting in improved combustion. The combustion chamber deposits build-up was shown to be related to an increase in hydrocarbon emission and to a very small extent carbon monoxide emission. The intake manifold pressure appeared to have a considerable effect on both hydrocarbons and carbon monoxide emissions. Although there was little change in hydrocarbon emission between 8-24 ins. of Hg intake manifold pressure, a higher concentration effect was produced between 24-29 ins. of Hg. Carbon monoxide concentrations also increased considerably during this pressure range. The reason given for this phenomenon is that at high pressure the carburettor power valve enriches the air-fuel mixture. These authors' findings also indicate a difference of level of pollutant concentrations, under similar conditions of operation, emitted from different engines. This indicates that the type of engine also has a significant effect on air pollution.

Yu (129) considered the air-fuel distribution problem from two points of view; firstly, the geometric variation concerning the problems involved when the fuel is not distributed uniformly among individual cylinders, and secondly, the problem of variation of air/fuel ratios with time for a particular cylinder. This paper describes an analysis apparatus using a gas chromatograph and exhaust gas analyser which measures air/fuel ratio of a single explosion of any individual cylinder. The time variation of air/fuel ratio is shown to induce 'surge' and is influenced by the rate of fuel flow rather than air-flow and also by the type of fuel used. The power 'surge' produced by time variation of air/fuel ratio can be reduced by enriching the mixture, which in turn results in loss of fuel economy. Geometric maldistribution results both in power loss and fuel wastage. These losses increase according to engine operational mode e.g. lean mixture and part load operation. The complete vaporisation of the fuel, if not accompanied by reasonable means of mixing, could result in poor distribution. However, complete vaporisation and good mixing can result in almost perfect geometric distribution. For example, inducing swirl and increasing the air and fuel volumes to mix, is shown to improve this distribution.

Freeman and Stahman (130) consider the effects of mixture distribution in terms of combustion efficiency. This efficiency is calculated by simply multiplying specific air consumption at the peak power mixture, or richer, by the heating value of air, in appropriate units. From such calculations they found the 'per cent fuel wasted' is given as :

$$\text{per cent fuel wasted} = \frac{\frac{1}{\eta}t(\text{fuel basis}) - \frac{1}{\eta}t(\text{air basis})}{\frac{1}{\eta}t(\text{fuel basis})}$$

and the combustion efficiency = 100 % - per cent fuel wasted. This wasted fuel is obviously emitted in one form or another through the tail-pipe. Maldistribution of fuel, serious fuel precipitation, and maldistribution of air are given as the reasons for loss in combustion efficiency. A technique was developed to measure the extent of maldistribution of air-fuel mixture on the assumption that the mixture strength in individual cylinders will result in corresponding spark plug core nose temperature. These temperature variations were recorded by using suitable thermocouples embedded in spark plug core noses. If the mixture was started lean, and strengthened in step-wise fashion, it was observed that the core nose temperature maxima for different cylinders occured at different air/fuel ratios. These theoretical assumptions and experimental techniques are used to establish the effects of air-fuel mixture distribution on air pollution. The authors express their doubts that the fuel system development alone could ever render automotive exhaust acceptably free of air pollutants.

The atomisation and therefore the distribution by a carburettor are treated mathematically by Lenz (131). While giving an expression for the calculations of carburettor atomisation characteristics he showed that in general terms, the carburettor must be regarded primarily as a fuel metering device, and to a lesser extent as fuel preparation equipment. In the view of the author, it follows that the mixture distribution depends on the whole of the 'breathing' arrangement which, in addition to the intake manifold includes the valve timing, firing order, and the exhaust system. He also stresses the atomisation of the fuel as the most basic factor for better distribution from cylinder to cylinder. His work also suggests that long and winding intake pipes will require better

atomisation as compared to short and straight ones. Working on similar lines, Sutton (132) achieved reductions in exhaust emissions by tuning and some modification of the carburettors on Rover 2,000 SC automatic and Land Rover 88 ins. station wagon. The object of his research was to reduce the spark retardation required for reducing emissions to a minimum during idling. It was realised of course, that ignition retard coupled with mixture control could achieve considerable reductions in hydrocarbon emissions. This would however, impose limitations on acceptable engine performance, an extra load on the vehicle cooling system, impairment of cold start ability and most important, the tendency for 'run-on'.
One of the modifications applied to both engines was the implanting of a toothed Fuel Deflector Plate after the throttle valve. This plate helped in atomising the fuel puddles and wall wetting film as a result of fuel movement immediately downstream of the carburettor butterfly. This is shown to improve the air/fuel mixture ratios and homogeneity. In addition, a spring loaded valve in the carburettor throttle plate was used to reduce hydrocarbon emissions during deceleration and gear change intervals by reducing the inlet manifold depression on over run and admitting a greater volume of air-fuel mixture.

Further studies on the air-fuel mixture formation and distribution were conducted by Dodd and Wisdom (133). Using two engines : (1) a single cylinder adaptation of a proprietary 1.3 litre, four cylinder unit, and (2) a'bath-tub' combustion chamber from a proprietary 2.2 litre, four cylinder unit fitted with a modified cylinder block. The authors studied four different ways of fuel supply. These four methods of fuel supply were :- (a) fully vaporised by fuel injection, (b) by carburettor (c) from a very coarse type of drip feed, and (d) using an ultra-sonic atomizer. Both engines were adjusted to give different intake and exhaust opening - and shutting-timing. The authors concluded that there was not much difference in the four major systems as regards the emissions. The most noticeable effect of an improvement in the mixture quality was to extend the weak limit. The fully vaporised mixture gave the lowest readings for hydrocarbon emissions at full throttle and half load, whereas carbon monoxide levels at a given air/fuel ratio were higher at full throttle. Increasing engine speed reduced both hydrocarbon and carbon monoxide emissions. Carbon monoxide levels also increased with a rise in the mixture temperature. Ignition timing seemed to have an effect due to the mixture quality and not due to the mixture strength. Residence time between air and fuel resulted mainly in mixture strength distribution range and increased nitrogen oxides emissions.

Haynes and Southall (134) confirm that simple engine maintenance reduced the carbon monoxide mass emission by 20 per cent and hydrocarbons by 10 per cent. The effect of idle mixture setting of the carburettors, depending on carburettor type, had a marked effect on the reduction of carbon monoxide. Hydrocarbons were affected to a lesser extend and were not clearly affected by carburettor type. In 1968, Werminghoff (135) considered the designing of the carburettor and concluded that all carburettors presently in use, perform adequately. For optimum matching, he suggested a close study of idling and part-load control, accelerating pump, mixture formation, and intake manifold. Minimum valve over-lap a compact combustion chamber, and lean carburettor setting, are some of the factors influencing the exhaust gas composition in conjunction with carburettor functioning. The demand for a lean air/fuel ratio setting for reduced emissions, cannot be met without providing satisfactory mixture distribution. This author has been able to achieve improved results providing a special configuration for mixture out-let in the venturi, the throttle valve, and inlet manifold.

To characterise the air-fuel mixture distribution quantitatively, Collins (136) used metallic sampling tubes probing into the inlet manifold at the branches of manifold supplying the individual cylinders of a 1475 cm^3 engine. The samples were collected and analysed to give information on the distribution. The air was uniformly distributed under wide open throttle conditions, while with the secondary choke throttle closed and the primary half-open, produced significant air maldistribution. Geometry of the inlet tract affected the distribution to individual cylinders to a great extent. Fuel was maldistributed under both half and full throttle conditions with the inner pair of cylinders receiving more than their 'share' of fuel. The maldistribution of unvaporised fuel flowing along the inlet manifold walls is the main reason for this maldistribution. Not all of the gasoline was found to vaporise. Under full throttle conditions, 81 per cent of the fuel was vaporised, while under other conditions only 69 per cent was found to evaporate. Heating of the air-fuel mixture is shown to reduce the maldistribution. To further the study of mixture distribution, Shinoda (137) showed theoretically that the behaviour of fuel in the transition region (between carburettor and cylinder) results from the fuel passage construction of the conventional type carburettor, and concluded that a uniform air/fuel ratio can never be supplied in the transition region without a main air-bleed system. Quantitative investigations were carried out to observe the effects of the main air-bleed system on fuel supplying characteristics at transition region on the actual parts. The results show a substantial improvement on fuel supply characteristics. Mills and Harrow (138) used a dielectric cell technique for continuous measurement of air/fuel ratio under transient conditions of engine operation, and showed that variations depended on several engine variables. Hansel (139) conducting studies on similar variables over a wide range of air/fuel ratios determined the combustion characteristics of the mixture. He concluded that the combustion variations lead to a general degradation of combustion processes at very lean air/fuel ratios which in turn, place limits on operating an engine very lean to achieve exhaust emission reductions.

Tanuma et al (140) conducted research on the effects of ignition and combustion of lean air-fuel mixture with respect to exhaust emissions. Misfiring and cycle-to-cycle combustion variation were both found to be serious obstacles to secure good engine performance, and low exhaust emissions by using extremely lean mixtures. Modifications in the ignition system and in combustion chamber, and increase in the mixture were studied with regard to their effects on the lean limit, the engine performance, and the exhaust emissions. It was found that the gap width and gap projection of a spark plug, and the spark energy, as well as mixture turbulence had a great effect on extending the lean limit and improving engine performance. A compact combustion chamber is found to favour the lean mixture operation. Smooth operation of the engine can be maintained even at retarded spark timing by applying the above-mentioned modifications and hot intake air injection. Consequently, exhaust emissions, including hydrocarbons and oxides of nitrogen, can be substantially reduced. A single cylinder engine operating at constant speed, using gasoline as fuel, was studied by Lee (141) for the effects of compression ratio, mixture strength, spark timing, and coolant temperature upon exhaust emissions and power under part throttle conditions. Of these variables, mixture strength and spark timing had the largest effect upon exhaust emissions, followed by coolant temperature, with compression ratio having minor effects. Spark timing followed by compression ratio had the greatest effect on power, and increased fuel comsumption. Control of exhaust pollution by using a mixture optimizer has been reported by Schweitzer

(142) to give good results. In combination with certain engine modifications, this optimizer has enabled a spark ignition engine to accept air-fuel mixture as lean as 22-23:1, without impairment of drivability, and reduced the exhaust pollutants to a very low level. The mixture optimizer studied was a feed-back type of electronic control device, which automatically selected for a carburettor or fuel injection system, the air/fuel ratio that yielded the minimum fuel consumption for any given power out-put. For all driving conditions, other than idling or coasting, the minimum fuel consumption occured at mixture ratios close to the border line misfiring limit. Therefore, the mixture optimizer by seeking such mixture ratios tended to reduce all pollutants. It also helped drivability by discouraging engine stalling.

Last year, Bond (143) reported some design parameters and development experience on a quick-heat intake manifold for evaporation of the fuel. This resulted in the achievement of good fuel evaporation soon after cold start. Used in conjunction with a fast-opening choke, this kind of manifold helped in reducing carbon monoxide emissions. This system was found to be more suitable for cars already fitted with catalytic convertors, since during cold enrichment carbon monoxide is produced at a time when the catalyst is not yet hot and effective.

Brandstetter and Carr (144) produced results of their research early this year, suggesting that to lower emissions from a multicylinder engine, the air/fuel ratio must be optimized in all cylinders. If uniform distribution is achieved then the cylinder-to-cylinder air distribution is of particular interest. A probe system was developed to measure mass flow rates to individual cylinders during operation of an engine. Fast response measurements of pressure, temperature, and low velocity were made in the intake ports near the inlet valve during the intake stroke. Collection of high speed data was accomplished through on-line use of an IBM-1800 computer. A

V.8455 CID (7457 cm^3) engine with standard intake and single exhaust system was used in the initial application of the mass flow probe. Measurements of 30-40 individual cycles were combined to calculate the mean volumetric efficiency for each cylinder. When the measurements for all the cylinders had been made, the cylinder-to-cylinder distributions were computed as deviations from the overall averages. Variations of 8 per cent were typical during motored operation, with some cylinders deviated by as much as ± 12 per cent. Fired operation produced variations greater than ±15 per cent. No characteristic distribution was found to be extended throughout the speed and load range tested. Typical cycle-to-cycle variations in the columetric efficiency for individual cylinders was found to be ±8 per cent.

Additives

Extensive studies are being made in recent years on the effects of various additives on exhaust emissions. One of such studies has been made by Mixen et al (145) who worked on the effects of additives in engine oil, in gasoline, and injected directly into the exhaust gas on exhaust emissions. Substantial reduction of hydrocarbons and carbon monoxide are reported. These reductions were obtained only when peroxides were injected in the presence of secondary air, into the exhaust gas ports. This seemed to promote extra oxidation of combustibles in the exhaust gas. Fuel additives were evaluated for favourably modifying combustion kinetics, and for reducing hydrocarbons emission related to combustion chamber deposits and quench volume, although no substantial effects were noticed. Engine oil additive types and concentrations also did not show anticipated effects, such as the reduction of hydrocarbons emission by control of combustion chamber deposits. Dable and Sheahan (146) also presented a paper

'The Contribution of Additives to the Elimination of Air Pollution'. This paper discussed the cleanliness of carburettors and their effect on exhaust emission. The deposits created inside the carburettor, under accelerated conditions during 1700 miles of urban driving, resulted in an average increase of 175 per cent in carbon monoxide at idle of two of the experimental cars. A series of laboratory and road tests proved that carburettor deposits deteriorate the engine operation and increase the pollutant emissions. These authors used polymeric detergent dispersants which are shown to be superior carburettor cleansing agents in keeping the carburettor clean and in reducing the exhaust emission by producing intended air/fuel ratios. Zimmerman et al (147) considered the effects of maldistribution on emission levels and also dealt with various approaches made to improve the fuel distribution. They emphasised that the lowering of surface tension of the fuel produces small and more entrainable fuel droplets from a carburettor jet. The formation of liquid fuel film, due to the impingement of fuel droplets on the manifold wall, is considered with regard to surface energy and contact angle of fuel droplets. Accordingly, gasoline will wet a metal or metal oxide surface to a much larger extent, as compared to a surface having sufficiently low surface energy. In the case of a surface with low energy, the droplets will stick on the surface separately instead of running along as a film. The contact angle of droplets will significantly enhance their tendency for entrainment into the incoming mixture stream. It is shown that the potential for droplet entrainment increases with increasing contact angle. The low energy surface condition can be produced either by pre-coating the inlet system with proper material e.g. Teflon, or with gasoline additives. The lowering of the surface tension of gasoline results in lowering of the surface energy. Various additives have been experimented with to produce this effect. One additive -HTA was found to be most successful, and a series of laboratory and road tests have shown marked reduction in hydrocarbons emission. It is concluded that this could be due to both the better mixture distribution, and cleansing of carburettors because of the detergent effect of the additives. A similar investigation was undertaken by Doelling et al (148) to determine the effect of gasoline additives on hydrocarbon emissions. Of a multitude of compounds studied, two were found to reduce the hydrocarbons emissions. These additives, by cleaning the lead-derived combustion chamber deposits, lowered the emissions by approximately 50 per cent. A practical combination of these compounds was evaluated in a fleet test which confirmed the laboratory engine results. Studies were also conducted in laboratory engines and fleet vehicles to determine the effect of fuel lead level upon the effectiveness of these additives, and the activity of the additive upon established lead-derived chamber deposits. Results obtained from these programmes indicated that the additive would function with fuel lead levels from ½ - 3 gms/gal., but that it was not capable of modifying established chamber deposits. Research conducted by Retzloff (149) indicates that the deposits which accumulate in the critical areas of the carburettor can adversely affect the design metering characteristics. Since this can cause an increase in vehicle exhaust emissions, it is important that these deposits be minimized. Fuel additives are shown to provide an effective means of cleansing carburettors and keeping them clean. Thirteen commercial and experimental additives of various chemical composition were screened in laboratory engine tests, and four of these were selected for further evaluation in vehicles operated in consumer type service. Detergent action of these additives resulted in reduced carburettor deposits, reduced exhaust emissions, and improved fuel economy. In most cases there was an additive concentration effect, in which effectiveness increased with increased concentration.

Franklin et al (150) developed a laboratory engine test procedure which measures the effect of gasoline additives on engine deposits and the resultant effect of these additives on exhaust emissions. These tests were carried out under the Department of Health, Education, and Welfare's 50,000 miles durability driving schedule. Several gasoline additives have been evaluated with varying effects on exhaust emissions. A strong dependence on base fuel composition was noticed.

2:4

APPROACH MADE UNDER PRESENT PROJECT

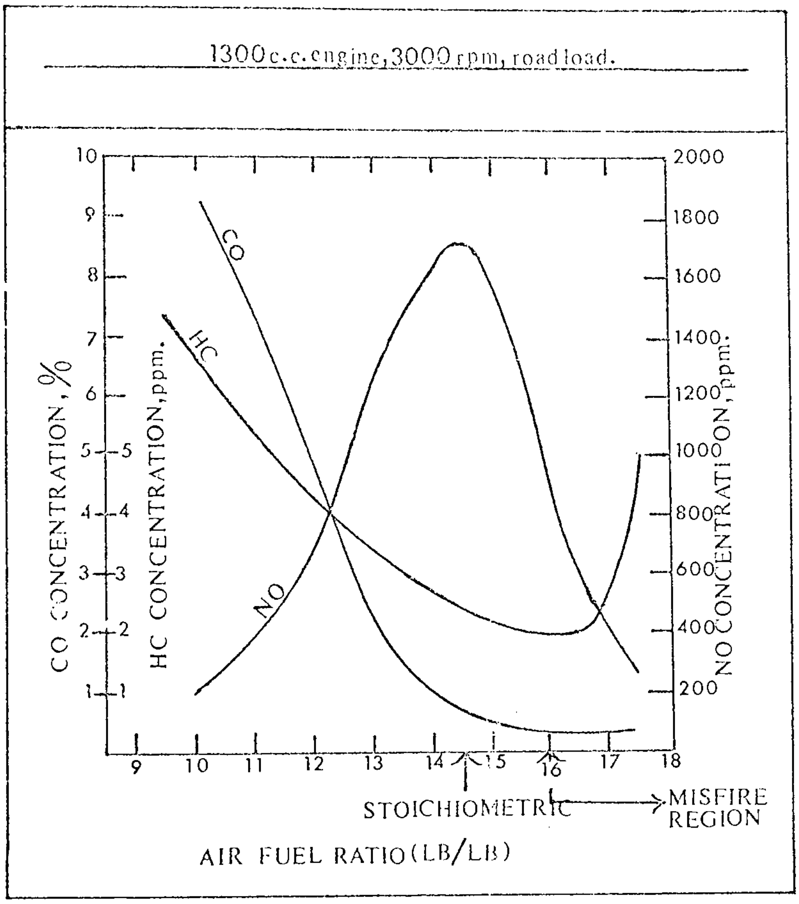


Fig.2:12 Effect of Air/Fuel ratio on Exhaust emissions

Fig. 2:12 shows the influence of air/fuel ratios on the concentrations of the most improtant pollutants emitted from a motor vehicle. This figure has been compiled from data obtained in Esso Research Centre, Abingdon, Berkshire and is in accordance with the results obtained by other workers (151). The present project is concerned only with the emissions of hydrocarbons and carbon monoxide. These emissions are significantly reduced as the air/fuel mixture ratio is increased. It should be noticed that operation of an engine over the range of air/fuel ratios between 14.5:1 to 16:1 (misfire region) will produce minimum amounts of these pollutants.

Unfortunately, merely increasing the air/fuel ratio is not the solution to this problem. The increase of air/fuel ratio is accompanied by a power loss and unsteady engine operation. This is attributed to the maldistribution of air-fuel mixture. As stated previously, the cylinder-to-cylinder maldistribution of the air-fuel mixture results in a number of undesirable operational difficulties. The ideal solution would be to provide each cylinder with the exact amount of air-fuel mixture to obtain consistent and complete combustion. In practice it is impossible to achieve these conditions. One major reason for maldistribution is the non-homogeneity of the air-fuel mixture and its manifolding. Attempts have been made in the past to obtain a homogeneous air-fuel mixture by either evaporating the fuel inside the inlet manifold, or using mechanical devices for atomisation. In the first case, the engine experienced a loss in volumetric efficiency due to expanded charge, which resulted in reduced engine power out-put. In addition the knocking tendencies of the fuel are enhanced. The mechanical devices for atomisation involved highly sophisticated and precise engineering design of the systems. This resulted in prohibitive increase in vehicle prices so that the benefit of such devices is not fully justified by the social benefits achieved.

During the present work, the simple method of adding surface active agents to the fuel was studied. This approach has two basic advantages in reducing the exhaust emissions. First, by reducing the surface tension of the fuel, it increases the chances of atomisation. The treated droplets would be smaller as compared to the untreated fuel. A decrease in the fuel droplet size then enables the incoming air stream to carry and retain the fuel more readily, till the mixture enters the cylinders. The smaller droplets will also increase the surface area which will help in a desirable degree of fuel evaporation, producing a more homogeneous mixture. The second advantage of this approach is the reduction of maldistribution. The turbulence characteristics of the mixture stream, due to manifold designing, will be able to distribute the small droplets more evenly in the air stream. Mixture stream, retaining the major portion of fuel in this form, will reduce the chances of fuel film formation along the manifold walls - the major factor producing the maldistribution in the engine.

By achieving the necessary conditions of air-fuel mixture formation i.e. atomisation and reduction of maldistribution, this approach will help to allow increased air/fuel ratios towards leaner limits requisite for lower emissions. In addition, this method will not require any fundamental changes in the conventional engine design and should produce the desired results with minimum possible cost.

Chapter 3

EXPERIMENTAL

3:1

ENGINE :-

An M.G.B. 1800c.c. engine was used for the present work. This particular engine was selected to allow comparison, because a racing engine tends to pollute more than the ordinary road vehicle engine. It also had a pre-built-in pollution control system. The work on such an engine could thus provide improvement over existing control systems. Plate 1 shows this engine mounted on the rig.

In this engine the pollutants can be oxidised inside the exhaust system by means of additional air introduced into every cylinder's exhaust port. The air is delivered under pressure, from an air pump. A check valve is connected between the pump and the air supply line to prevent the blow-back from high pressure exhaust gases. The air is also fed into the inlet manifold through a gulp valve from the same pump. This provides the additional air needed during deceleration and engine run-over. Further specifications of this engine are given below:-

Model M.G.B.

Engine	Twin Carburettor
Type	18C (American export)
Firing order	1, 3, 4,2
Capacity	1798 c.c. (109.8 cu.in.)
Compression Ratio	8.8:1
Compression Pressure	160 lbs./sq.in (11.25 kg/cm^2)
Stroboscopic ignition timing	20^0 BTDC at 1,000 r.p.m.
Static Ignition timing	10^0 BTDC
Vacuum advance starts	5 in. Hg.
Finishes	13 in. Hg
Total crankshaft degrees	20^0 ± 2

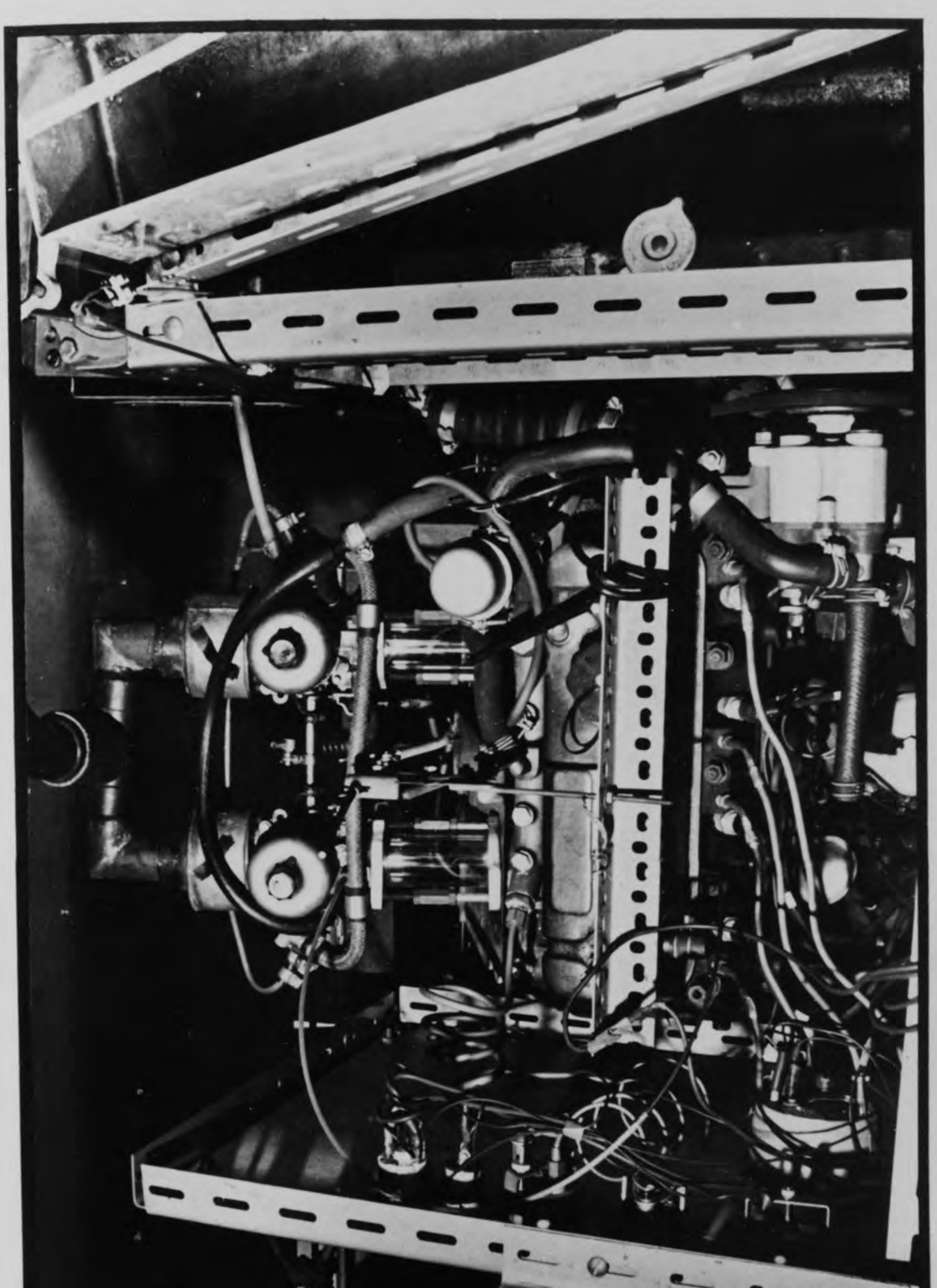


Plate 1. M.G.B. 1800 Engine mounted on the rig.

Gear Box :-

Overall gear ratios

Top Gear ratio	1.000 x 3.909 = 3.909:1
3rd Gear Ratio	1.3817 x 3.909 = 5.4010:1
2nd Gear Ratio	2.1667 x 3.909 = 8.4646:1
1st Gear Ratio	3.4440 x 3.909 = 13.4642:1
M.P.H. per 1,000 r.p.m. in top gear	= 17.9

3:2

DYNAMOMETER :-

A Heenan and Froude, Model DPX2, dynamometer is used to measure the torque, and load, and to absorb the energy created by the engine.

The dynamometer is built with a main shaft which is carried by the bearing fixed inside the casing. The casing in turn is carried by anti-friction trunnions which enable the casing to swivel about the same axis as the main shaft. The main shaft is fitted with a rotor. In each face of this rotor, semi-elliptical cross-section pockets are built. These pockets are separated from each other by means of oblique vanes. The internal vanes of the casing are also divided in the same way.

The engine is directly connected to the main shaft. When revolving, the rotor discharges water at high speed from its periphery into the space formed in the casing. The water is then passed into the rotor at a slower speed, near the same shaft. Thus the pockets in the rotor and casing together form elliptical receptacles around which the water courses at high speed, creating vortices which absorb the energy from the engine as soon as it is produced. These high speed vortices also provide the resistance to the rotation of the main shaft. This results in the absorption of the horse power which is measured as roughly $(\text{rev./min.})^3$. Since every force resisting the rotation of the dynamometer shaft assembly is transmitted to the casing, the casing tends to revolve on its own anti-friction roller support. The revolutions of the casing are counteracted by means of a lever arm terminating in a weighing device which indicates directly the torque produced.

The dynamometer is also used to control the load by introducing adjustable sluice gates between the semi-elliptical pockets. These sluice gates can be controlled from the outside by a single hand wheel, thus regulating the amount of water circulating and therefore, the power absorbed. The amount of the power is calculated using the formula :

$$BHP = \frac{WN}{K}$$

where W = load indicated weighing device

N = dynamometer shaft speed (rev./min.)

K = a constant (4500 in present case)

<u>Water Supply</u> :- As the power generated is absorbed in producing heat, it is essential to have enough water flowing through the dynamometer to absorb all the heat produced. Destruction of one brake horse power produces 2545 B.T.U. An outlet temperature (from dynamometer), below 140°F, is maintained by passing 2.85 gallons of water per brake horse power per hour. This amount is recommended if the water is coming from a cooler at about 95°F. The amount of water varies in accordance with the inlet temperature. The manufacturers also recommend a minimum pressure between 15-25 pounds per square inch for dynamometer's revolutions up to 4500 .

During this work, a Heenan-Marley aqua tower-model 4413 was used to produce the desired temperature for the amount of water required. The water from the aqua tower is pumped into the dynamometer using a Beresford, Type B.30, 1.5 B.H.P., self-priming centrifugal pump at required pressure. The water coming out of the dynamometer is collected in a storage tank. The water from the storage tank is pumped back on to the aqua tower through another Beresford pump with the same specification. A 1 inch diameter water pipe line was used throughout this system.

3:3

HYDROCARBON AND CARBON MONOXIDE MEASUREMENTS :-

Two separate Hilger and Watts, type SC/F Mark II, infra-red gas analyses were used to measure the concentrations of hydrocarbons (HC) and carbon monoxide (CO). The analysers are adjusted to analyse the hydrocarbons as N-hexane as parts per million (ppm) and carbon monoxide as per cent (%). These analysers are shown in Plate 2.

Both these analysers work on the principle of thermal radiation (infra-red) absorption. As it is known that the thermal radiation absorbed by a certain gas corresponds to its electronic and molecular configuration it is possible to measure the extent of radiation absorption. The amount of infra-red radiation absorbed is a characteristic of that particular gas. This extent of characteristic absorption of infra-red radiation is used to indicate the concentrations of the passing gases.

The basic lay-out of the analyser is shown in Fig. 3:1. The

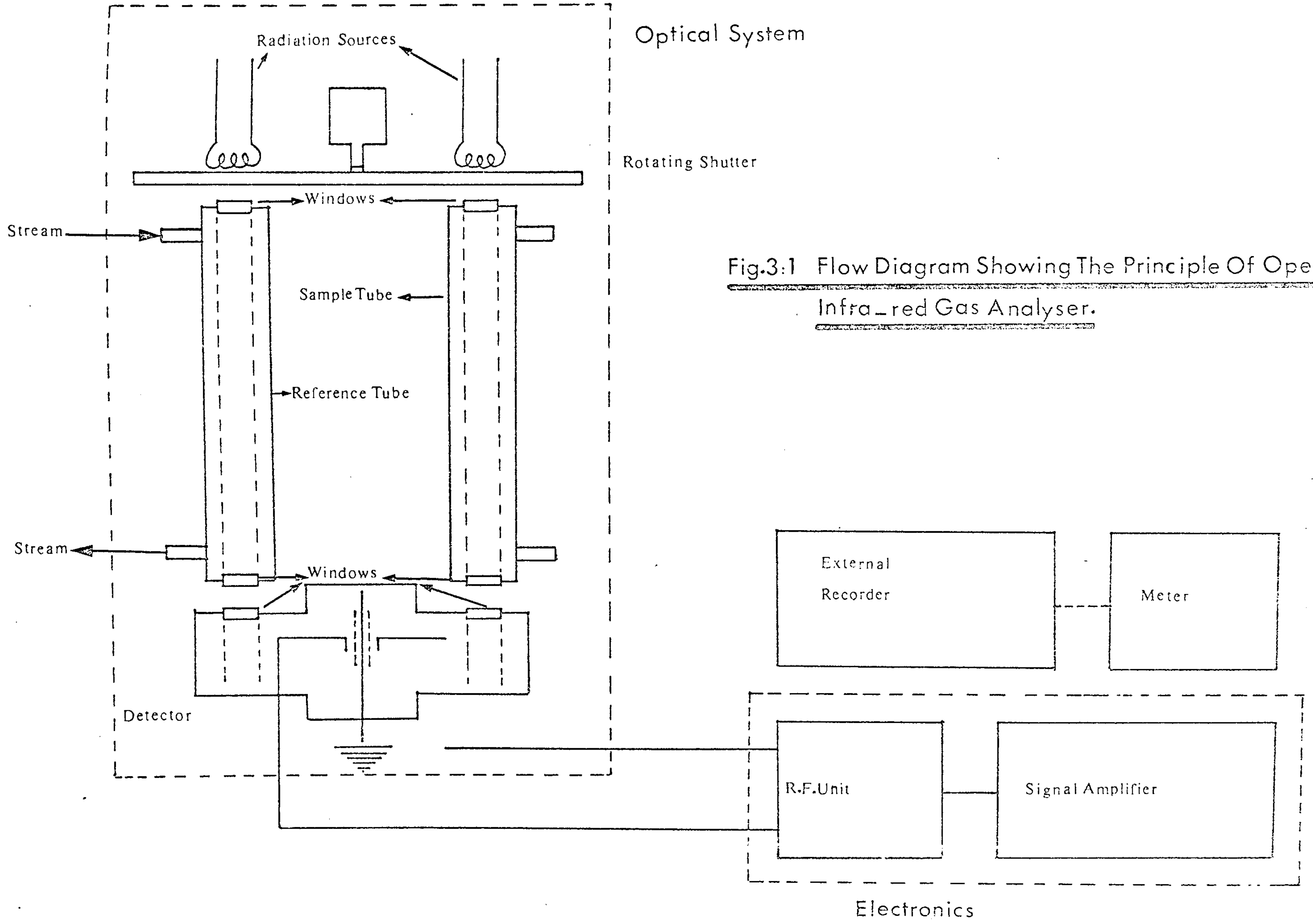


Fig.3:1 Flow Diagram Showing The Principle Of Operation Of Infra_red Gas Analyser.

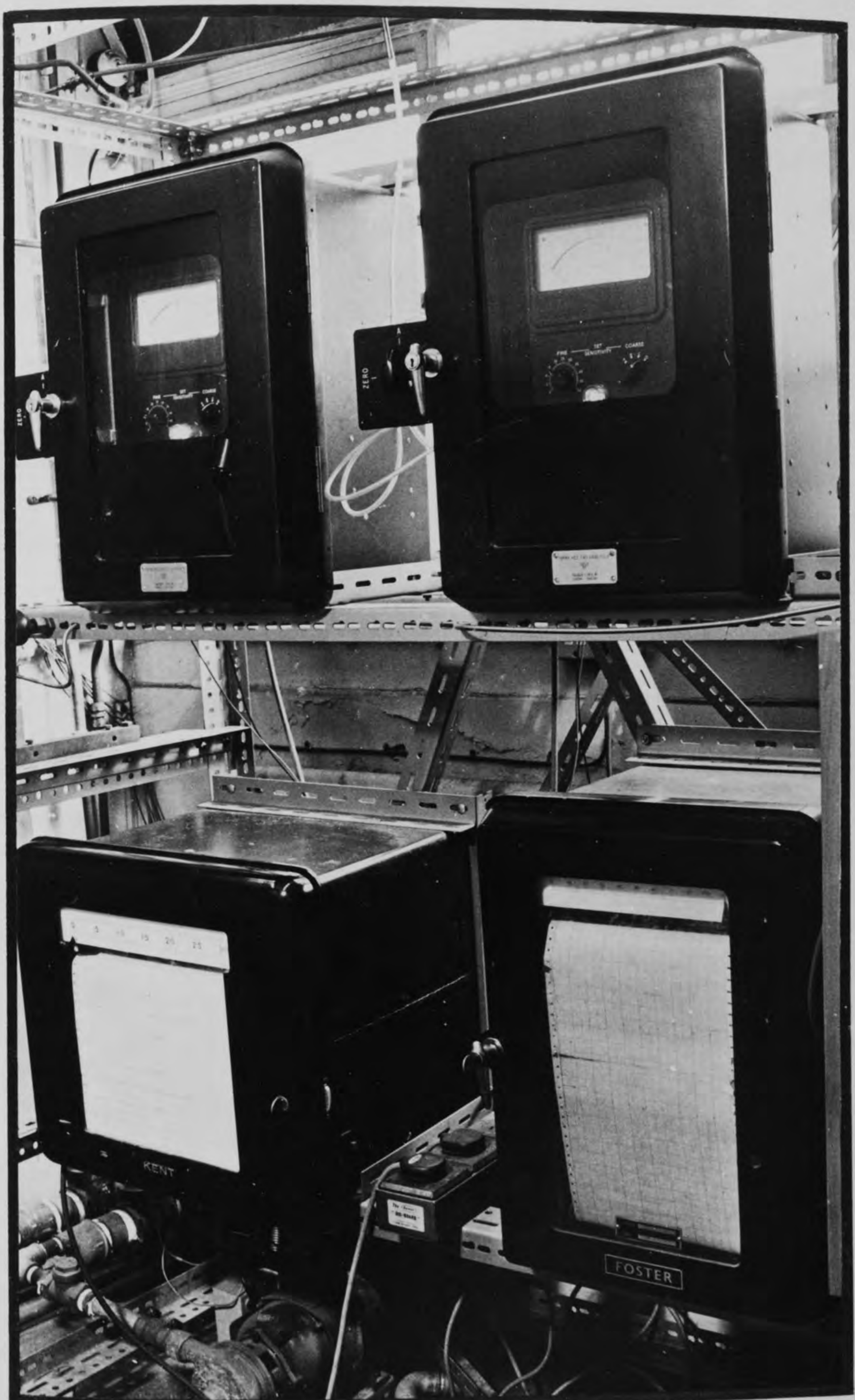


Plate 2. Infra-red analysers with Foster and Kent recorders.

infra-red radiation is produced in a radiation unit, by using a set of two equi-resistant filaments to produce exactly the same amount of radiation. This radiation passes through a rotating shutter into two similar sampling tubes. One tube is used as a reference tube which contains zero setting gas (nitrogen in the present case), and the other tube is used for the measurement of the unknown gas concentrations. At the bottom end of these tubes is a detector unit which constitutes two similar chambers separated by a diaphragm used as a common wall. Both these chambers are filled with a sample of the gas to be measured (exhaust gas).

The infra-red radiation passing through the tubes containing sample and zero gas will be absorbed as different amounts of thermal energy. This differential absorption of thermal energy will result in differential expansion of the gas samples contained in the detector unit. This will result in the movement of the separating diaphragm. It is the movement of the separating diaphragm which is measured and used to give the concentrations of gases. The expansion of the gas and therefore the movement of the diaphragm is a slow process. To produce a measurable frequency of vibration it is necessary to enhance the rate of diaphragm pulsation. Hence the rotating shutter is introduced at the top of the analysis tubes. This shutter, while rotating at a specific speed, produces a chopping effect on the radiation beam. This results in the pulsation of the diaphragm in step with the chopping rate. The amplitude of this pulsation is proportional to the concentration of the sample gas.

The signal obtained from the pulsation of the diaphragm is fed into a radio frequency unit (R.F. Bridge). The change of impedence is produced by the pulsating diaphragm and the resulting voltage output is amplified and rectified in the signal amplifier unit and shown on the meter as the gas concentration.

Standardization of the analysers :- Nitrogen was used as the zero setting gas. The gas was passed through both analysers at a rate ½ litre/minute. The analyser was left in this condition for approximately one hour to warm up. The zero on both instruments was adjusted by using the zero control knobs.

A standard gas mixture, with the following composition, was used to standardize the analyser :

N-hexane	=	0.94%
Carbon monoxide	=	6.7%
Nitrogen	=	Remainder

Nitrogen supply was replaced by standard gas. The readings given by the meters were compared against the actual concentrations and the pointer adjusted to the right values using Fine and Coarse gain controls.

3:4

TEMPERATURE MEASUREMENTS :-

The temperature was measured at the following points of the experimental rig. :

1. Every cylinder's exhaust port holes.
   (individual cylinder exhaust temperatures).
2. Junction of silencer and the exhaust manifold (mixed exhaust temperature)

3. Water inlet and outlet temperatures.
4. Sump oil temperatures.

Eight Chromel-Alumel thermocouples were used at respective. points, to give the desired measurements. The thermocouples were sheathed with a stainless steel jacket. The temperature was recorded in mv., by a 16 point Kent recorder. The points of each thermocouple were duplicated inside the recorder, to give a double check on the readings. Both thermocouples and recorder were standardised by using a potentiometer.

3:5

FUEL AND AIR FLOW RATE MEASUREMENTS :-

FUEL : The fuel coming from the petrol storage tank was collected in a graduated Q.V.F. cylinder. The cylinder was directly connected to the fuel supply of the carburettors. The fuel flow rate was measured as the time taken by a known volume of the fuel to flow.

AIR : An Alcock Viscous Flow Air Meter was used to measure the air flow rate. The metre is shown in Fig. 3:2

The air is passed through a venturi, constructed inside the meter body, to produce a pressure differential. This pressure differential is measured by an inclined manometer filled with blended paraffin of specific gravity 0.787. The differential pressure given by the manometer is then jultiplied by a meter constant to give the air flow. Appendix 1:A gives an example of a model calculation for such measurements.

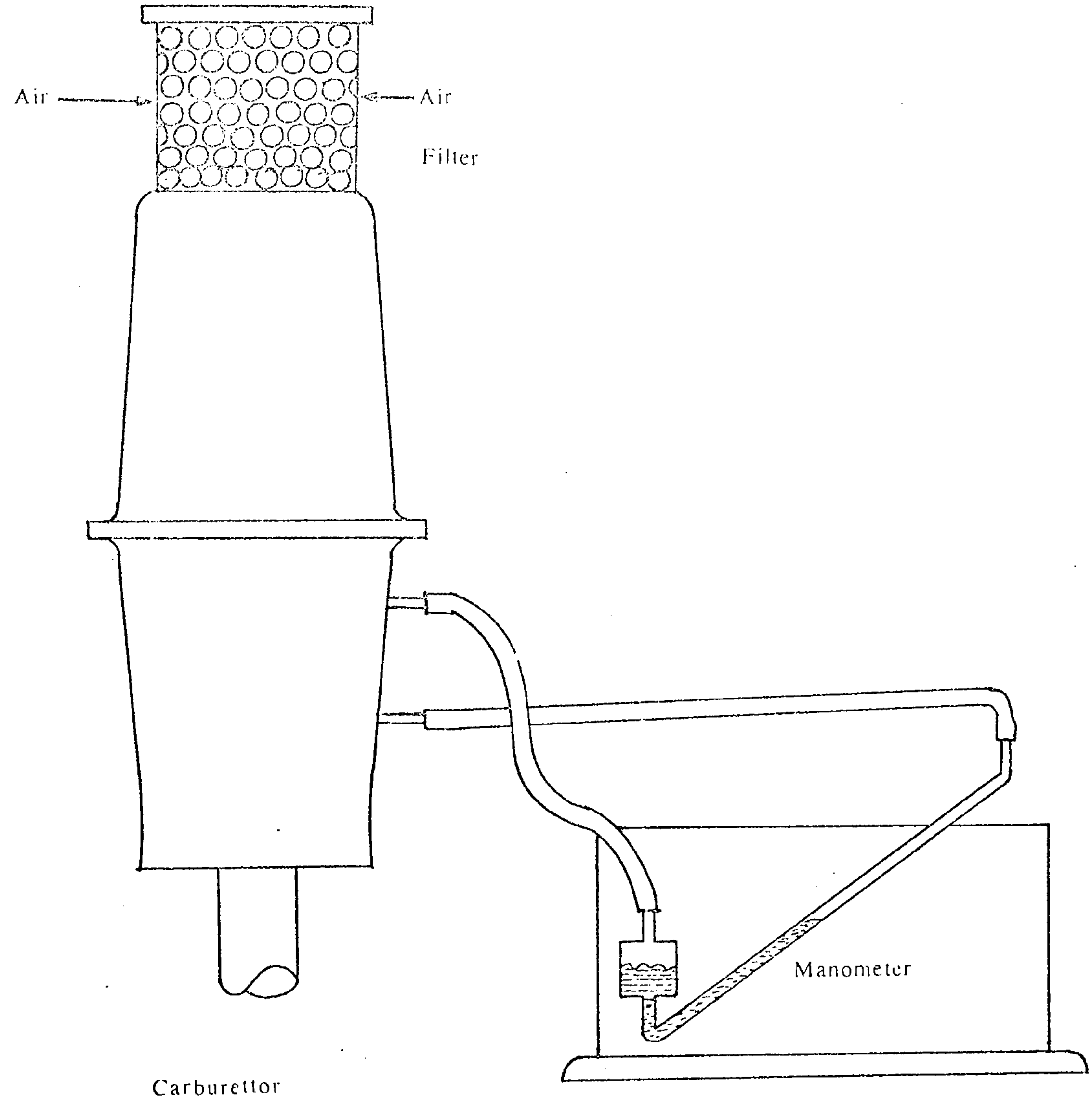


Fig 3:2 Alcock Viscous Flow Air Meter

3:6

THE EQUIPMENT LAY-OUT

The flow diagram of the equipment lay-out is given in Fig. 3:3 and this arrangement is also shown in Plate 3. The engine was mounted on a cast-iron framework bolted to the ground over a shock-absorbing padding to avoid vibrations. The radiator was erected in front of the engine on a dixion frame. The air for cooling the radiator water and the engine was provided by an 18" fan mounted on the open-air side of the wall. This air also served for ventilation purposes. The crankshaft of the engine was directly connected to the chassis dynamometer through a double-jointed cardan shaft shown in Plate 4.

The analysers were mounted on a separate dixion framework. The samples of exhaust gas were drawn through a $\frac{1}{4}$" stainless steel tube. The exhaust gas was passed through a particulate filter, packed with soda lime before entering the analyser. This filter acted as a dessicant and a carbon dioxide absorber. The exhaust gas was sucked through the sample line and the analyser by a vacuum pump at the end of the sampling line. The exhaust was then passed through an alkaline solution before going to the atmosphere. The flow rate of the gas was measured by rotameters before entering each analyser.

To observe the visual effects on the flow patterns, two $1\frac{1}{2}$" diameter pyrex glass tubes were clamped between the carburettors and the inlet manifold. These tubes were held in place with air-tight packing by four flanges. This arrangement is shown in Fig. 3:4 and Plate 5.

The visual observations were recorded using a Beulieu, high-speed movie camera. Various backgrounds and lighting arrangements were tried

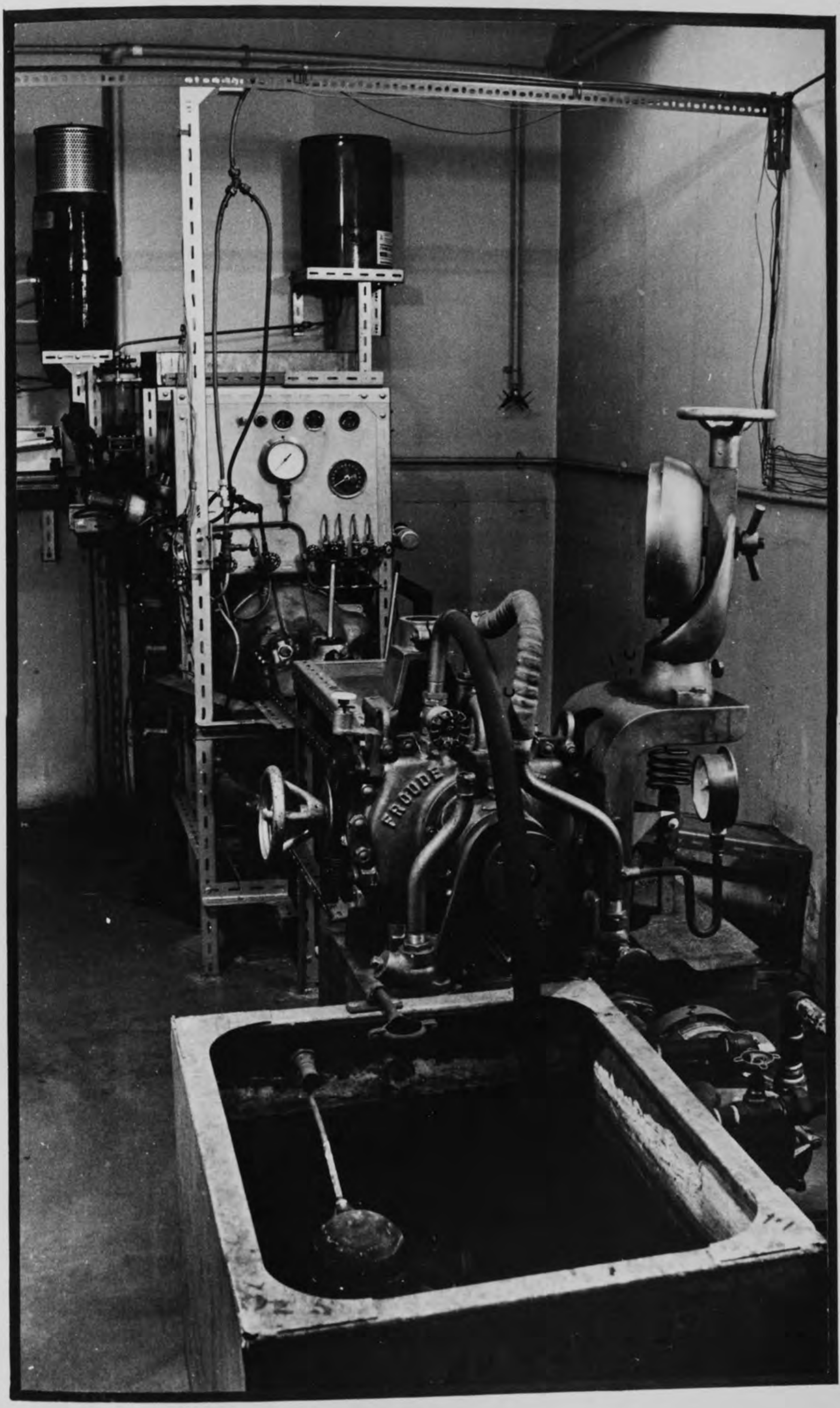


Plate 3. Equipment lay-out.

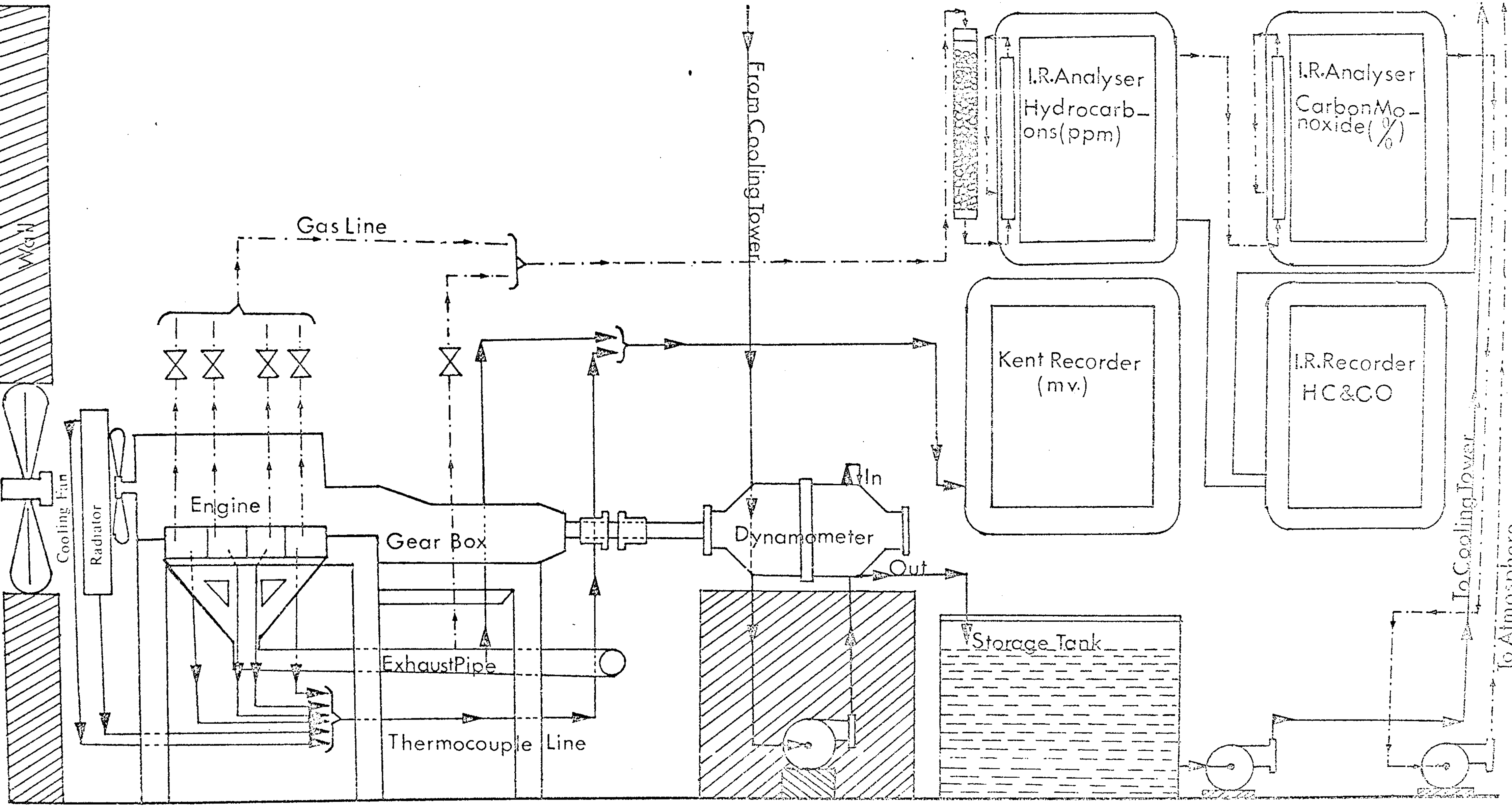


Fig 3:3 Diagrammatic Lay-out Of The Equipment

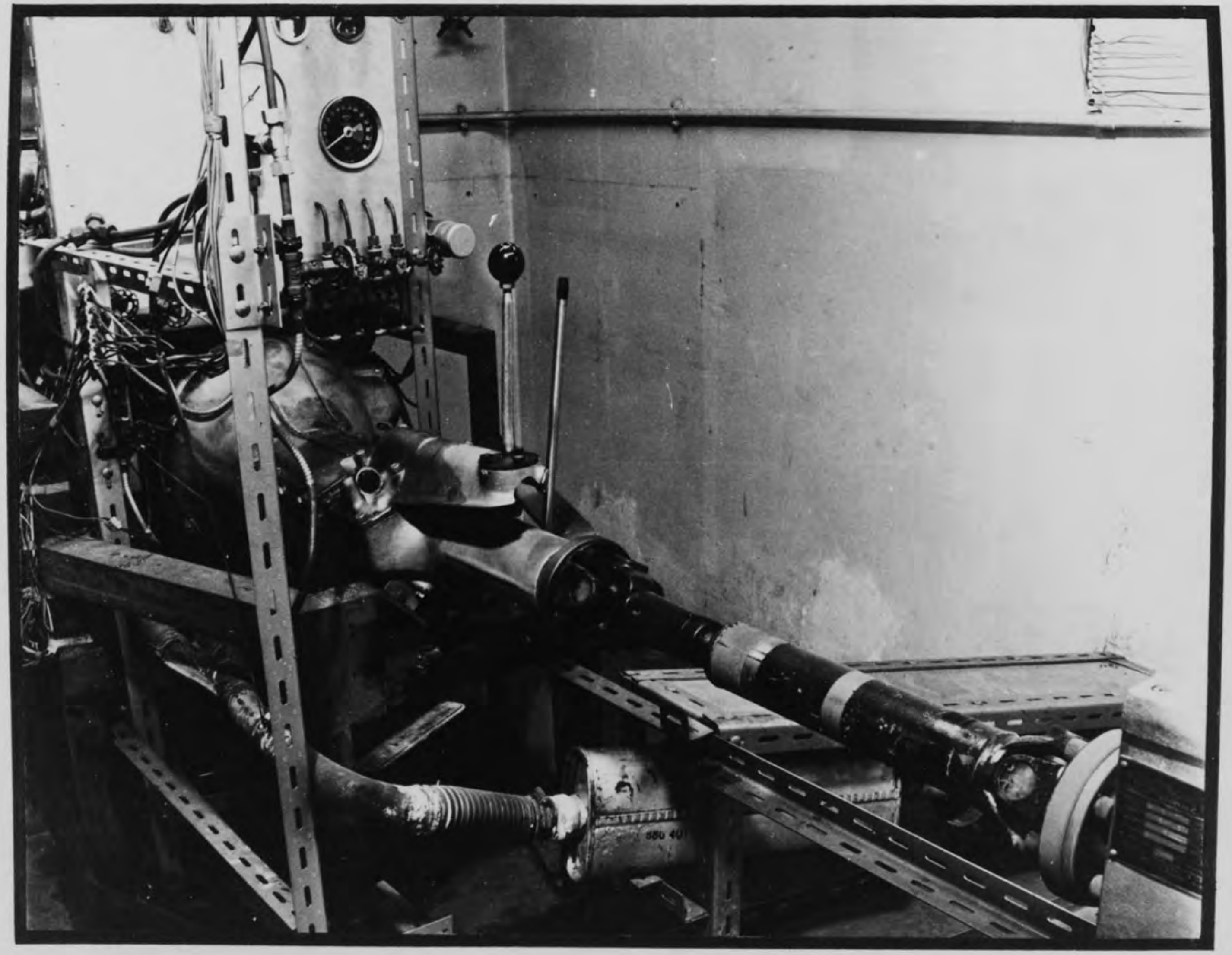


Plate 4. Cardan shaft connecting Engine's crank-shaft and Dynamometer's main-shaft.

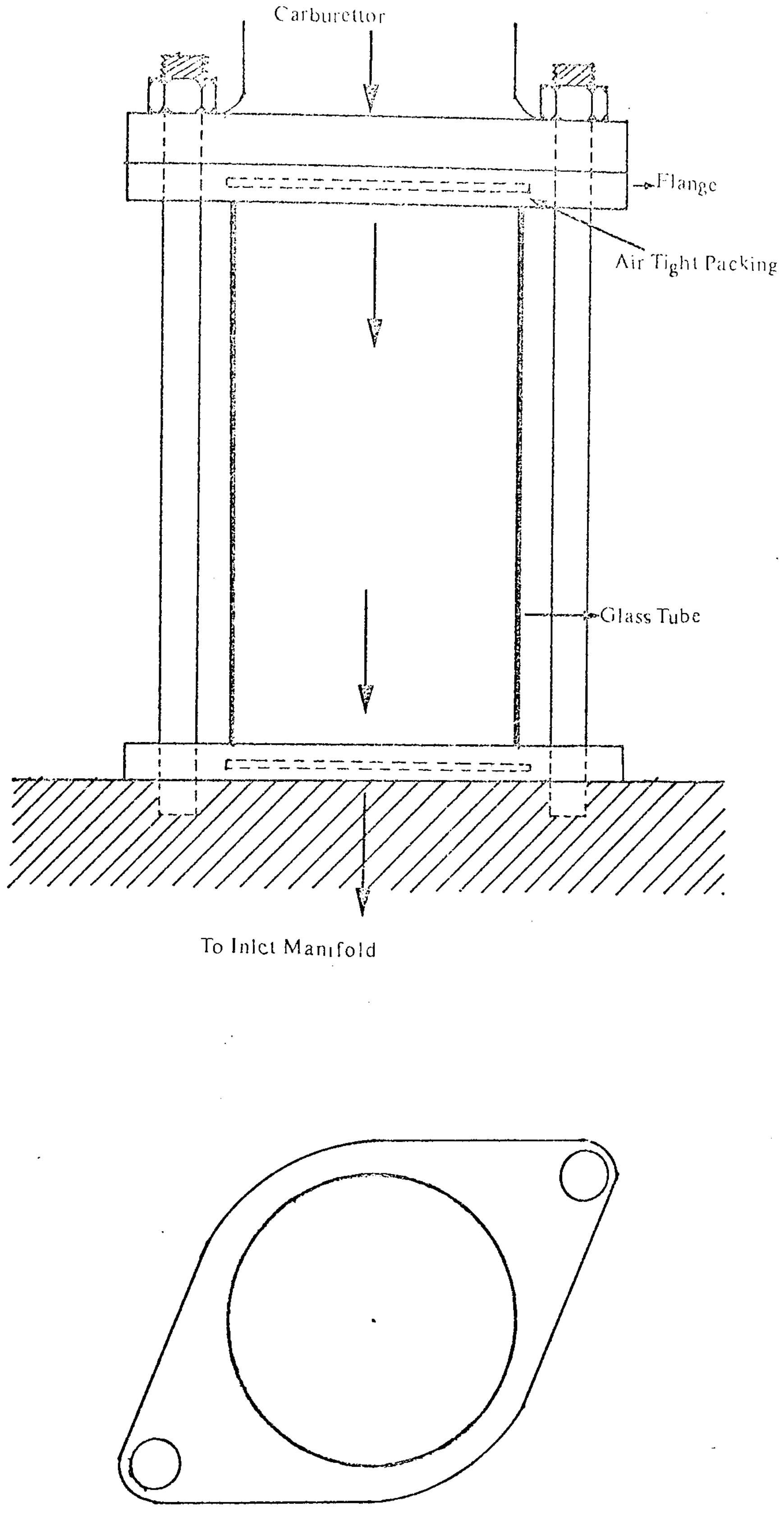


Fig 3:4 Visual Observation Assembly

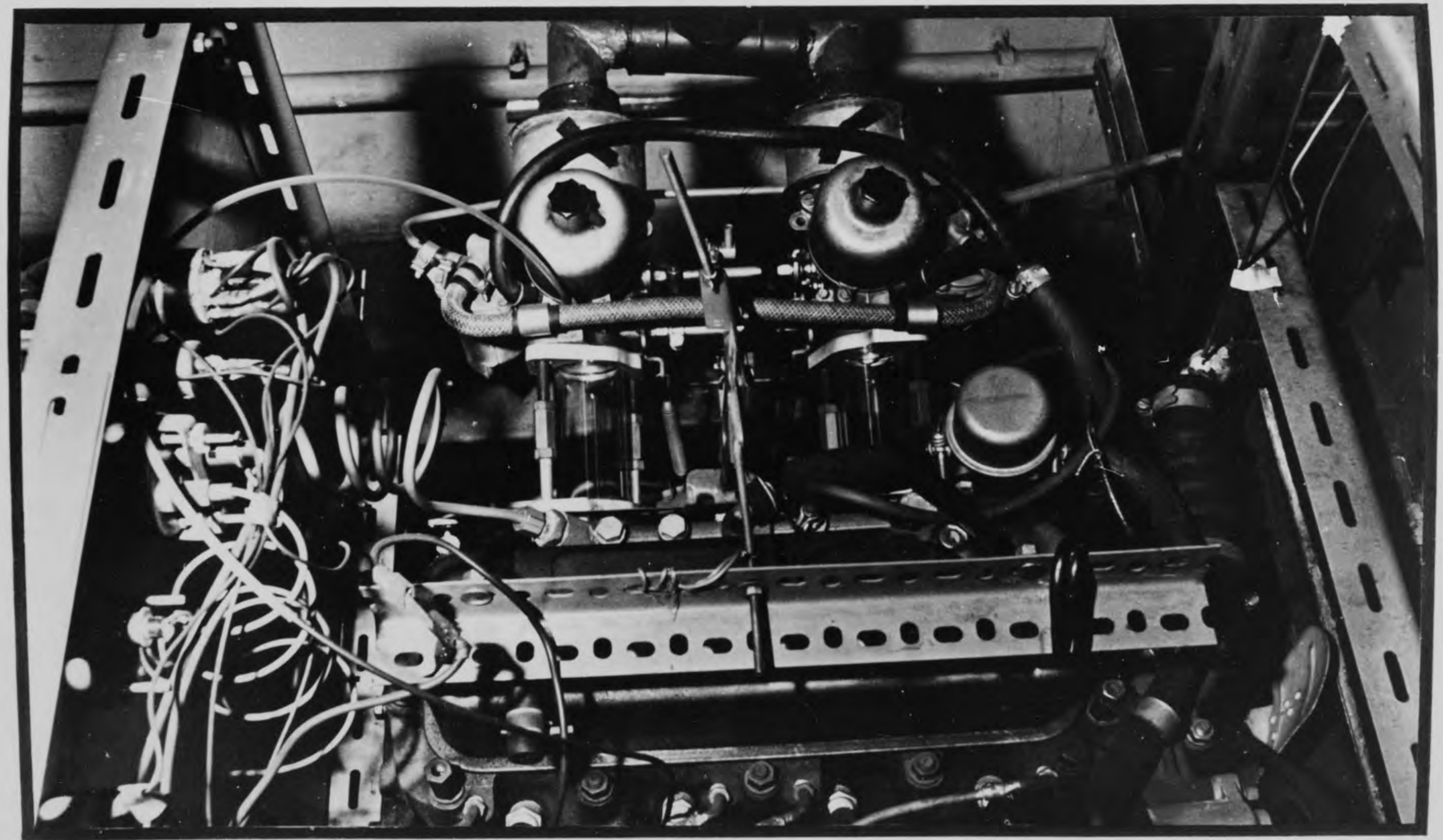


Plate 5. Visual observation assembly showing carburettors and glass tubes.

to give the best high-speed films (64 frames/sec.) Best results were obtained with a white background with the light being reflected on to the tube. The films were made with the camera at the top. Kodak Tri-X Reversal, Type 7278, 16 mm films were used throughout.

3:7

EXPERIMENTAL PROCEDURE :-

All the tests were carried out under the normal room conditions of temperature, pressure and humidity. The slight variation of these factors was considered to be too small to affect the results.

Engine was started and let to run for a fixed period ($\frac{3}{4}$ - 1 hour) to warm up. Afterwards the engine was run at a known speed (between 1,000 - 3,500 R.P.M.). The load was adjusted for every different speed and was kept fixed throughout the following tests. The speed of the engine was varied at 500 R.P.M. intervals e.g. 1,000 - 1,500 - 2,000 R.P.M. and so on. This procedure was repeated for all four gears with corresponding different loads. Appendix 1:B gives the list of various fixed loads applied during these experiments.

The exhaust gas was passed through the analysers at a rate of 0.8 litre/min. The samples from individual cylinders or mixed exhaust were separated by using corresponding valves in the gas sampling line.

Two different fuels with different specifications were used. Main work was carried out using delivery pump quality commercial gasoline (Esso Plus). Then the most significant tests were repeated using Reference gasoline provided by Esso Research Centre, Abingdon, Berkshire. The specifications of the fuel is given in Appendix 1:C.

The list of additives is given in Appendix 1:D. All these additives were provided by Esso Research Centre. The various quantities of these additives were blended with the fuel and the test procedure, as stated above, repeated.

The visual effects of the additives on flow patterns was cine photographed for every stage through the tests performed.

Chapter 4

RESULTS

4.1

REPRESENTATION OF RESULTS

The results obtained from the experimental work performed with both types of fuel i.e. Esso Plus and Reference Gasoline, are divided into three main sections. Section 'A' contains the results as obtained during the work conducted with Esso Plus (Fig. 4:1 - 4:68), while Section'B' those with Reference Gasoline (Fig. 4:69 - 4:86). Section 'C' contains results showing the influence of air/fuel ratios and calculated percentage reduction or increase in pollutants for the best quantities of various additives used (Fig. 4:87 - 4:104). All these sections, except Fig. 4:87 and Fig. 4:88 in Section 'C', are further divided into two sub-sections, each representing the quantities of hydrocarbons and carbon monoxide emitted. Corresponding tables for all the profiles are given in Appendix 1:E.

The profiles contained in the first two sections represent the concentrations of either of these pollutants related to engine speed - varying between 1000 - 3500 RPM. Each graph is divided into four sections giving the comparative studies of four-gear driving modes of the engine in terms of pollutant concentrations, engine speed, and the load applied throughout these experiments (Appendix 1:C). Hydrocarbon concentrations are represented as parts per million (ppm) and carbon monoxide as per cent of the total exhaust volume.

The first profiles starting Section A:1 (Fig.4:1) and Section A:2 (Fig.4:35) give the concentration of hydrocarbons and carbon monoxide respectively. These graphs show the concentration of the respective pollutants from all four cylinders and from the mixed exhaust. To simplify and represent the results in a more comprehensive and comparative form, the rest of the profiles give the concentrations of pollutants only from mixed exhaust, best cylinder, worst cylinder, with an average concentration value for all four cylinders. The 'best' and 'worst' cylinders are selected by the hydrocarbon concentrations as these emissions are more active during smog formation. Corresponding concentrations for carbon monoxide are expressed for the same selected cylinders.

The first two profiles of each sub-section give the results as obtained during the experiments performed with respective fuels without any additives. These results are taken as the maximum limits of pollutants emitted and subsequent reductions or increases in concentrations are presented in comparison with these values. The rest of the sub-section, in the case of Section 'A', is divided into five sets of graphs. The first four sets consist of seven profiles, each representing the results from the experiments conducted with various additives used. First three of these seven graphs give a study of results recorded during the work with respective additive. Last four graphs give comparisons of these results for 1. mixed exhaust, 2. best cylinder, 3. worst cylinder, and 4. average concentrations. These sets of profiles while showing the effects of various additives used, also show the most effective quantity of respective additive. These four sets of graphs are followed by a set of comparison graphs, the fifth set, giving a comprehensive study of the most efficiacious quantities of the four additives used and indicating the most significant and successful additive.

The second main section, Section 'B', contains the results with only the most effective quantities of the additives used while working with Reference Gasoline. The results are analysed and represented in similar fashion as for Section 'A'. The first two profiles (Fig. 4:87

and 4:88) of Section 'C' show the effect of air/fuel ratios on the concentrations of hydrocarbon and carbon monoxide, from mixed exhaust only, at an engine speed of 2500 RPM. Fig. 4:87 shows the results obtained with Esso Plus without any additive. Fig. 4:88 shows similar studies for Esso Plus with the most effective quantity of the most effective additive i.e. F.71, 600 ppm.

The visual study high speed cine film of the best additive and the worst additive , present in the most effective quantities indicate the flow pattern changes of air-fuel mixture. A set of eight plates is taken from the cine film (Plates 6-13). These photographs are grouped into two sections each containing four plates representing the studies of the two different fuels used. Each plate consists of three prints representing the flow patterns without additives, best additive, and worst additive, respectively. The four plates contained in each section, represent the four gears separately at an engine speed of 2500 RPM.

Fig. 4:1. Hydrocarbon emissions analysis from mixed exhaust and four individual cylinders for Esso Plus

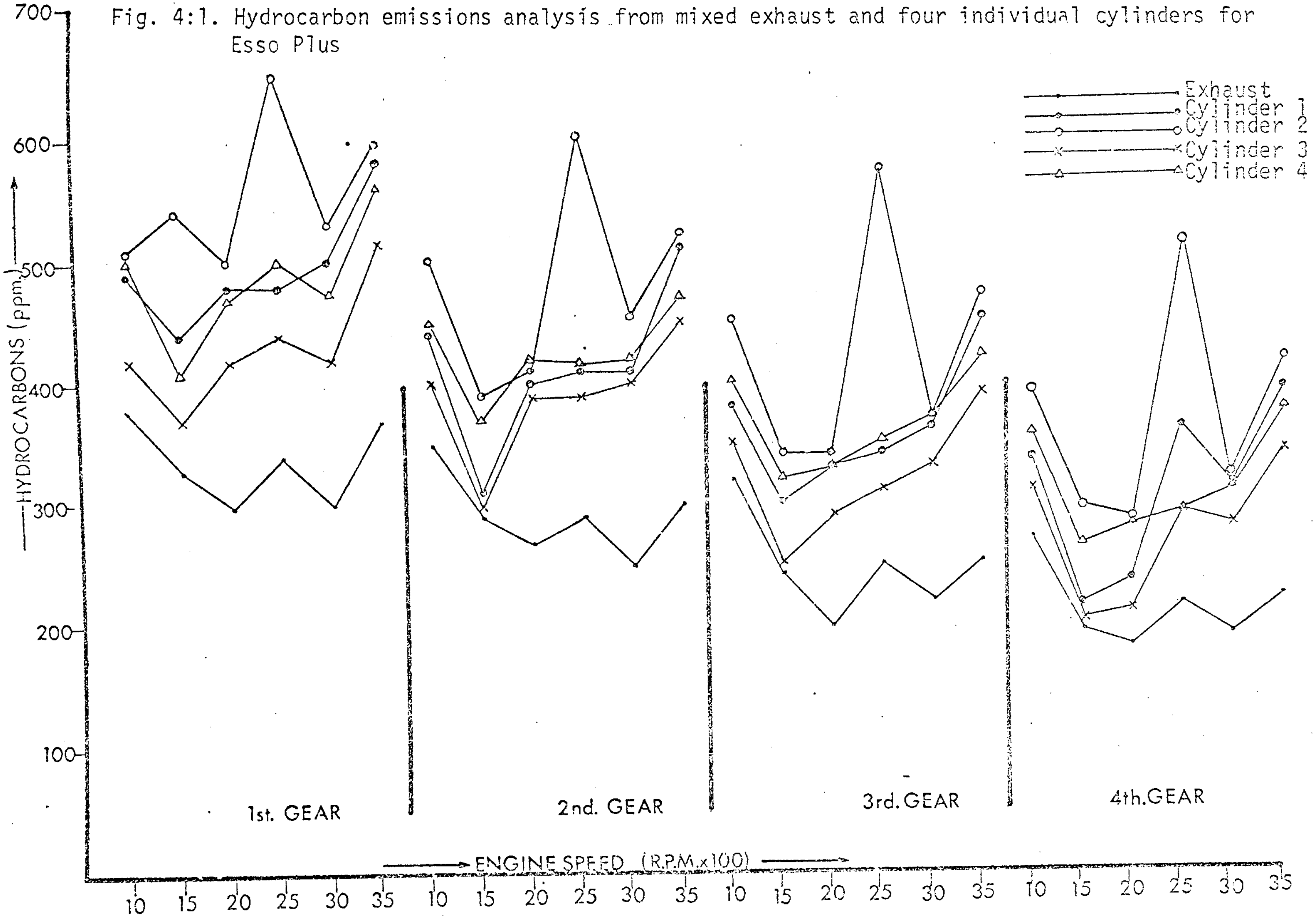


Fig. 4:2. Hydrocarbon emissions analysis from mixed exhaust, Best & Worst Cylinders with Averages for Esso Plus

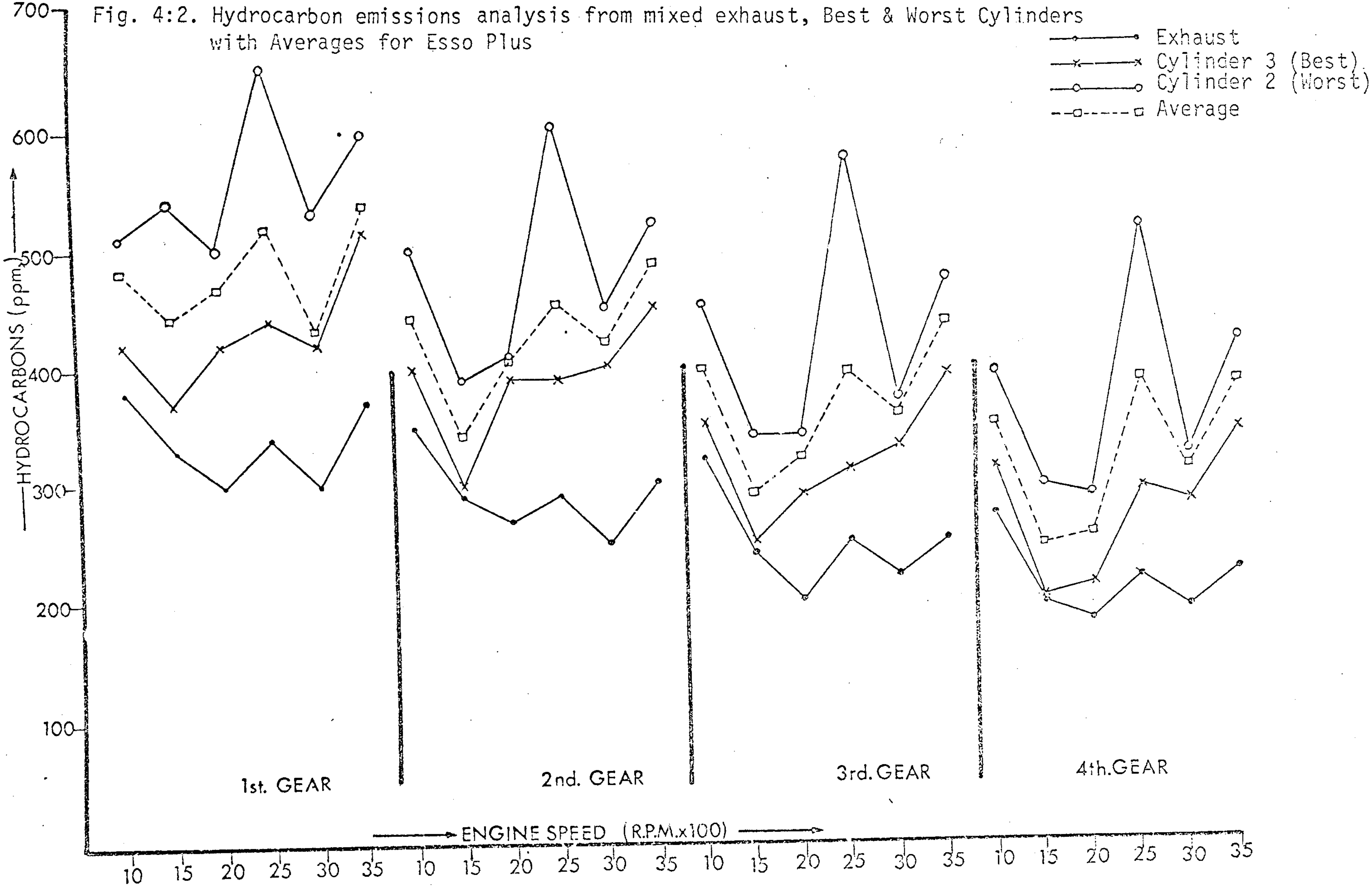


Fig. 4:3: Hydrocarbon emissions analysis for Esso Plus + ECA 4360 - 100 ppm.

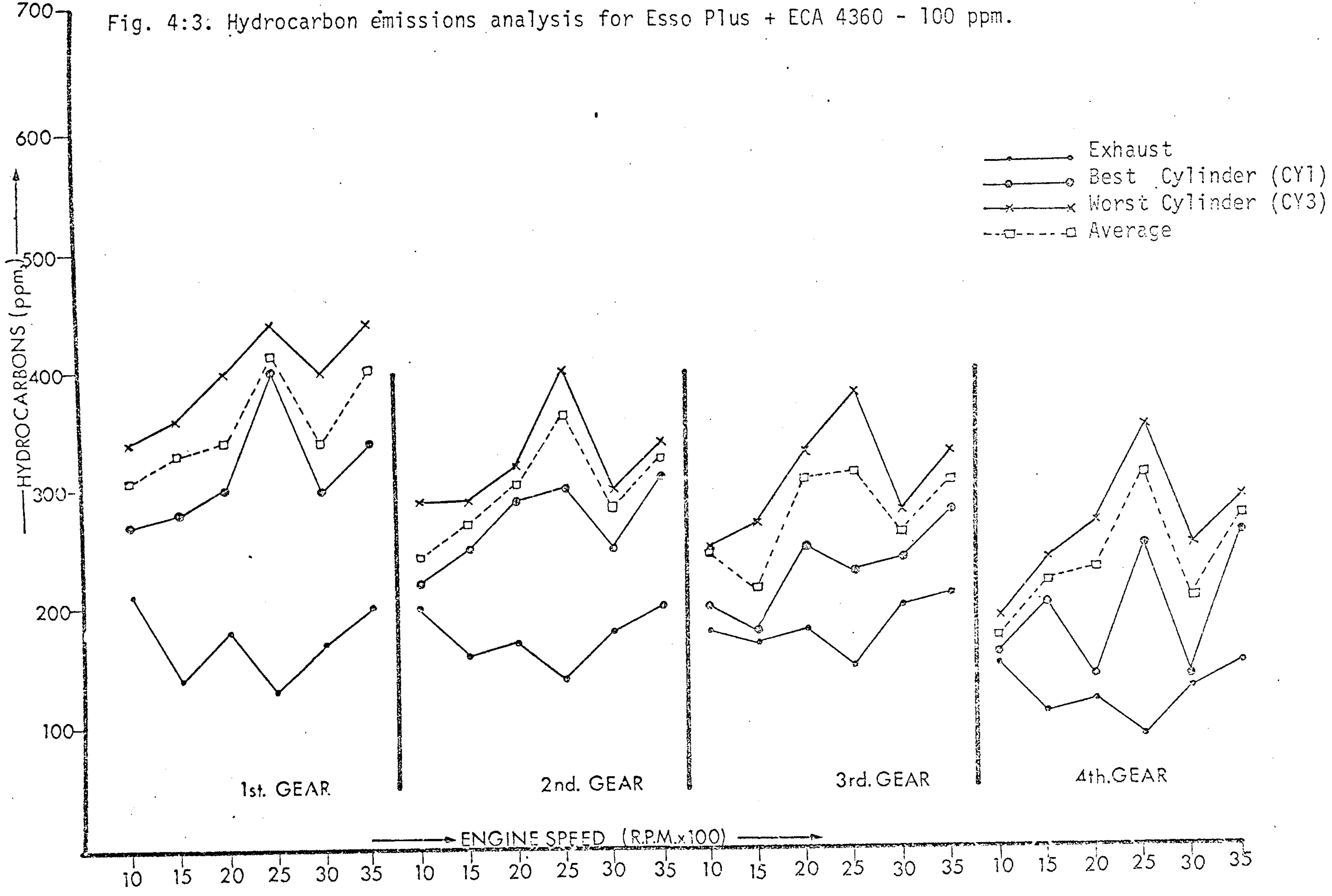


Fig. 4:4. Hydrocarbon emissions analysis for Esso Plus + ECA 4360 - 500 ppm.

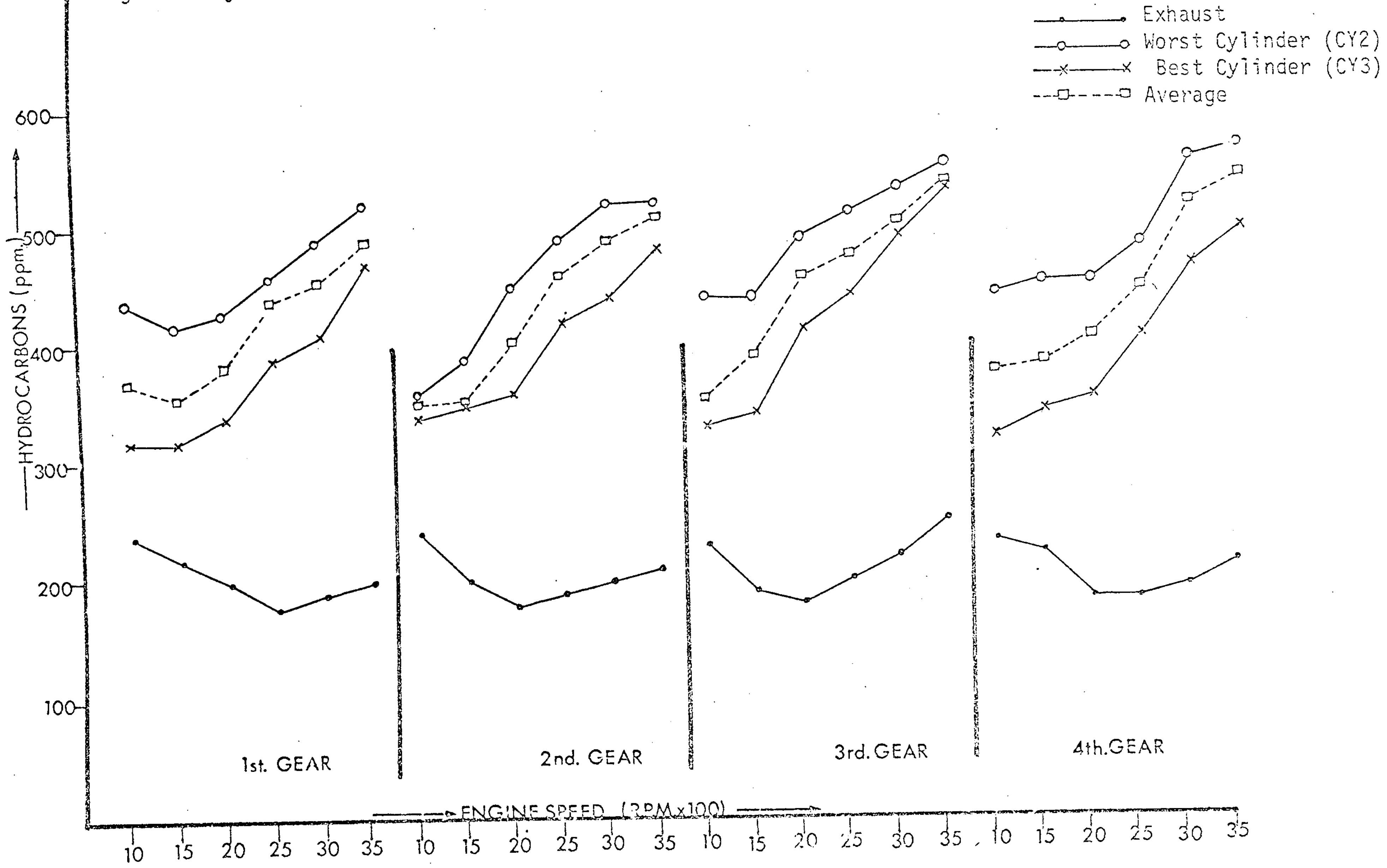


Fig. 4:5. Hydrocarbon emissions analysis for Esso Plus + ECA 4360 - 1000 ppm.

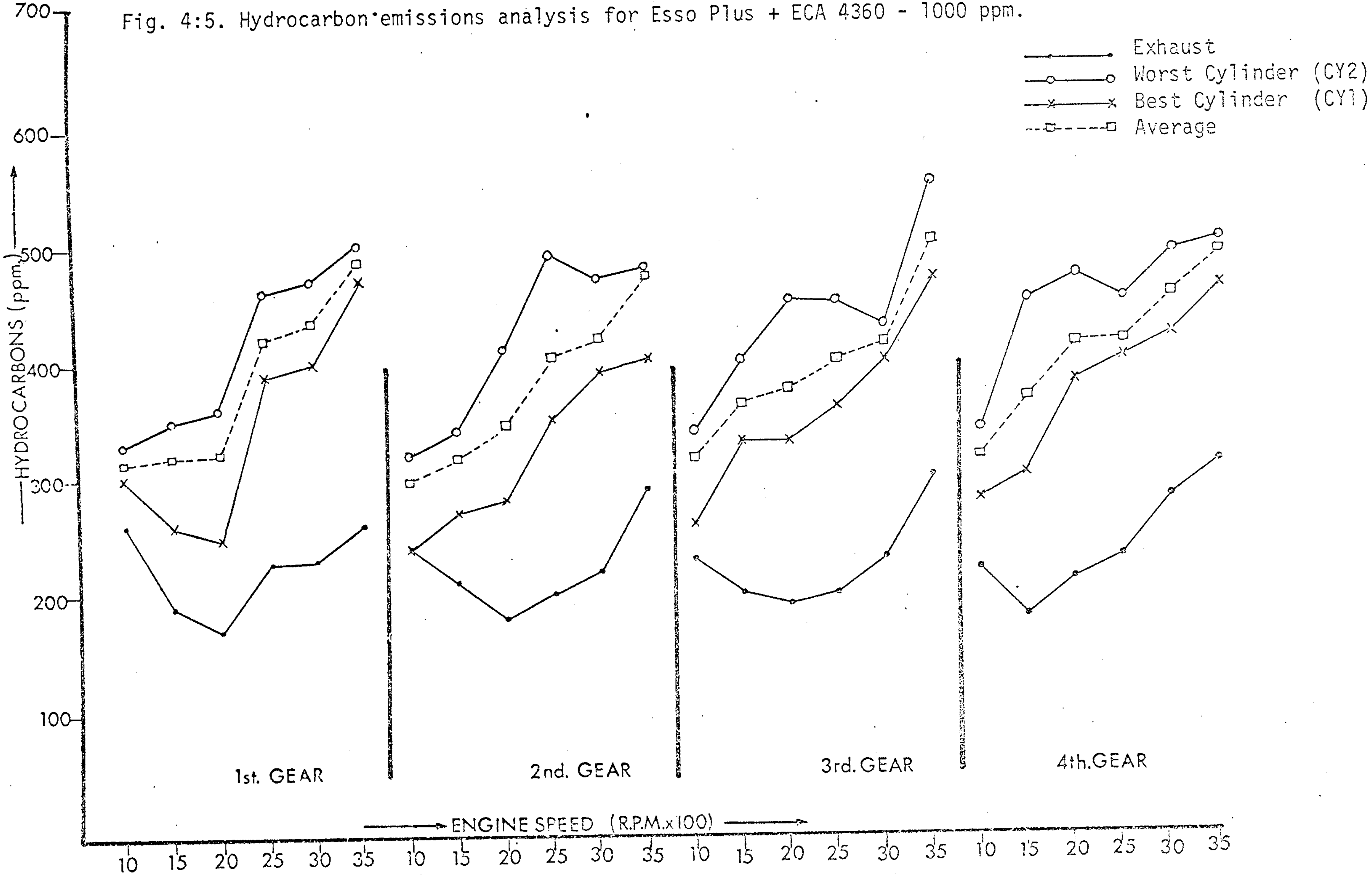
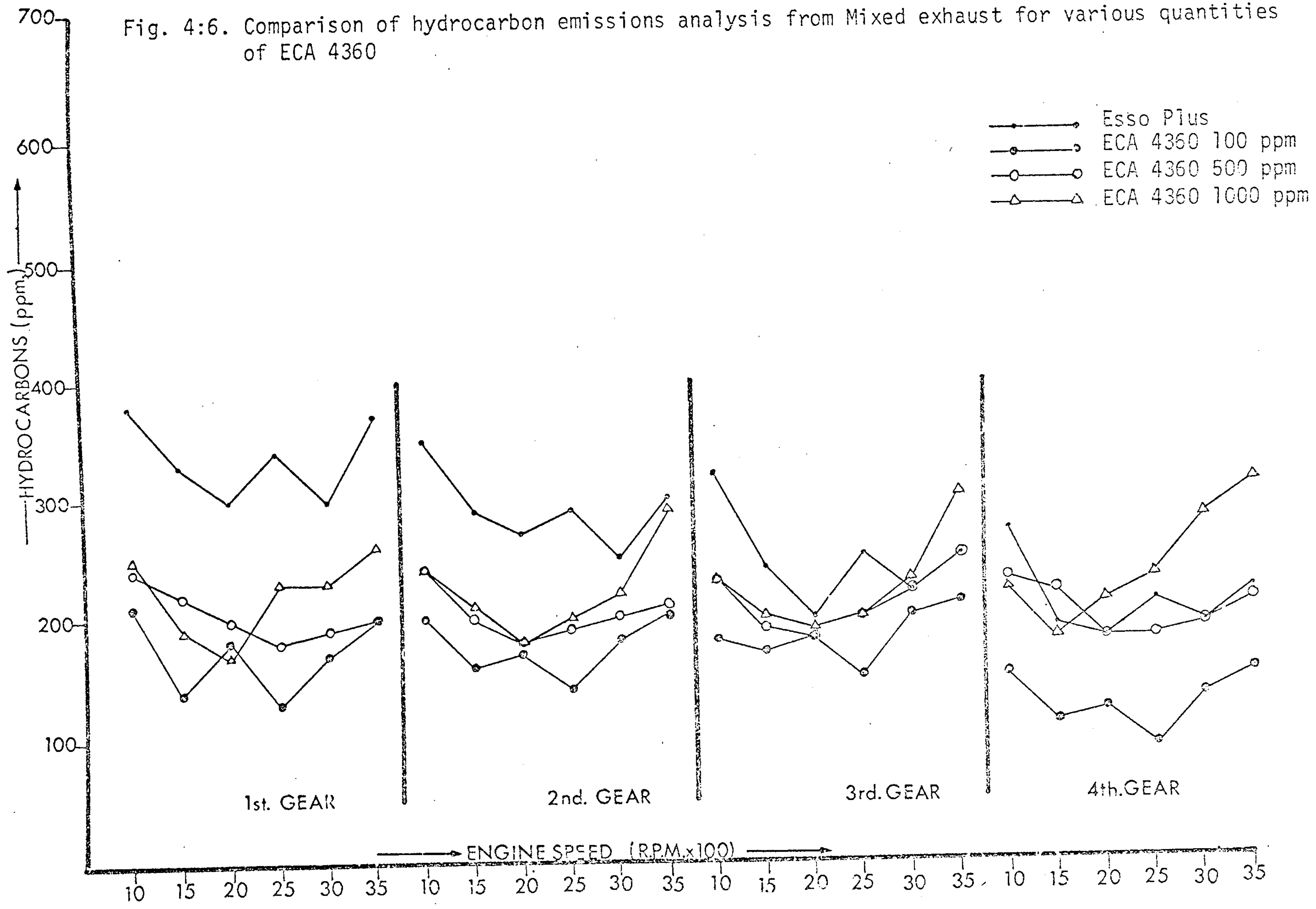


Fig. 4:6. Comparison of hydrocarbon emissions analysis from Mixed exhaust for various quantities of ECA 4360



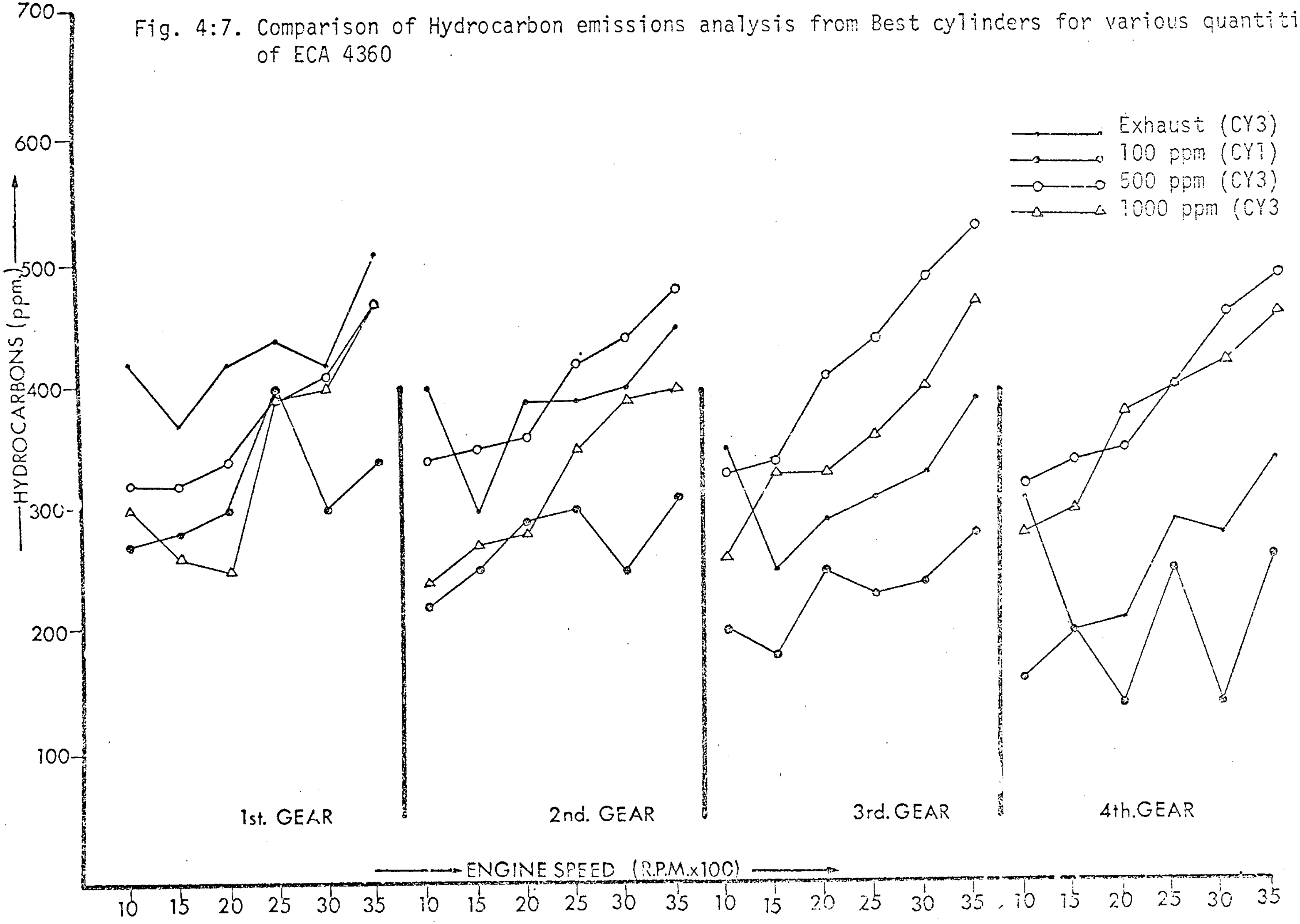


Fig. 4:7. Comparison of Hydrocarbon emissions analysis from Best cylinders for various quantities of ECA 4360

Fig. 4:8. Comparison of Hydrocarbon emissions analysis from Worst Cylinders for various quantities of ECA 4360

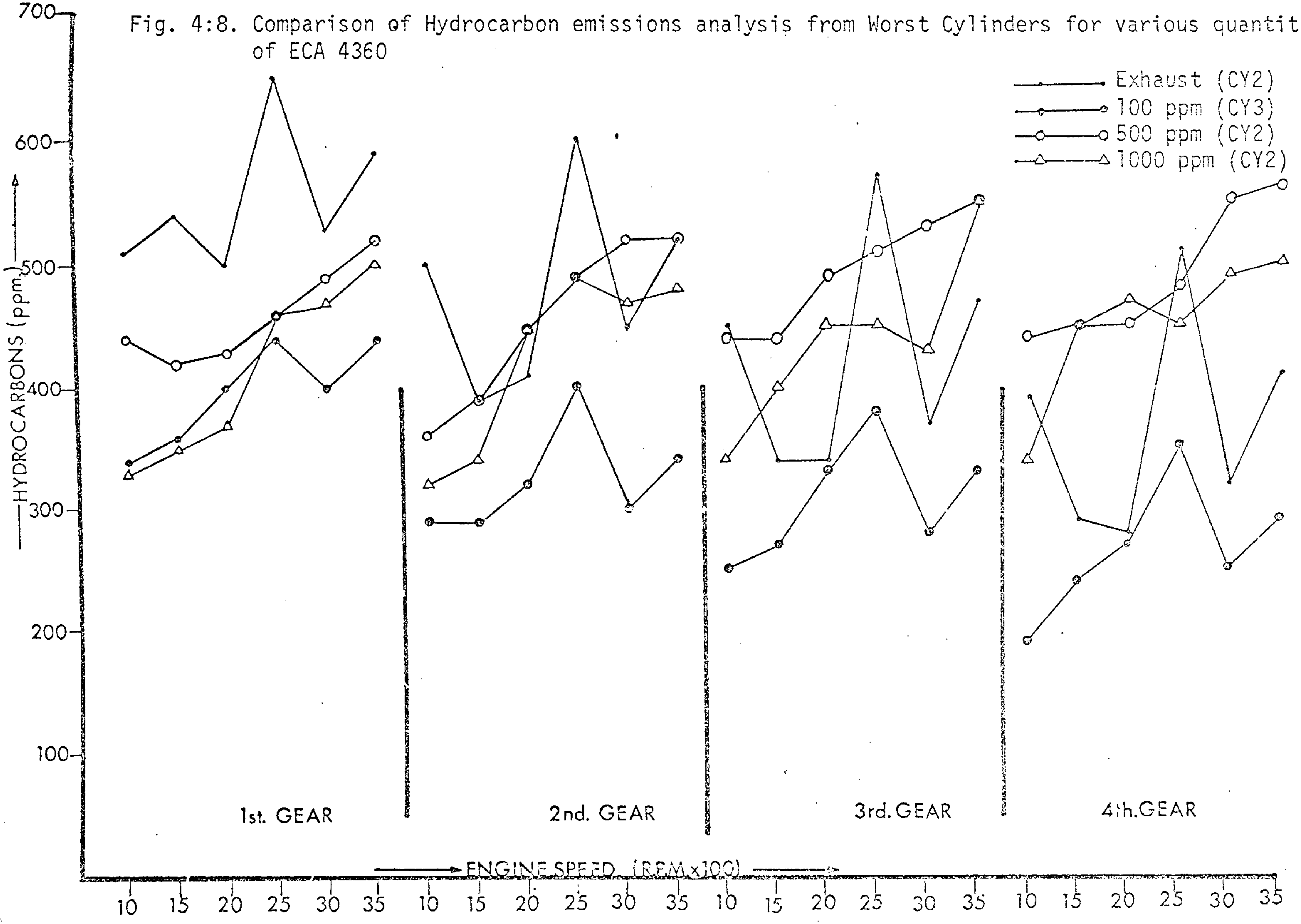


Fig. 4:9. Comparison of Hydrocarbon emissions Averages for various quantities of ECA 4360

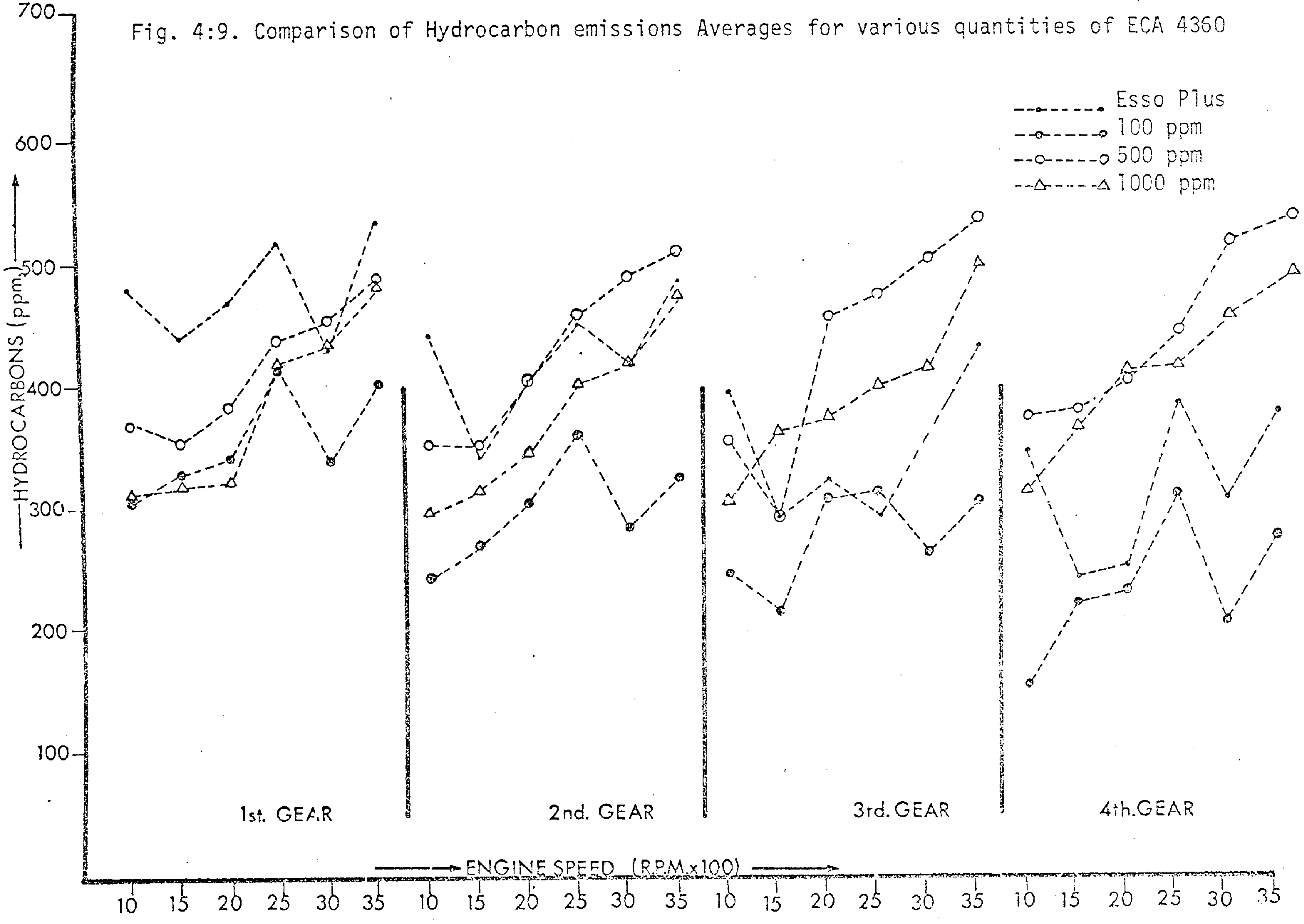


Fig. 4:10. Hydrocarbon emissions analysis for Esso Plus + F.71 - 600 ppm

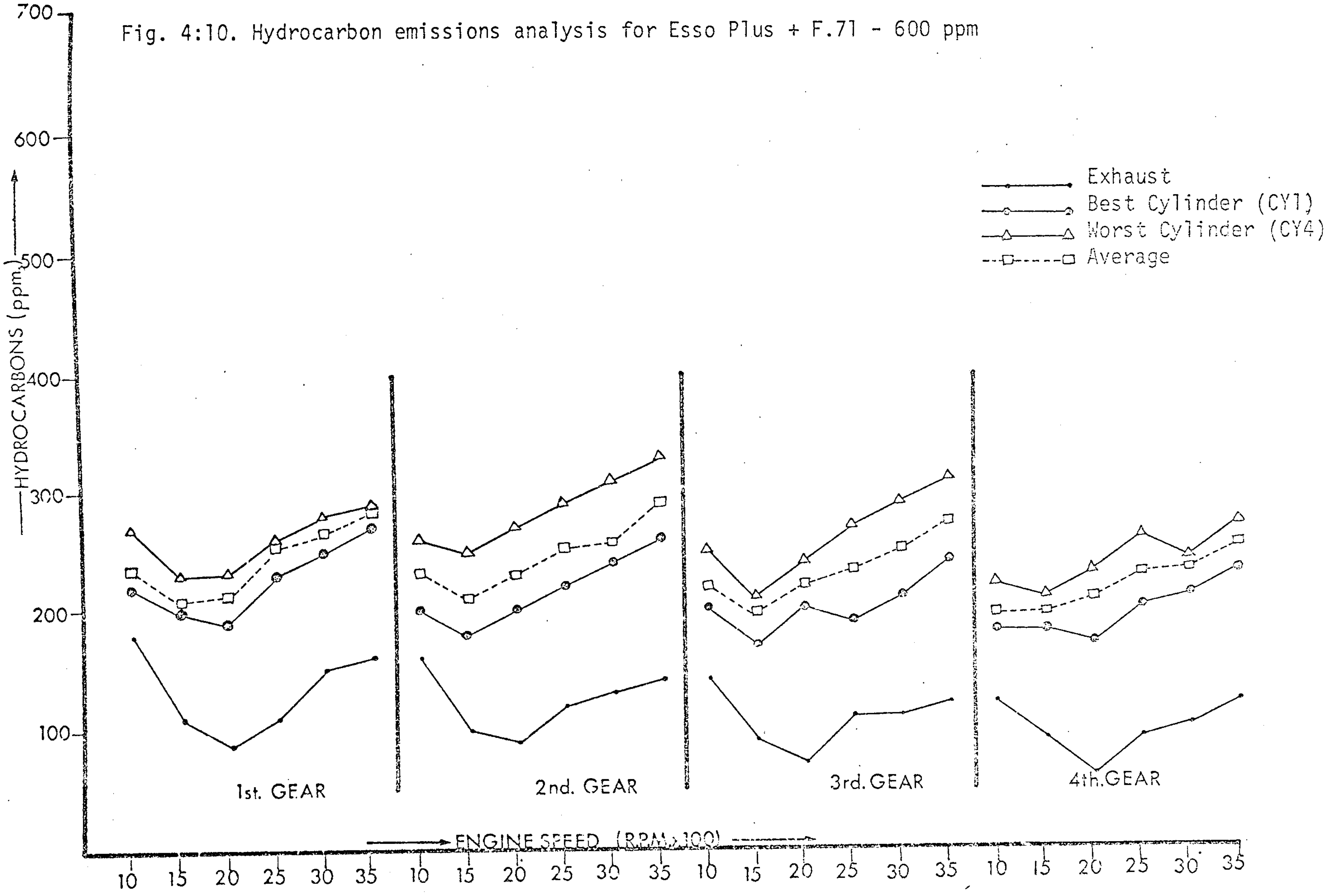


Fig. 4:11. Hydrocarbon emissions analysis for Esso Plus + F.71 - 1000 ppm

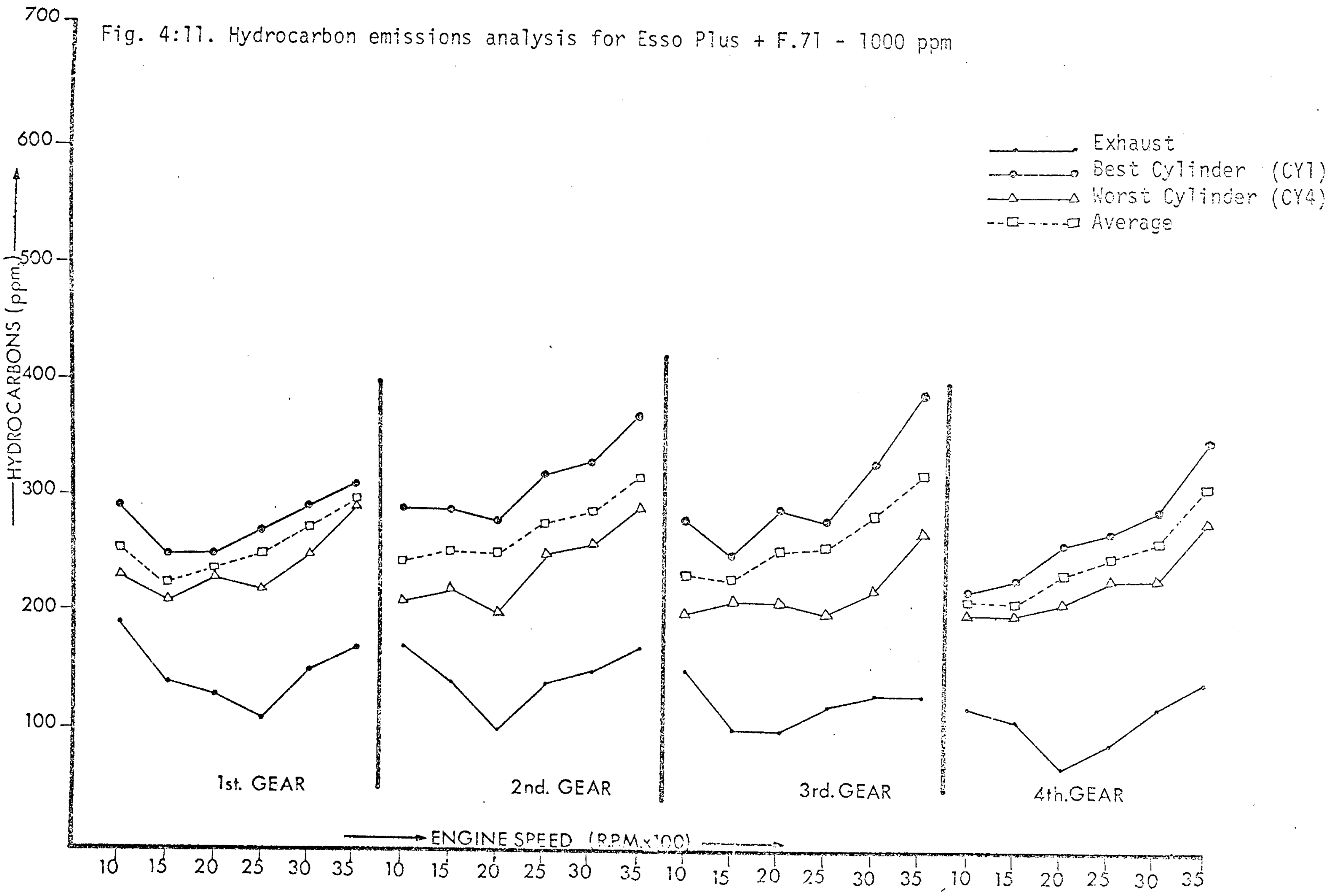
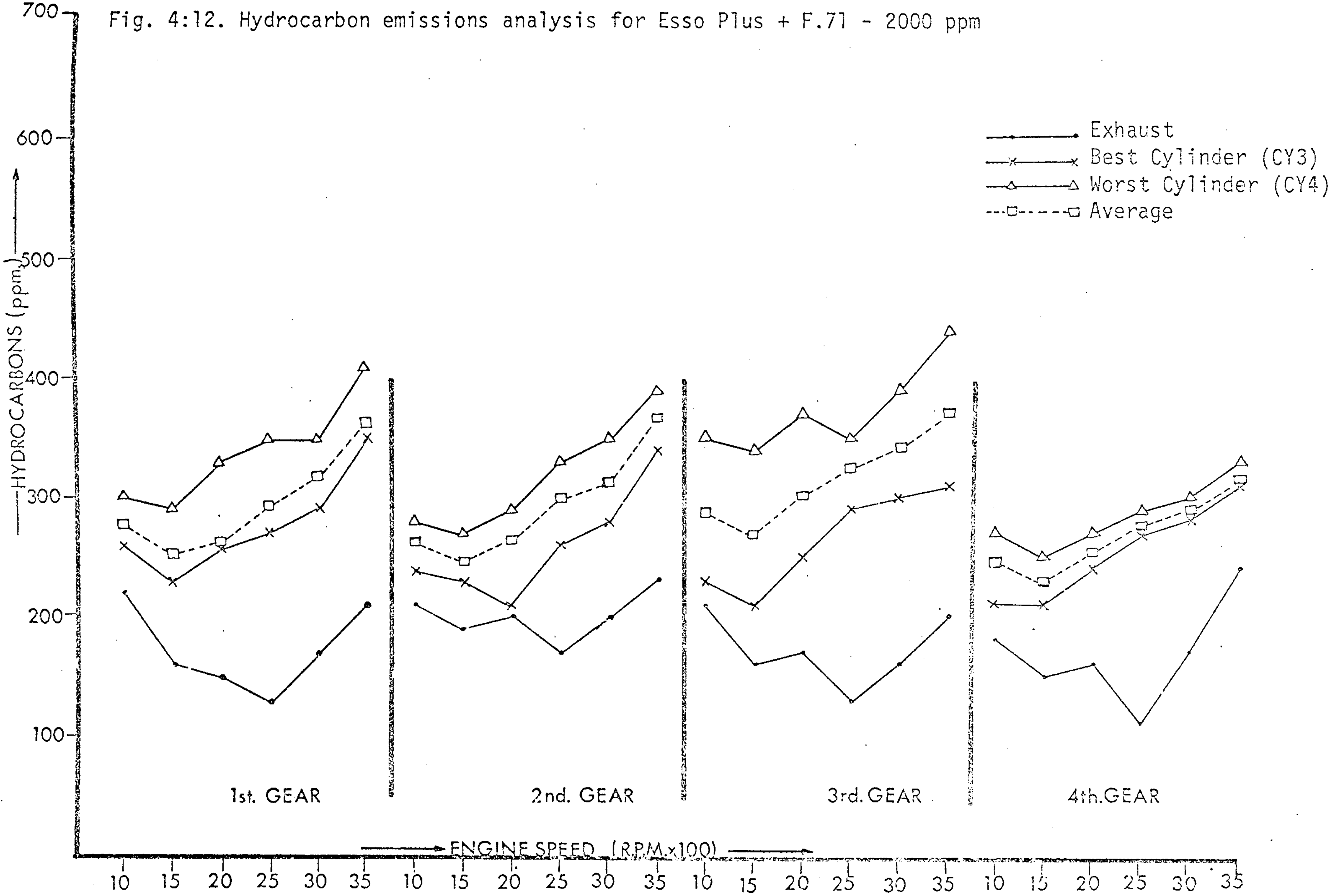


Fig. 4:12. Hydrocarbon emissions analysis for Esso Plus + F.71 - 2000 ppm



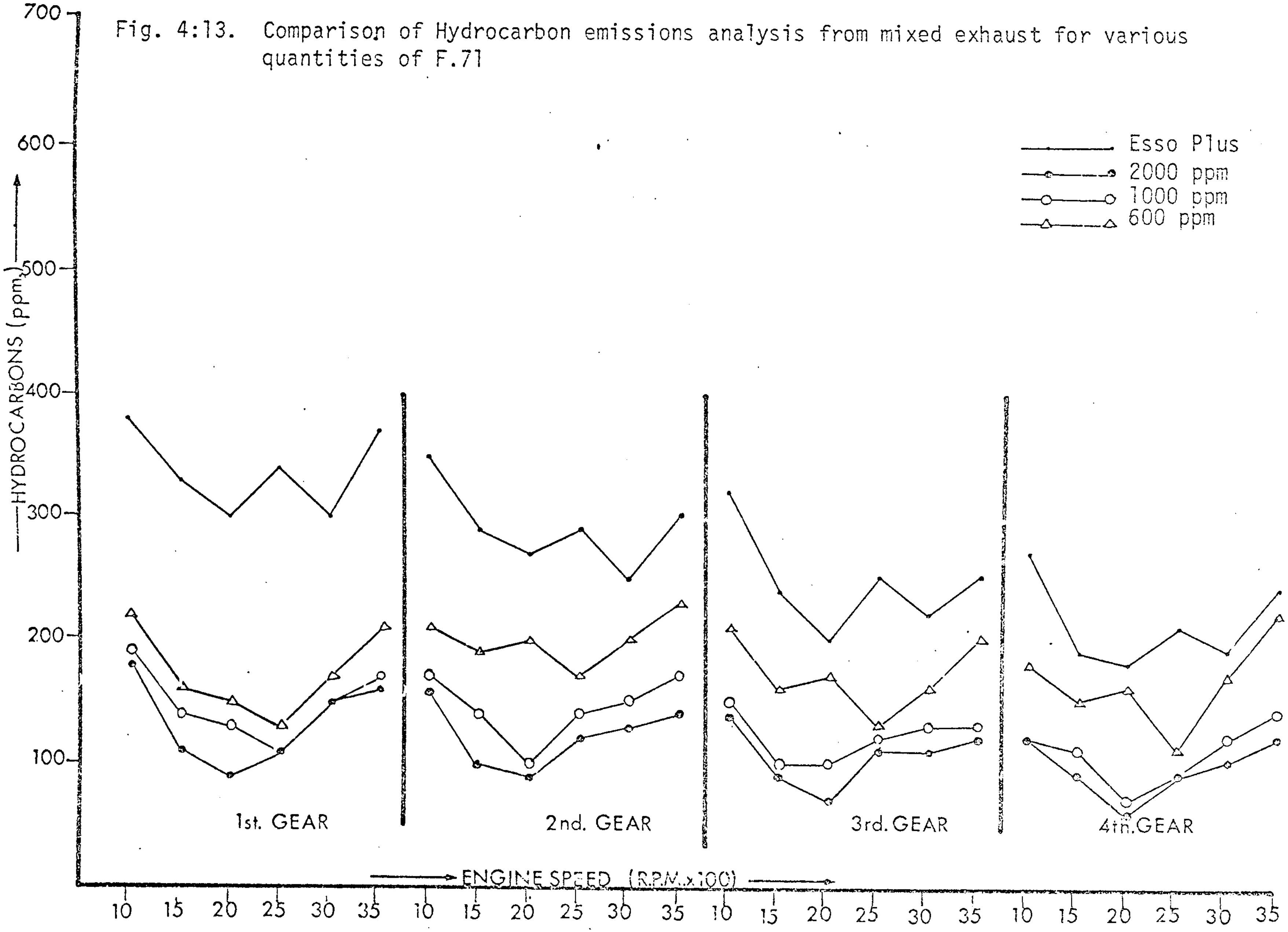


Fig. 4:13. Comparison of Hydrocarbon emissions analysis from mixed exhaust for various quantities of F.71

Fig. 4:14. Comparison of Hydrocarbon emissions analysis from Best cylinders for various quantities of F.71

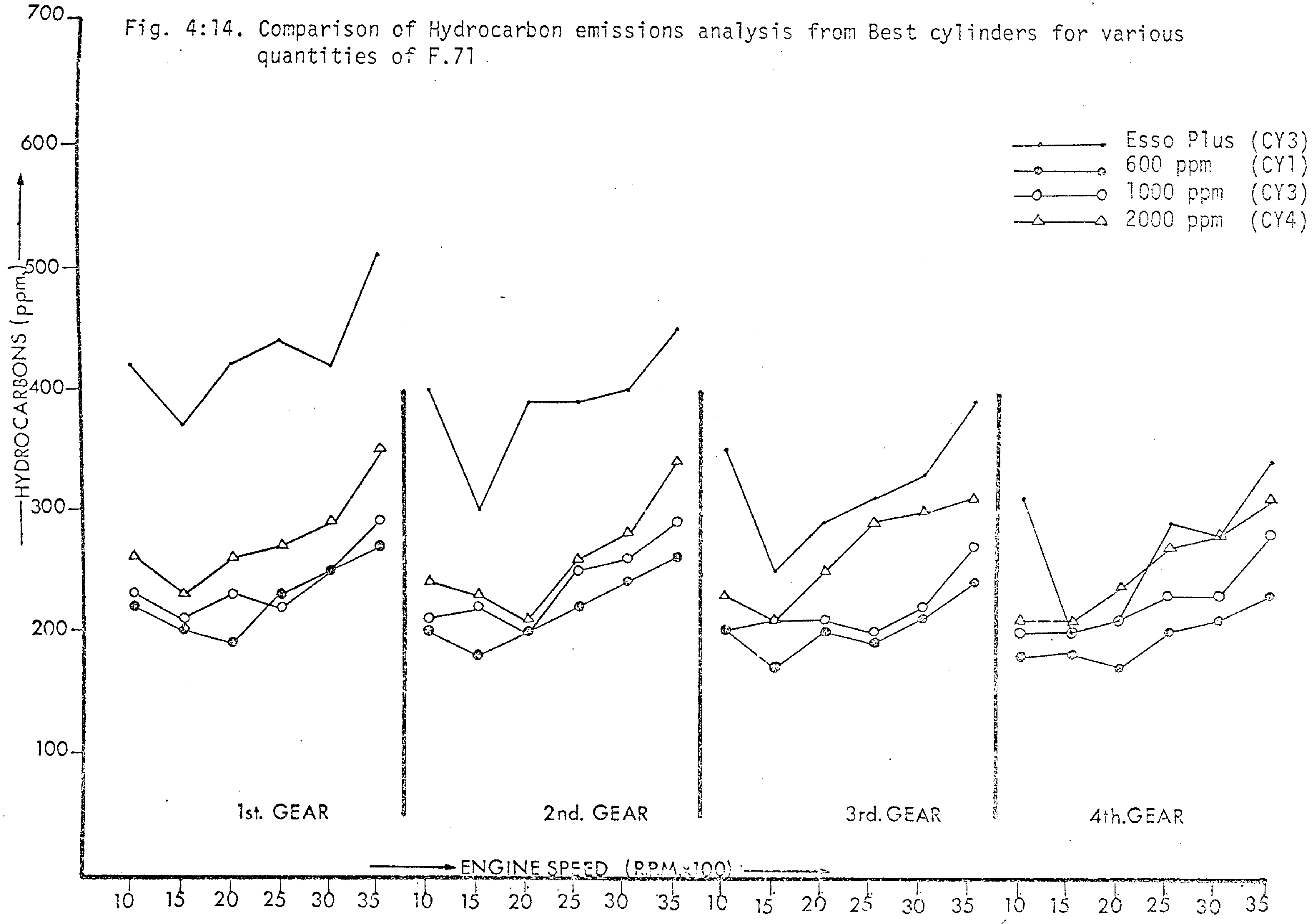
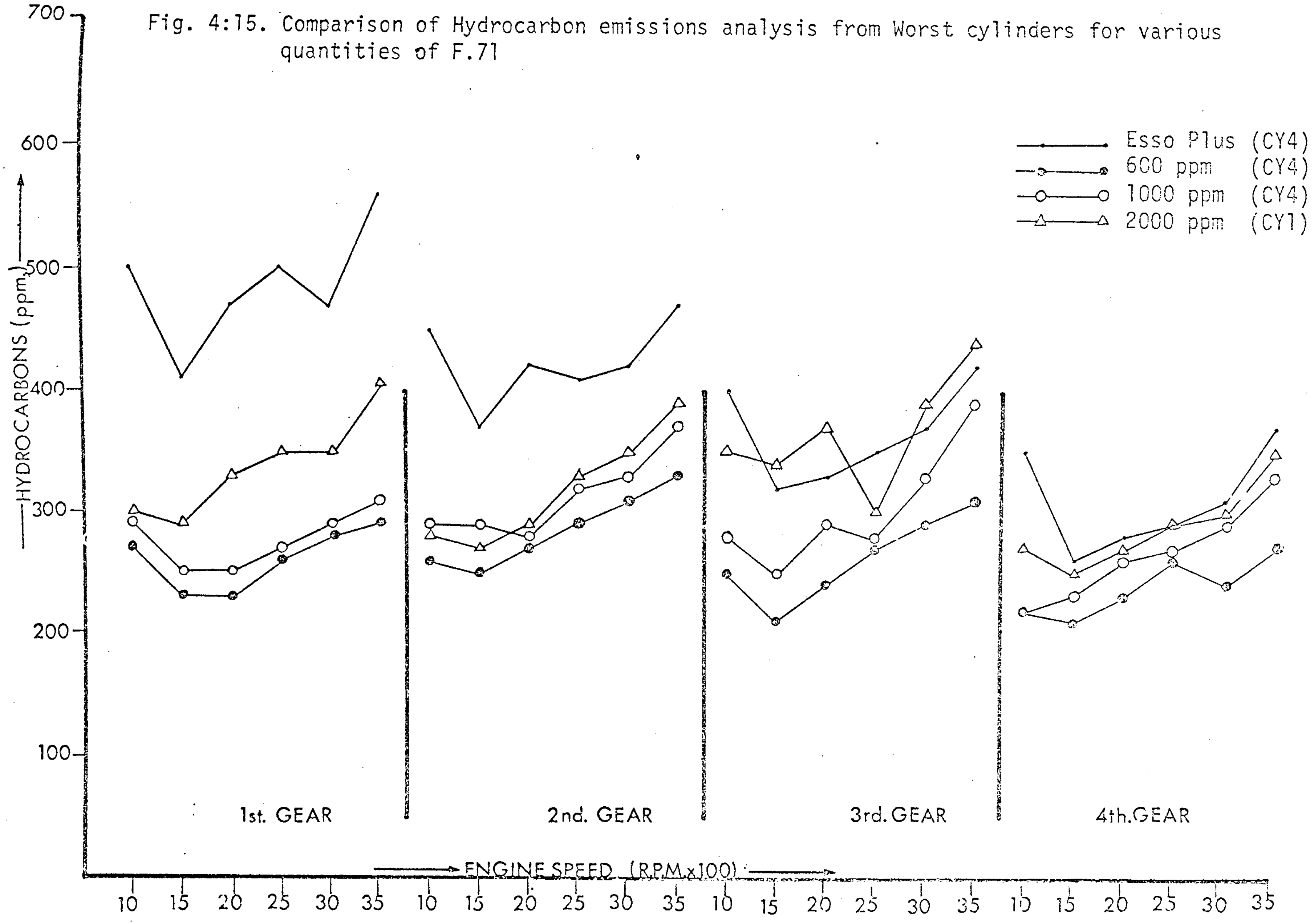


Fig. 4:15. Comparison of Hydrocarbon emissions analysis from Worst cylinders for various quantities of F.71



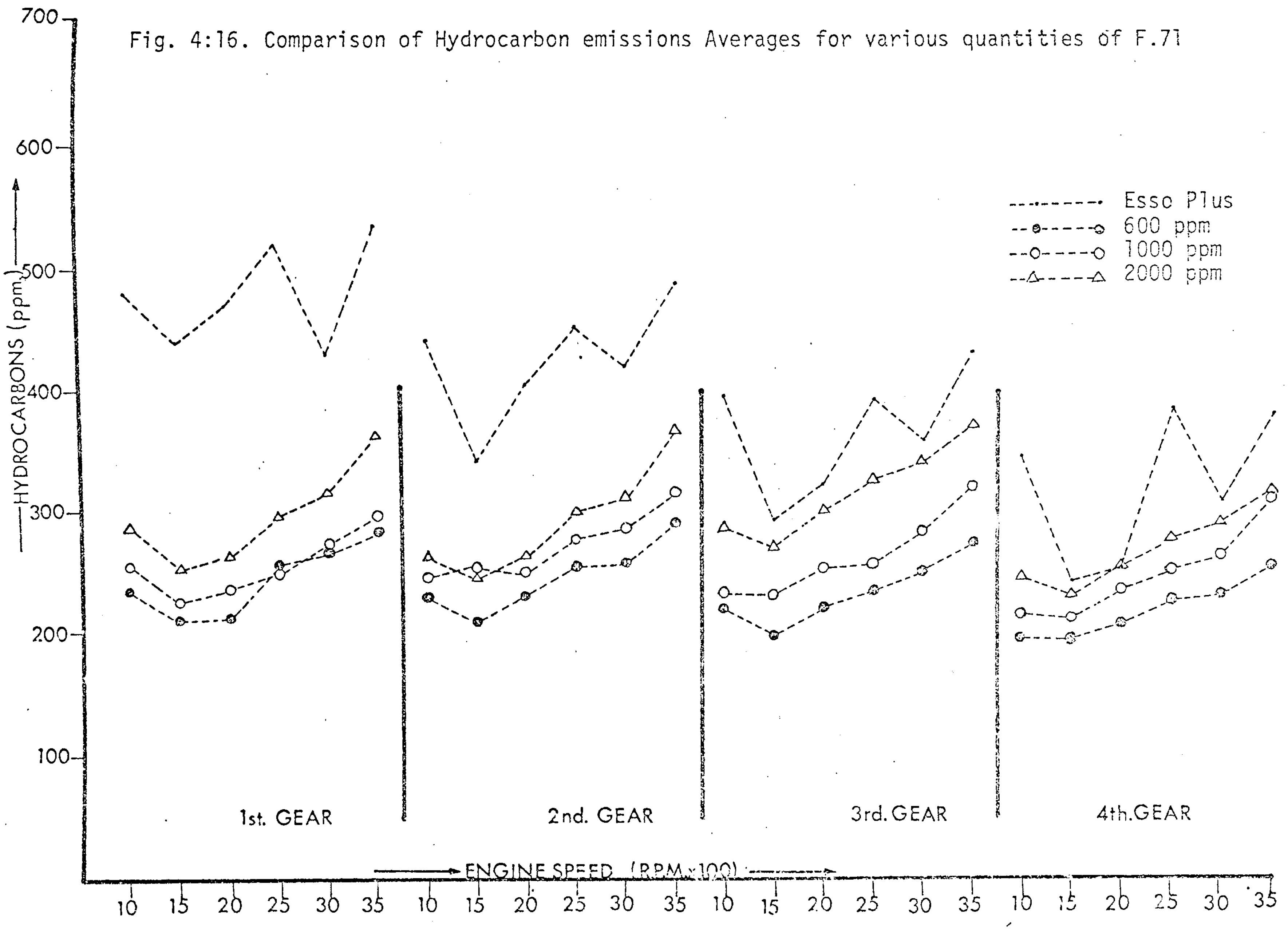


Fig. 4:16. Comparison of Hydrocarbon emissions Averages for various quantities of F.71

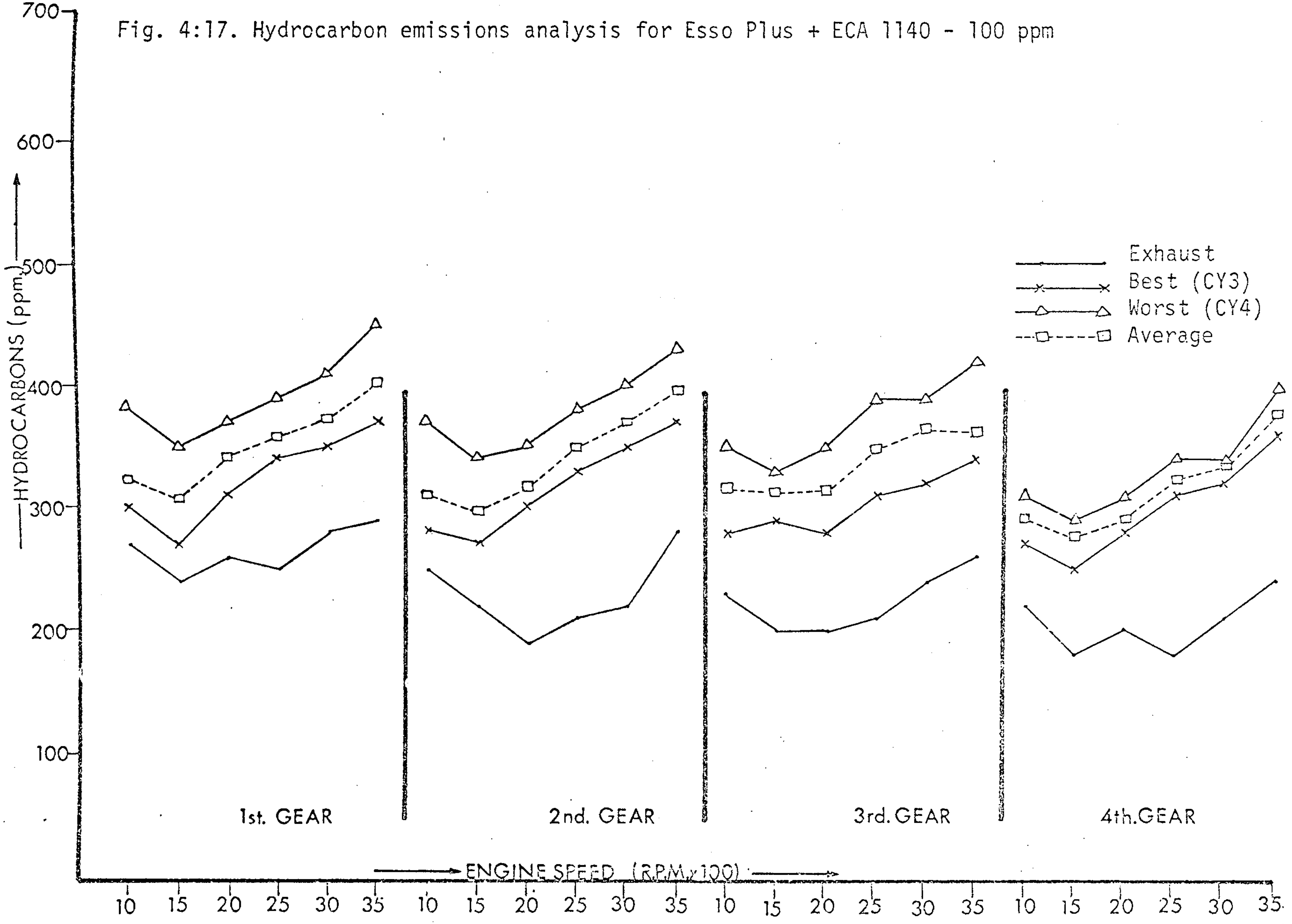


Fig. 4:17. Hydrocarbon emissions analysis for Esso Plus + ECA 1140 - 100 ppm

Fig. 4:18: Hydrocarbon emissions analysis for Esso Plus + ECA 1140 - 500 ppm

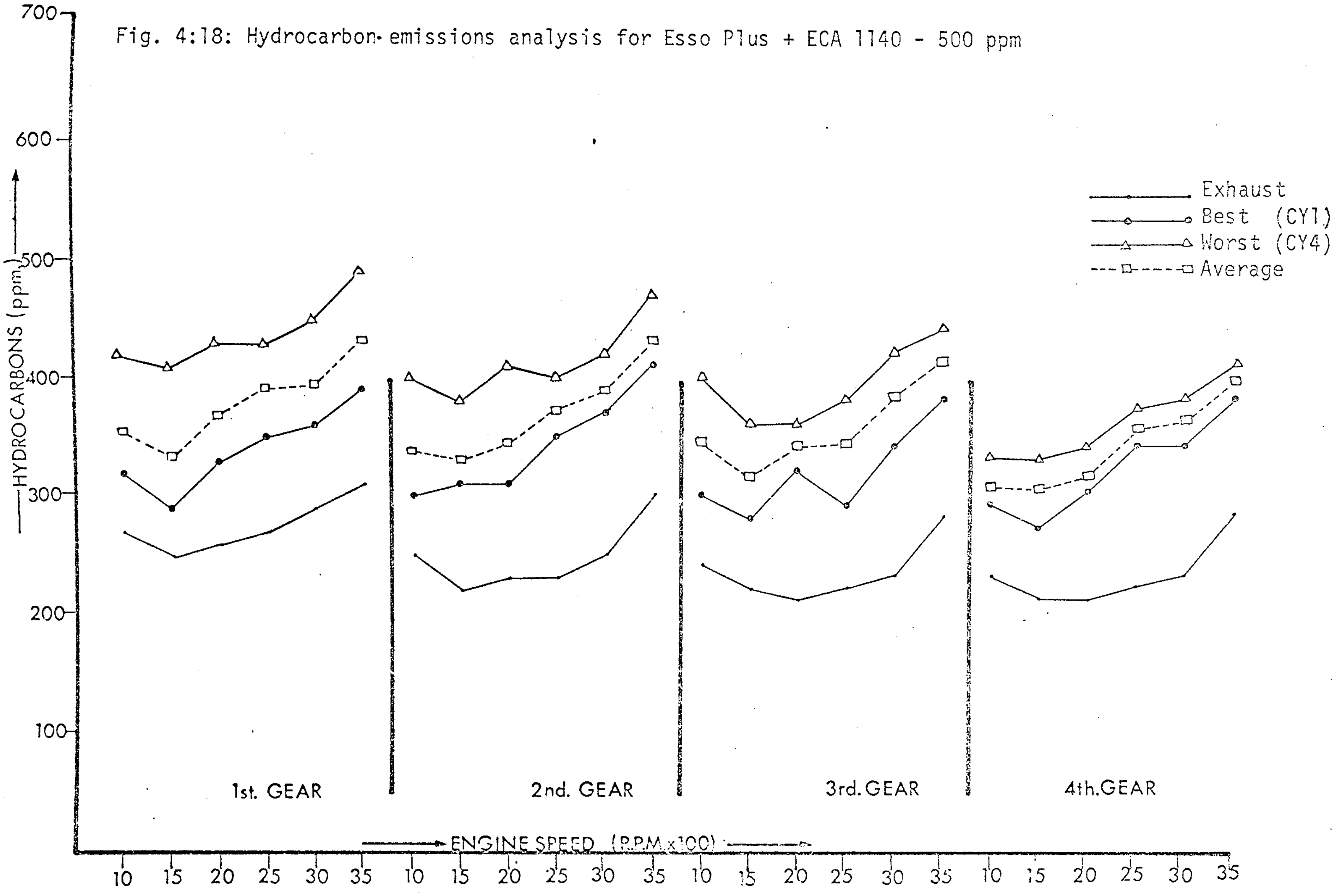


Fig. 4:19. Hydrocarbon emissions analysis for Esso Plus + ECA 1140 - 1000 ppm

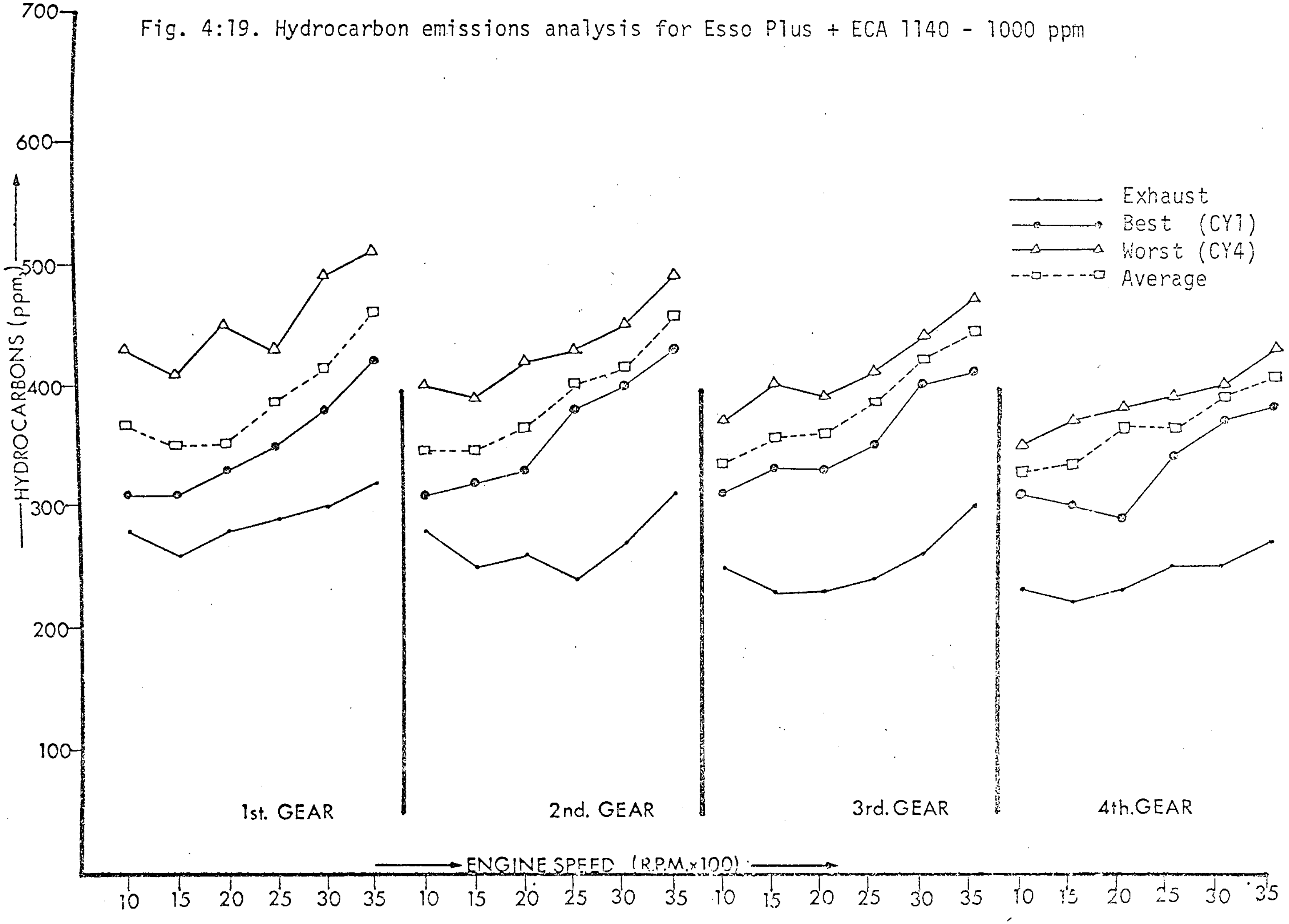


Fig. 4:20 Comparison of Hydrocarbon emissions analysis from Mixed exhaust for various quantities of ECA 1140

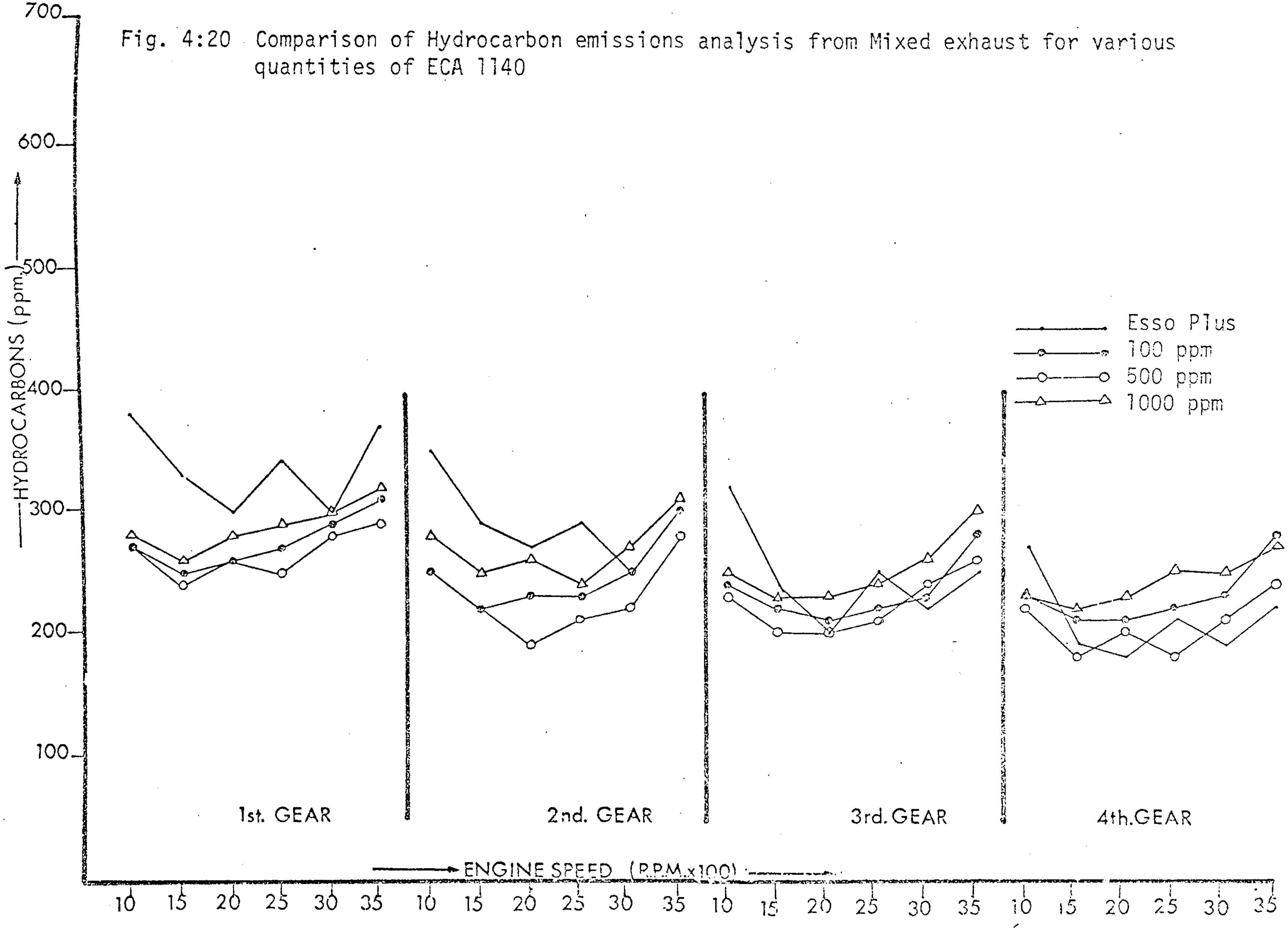


Fig. 4:21. Comparison of Hydrocarbon emission analysis from Best cylinders for various quantities of ECA 1140

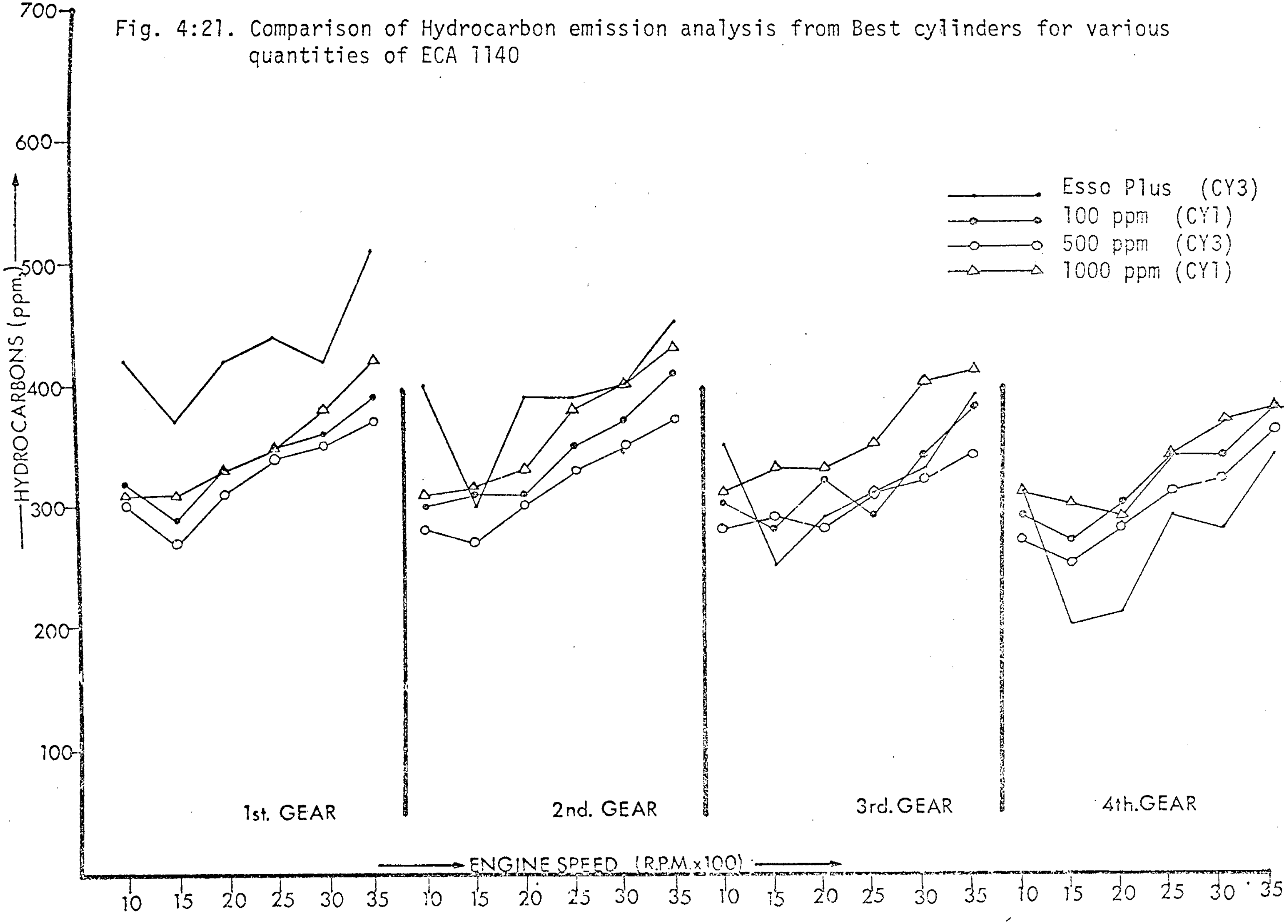


Fig. 4:22. Comparison of Hydrocarbon emission analysis from Worst cylinders for various quantities of ECA 1140

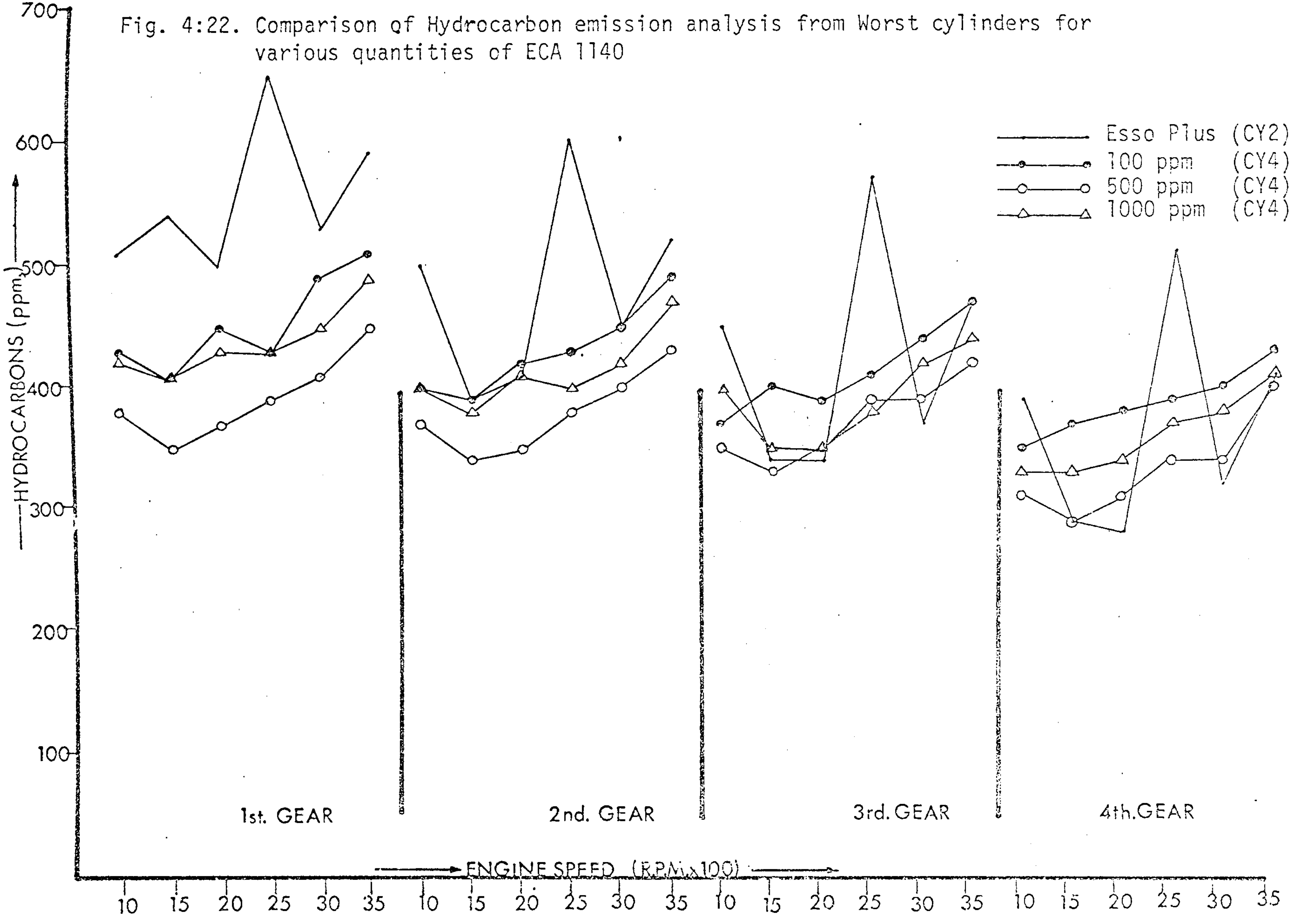


Fig. 4:23. Comparison of Hydrocarbon emission Averages for various quantities of ECA 1140

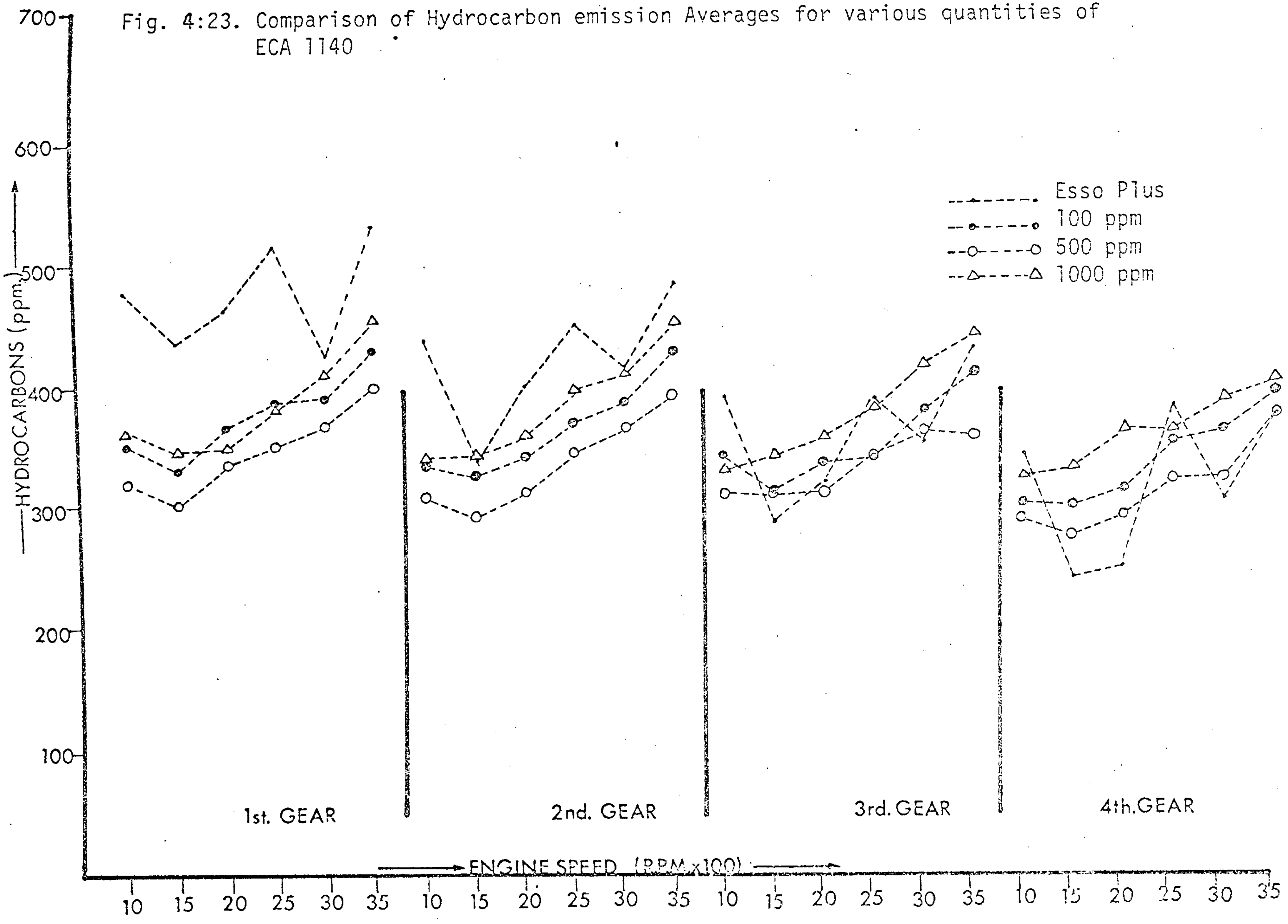
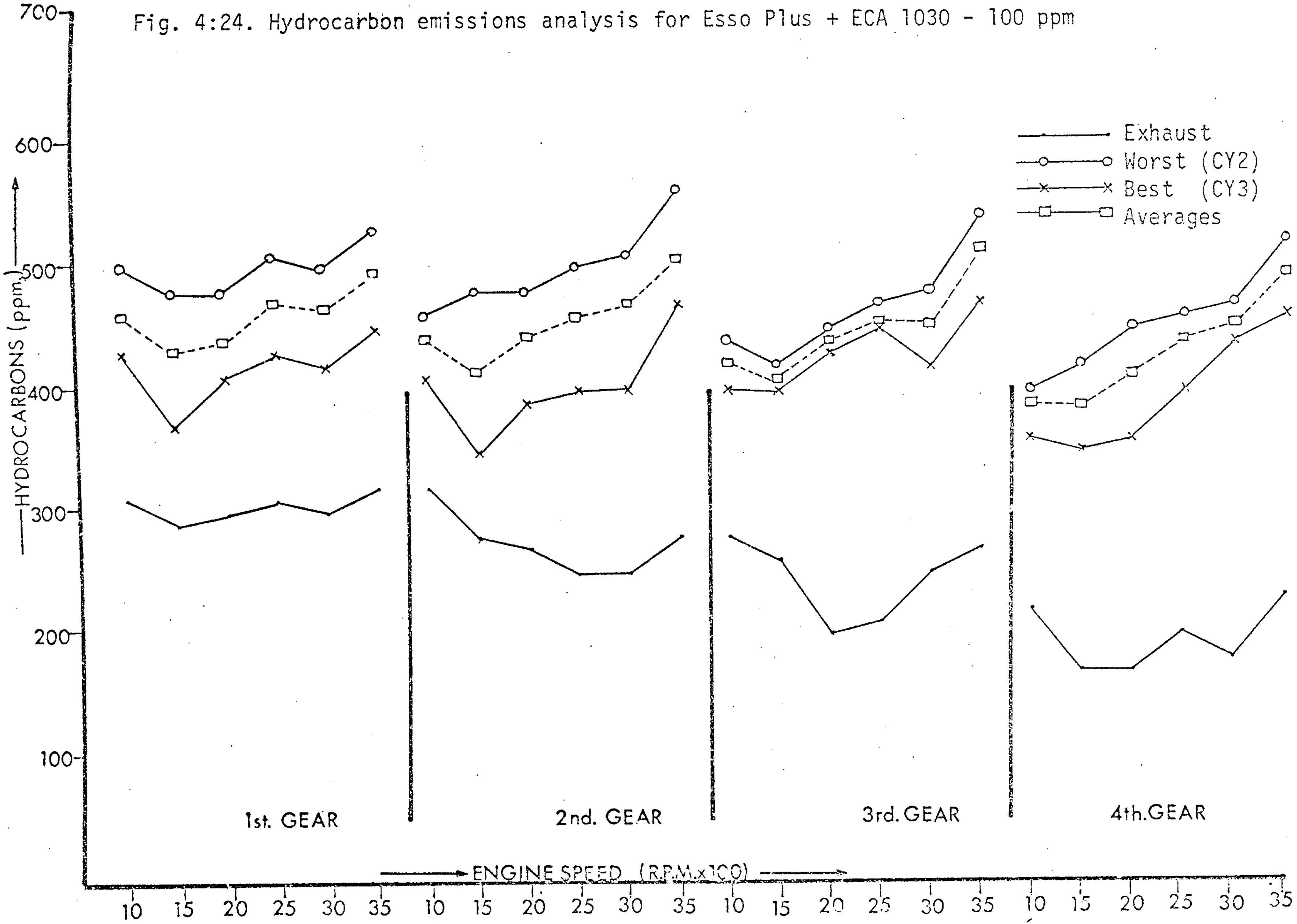


Fig. 4:24. Hydrocarbon emissions analysis for Esso Plus + ECA 1030 - 100 ppm



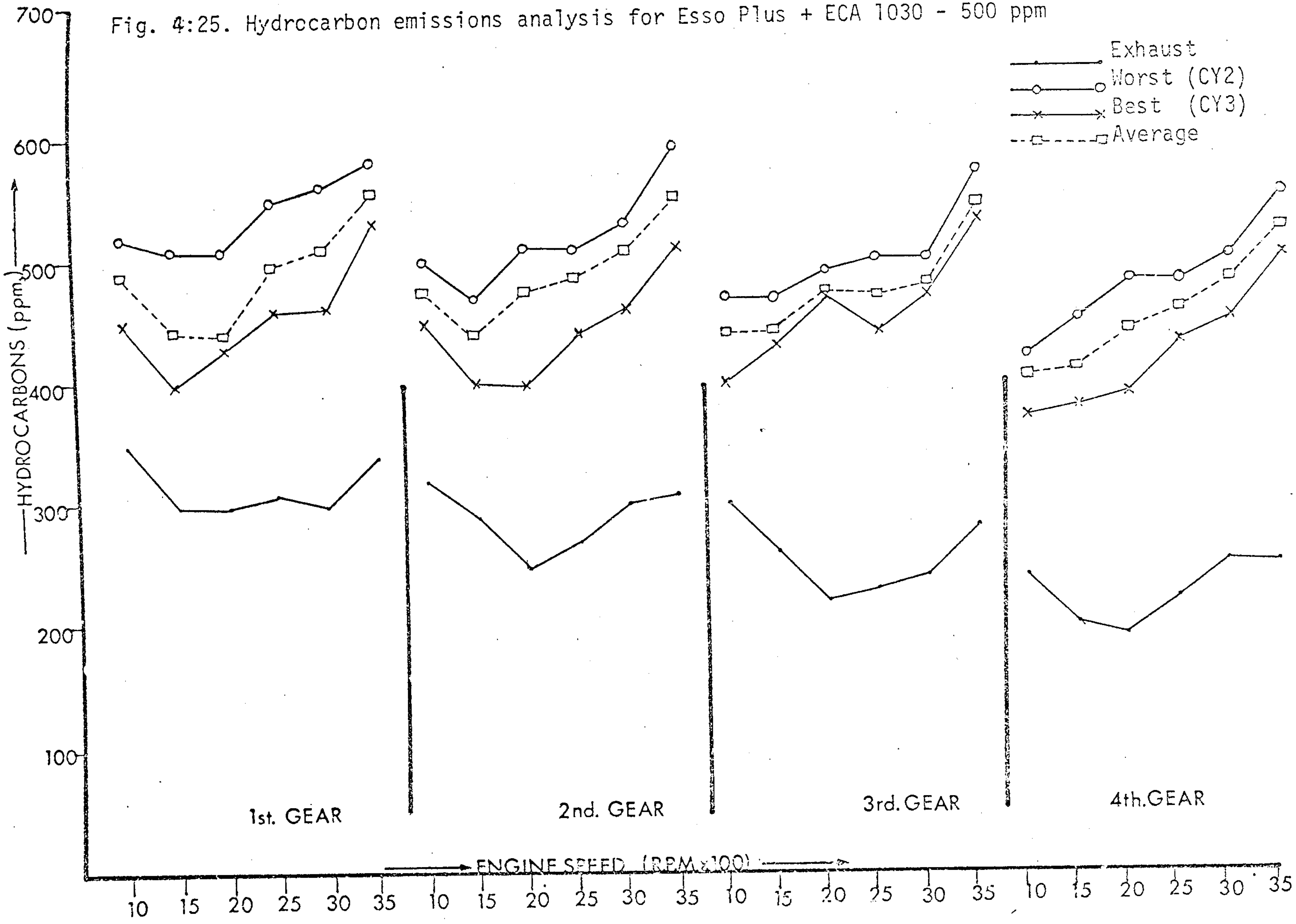


Fig. 4:25. Hydrocarbon emissions analysis for Esso Plus + ECA 1030 - 500 ppm

Fig. 4:26. Hydrocarbon emissions analysis for Esso Plus + ECA 1030 - 1000 ppm

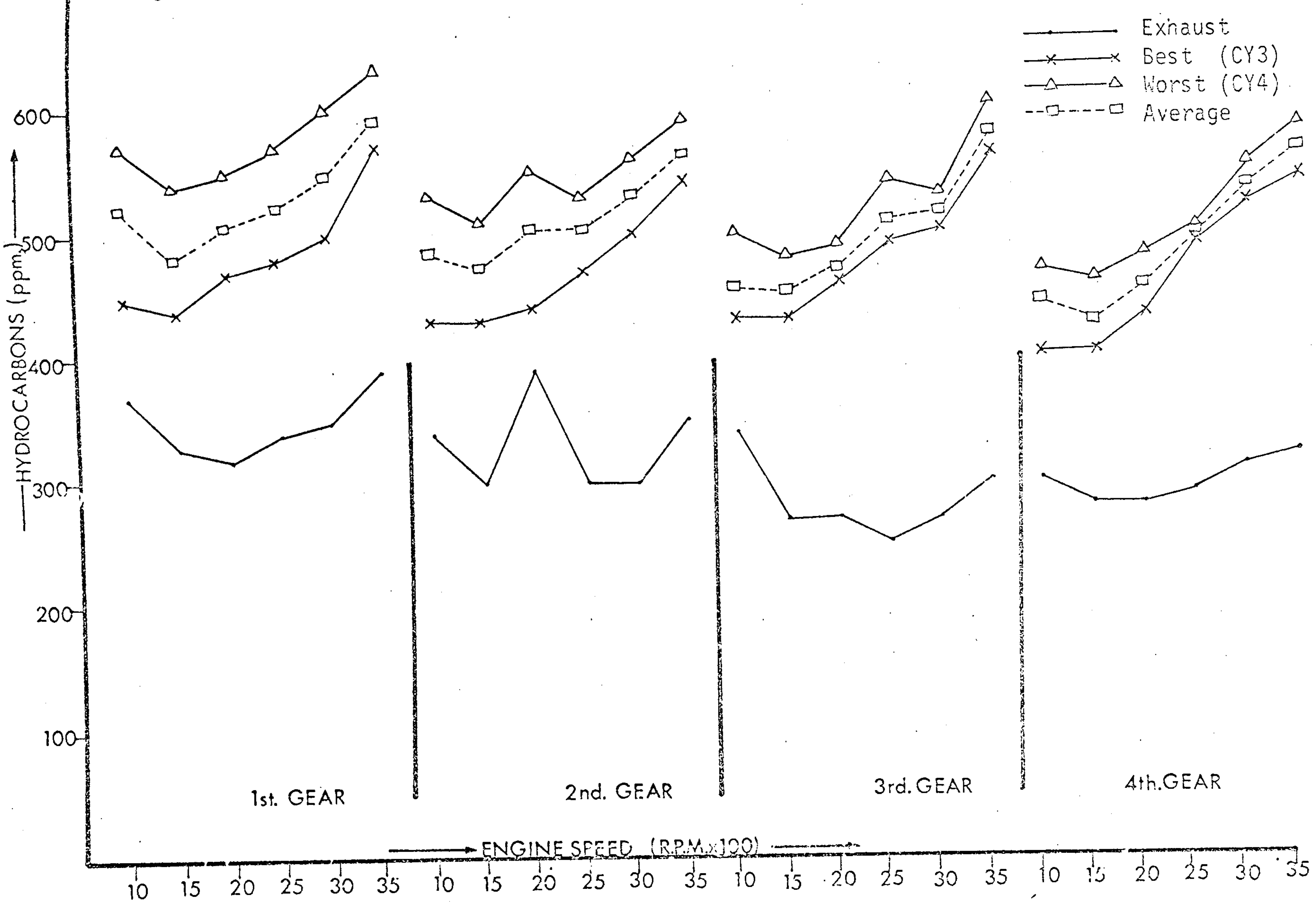


Fig. 4:27. Comparison of Hydrocarbon emissions from Mixed exhaust for various quantities of ECA 1030

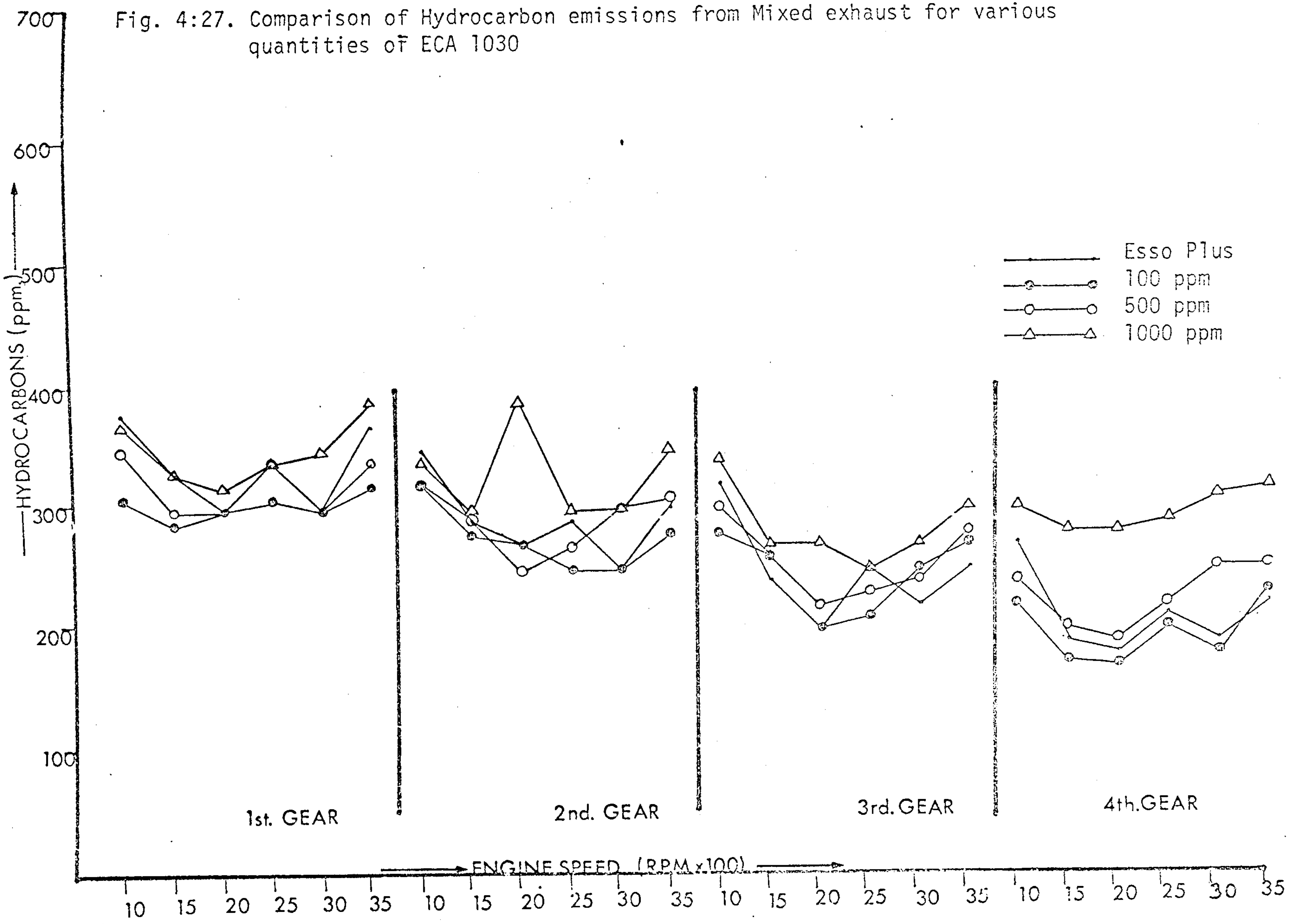


Fig. 4:28. Comparison of Hydrocarbon emissions analysis from Best cylinders for various quantities of ECA 1030

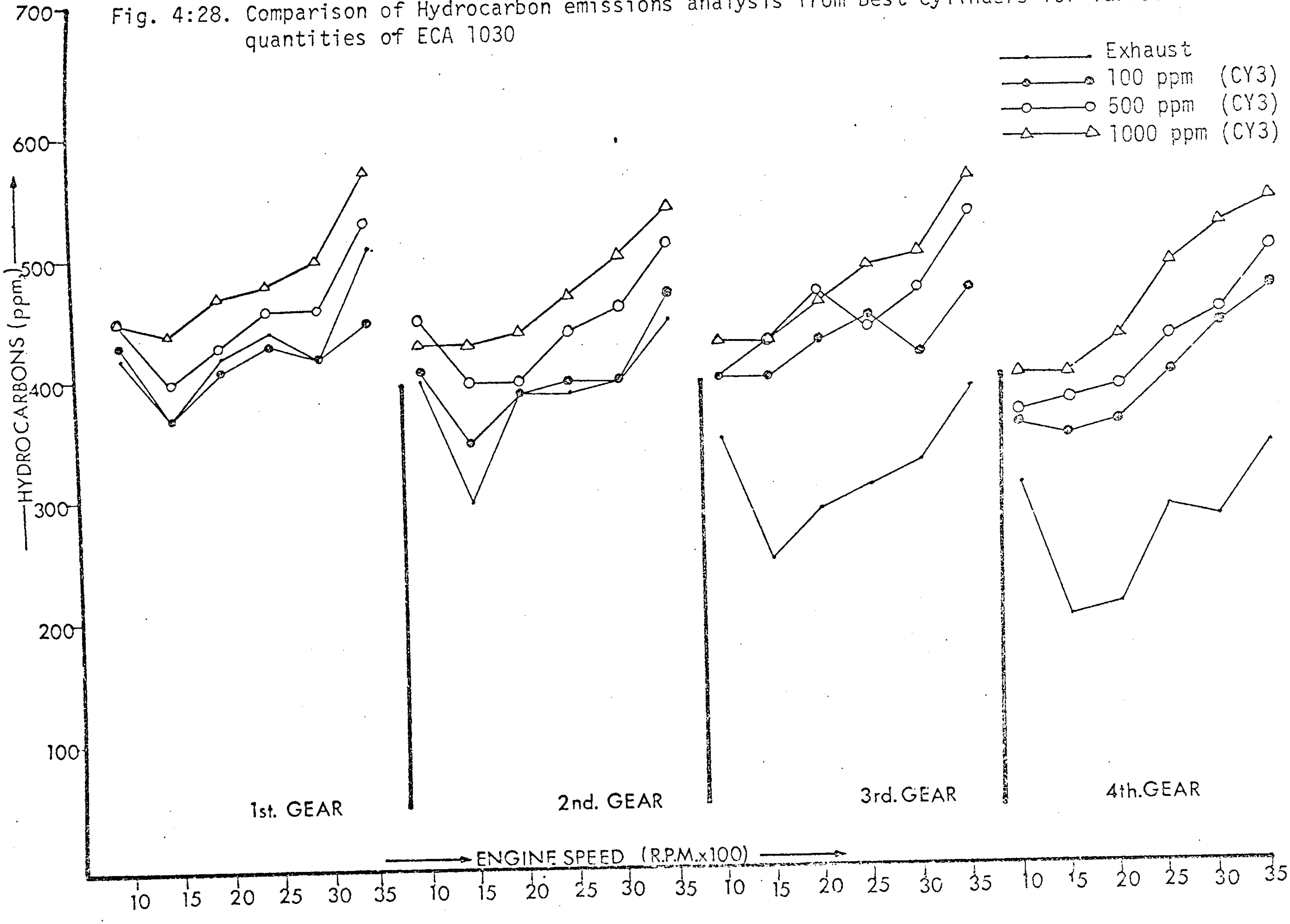


Fig. 4:29. Comparison of Hydrocarbon emissions analysis from Worst cylinders for various quantities of ECA 1030

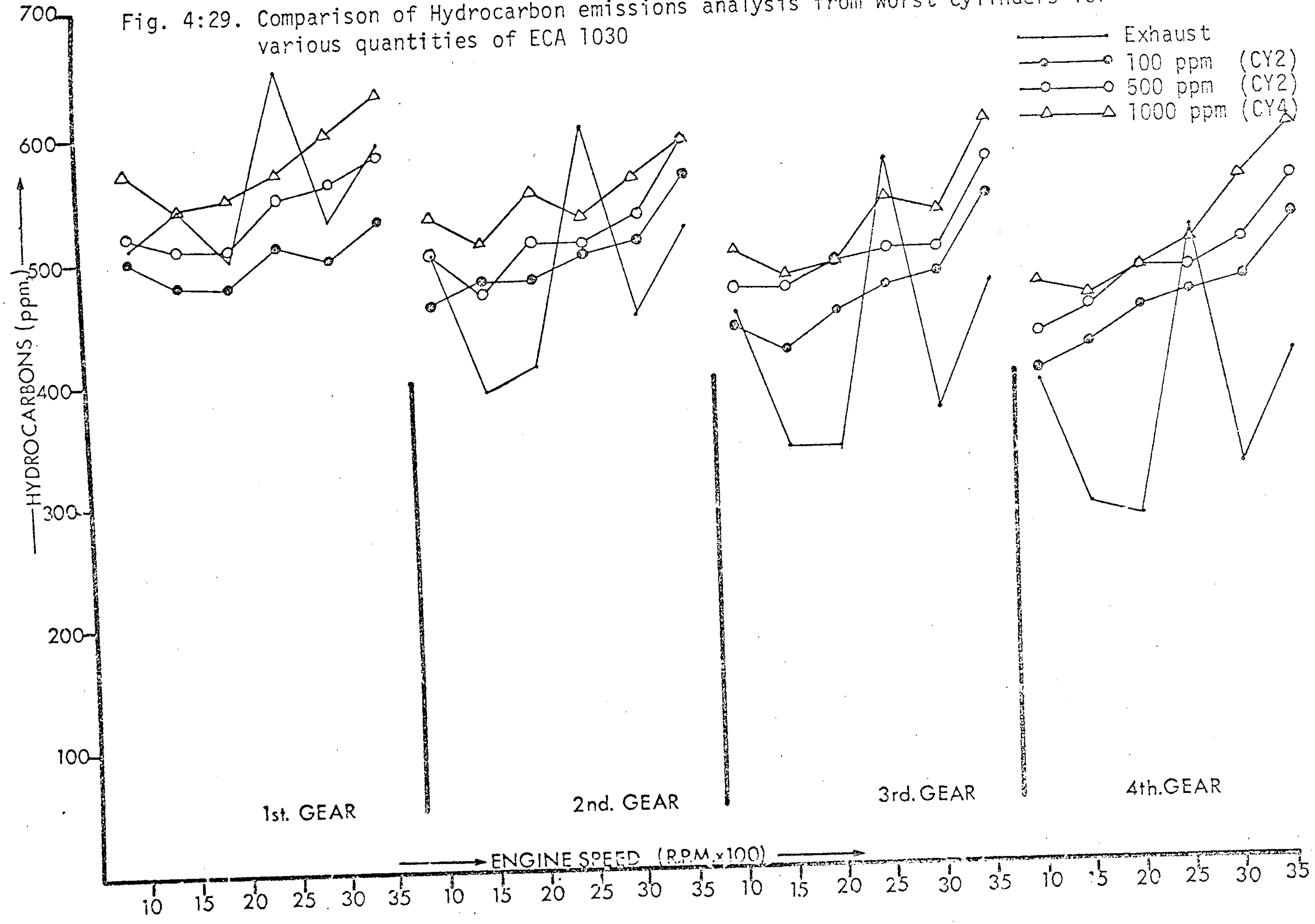


Fig. 4:30. Comparison of Hydrocarbon emissions Averages for various quantities of ECA 1030

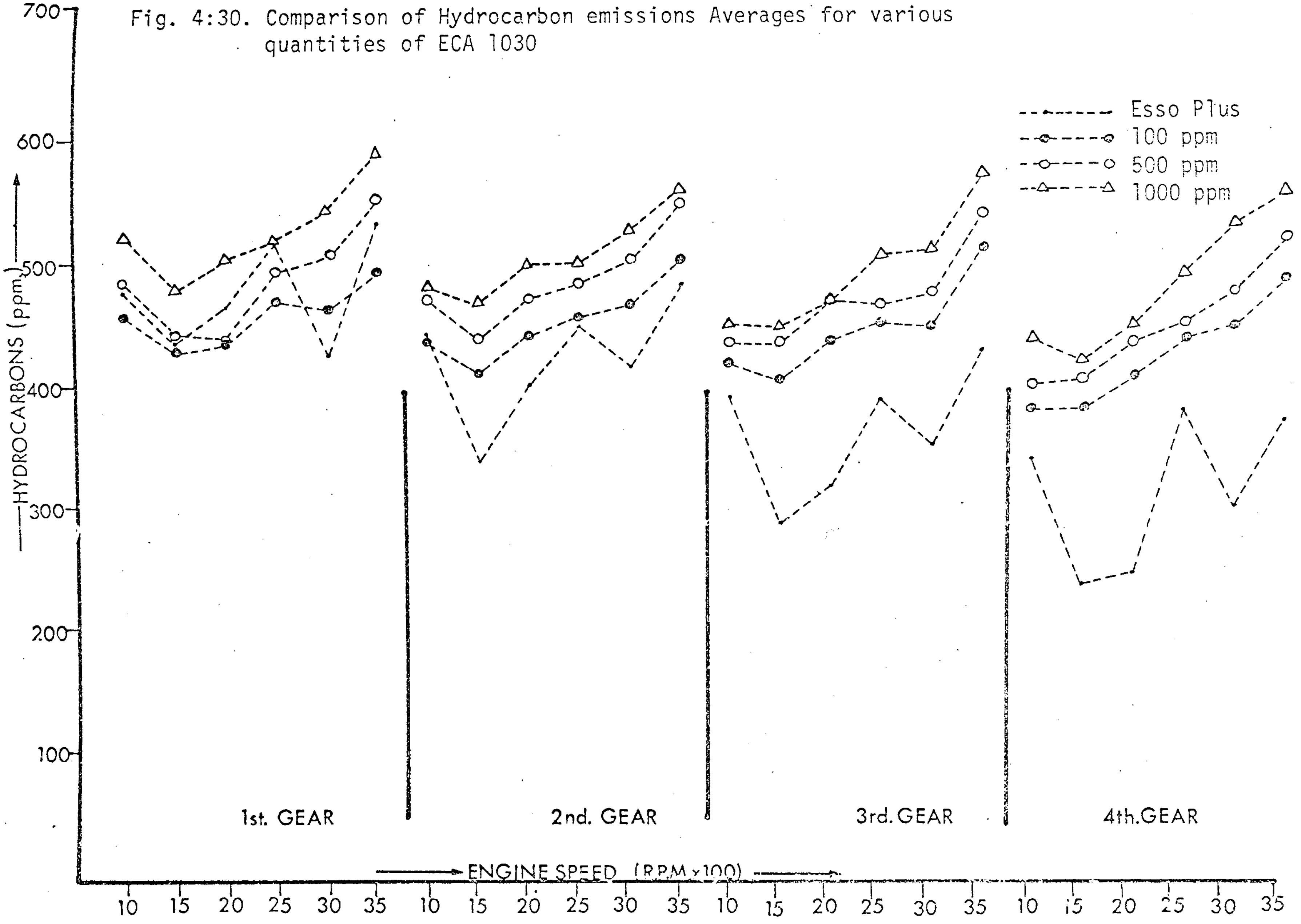


Fig: 4:31. Comparison of Hydrocarbon emissions from Mixed exhaust for the best quantities of additives used

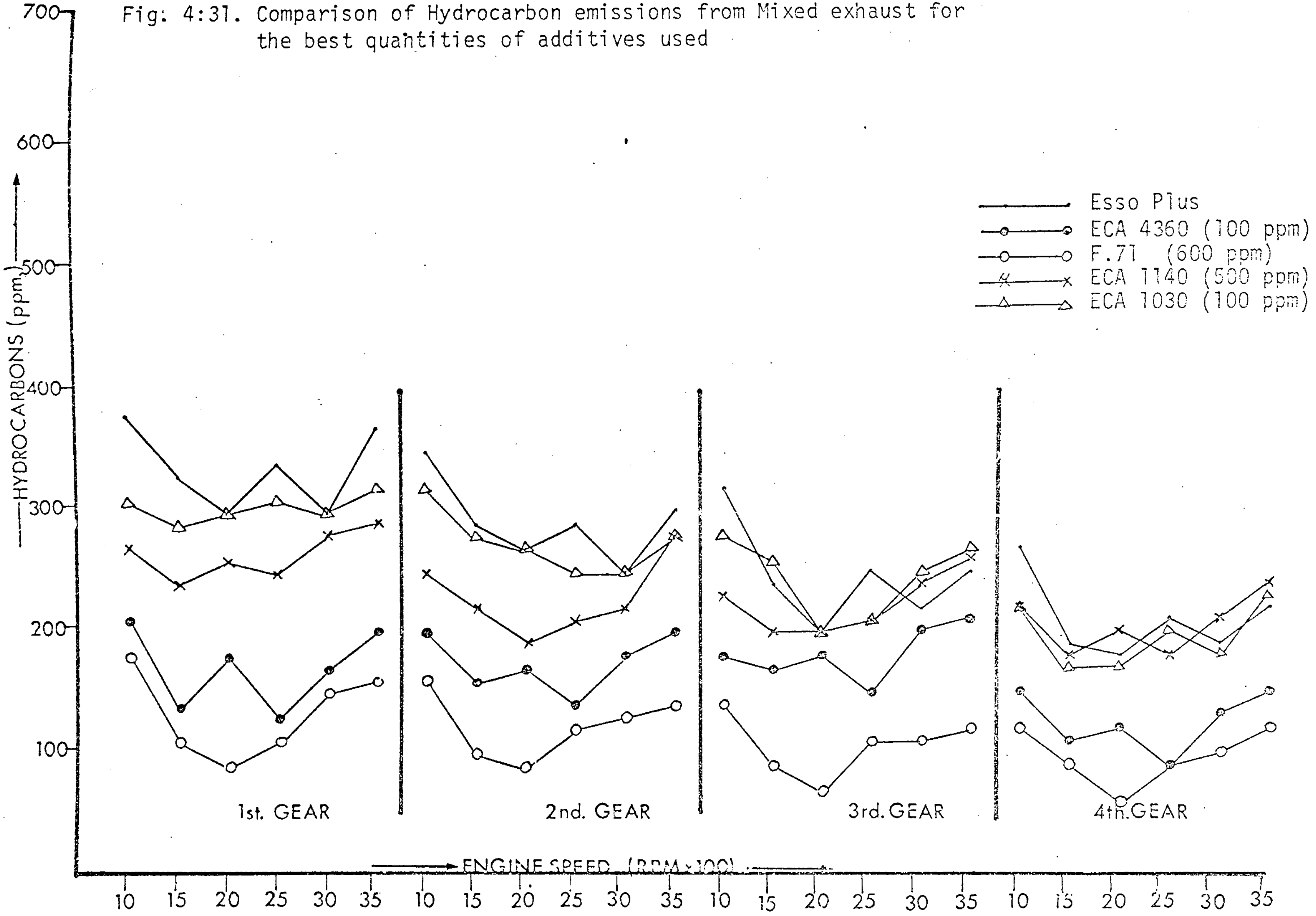


Fig. 4:32. Comparison of Hydrocarbon emissions from Best cylinders for the best quantities of additives used

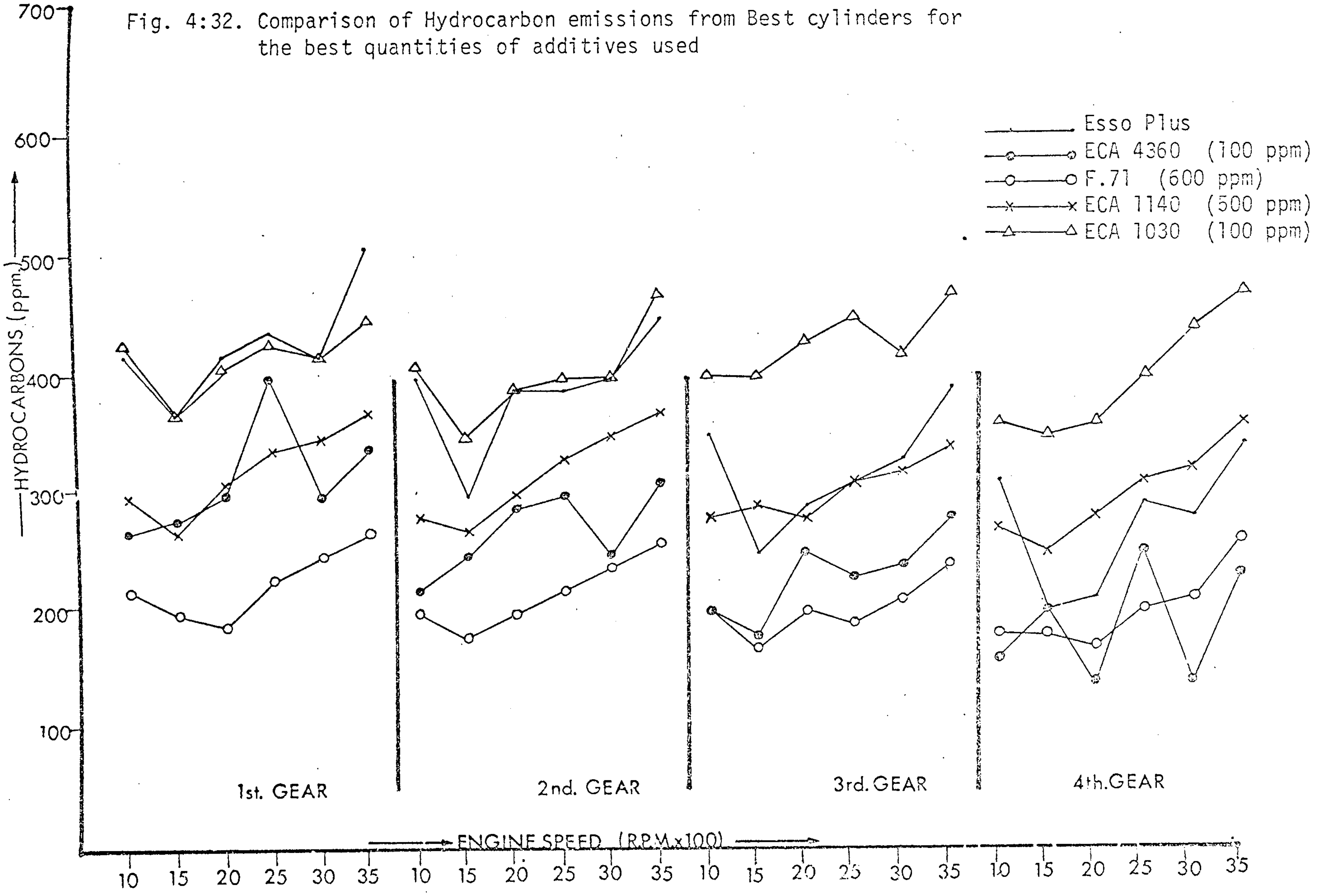


Fig. 4:33. Comparison of Hydrocarbon emissions from Worst cylinders for the best quantities of additives used

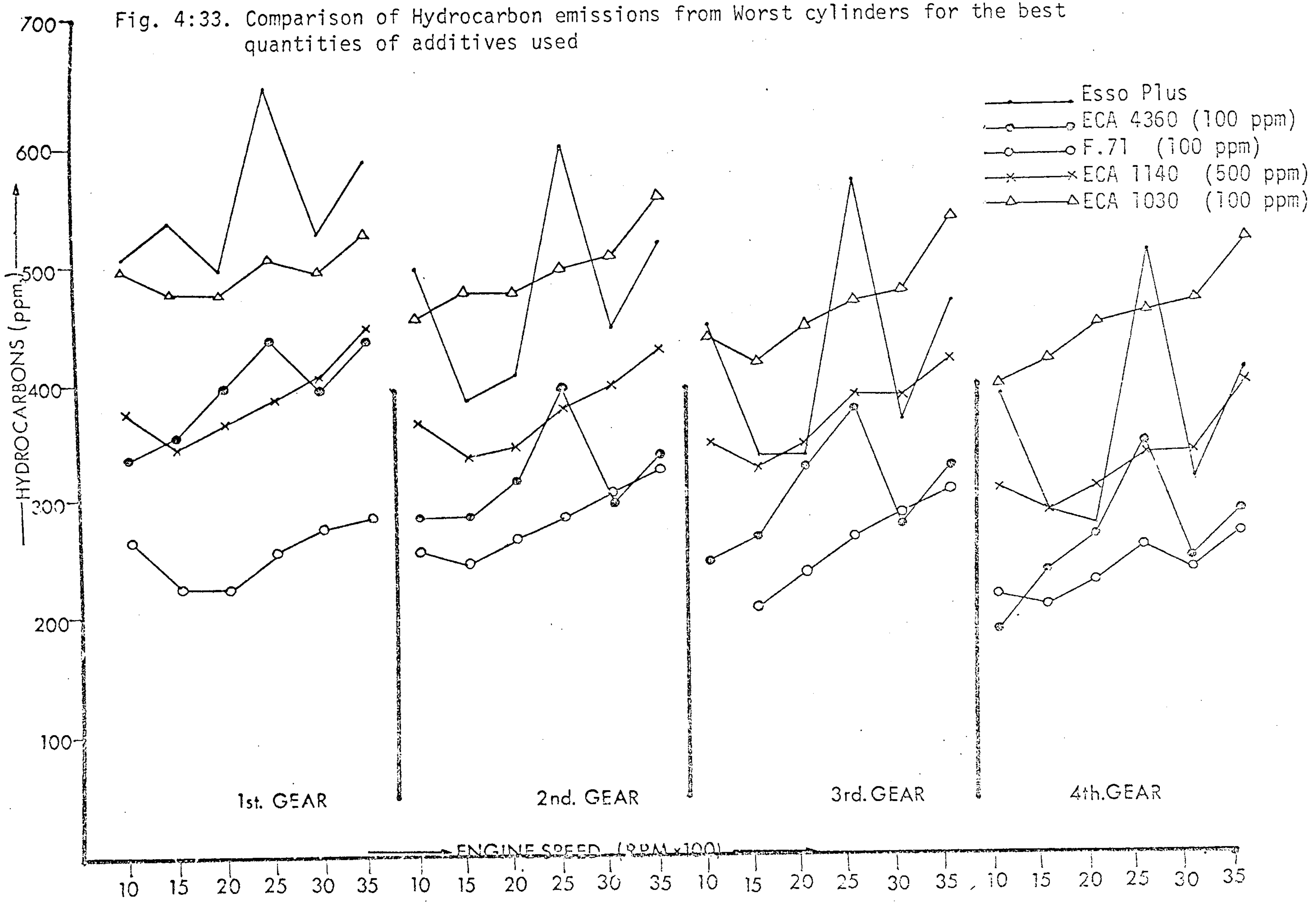


Fig. 4:34. Comparison of Hydrocarbon emissions for Averages for the best quantities of additives used

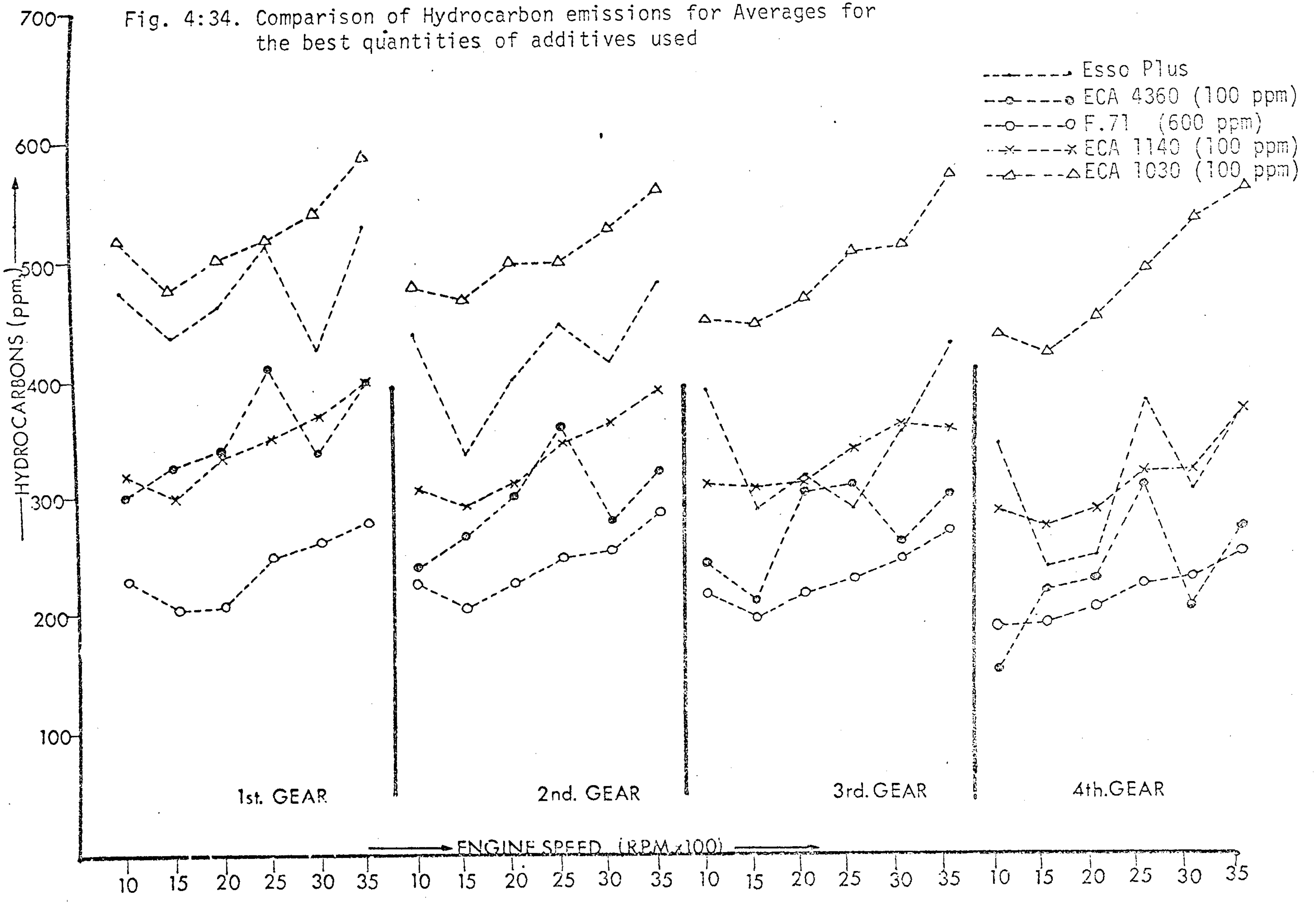
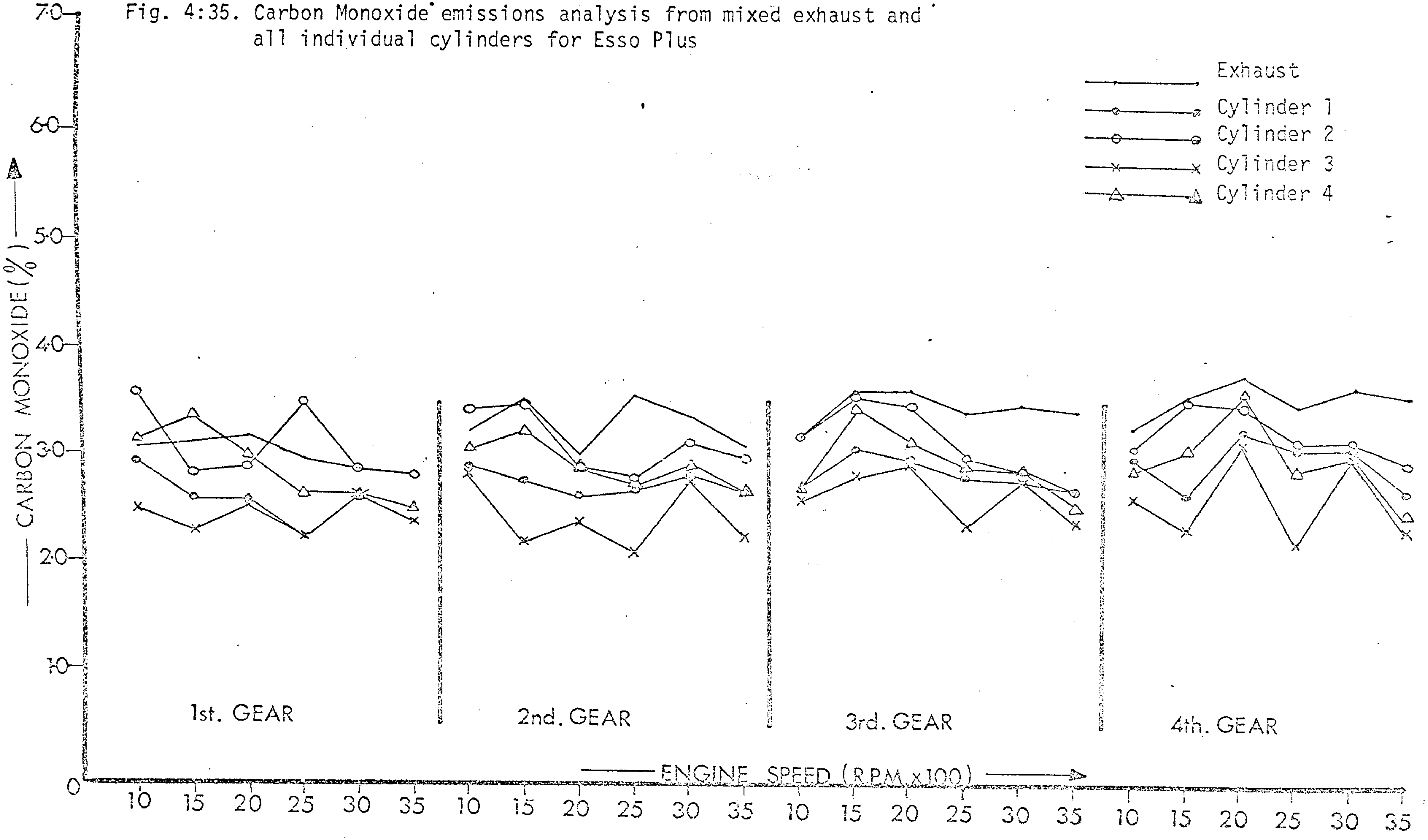


Fig. 4:35. Carbon Monoxide emissions analysis from mixed exhaust and all individual cylinders for Esso Plus



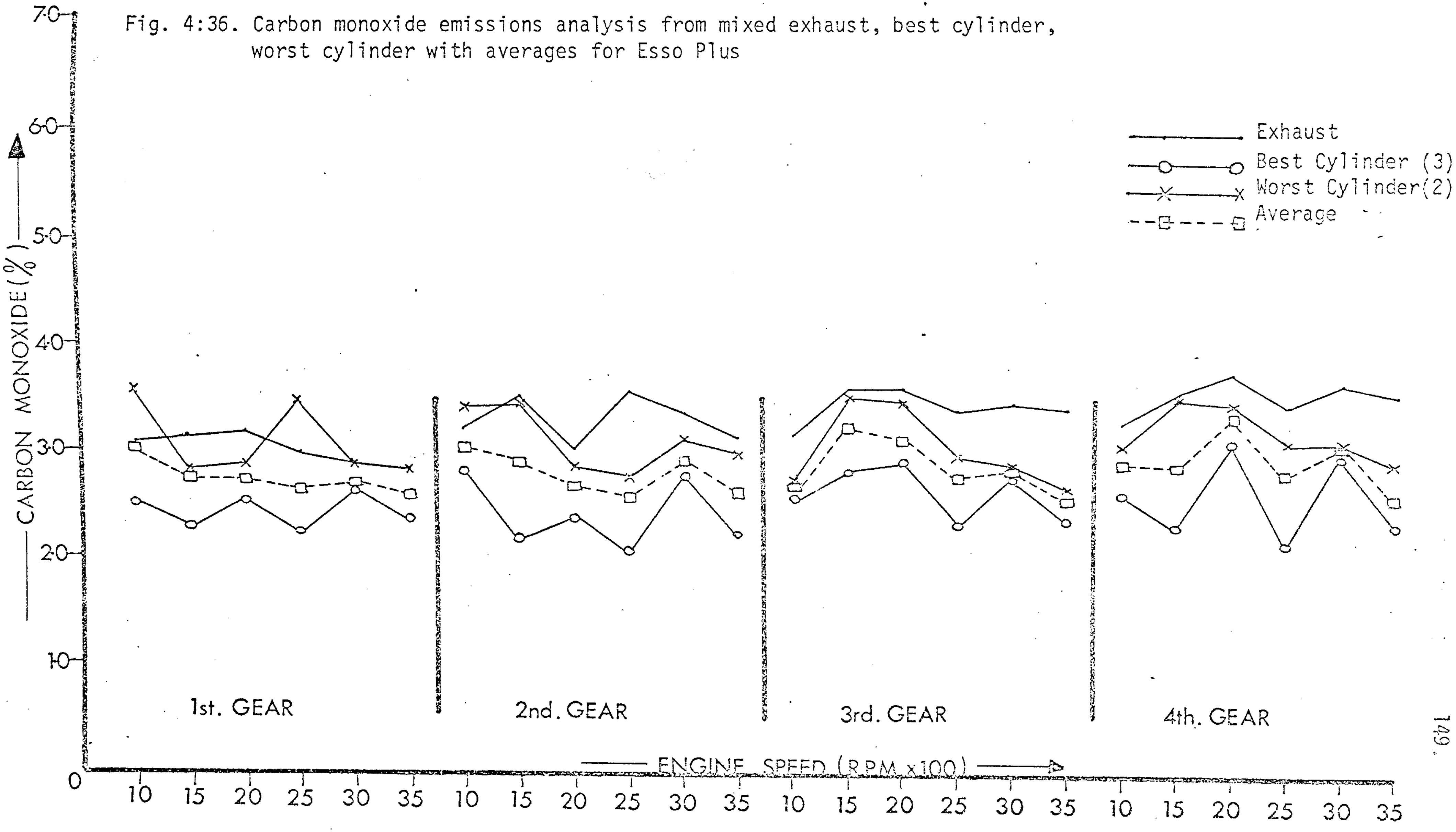


Fig. 4:36. Carbon monoxide emissions analysis from mixed exhaust, best cylinder, worst cylinder with averages for Esso Plus

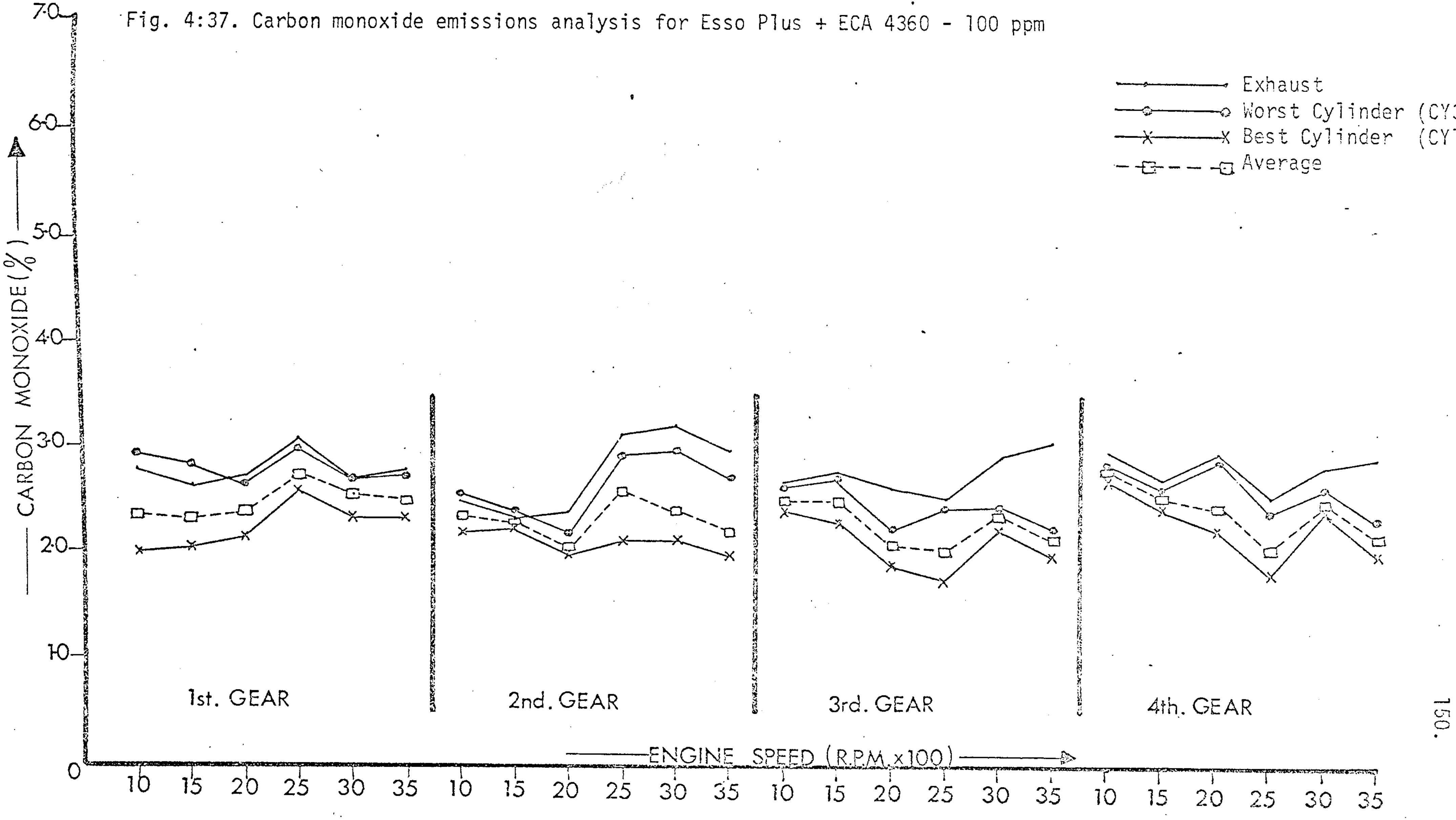


Fig. 4:37. Carbon monoxide emissions analysis for Esso Plus + ECA 4360 - 100 ppm

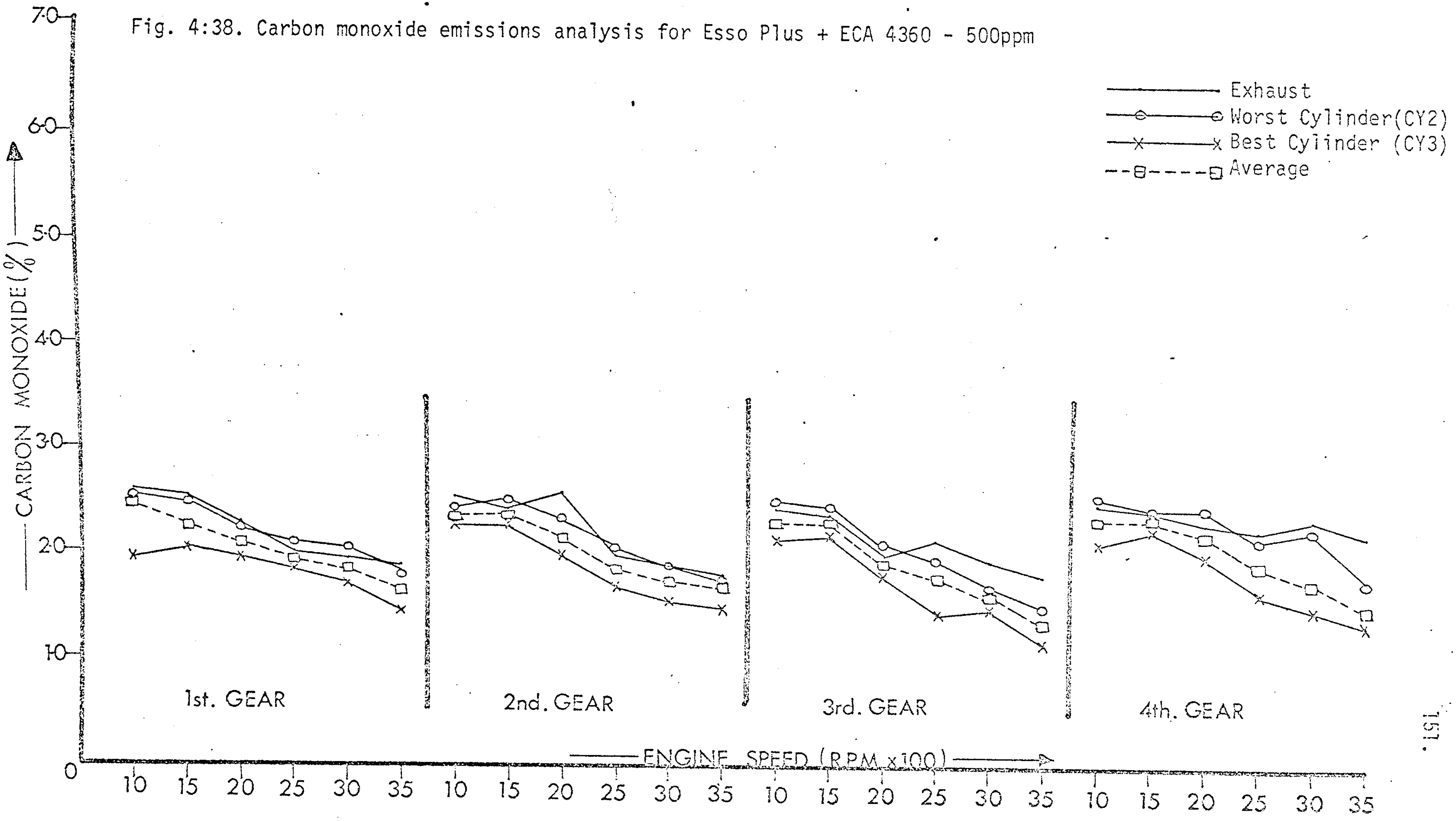


Fig. 4:38. Carbon monoxide emissions analysis for Esso Plus + ECA 4360 - 500ppm

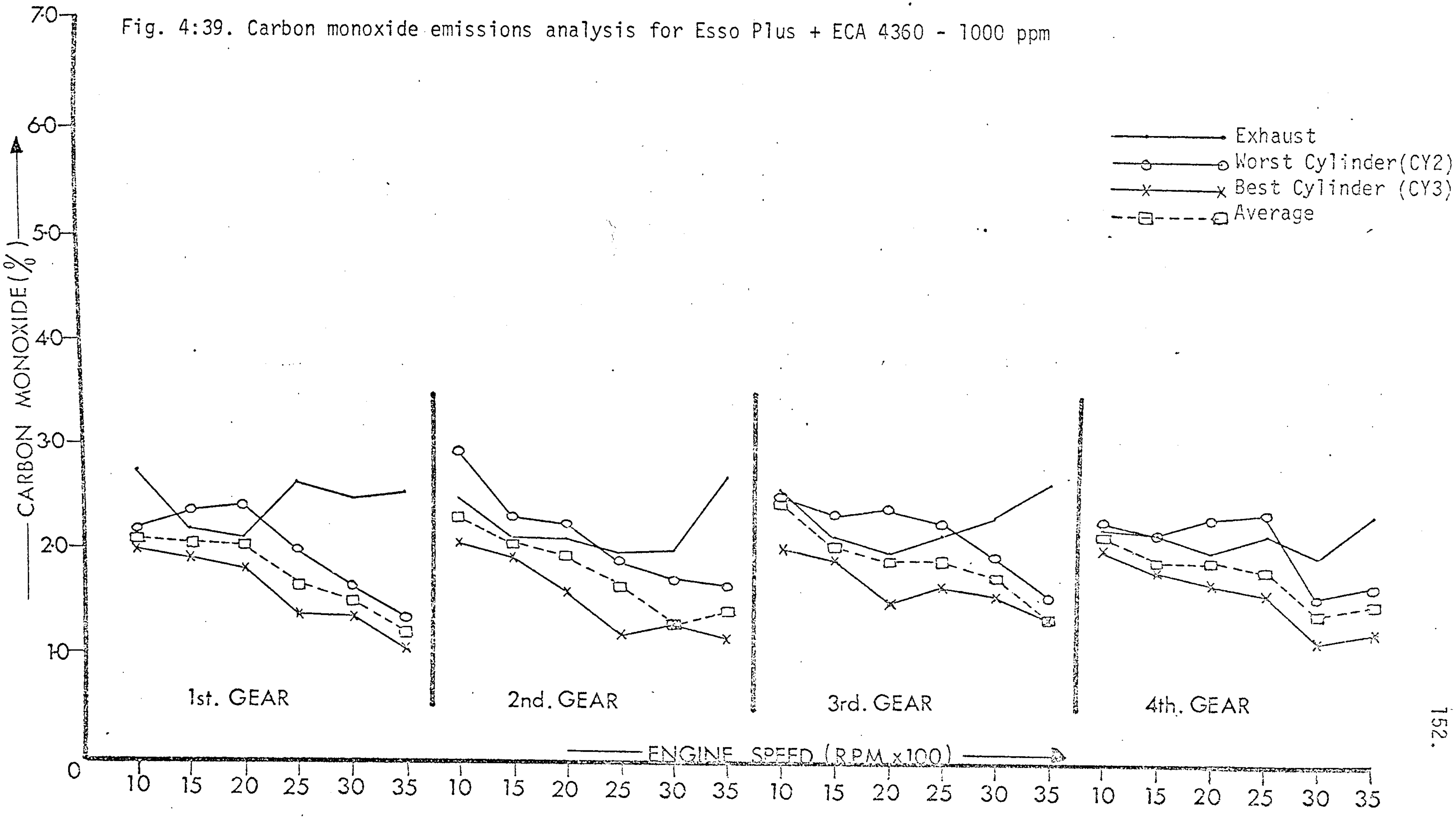


Fig. 4:39. Carbon monoxide emissions analysis for Esso Plus + ECA 4360 - 1000 ppm

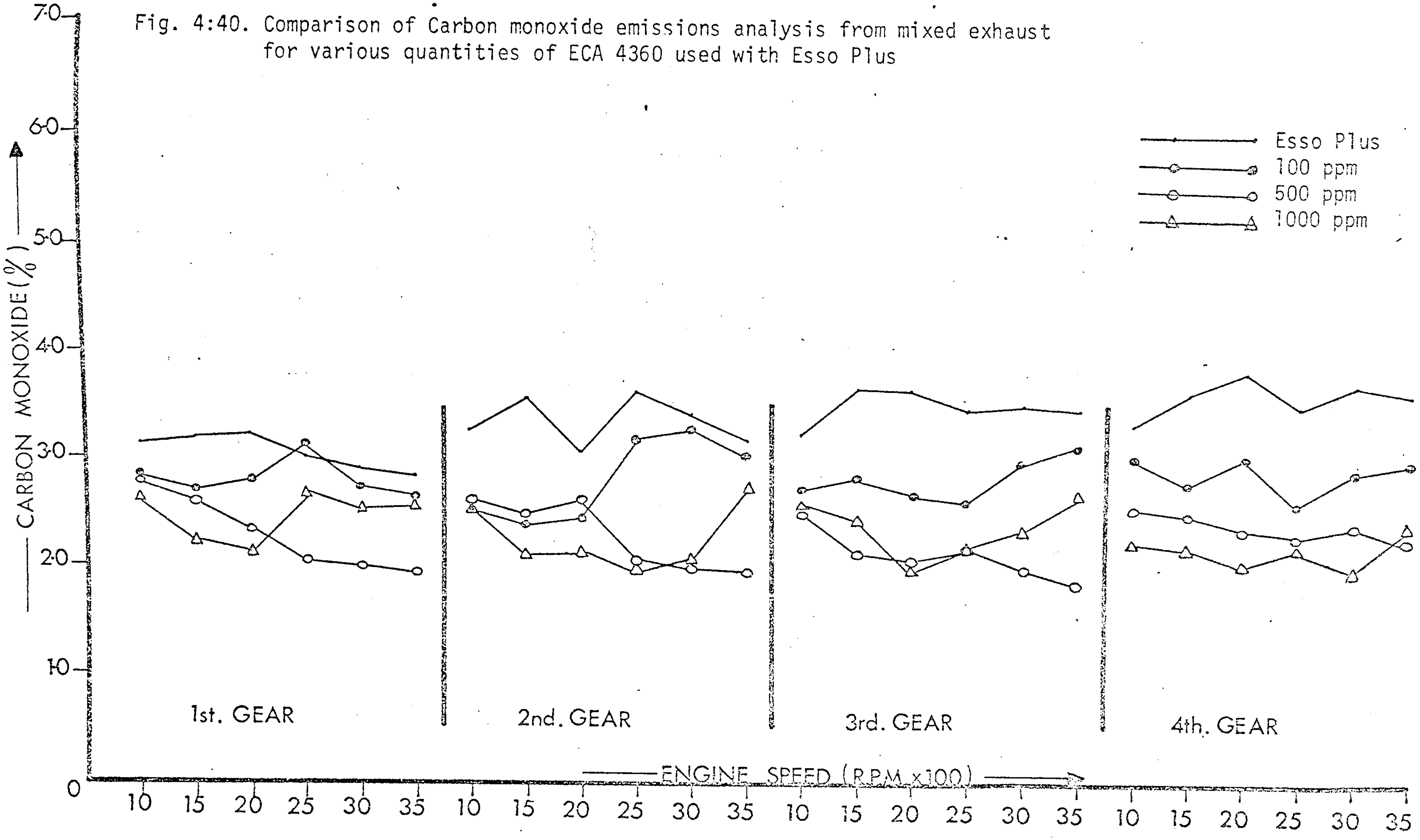
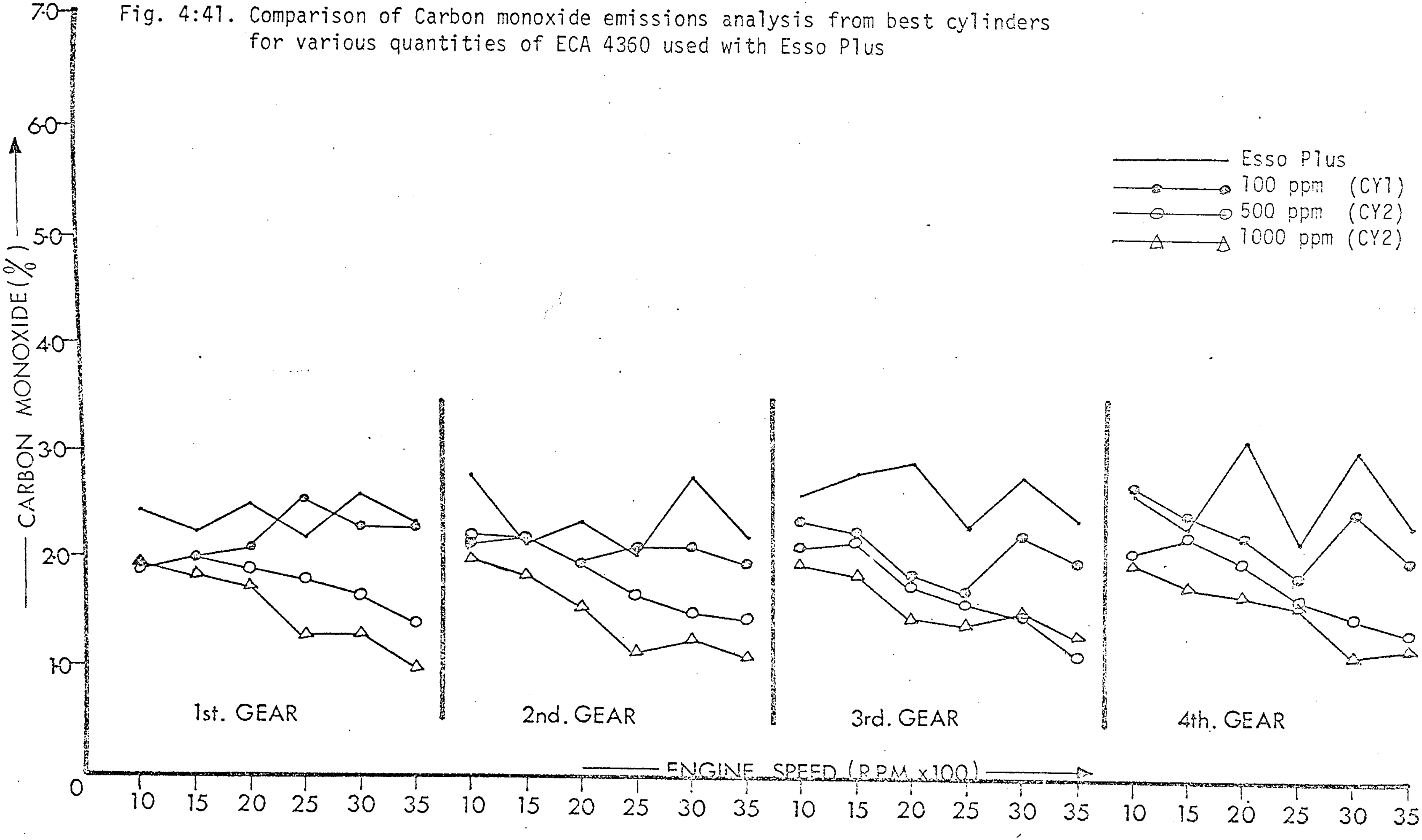


Fig. 4:40. Comparison of Carbon monoxide emissions analysis from mixed exhaust for various quantities of ECA 4360 used with Esso Plus

Fig. 4:41. Comparison of Carbon monoxide emissions analysis from best cylinders for various quantities of ECA 4360 used with Esso Plus



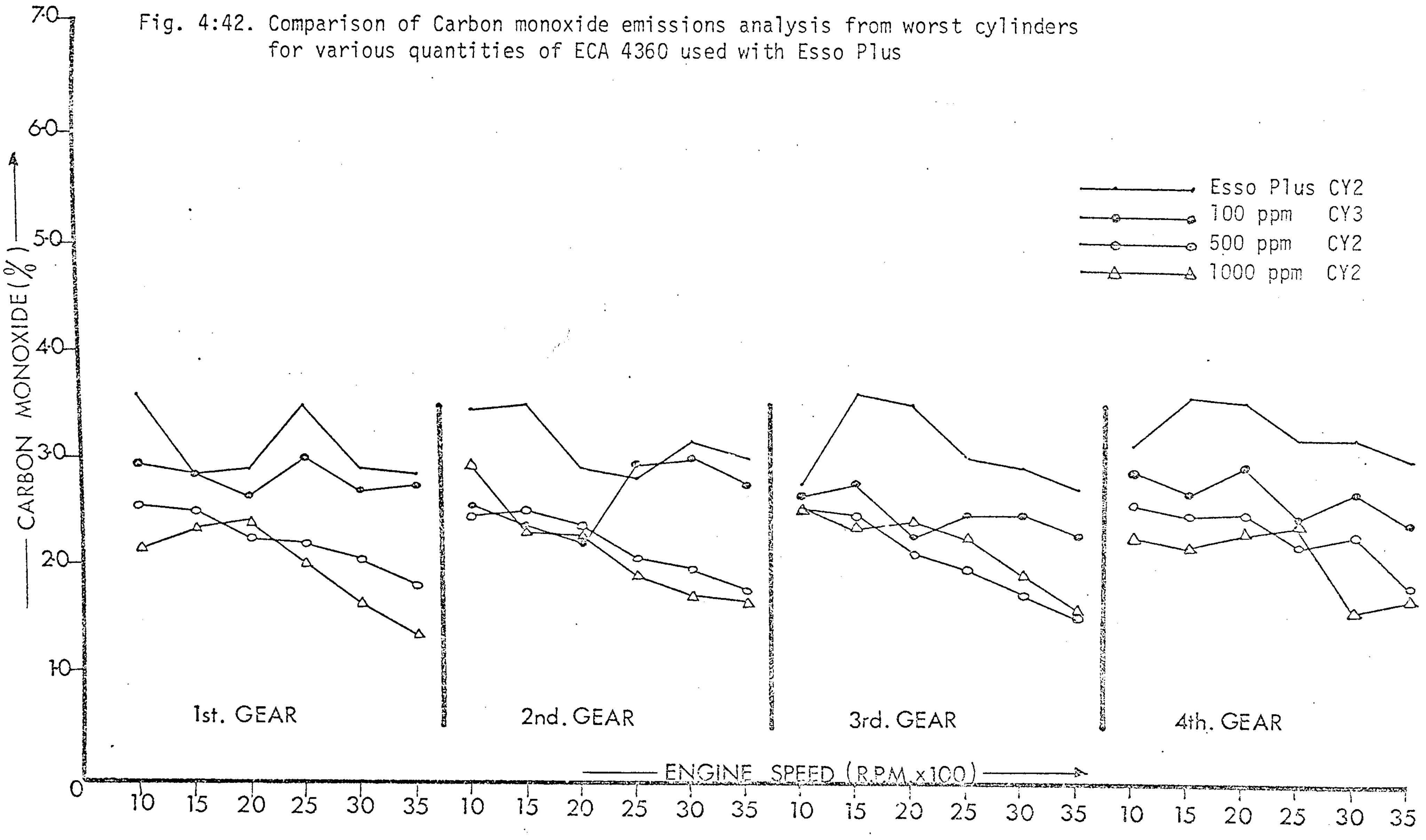


Fig. 4:42. Comparison of Carbon monoxide emissions analysis from worst cylinders for various quantities of ECA 4360 used with Esso Plus

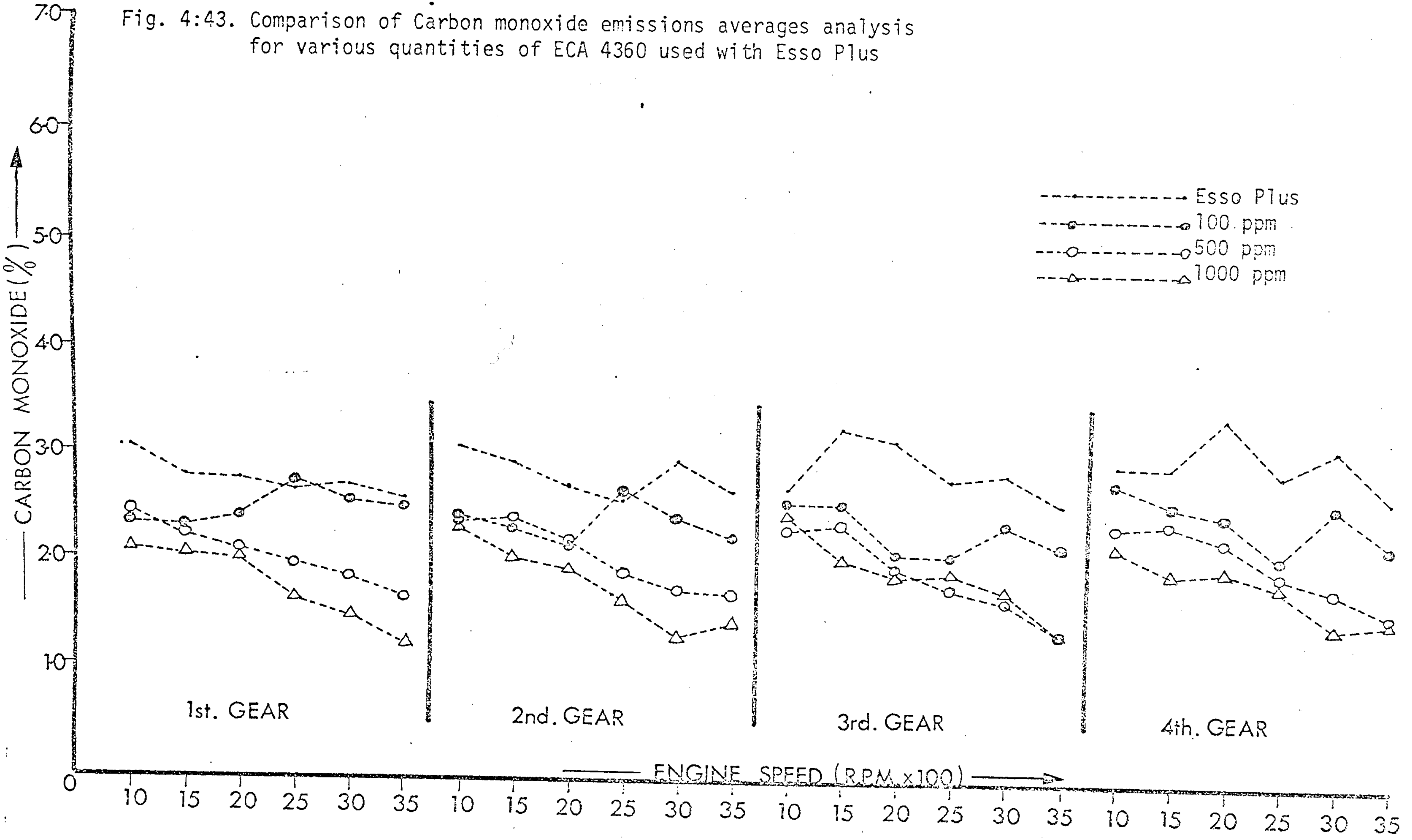


Fig. 4:43. Comparison of Carbon monoxide emissions averages analysis for various quantities of ECA 4360 used with Esso Plus

Fig. 4:44. Carbon monoxide emissions analysis for Esso Plus + F.71 - 600 ppm

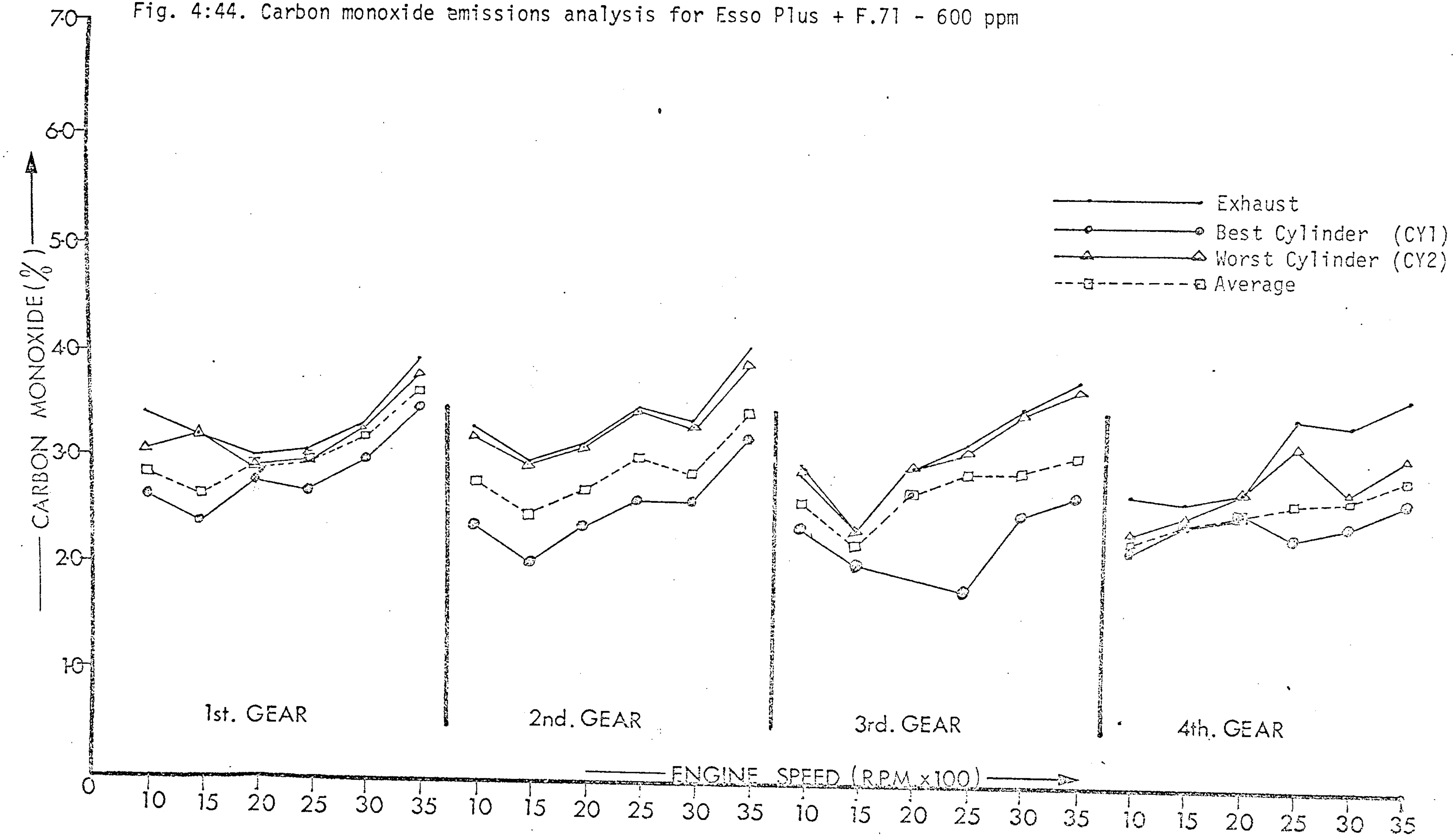


Fig. 4:45. Carbon monoxide emissions analysis for Esso Plus + F.71 - 1000 ppm

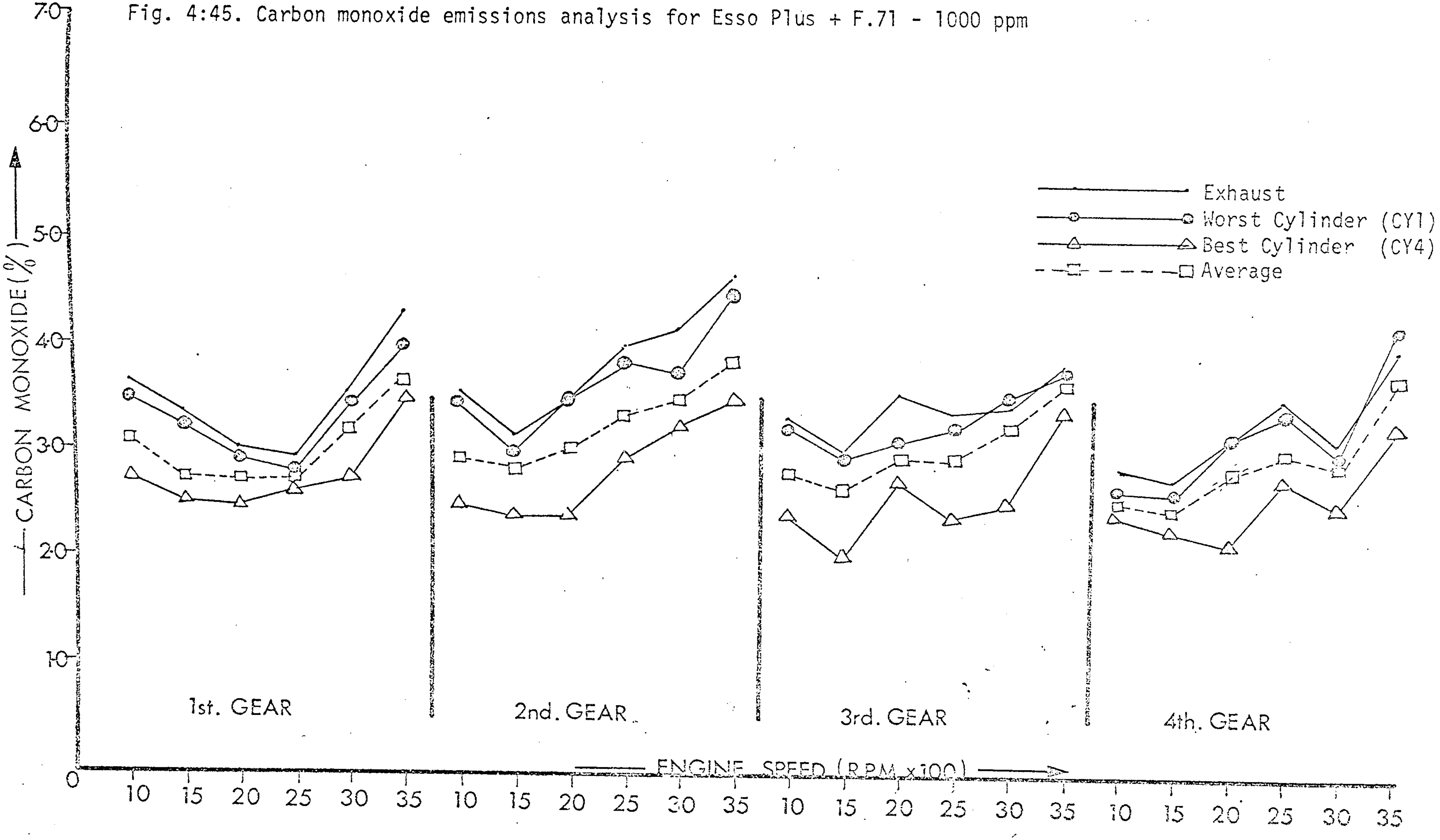


Fig. 4:46. Carbon monoxide emission analysis for Esso Plus + F.71 - 2000 ppm

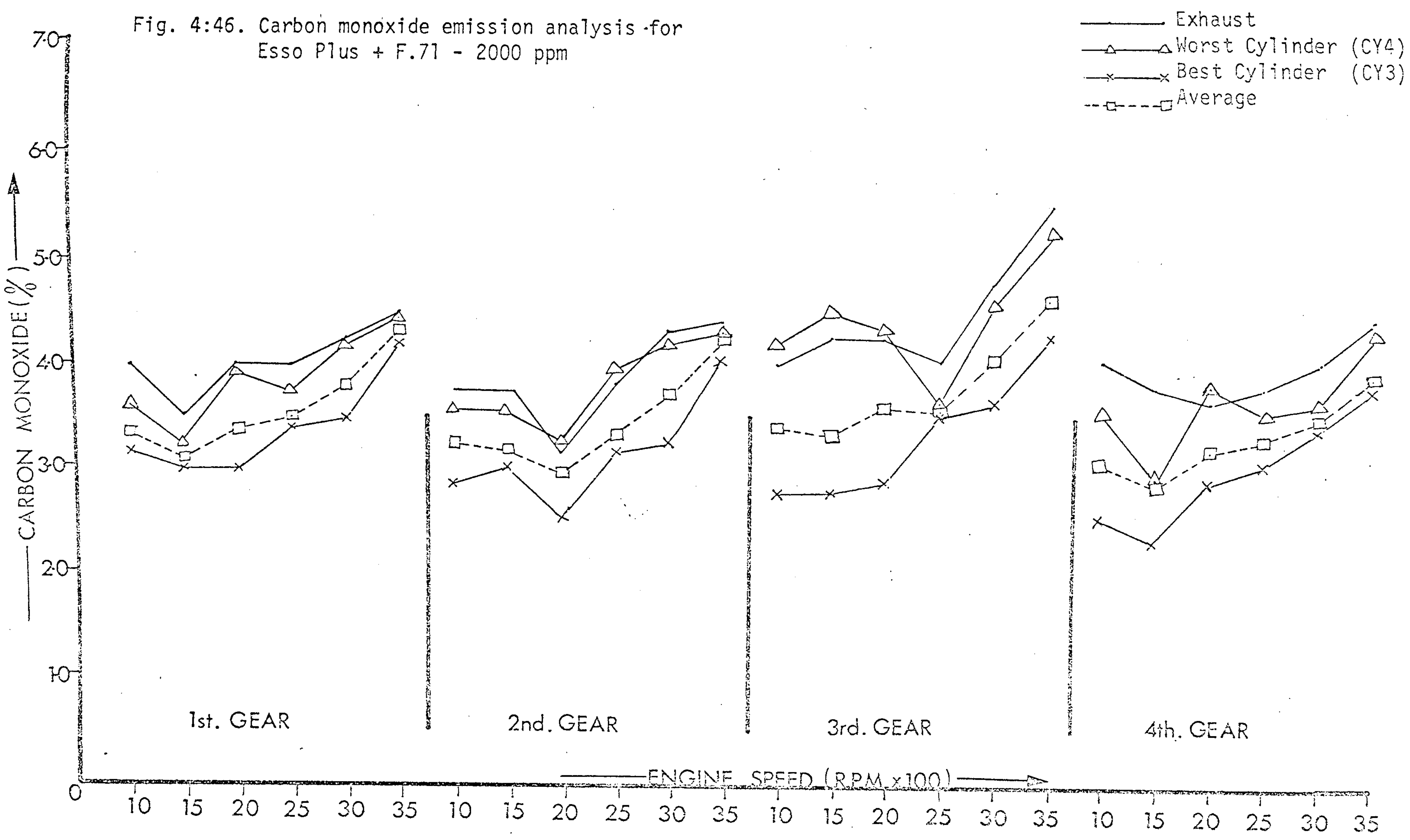
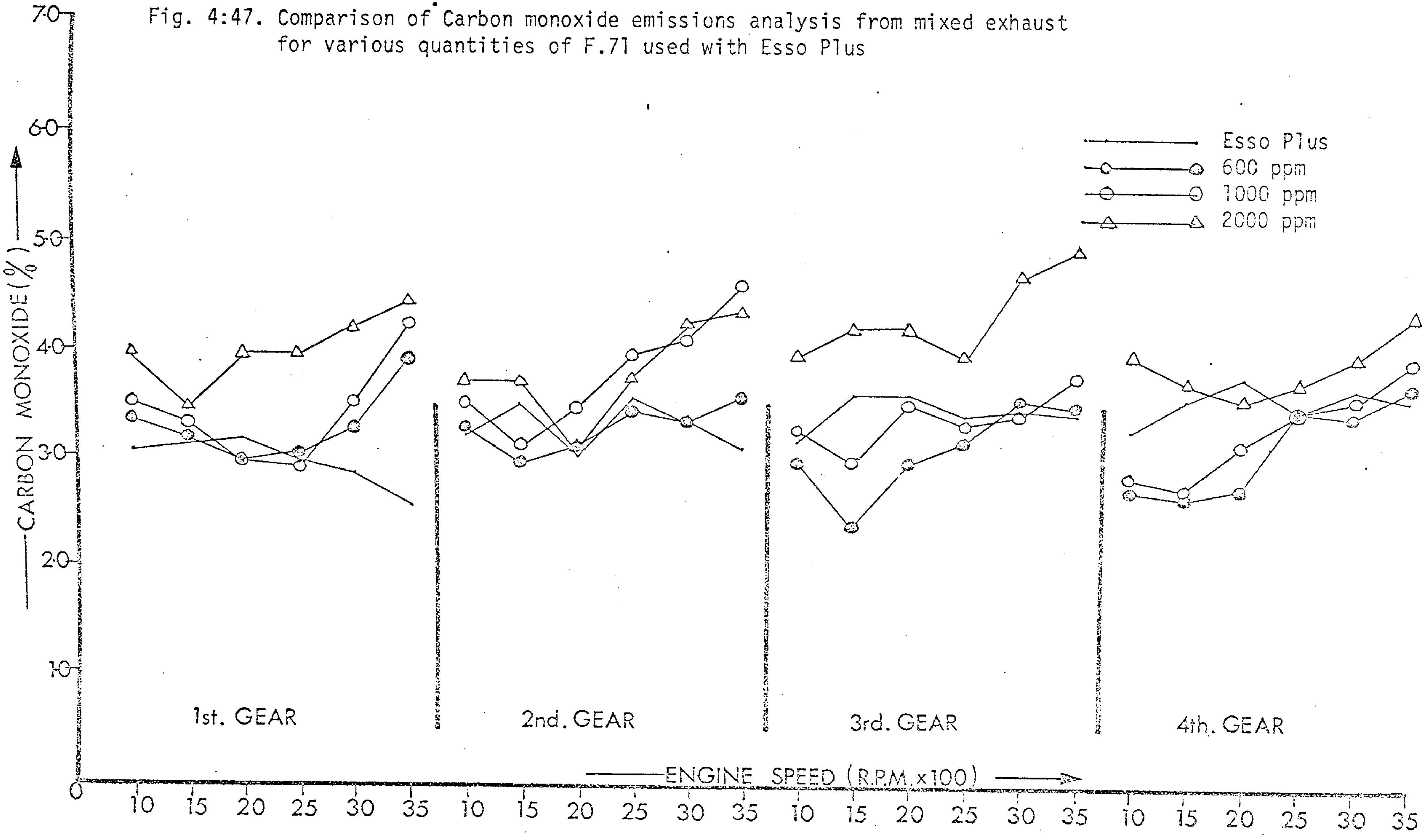


Fig. 4:47. Comparison of Carbon monoxide emissions analysis from mixed exhaust for various quantities of F.71 used with Esso Plus



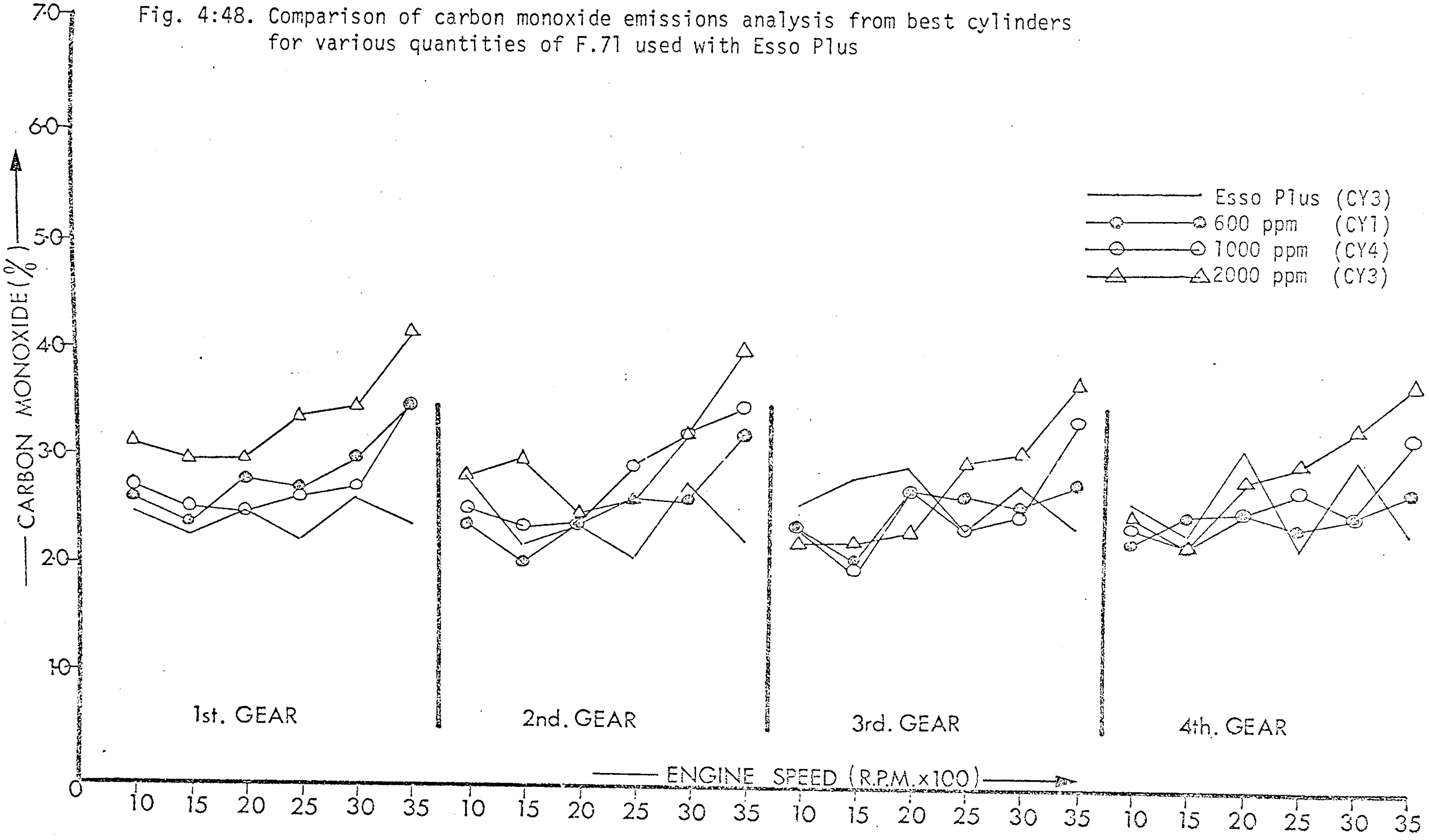


Fig. 4:48. Comparison of carbon monoxide emissions analysis from best cylinders for various quantities of F.71 used with Esso Plus

Fig. 4:49. Comparison of carbon monoxide emissions analysis from worst cylinders for various quantities of F.71 used with Esso Plus

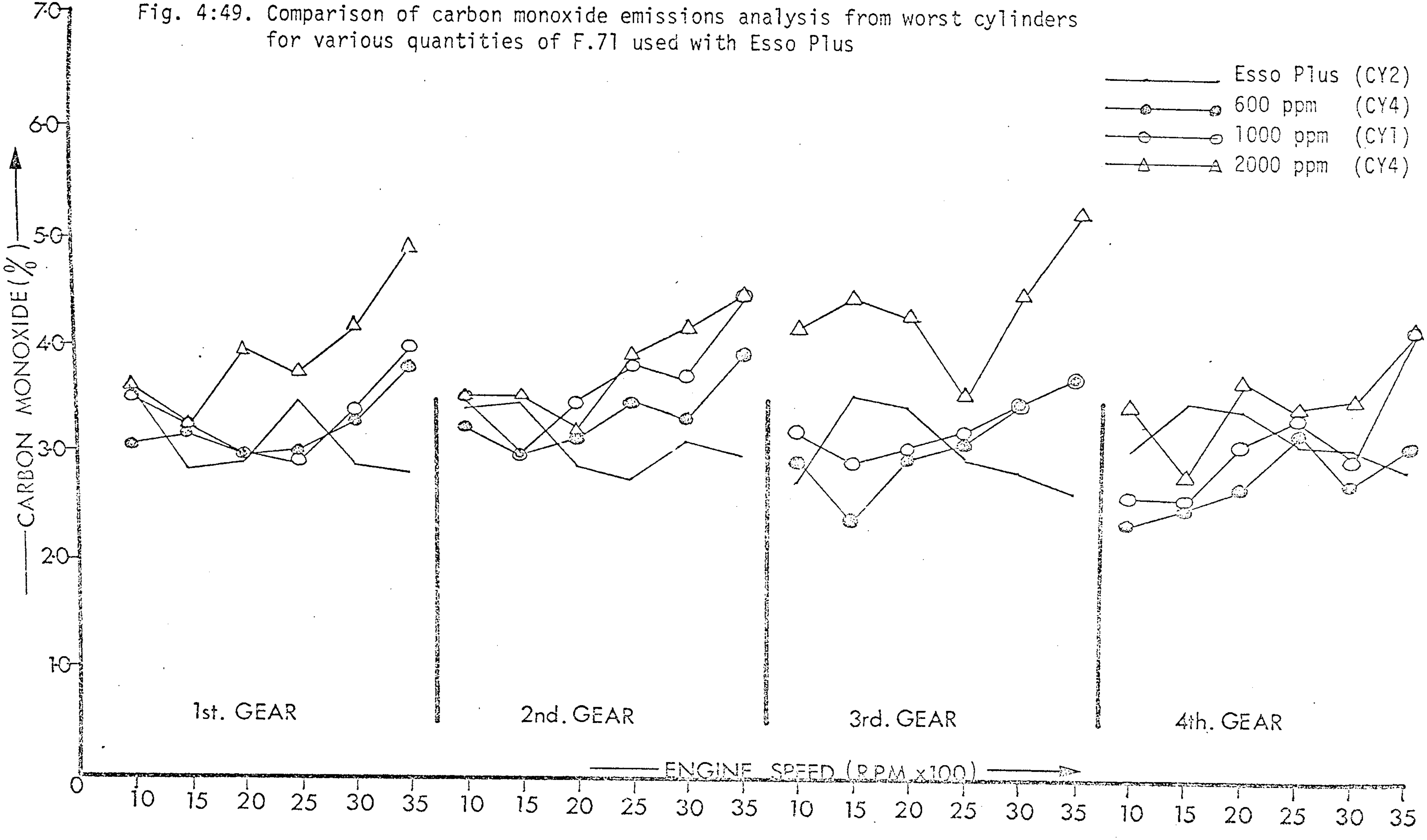


Fig. 4:50 Comparison of carbon monoxide emissions averages analysis for various quantities of F.71 used with Esso Plus

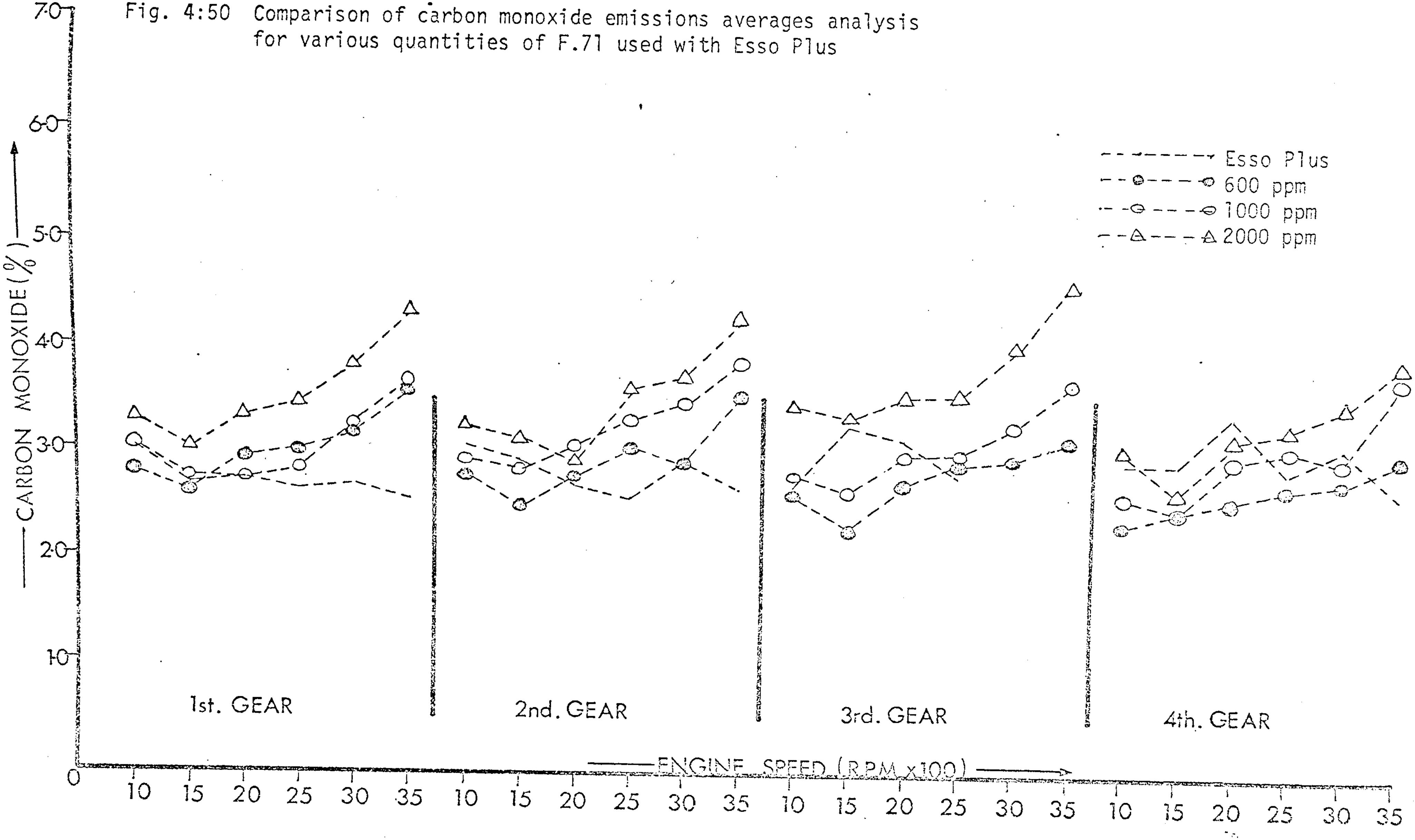
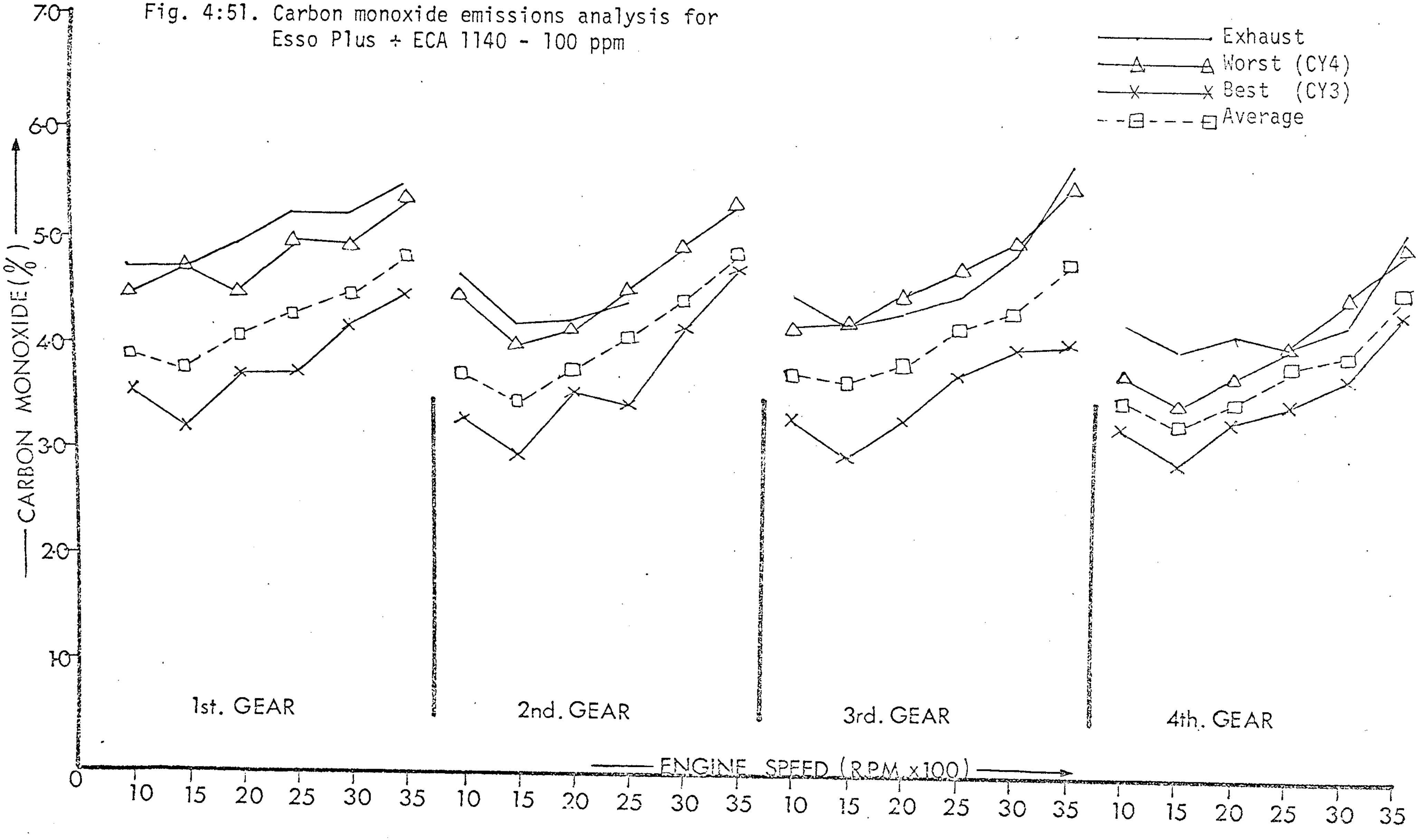


Fig. 4:51. Carbon monoxide emissions analysis for Esso Plus + ECA 1140 - 100 ppm



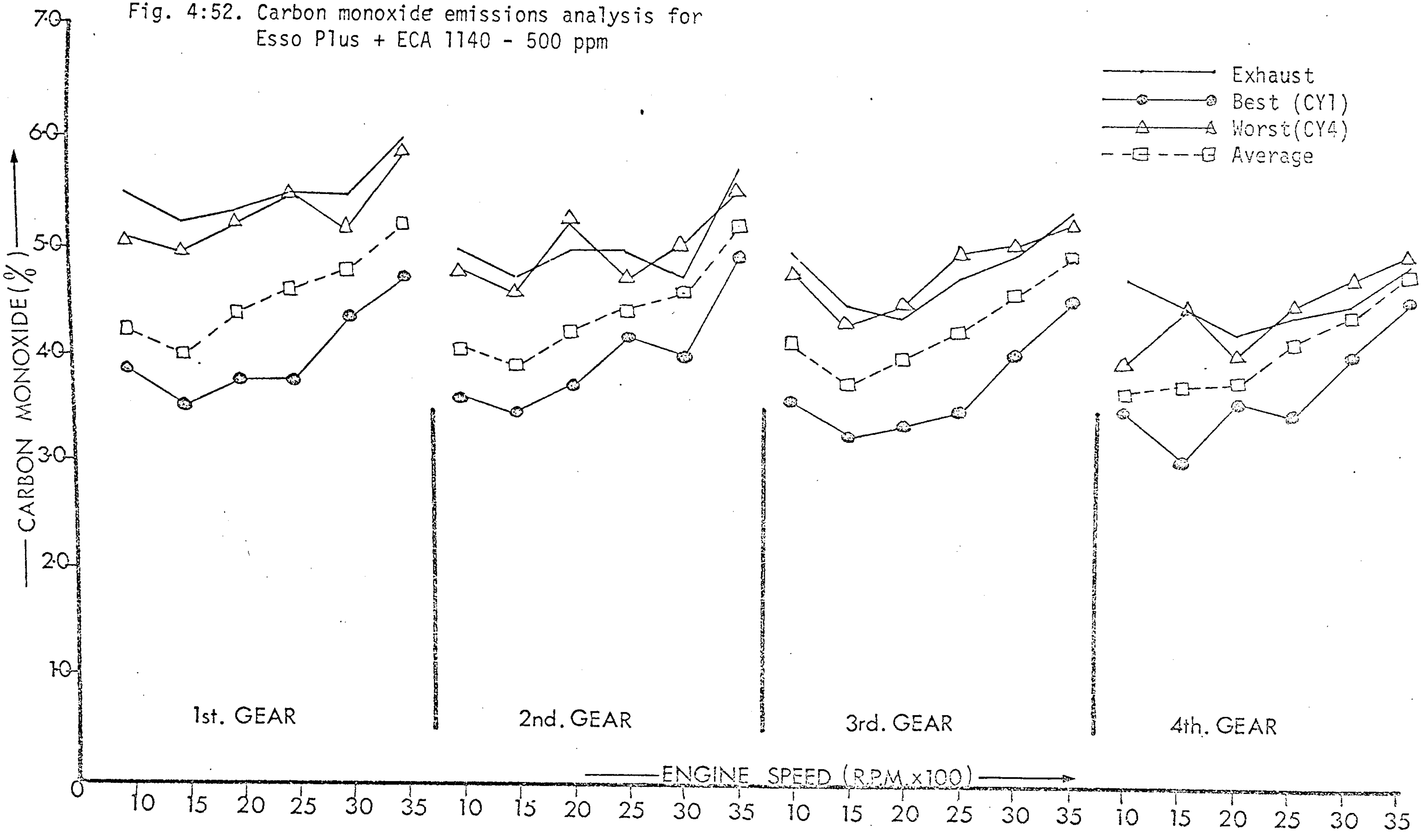


Fig. 4:52. Carbon monoxide emissions analysis for Esso Plus + ECA 1140 - 500 ppm

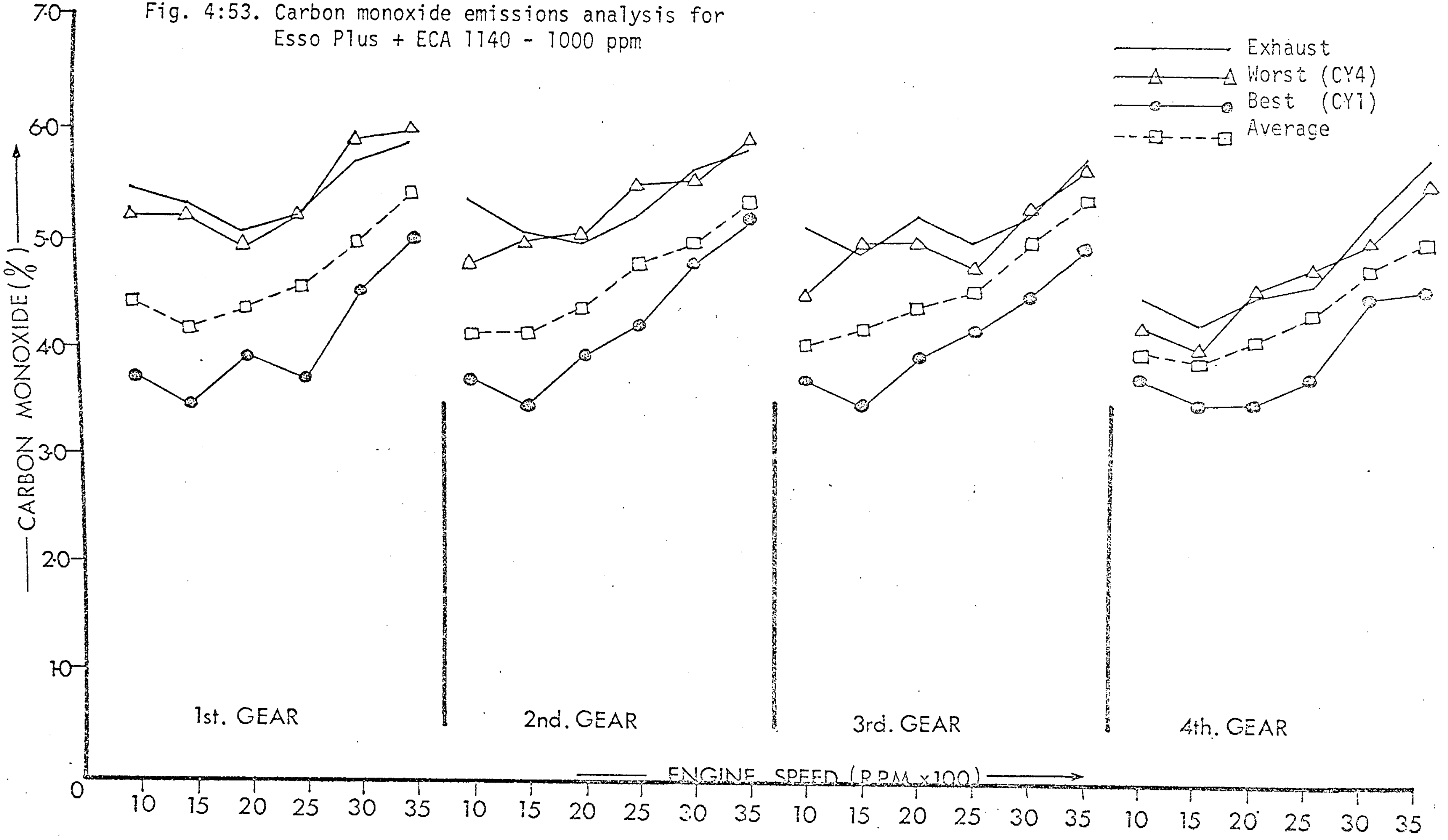


Fig. 4:53. Carbon monoxide emissions analysis for Esso Plus + ECA 1140 - 1000 ppm

Fig. 4:54. Comparison of carbon monoxide emissions analysis from mixed exhaust for various quantities of ECA 1140 used with Esso Plus

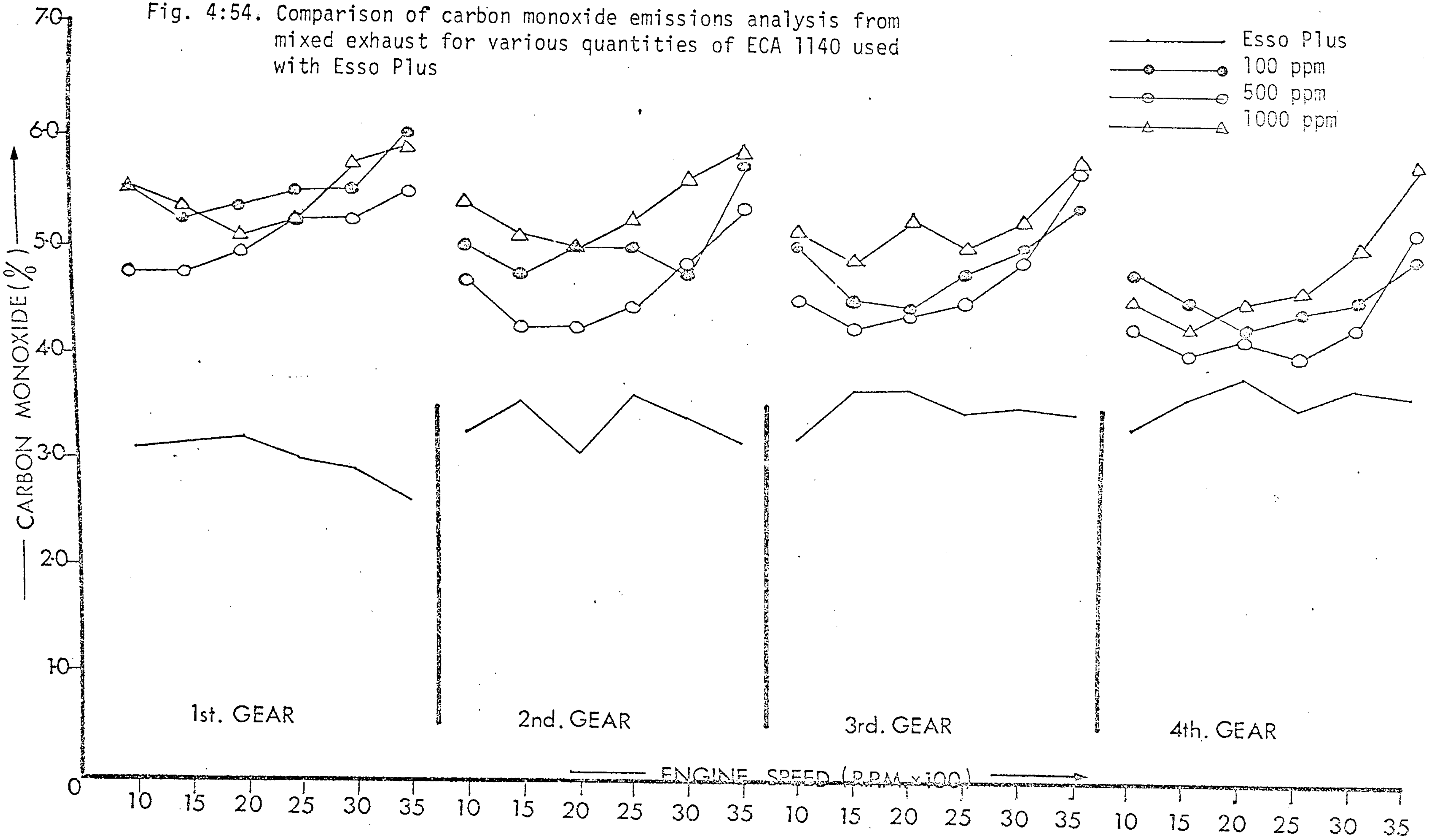
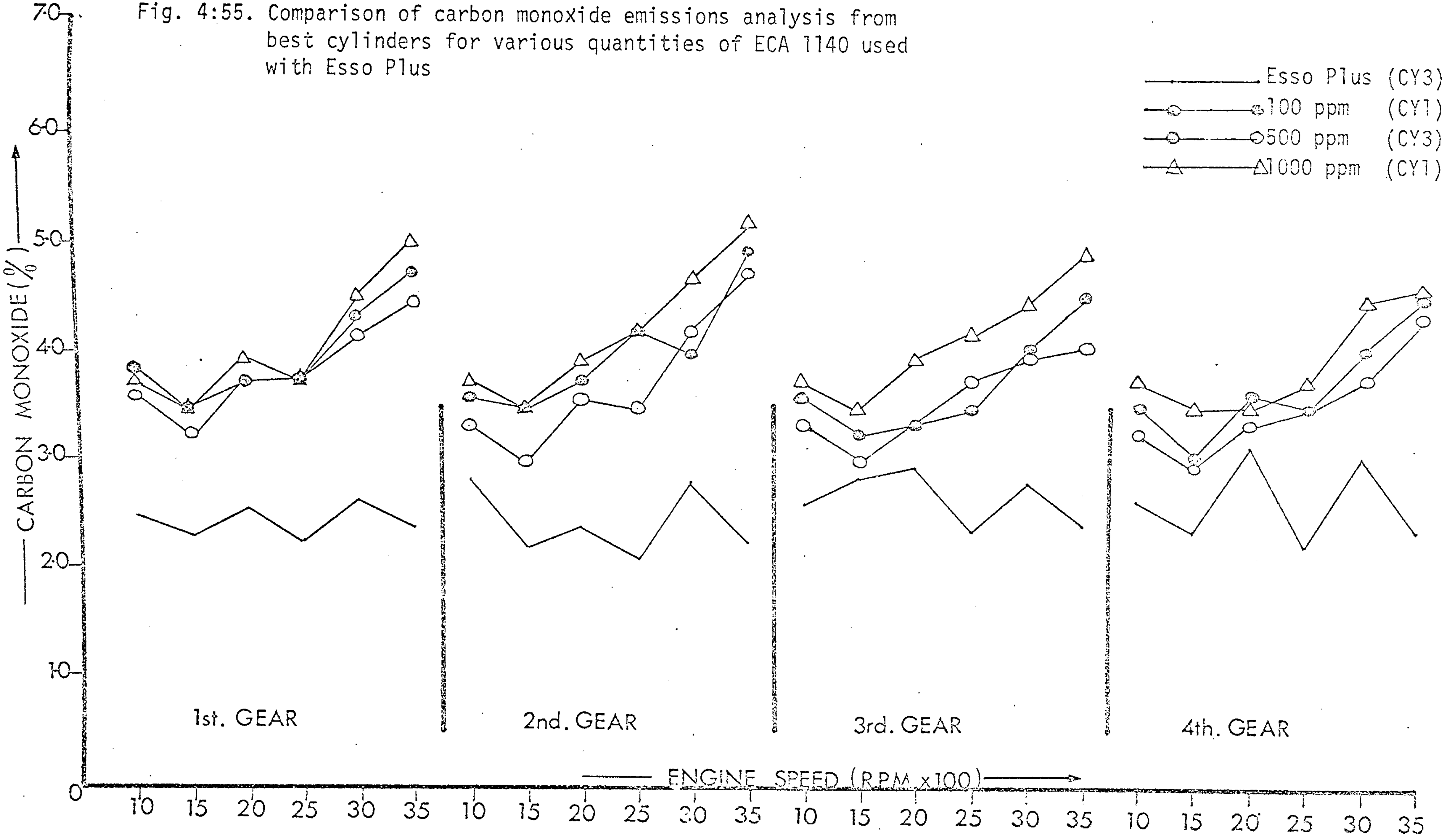


Fig. 4:55. Comparison of carbon monoxide emissions analysis from best cylinders for various quantities of ECA 1140 used with Esso Plus



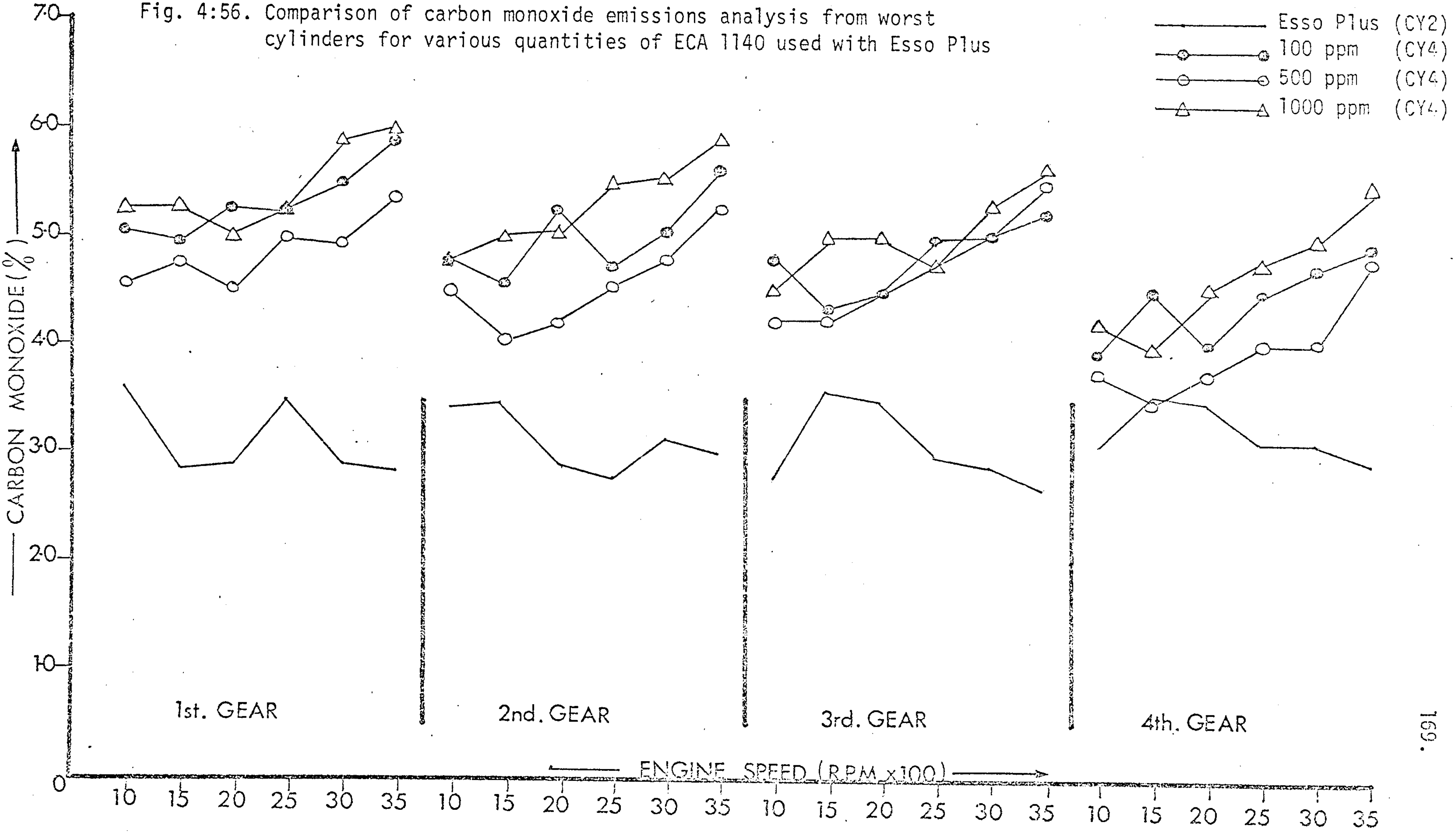


Fig. 4:56. Comparison of carbon monoxide emissions analysis from worst cylinders for various quantities of ECA 1140 used with Esso Plus

Fig. 4:57. Comparison of carbon monoxide emissions averages analysis for various quantities of ECA 1140 used with Esso Plus

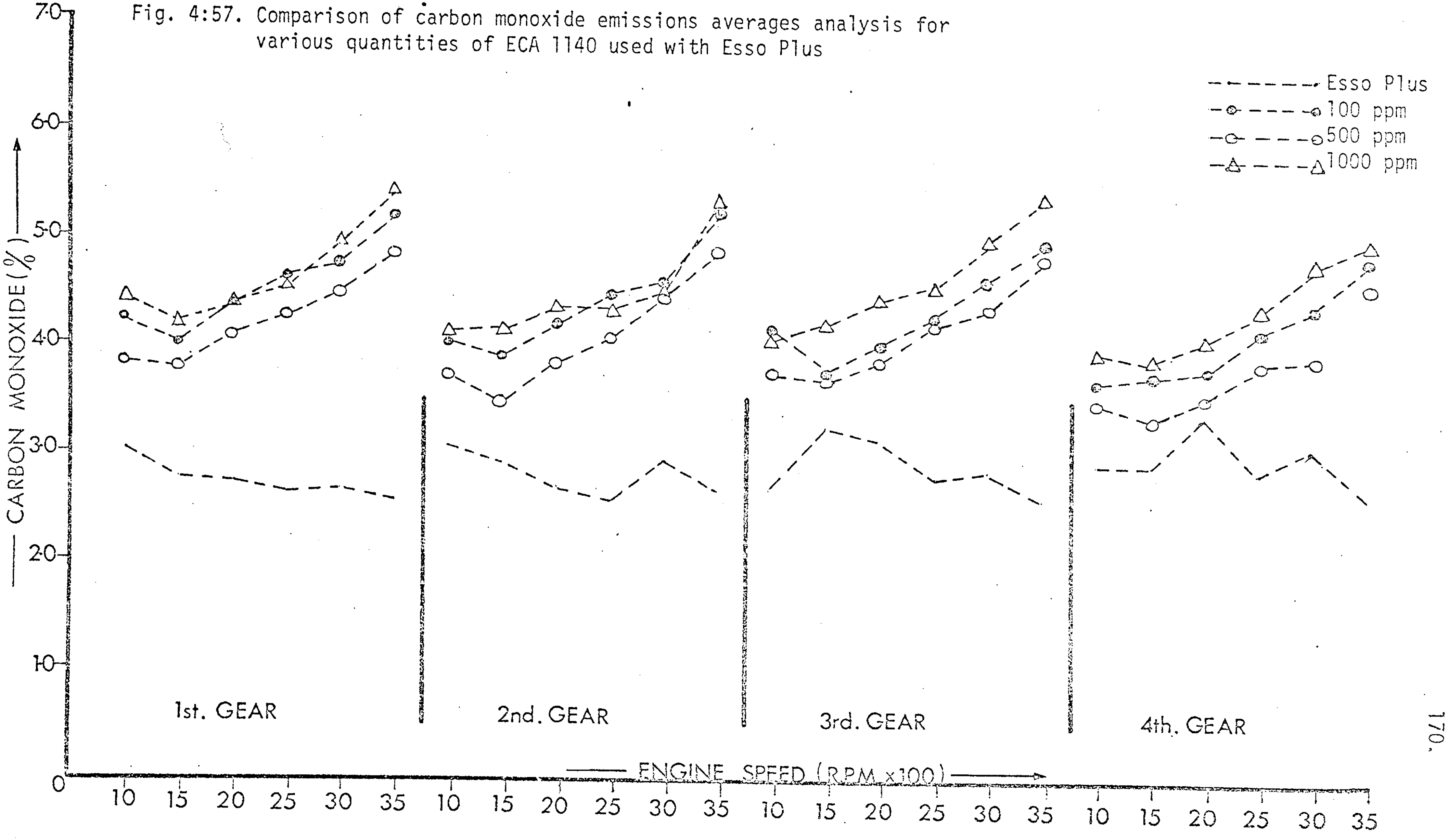


Fig. 4:58. Carbon monoxide emissions analysis for Esso Plus + ECA 1030 - 100 ppm

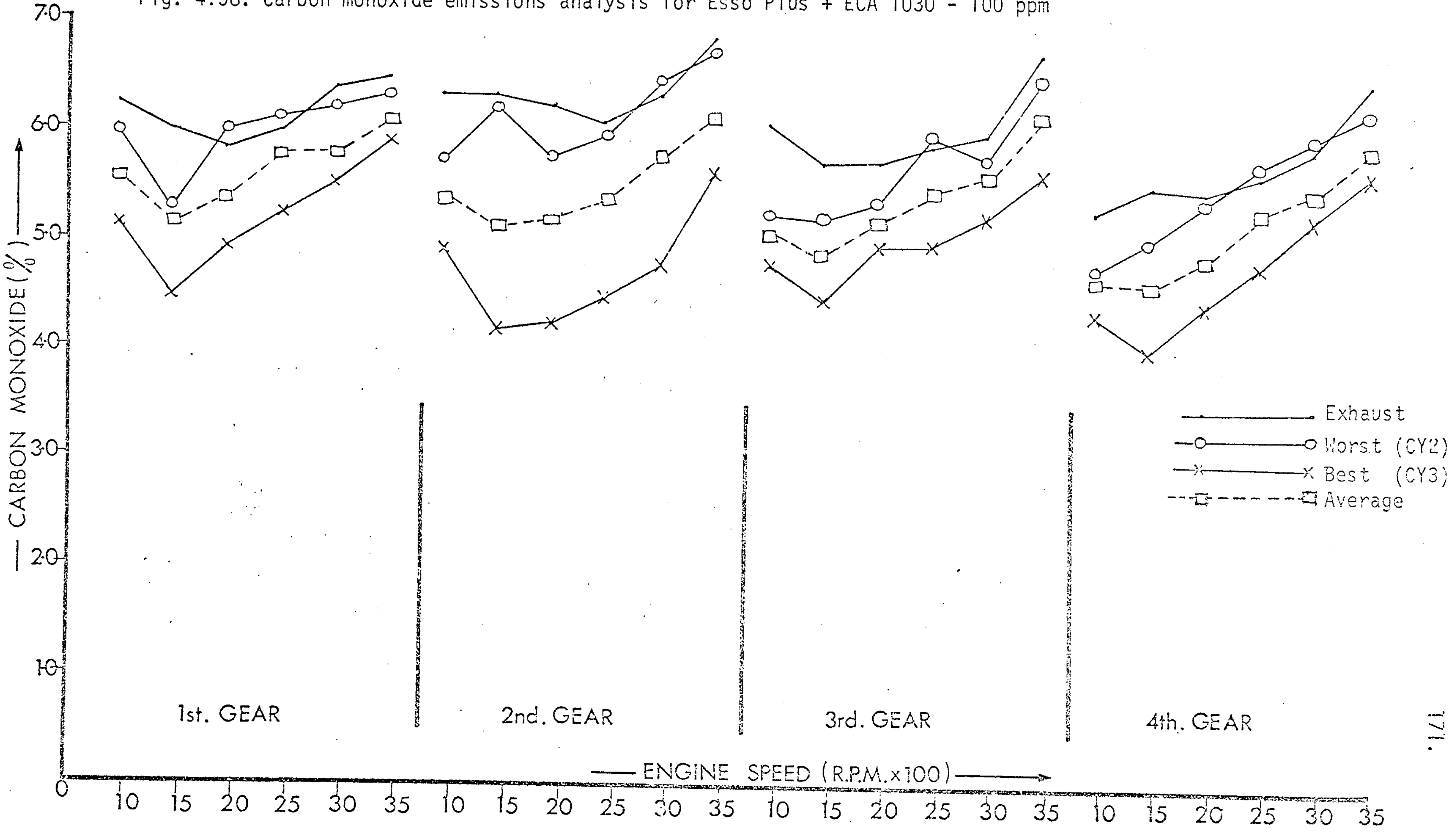


Fig. 4:59. Carbon monoxide emissions analysis for Esso Plus + ECA 1030 - 500 ppm

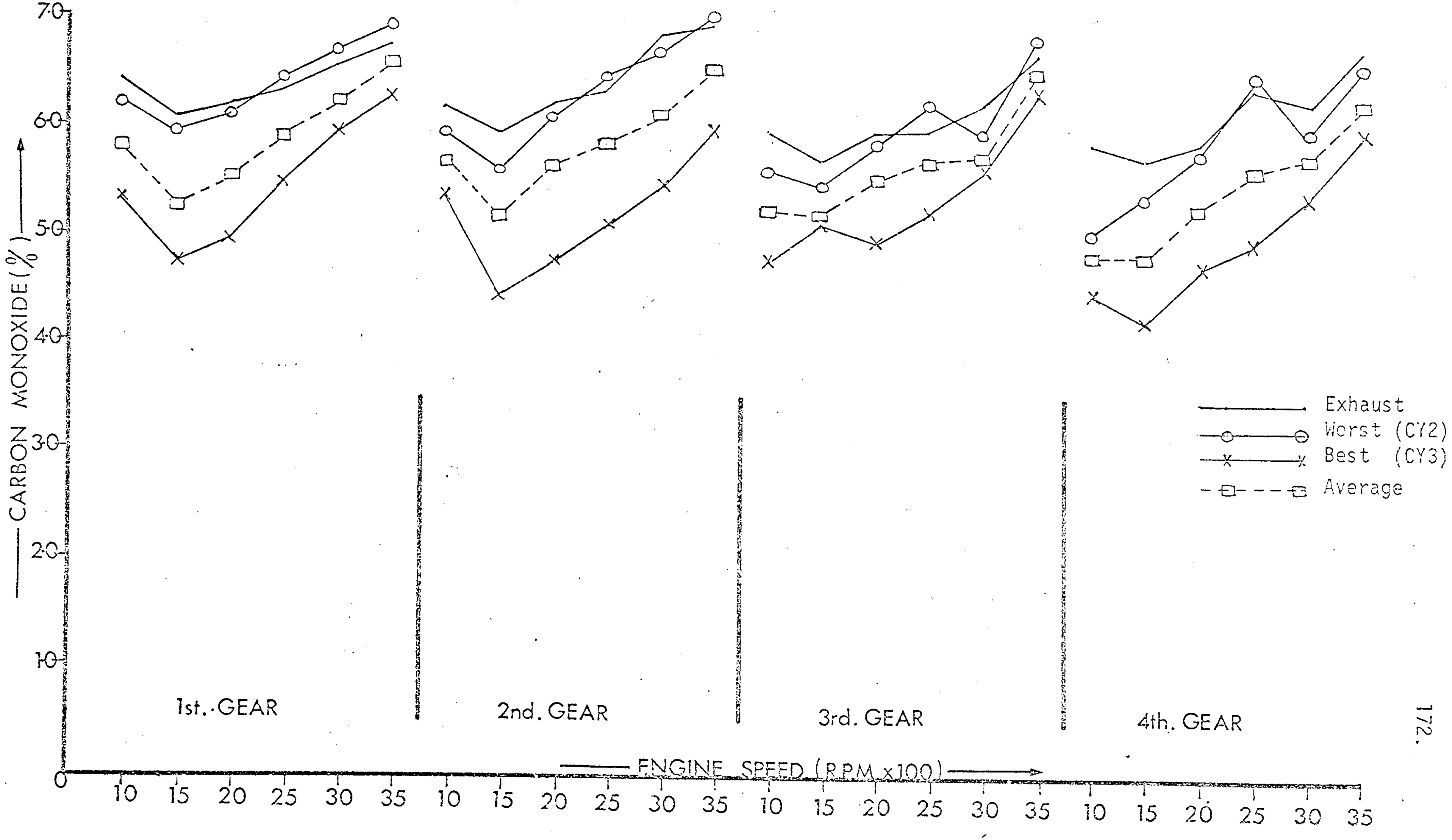


Fig. 4:60. Carbon monoxide emissions analysis for Esso Plus + ECA 1030 - 1000 ppm

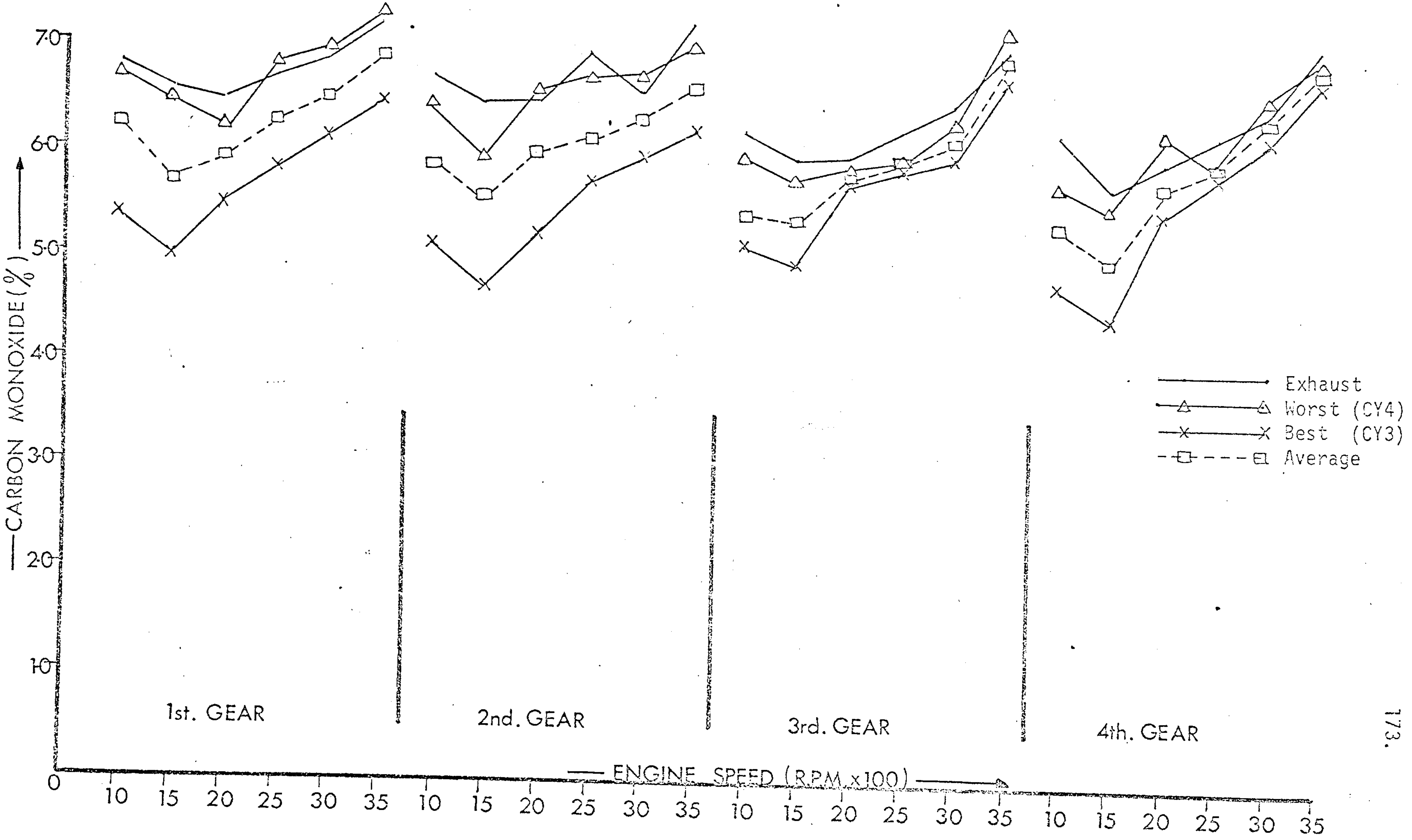


Fig. 4:61. Comparison of carbon monoxide emissions analysis from mixed exhaust for various quantities of ECA 1030 used with Esso Plus

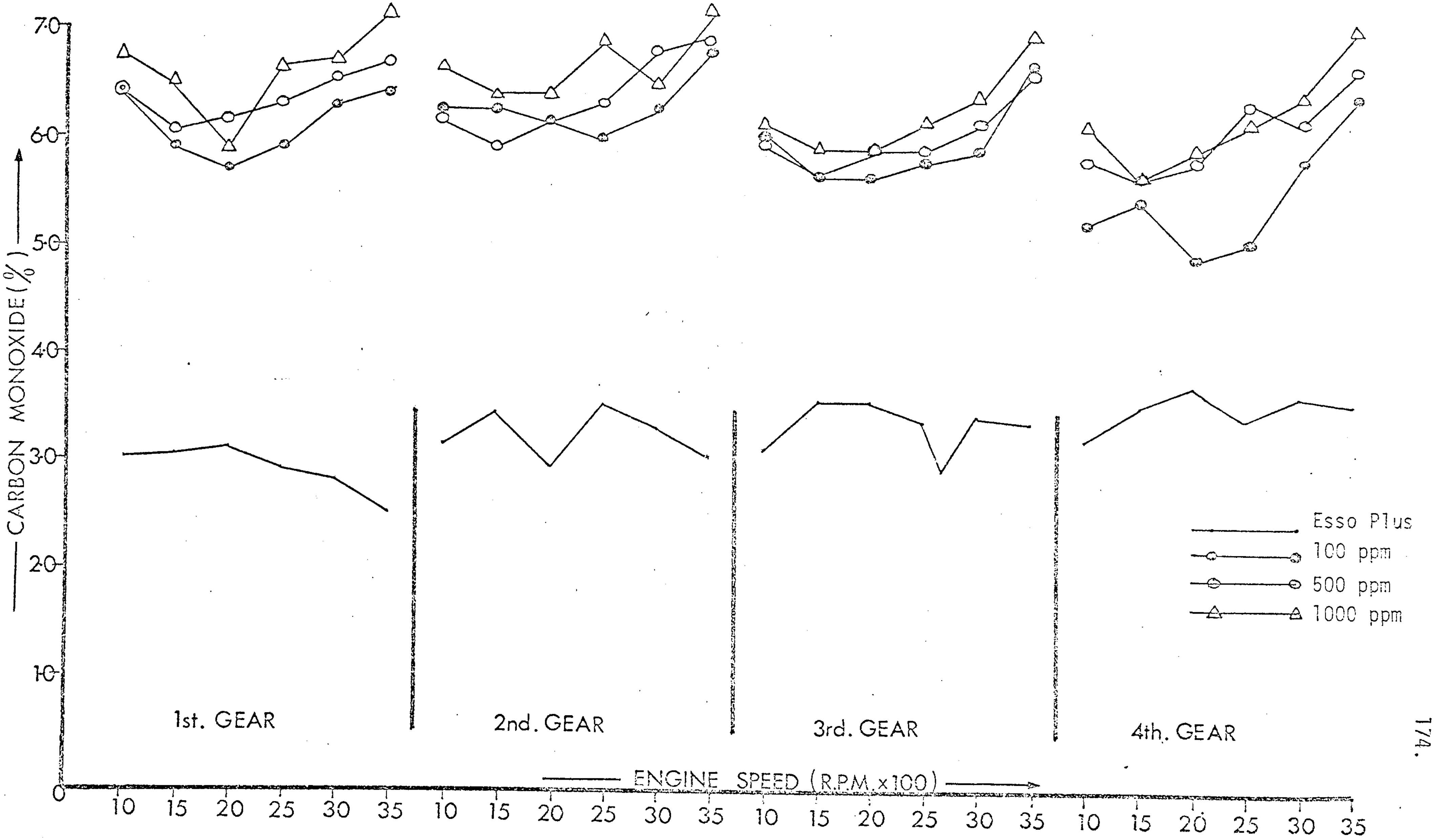


Fig. 4:62. Comparison of carbon monoxide emissions analysis from best cylinders for various quantities of ECA 1030 used with Esso Plus

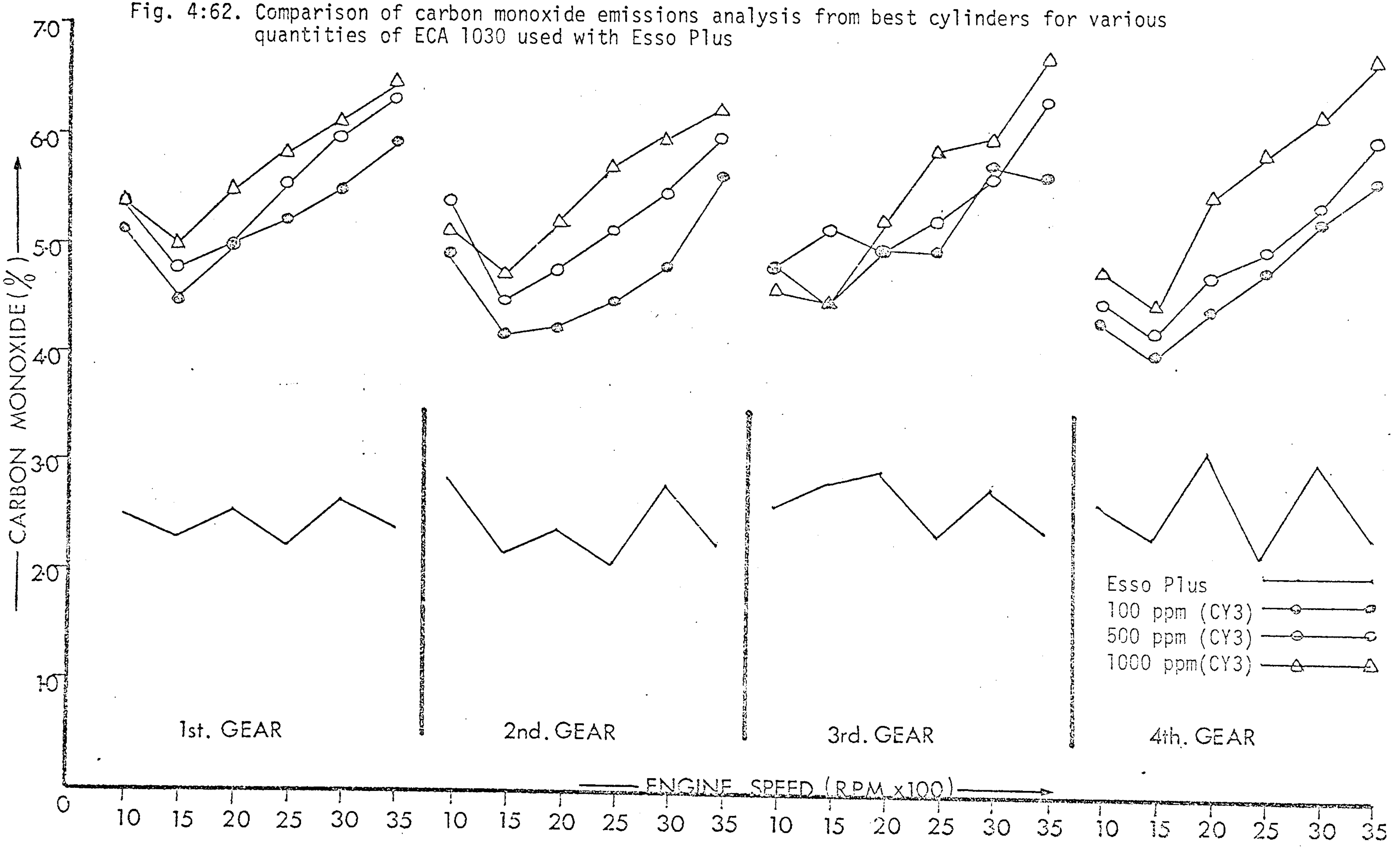


Fig. 4:63. Comparison of carbon monoxide emissions analysis from worst cylinders for various quantities of ECA 1030 used with Esso Plus

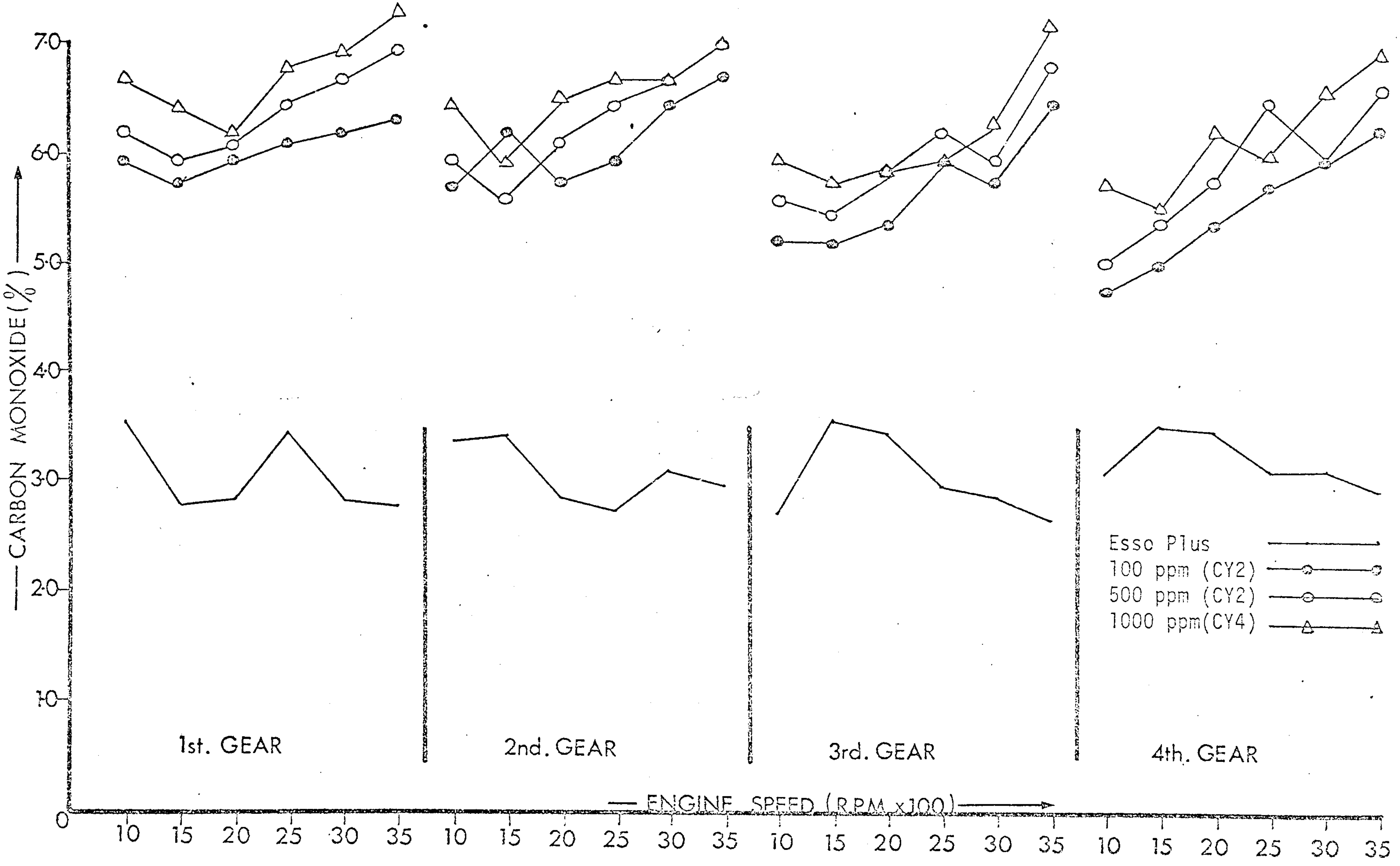


Fig. 4:64. Comparison of carbon monoxide emissions averages analysis for various quantities of ECA 1030 used with Esso Plus

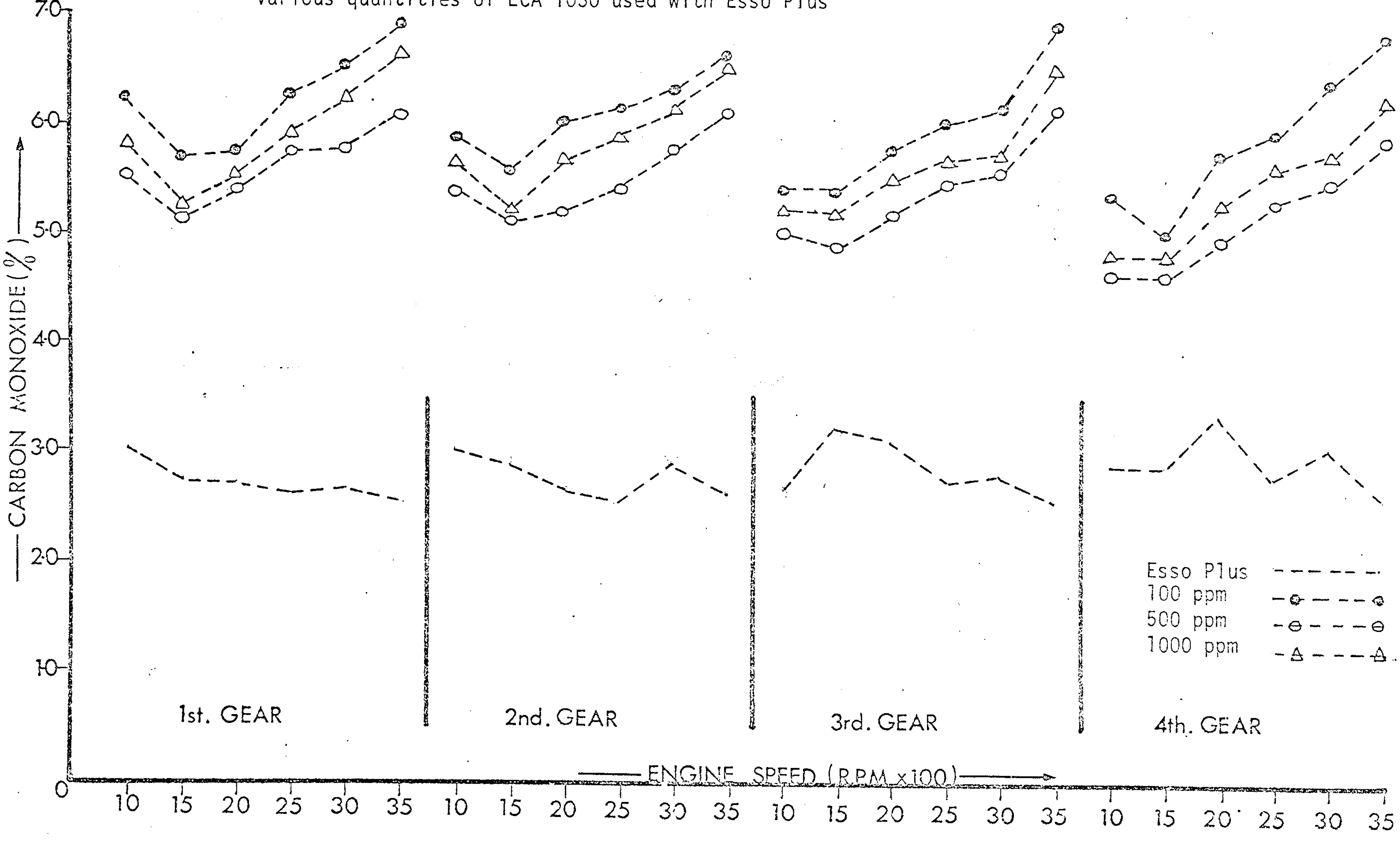


Fig. 4:65. Comparison of carbon monoxide emissions analysis from mixed exhaust for best quantities of additives used with Esso Plus

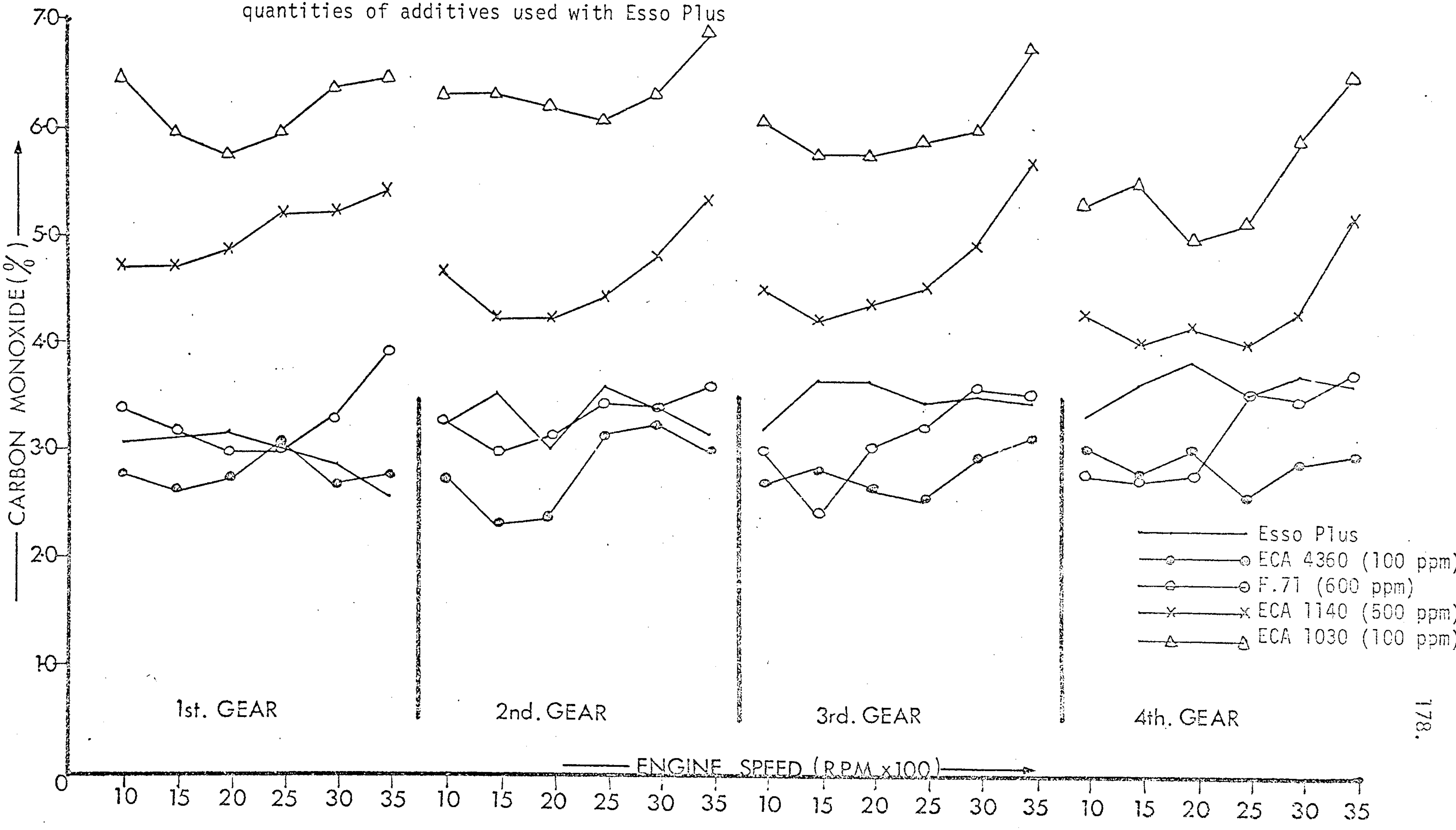


Fig. 4:66. Comparison of çarbon monoxide emissions analysis from best cylinders for best quantities of additive used with Esso Plus

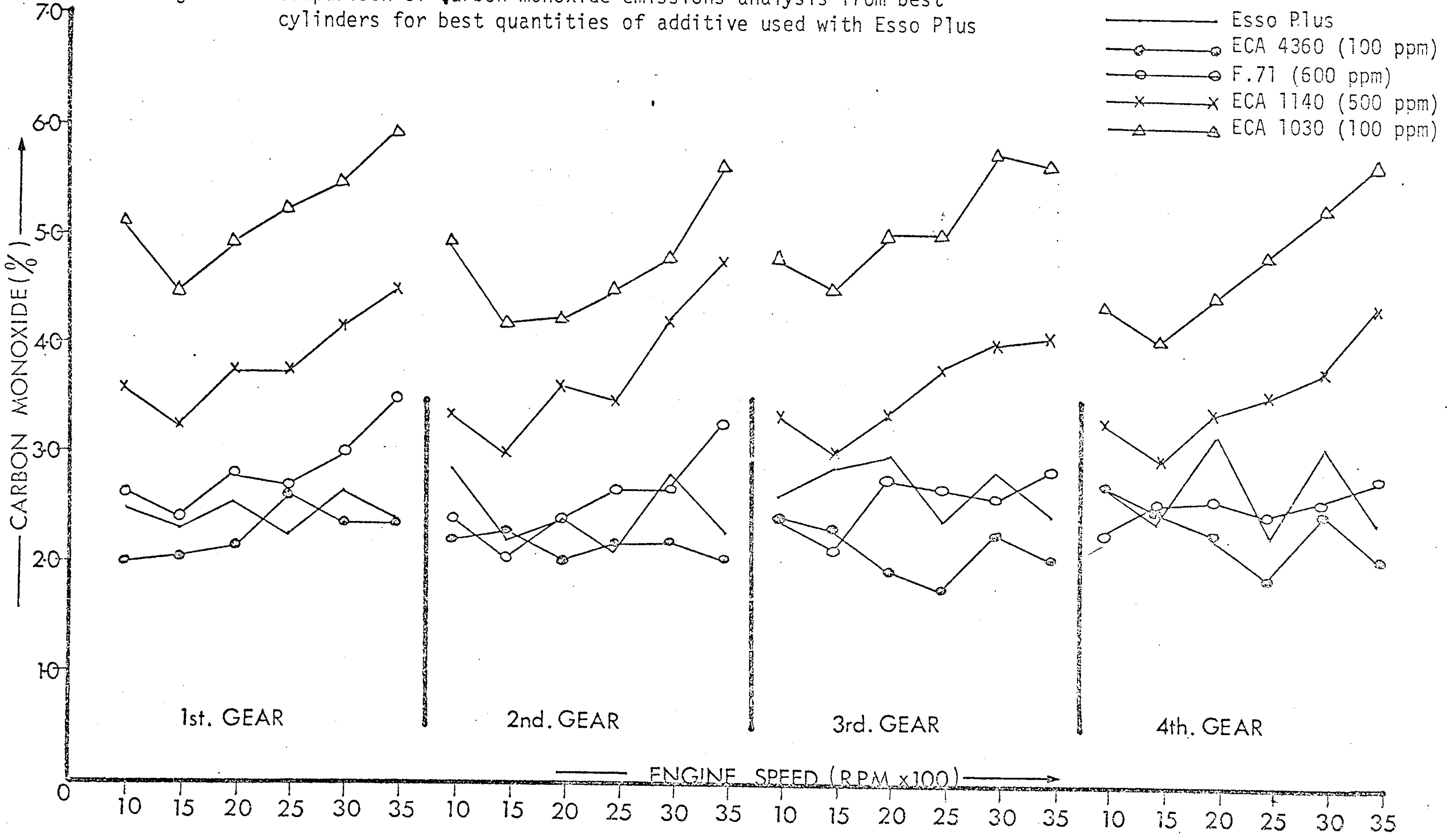
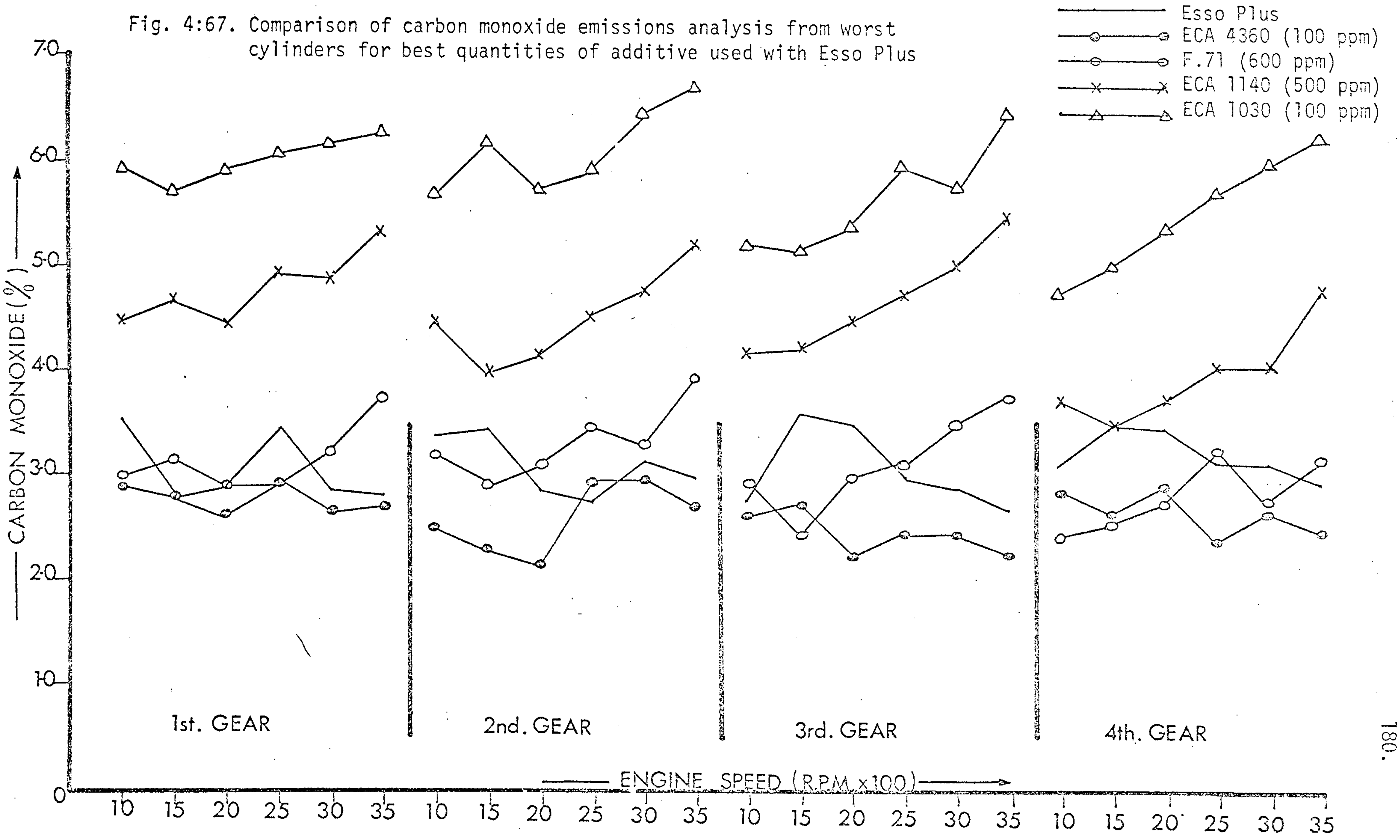


Fig. 4:67. Comparison of carbon monoxide emissions analysis from worst cylinders for best quantities of additive used with Esso Plus



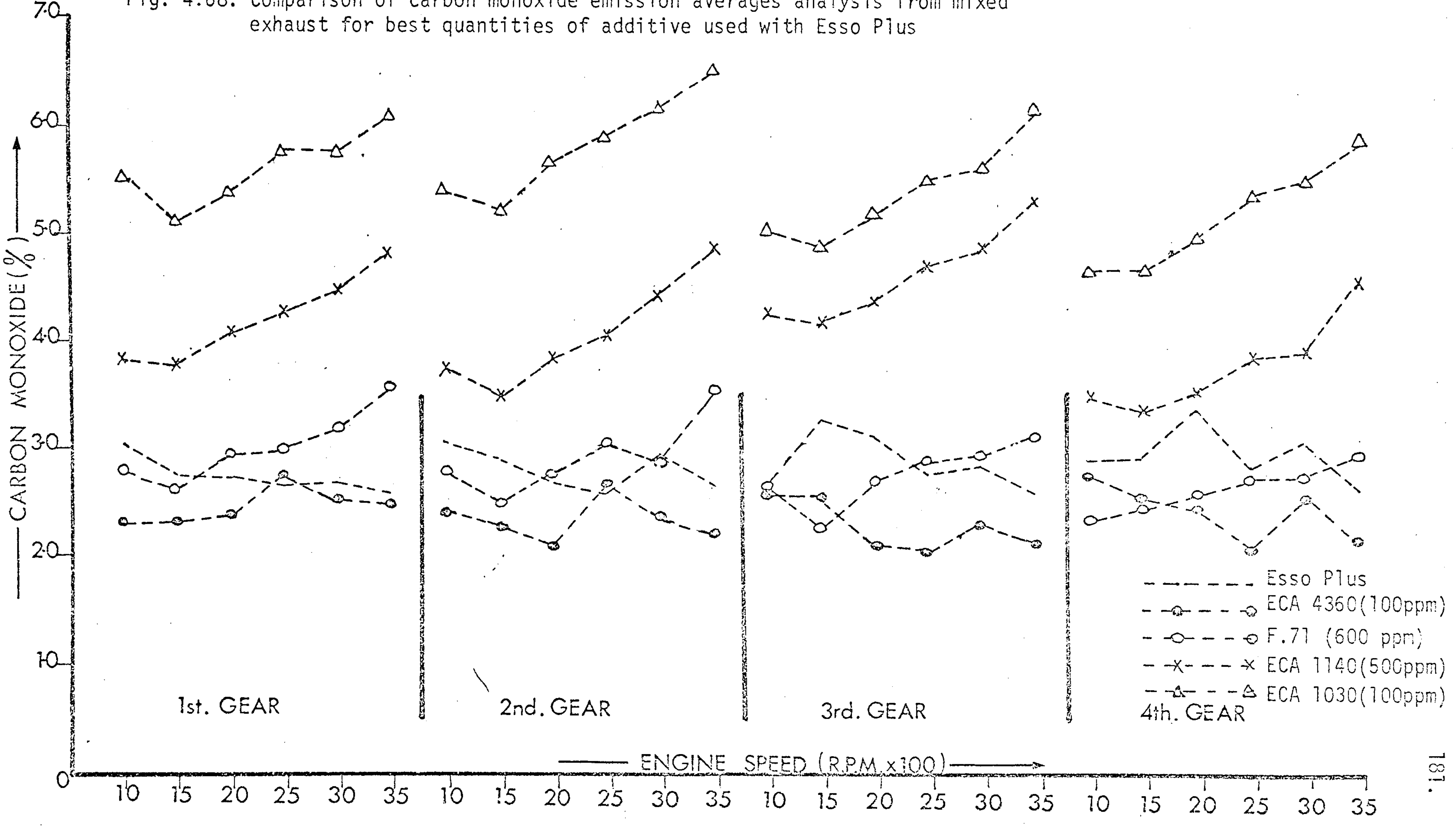


Fig. 4:68. Comparison of carbon monoxide emission averages analysis from mixed exhaust for best quantities of additive used with Esso Plus

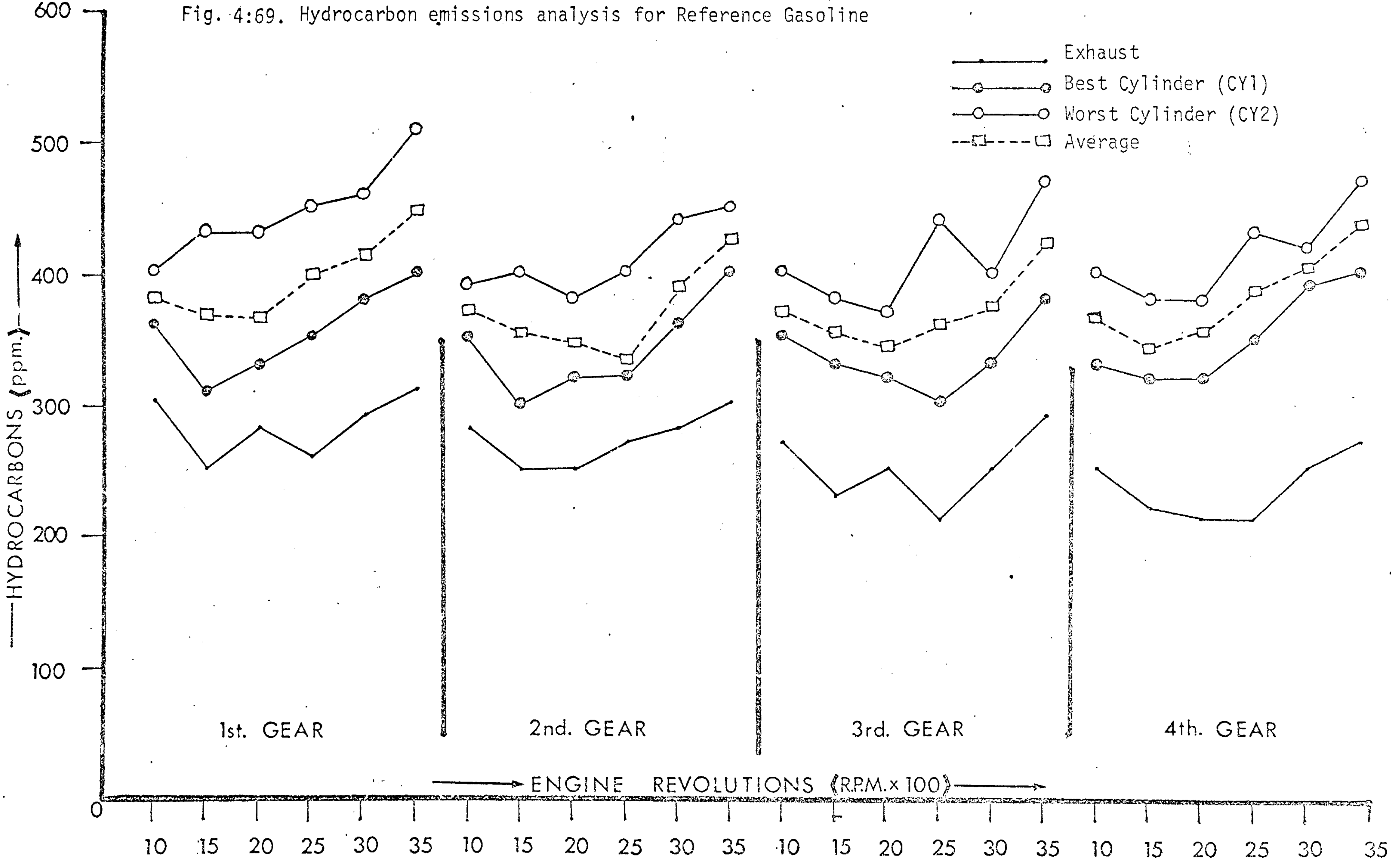


Fig. 4:69. Hydrocarbon emissions analysis for Reference Gasoline

Fig: 4:70. Hydrocarbon emissions analysis for Reference Gasoline + ECA 4360 - 100 ppm

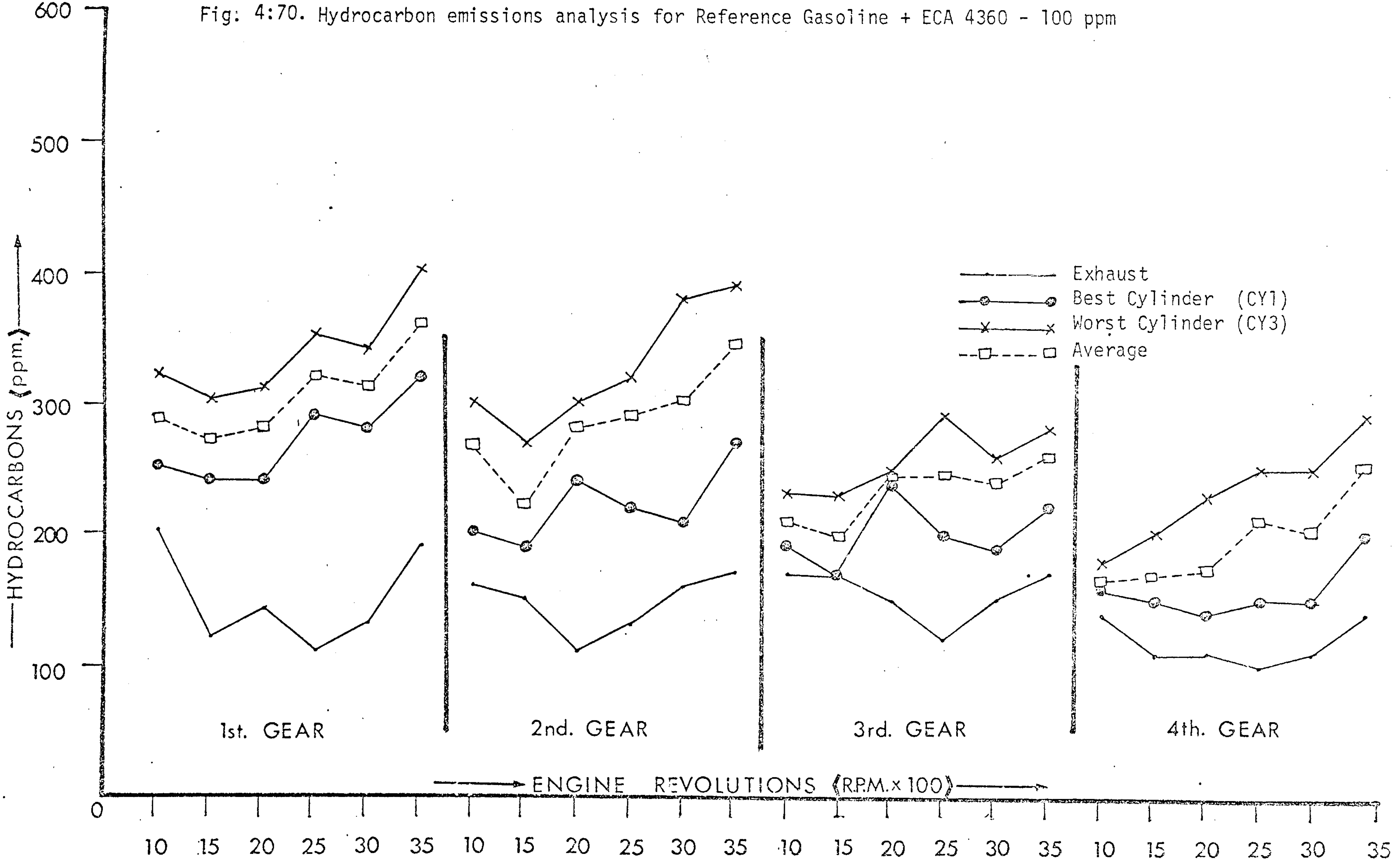
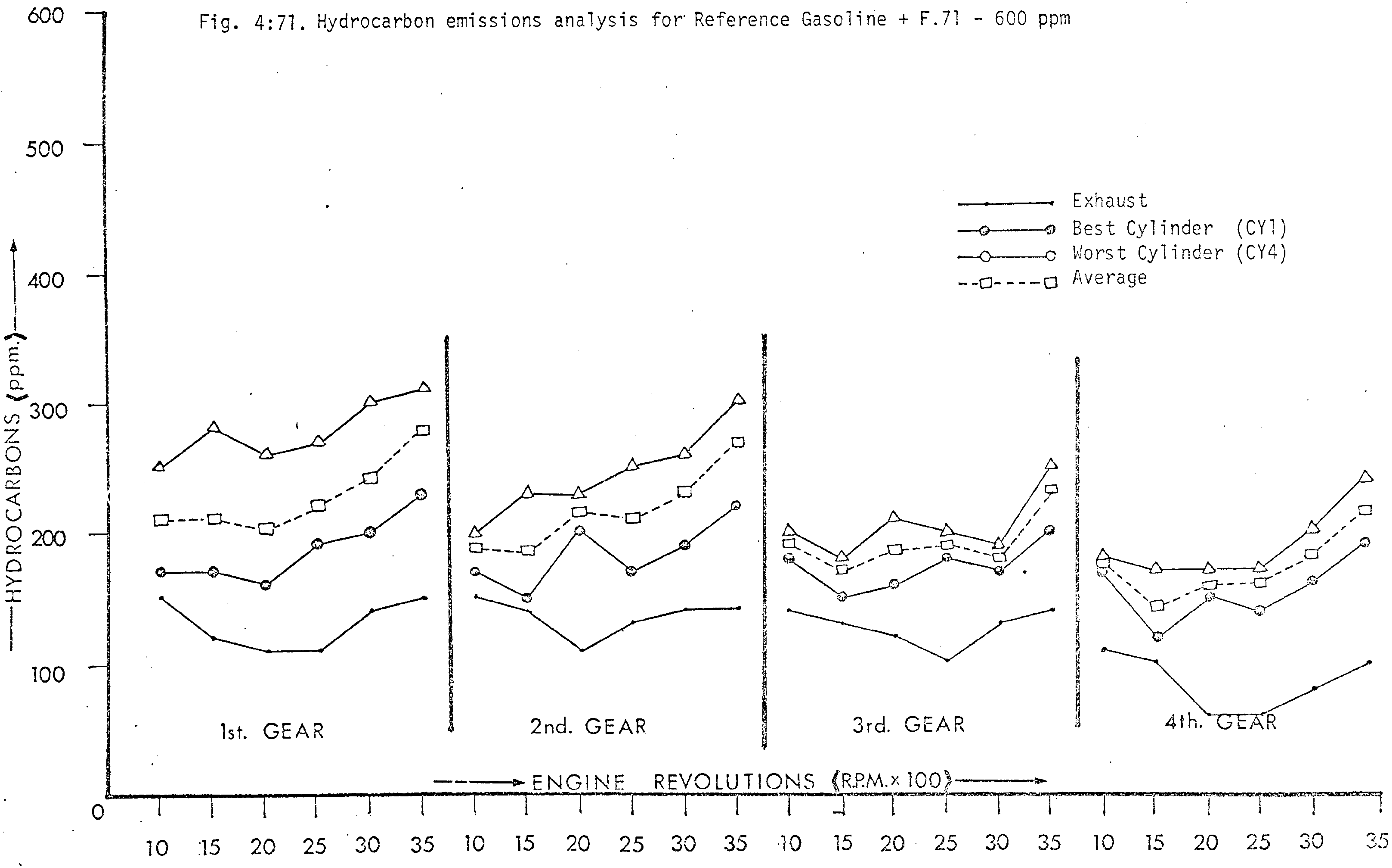


Fig. 4:71. Hydrocarbon emissions analysis for Reference Gasoline + F.71 - 600 ppm



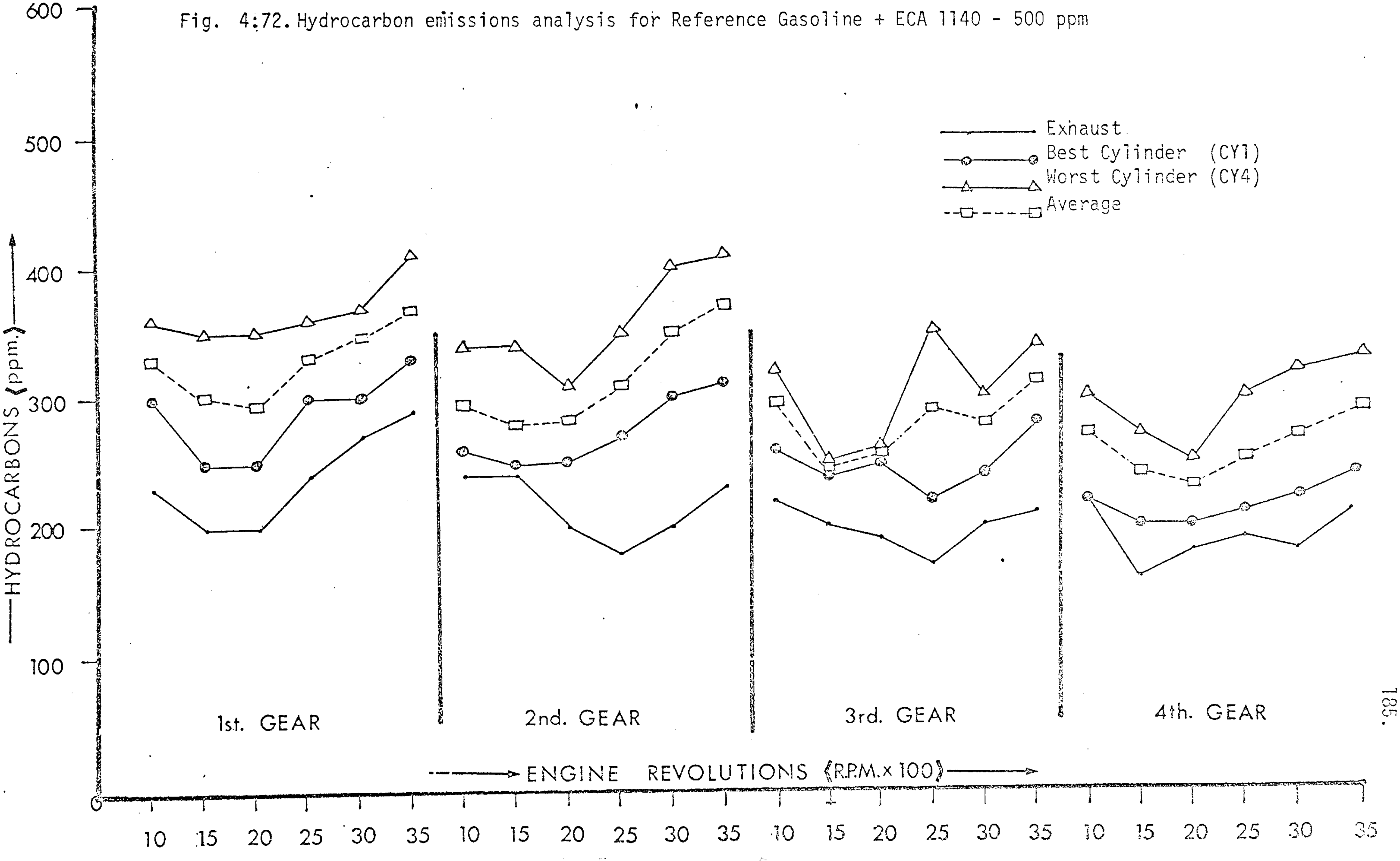


Fig. 4:72. Hydrocarbon emissions analysis for Reference Gasoline + ECA 1140 - 500 ppm

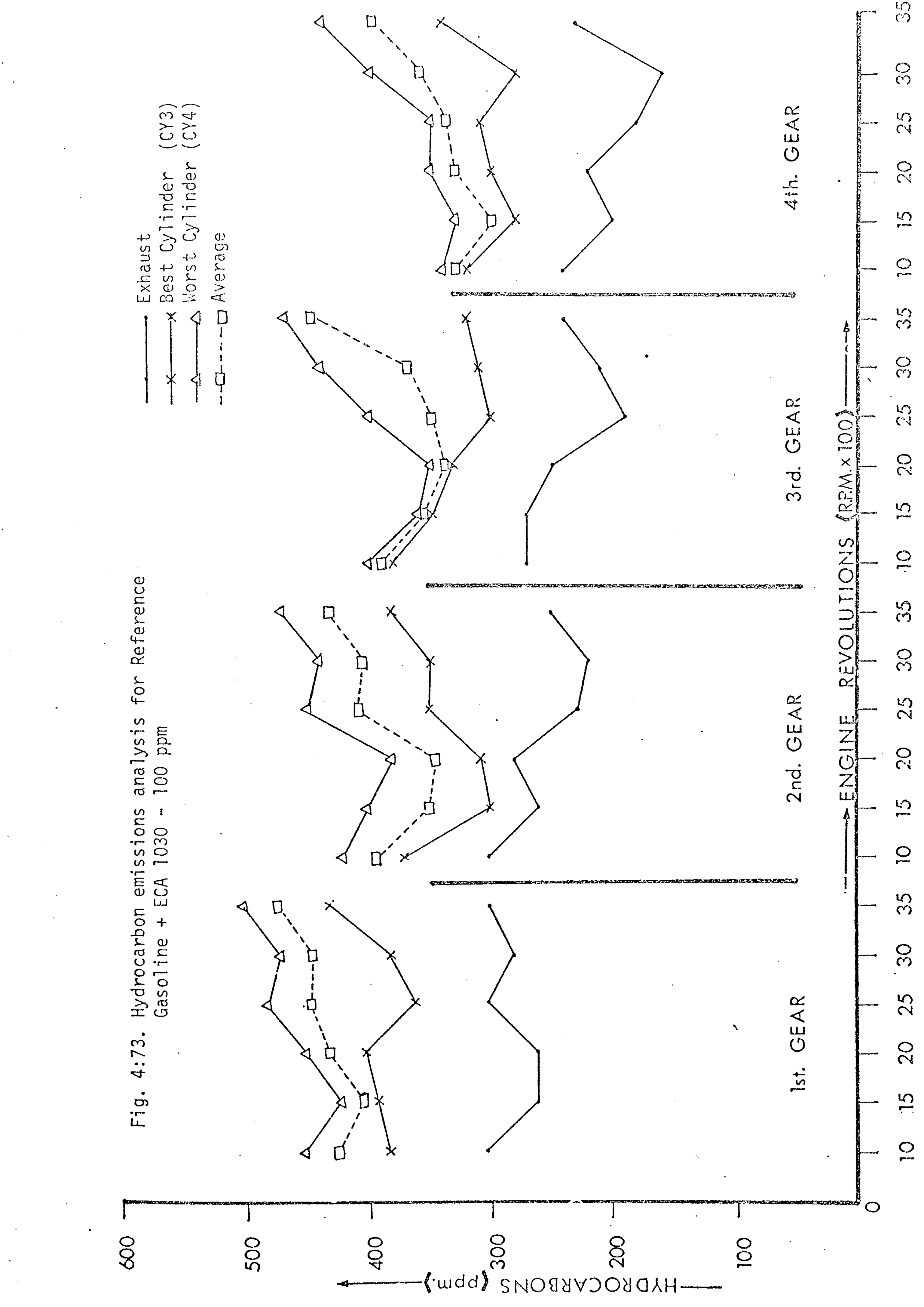


Fig. 4:73. Hydrocarbon emissions analysis for Reference Gasoline + ECA 1030 - 100 ppm

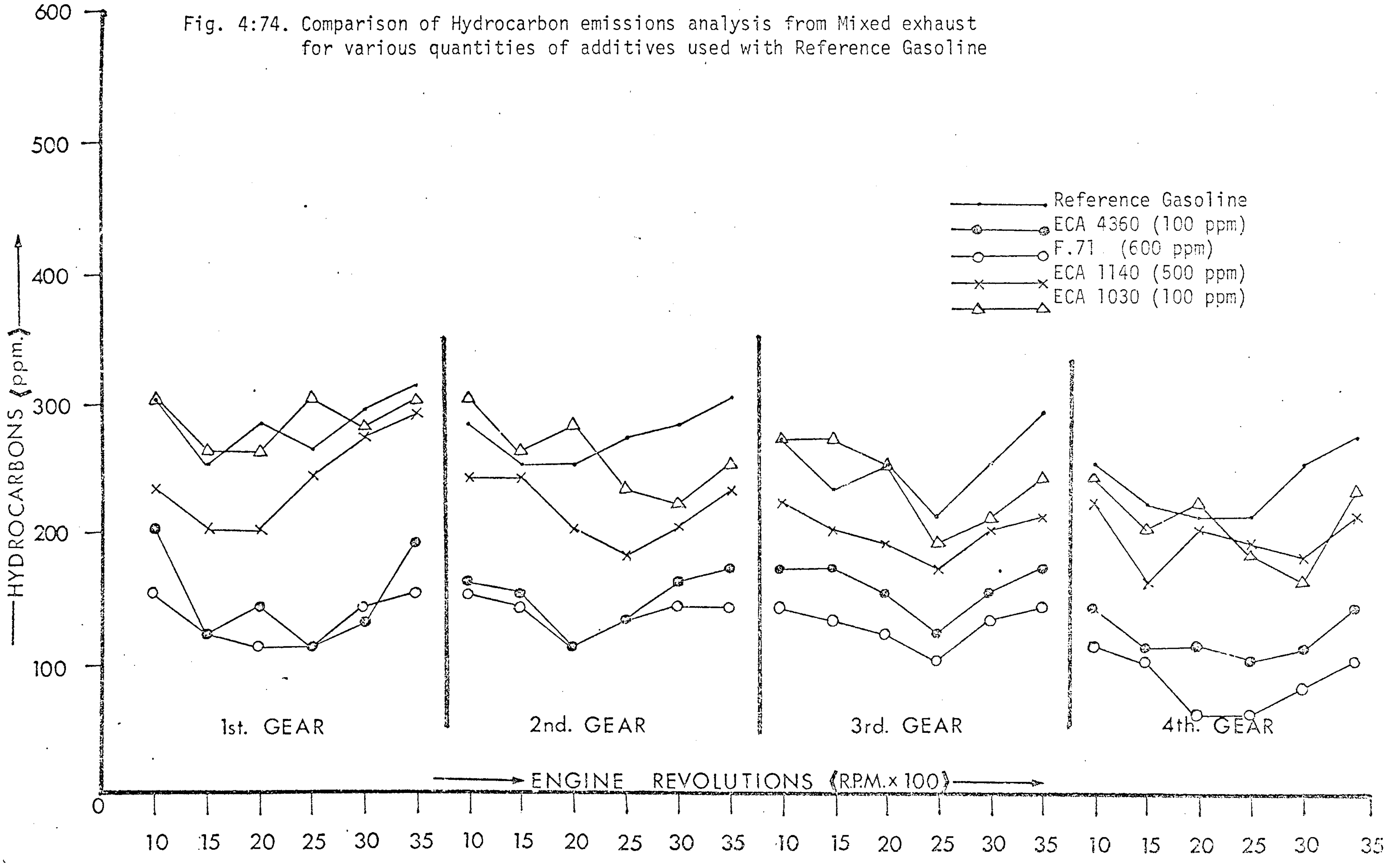


Fig. 4:74. Comparison of Hydrocarbon emissions analysis from Mixed exhaust for various quantities of additives used with Reference Gasoline

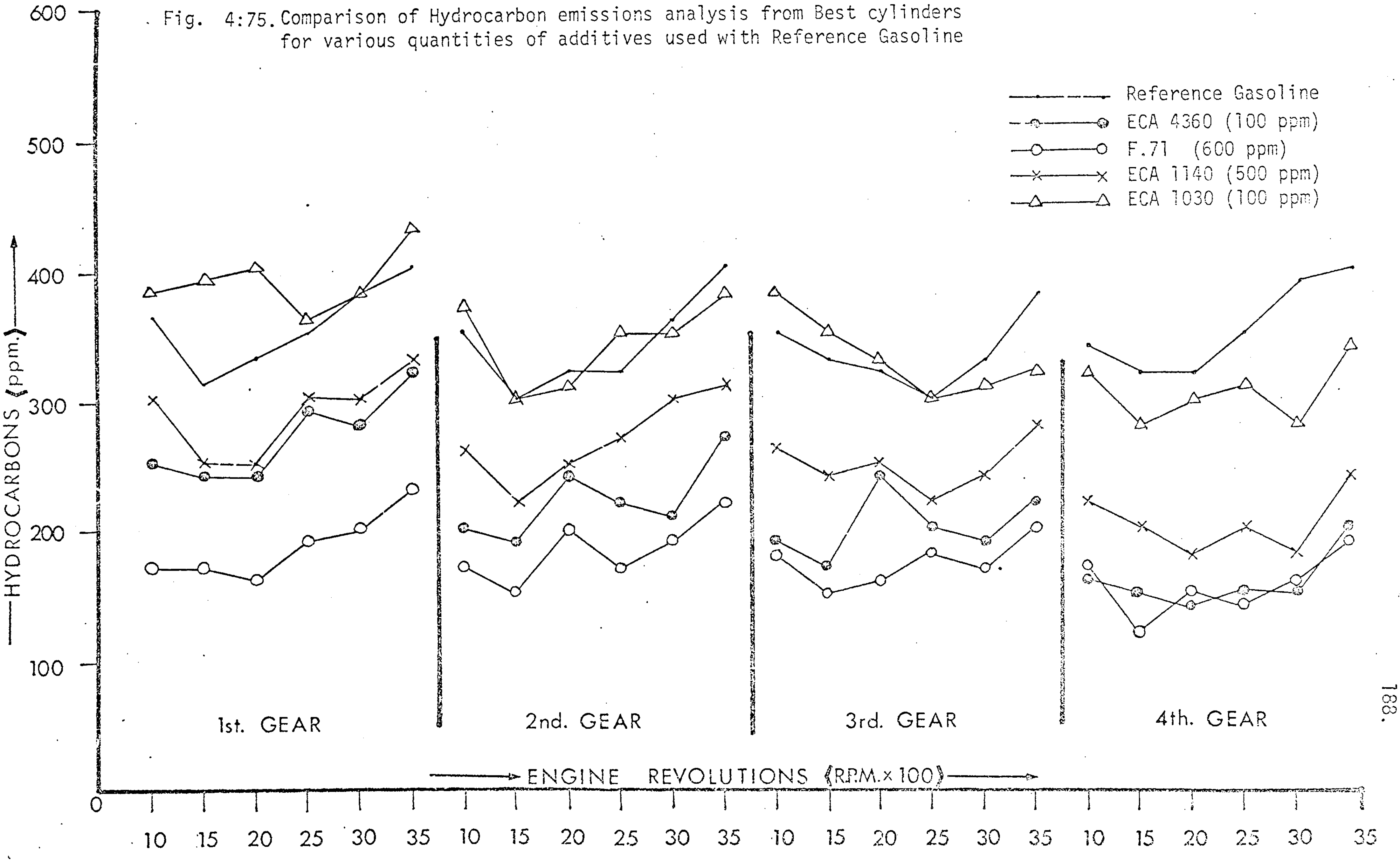
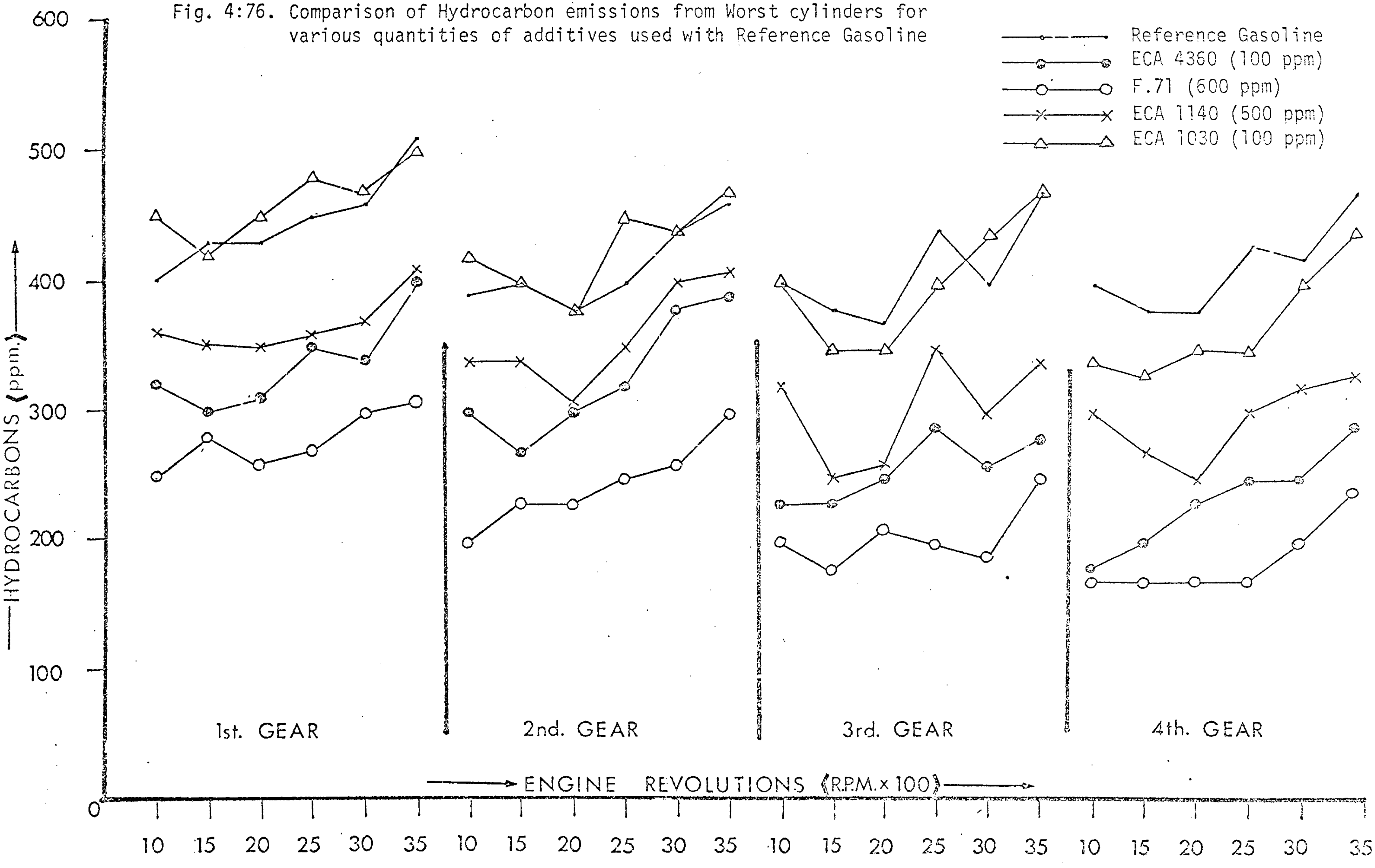


Fig. 4:75. Comparison of Hydrocarbon emissions analysis from Best cylinders for various quantities of additives used with Reference Gasoline

Fig. 4:76. Comparison of Hydrocarbon emissions from Worst cylinders for various quantities of additives used with Reference Gasoline



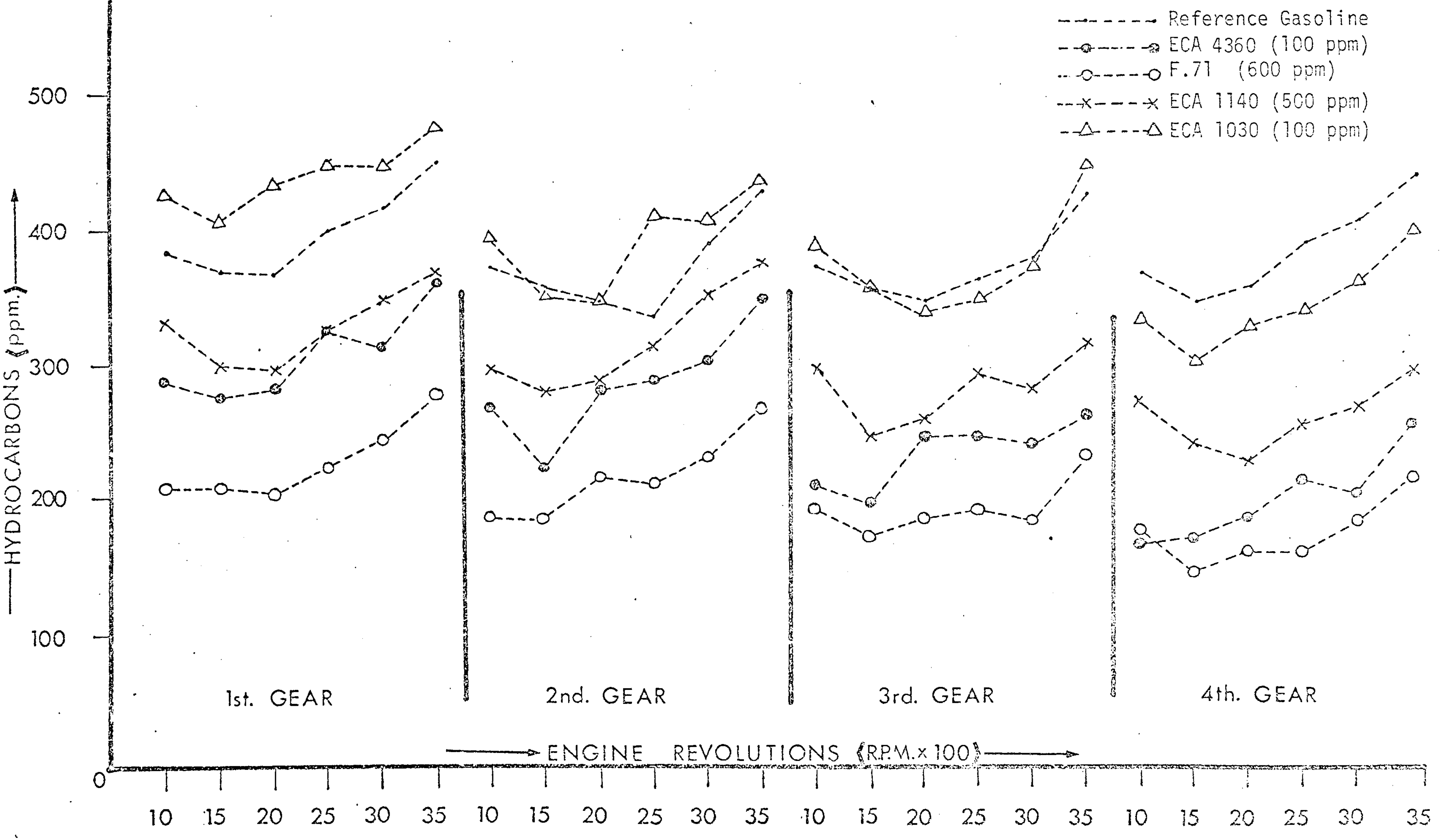


Fig. 4:77. Comparison of Hydrocarbon emissions Averages for various quantities of additives used with Reference Gasoline

Fig. 4:78. Carbon monoxide emissions analysis for Reference Gasoline

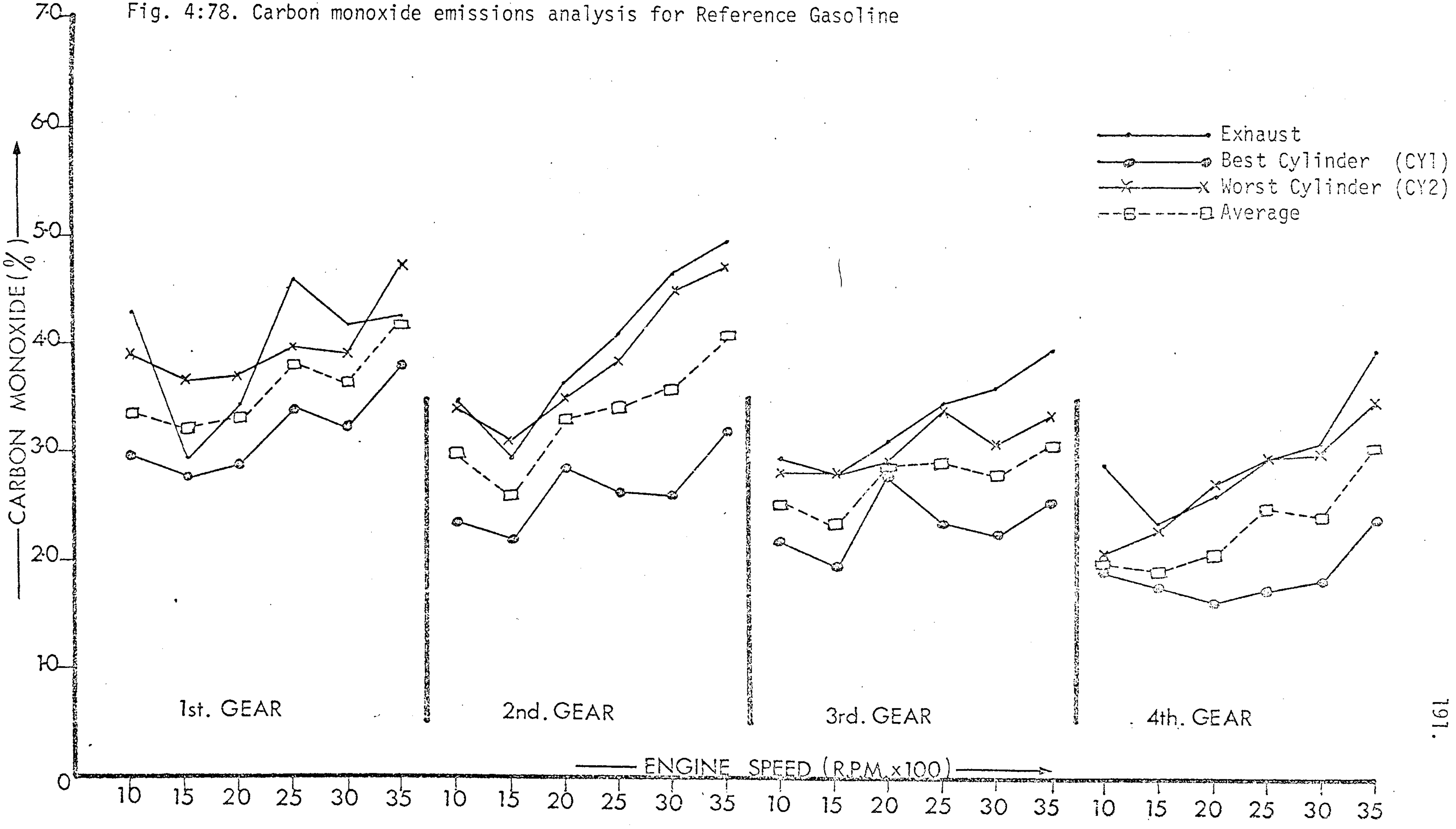


Fig. 4:79. Carbon monoxide emissions analysis for Reference Gasoline + ECA 4360 - 100 ppm

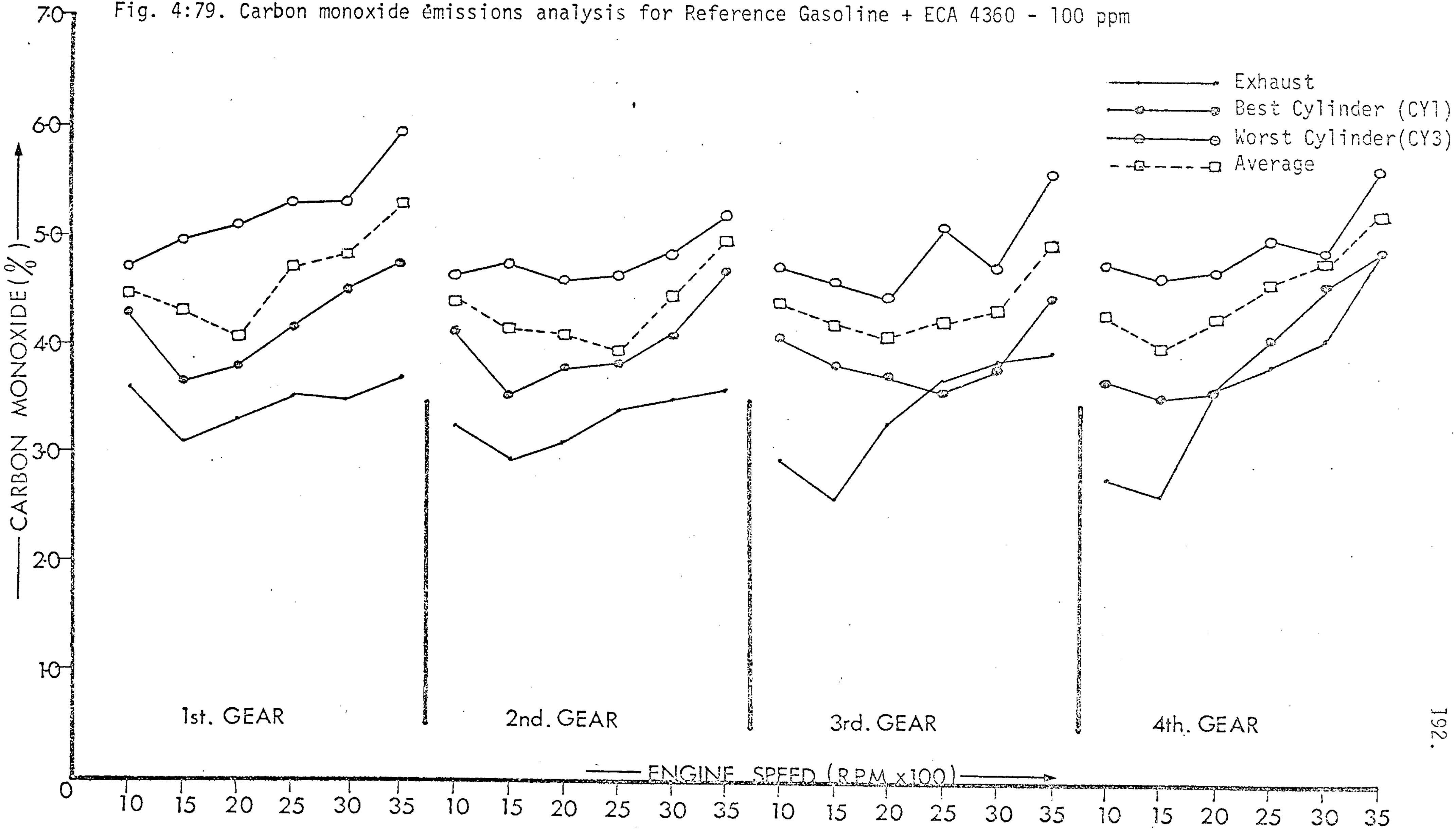
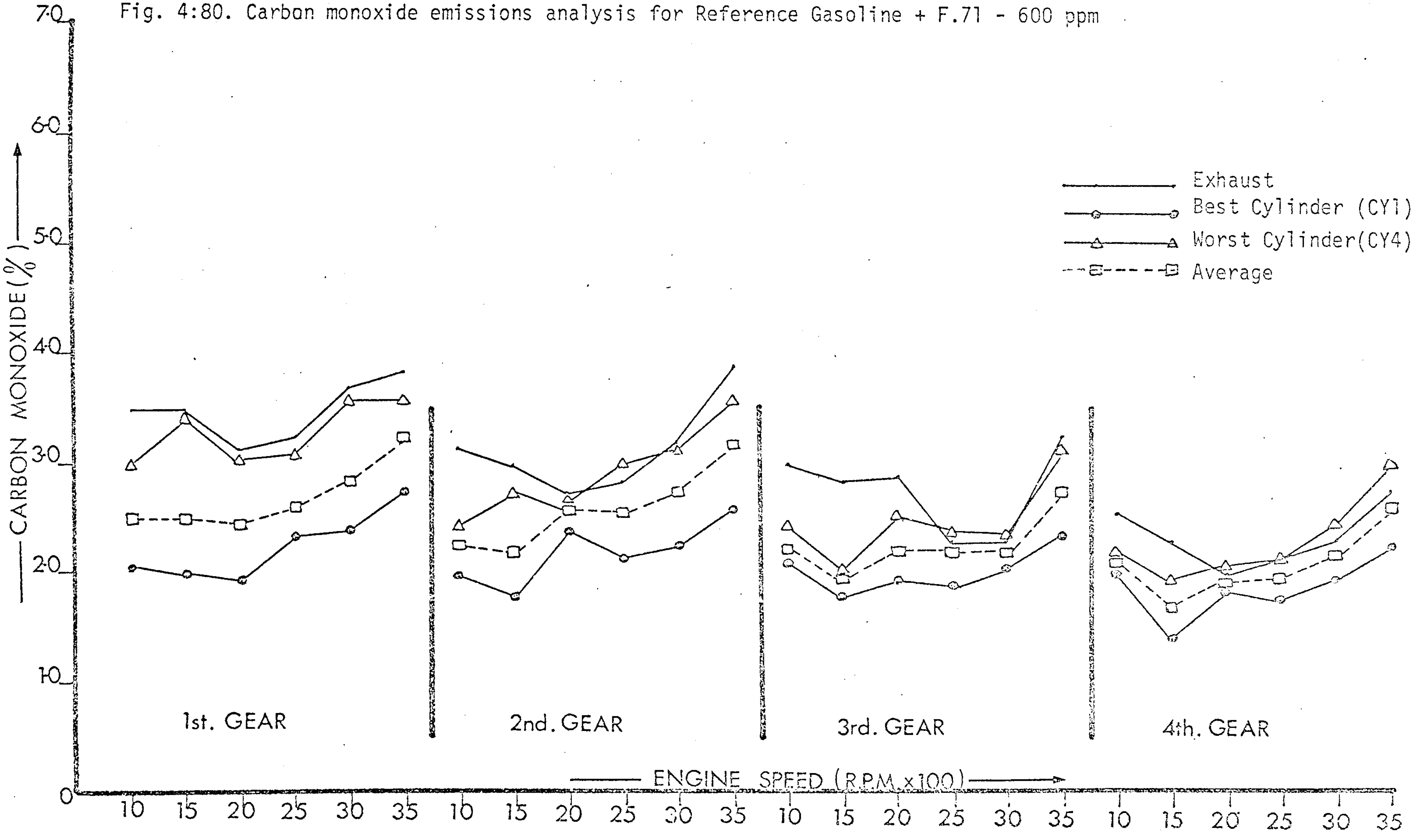


Fig. 4:80. Carbon monoxide emissions analysis for Reference Gasoline + F.71 - 600 ppm



Fig, 4:81. Carbon monoxide emissions analysis for Reference Gasoline + ECA 1140 - 500 ppm

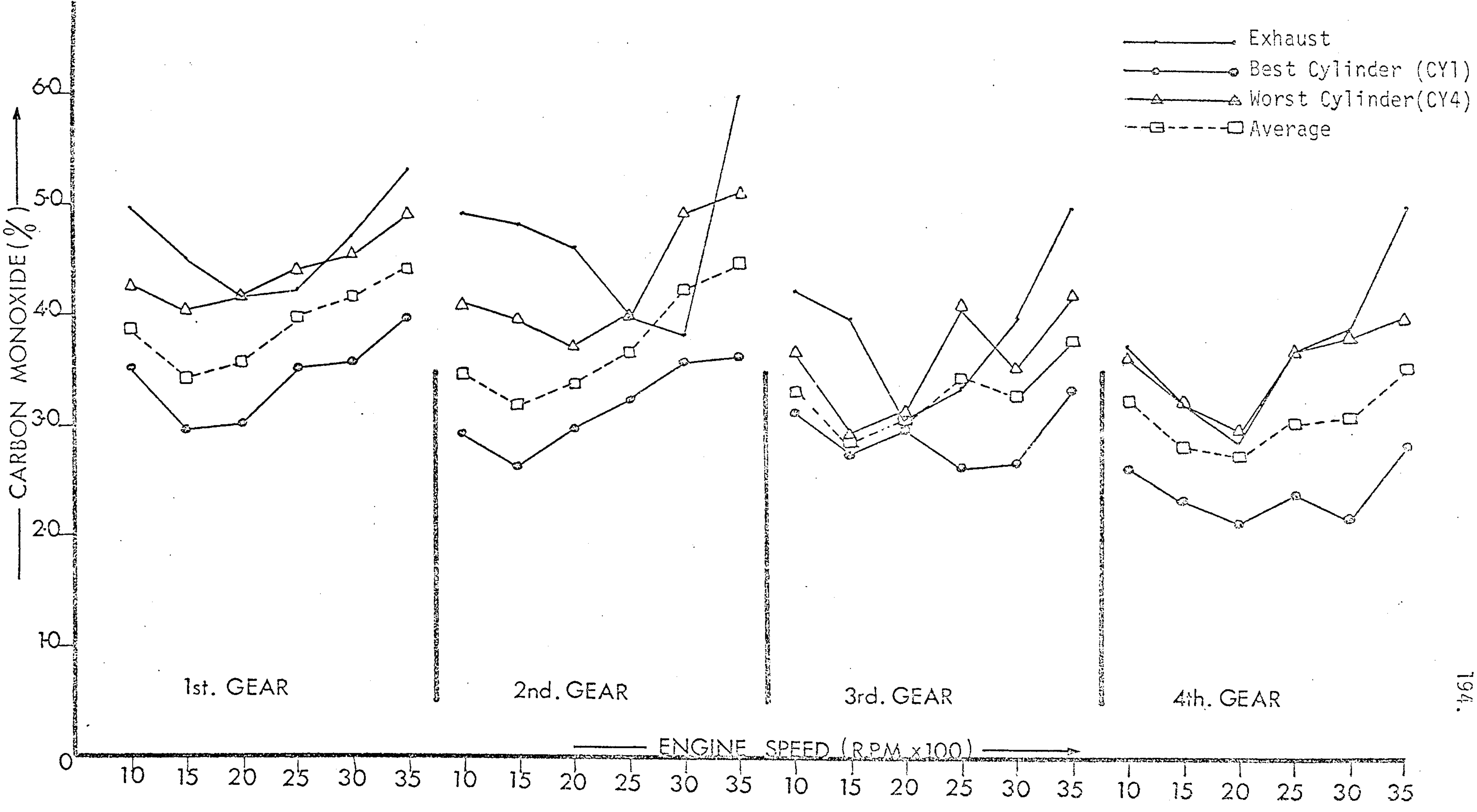


Fig. 4:82. Carbon monoxide emissions analysis for Reference Gasoline + ECA 1030 - 100 ppm

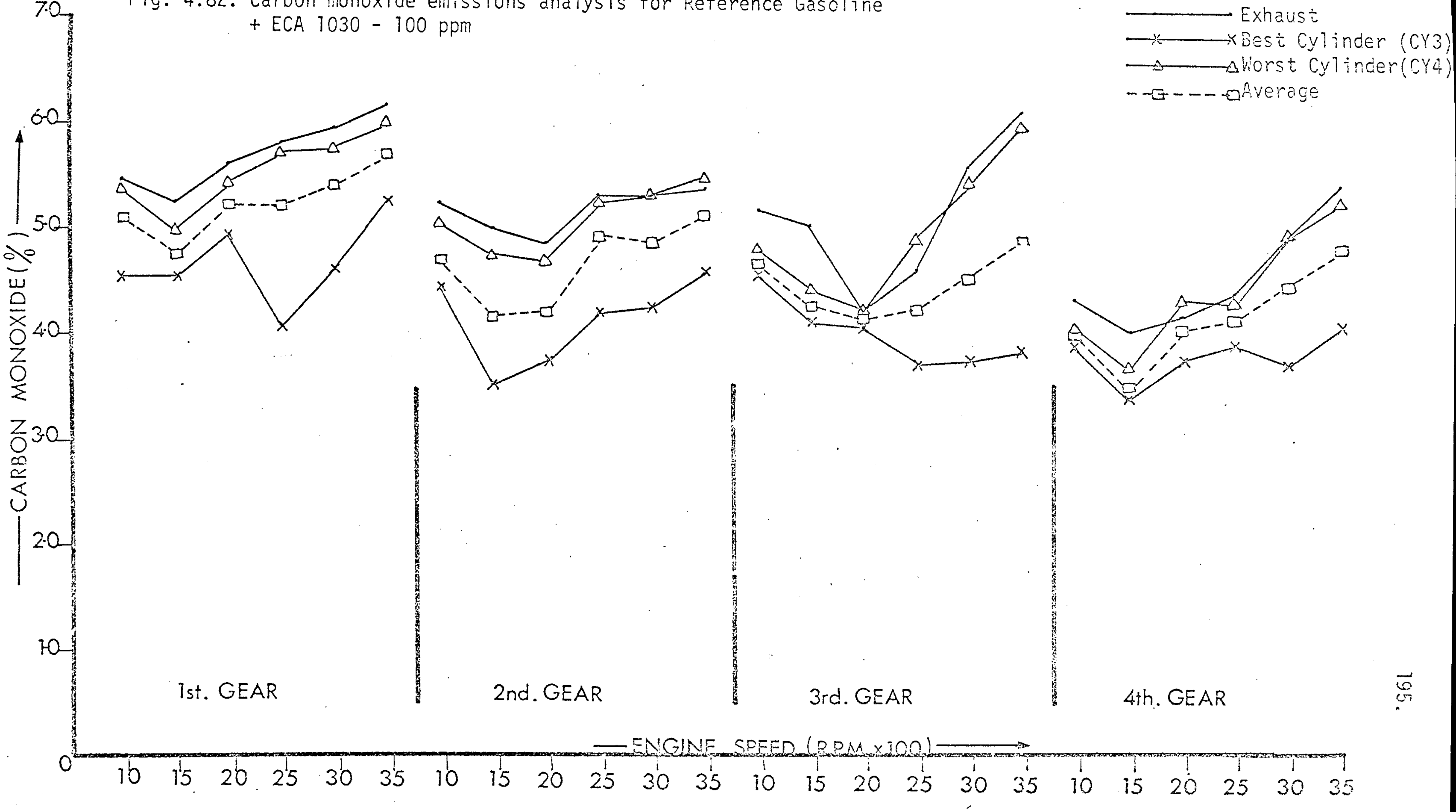


Fig. 4:83. Comparison of carbon monoxide emissions analysis from mixed exhaust for best quantities of additive used with Reference Gasoline

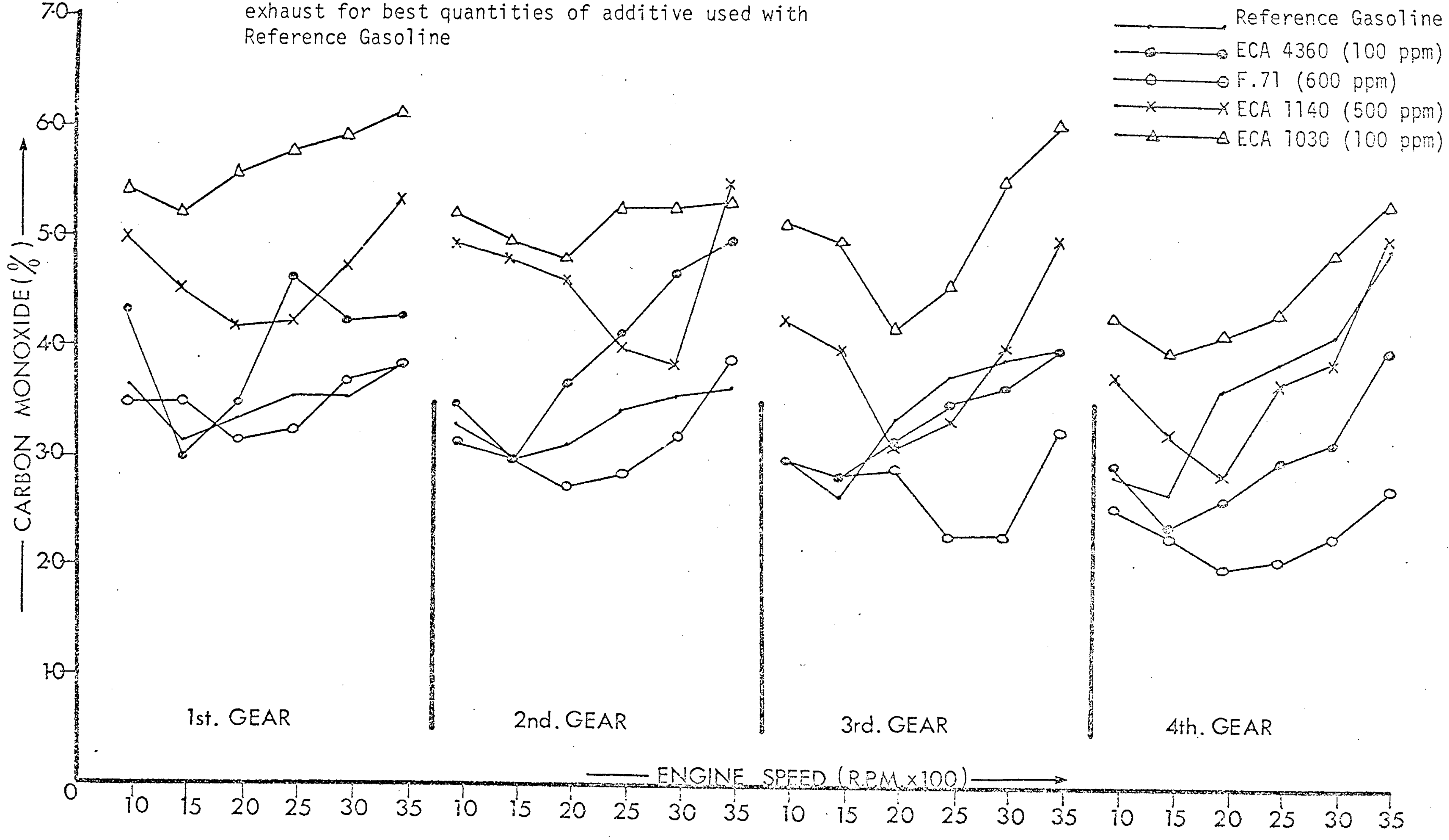


Fig. 4:84. Comparison of carbon monoxide emissions analysis from best cylinders for best quantities of additive used with Reference Gasoline

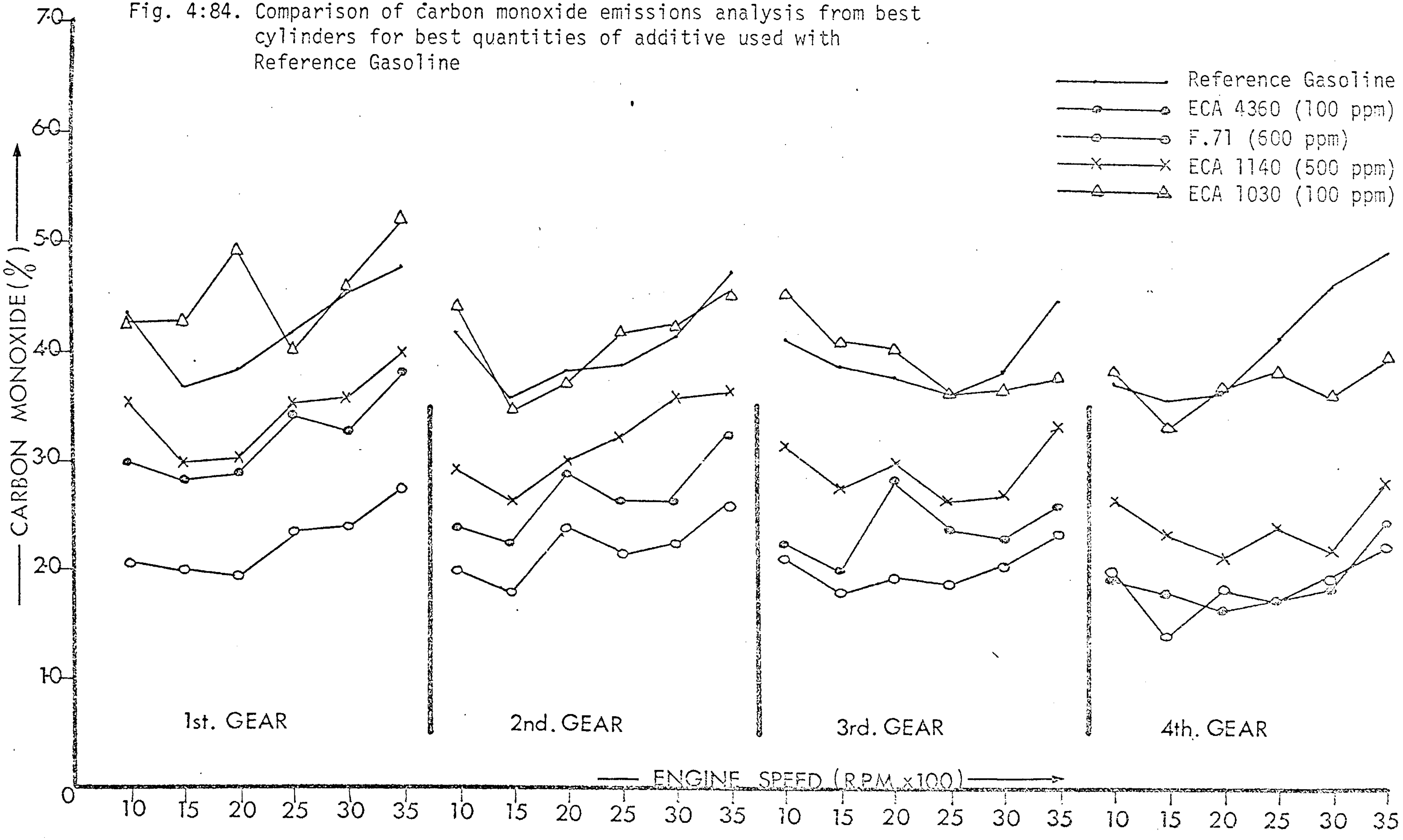
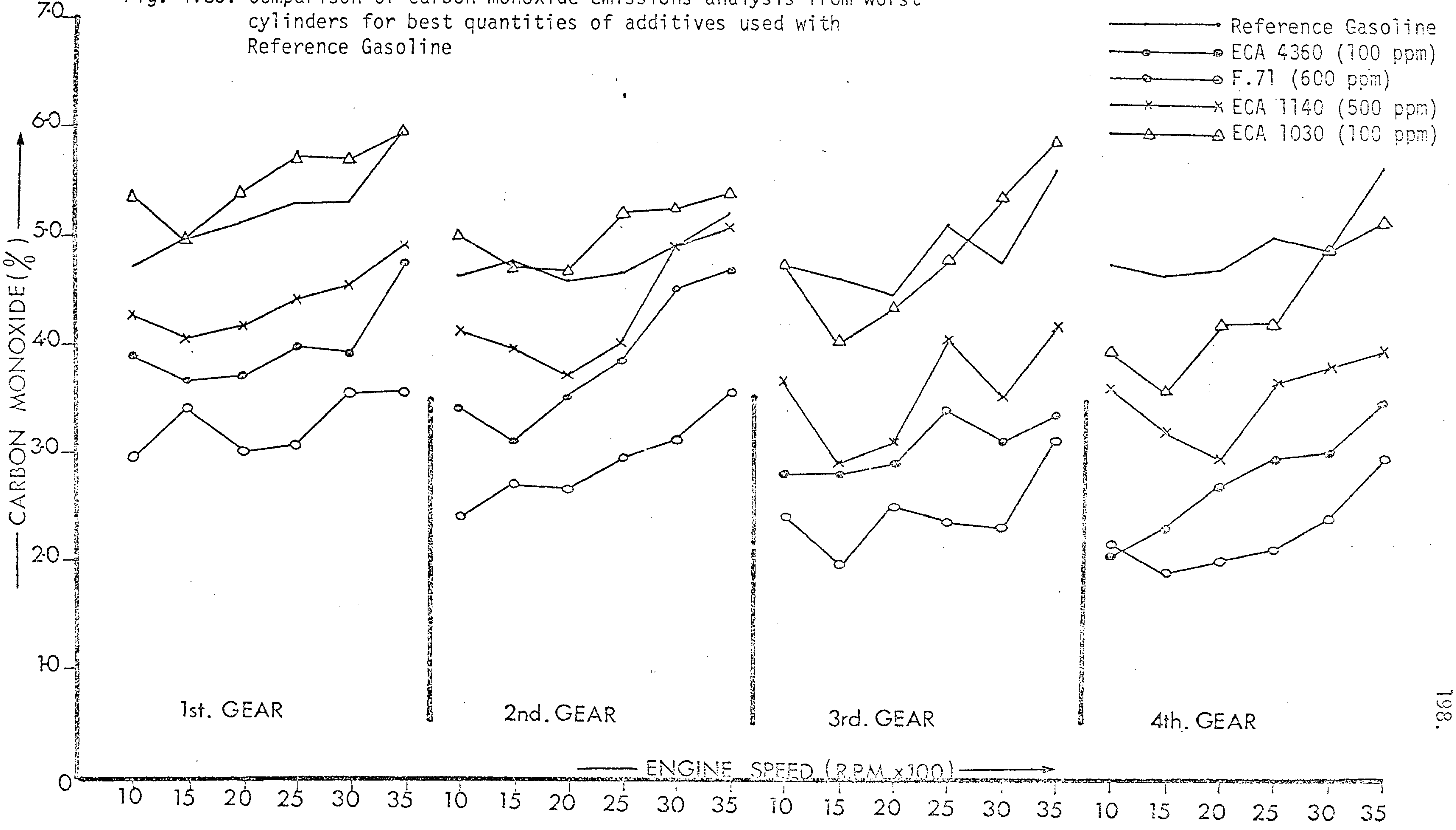


Fig. 4:85. Comparison of carbon monoxide emissions analysis from worst cylinders for best quantities of additives used with Reference Gasoline



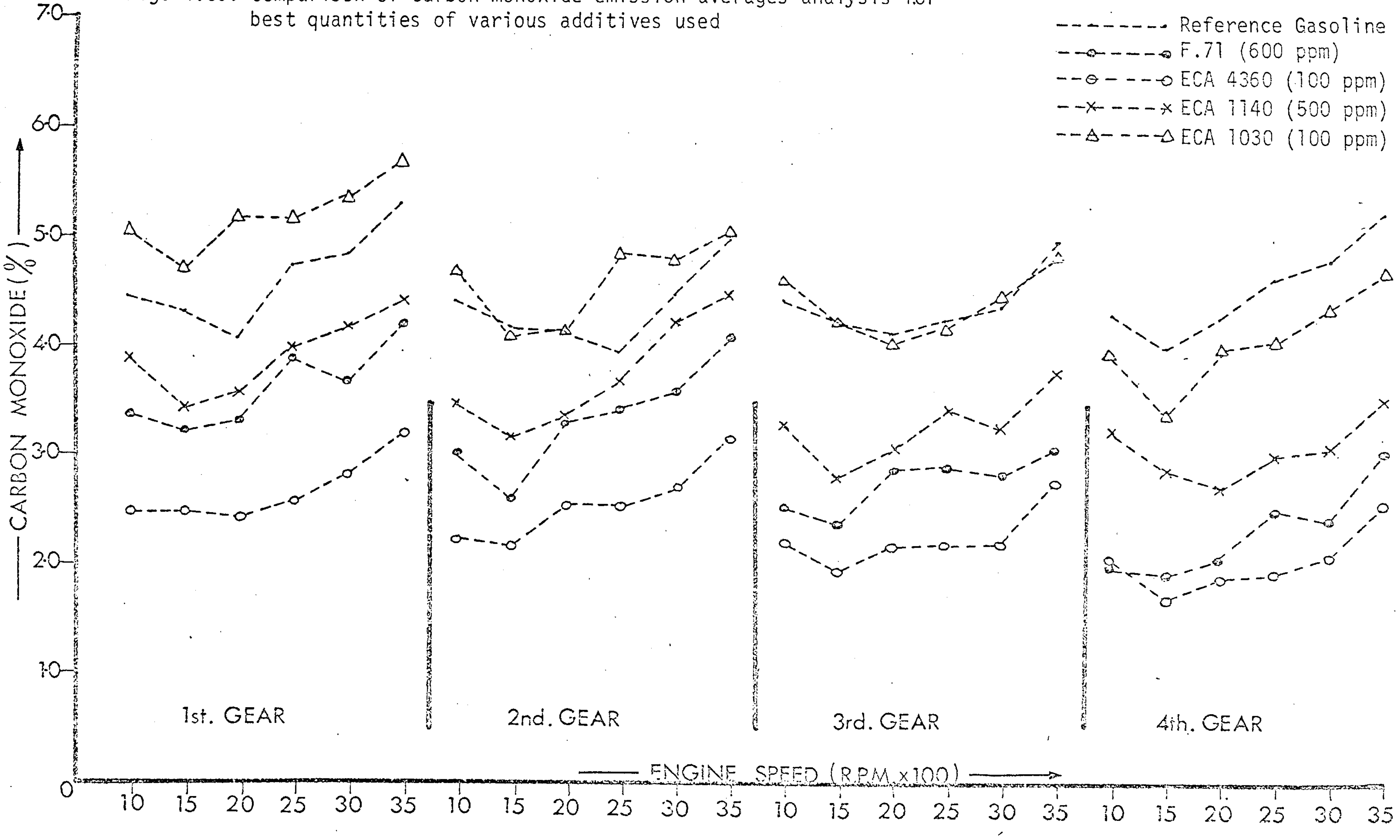


Fig. 4:86. Comparison of carbon monoxide emission averages analysis for best quantities of various additives used

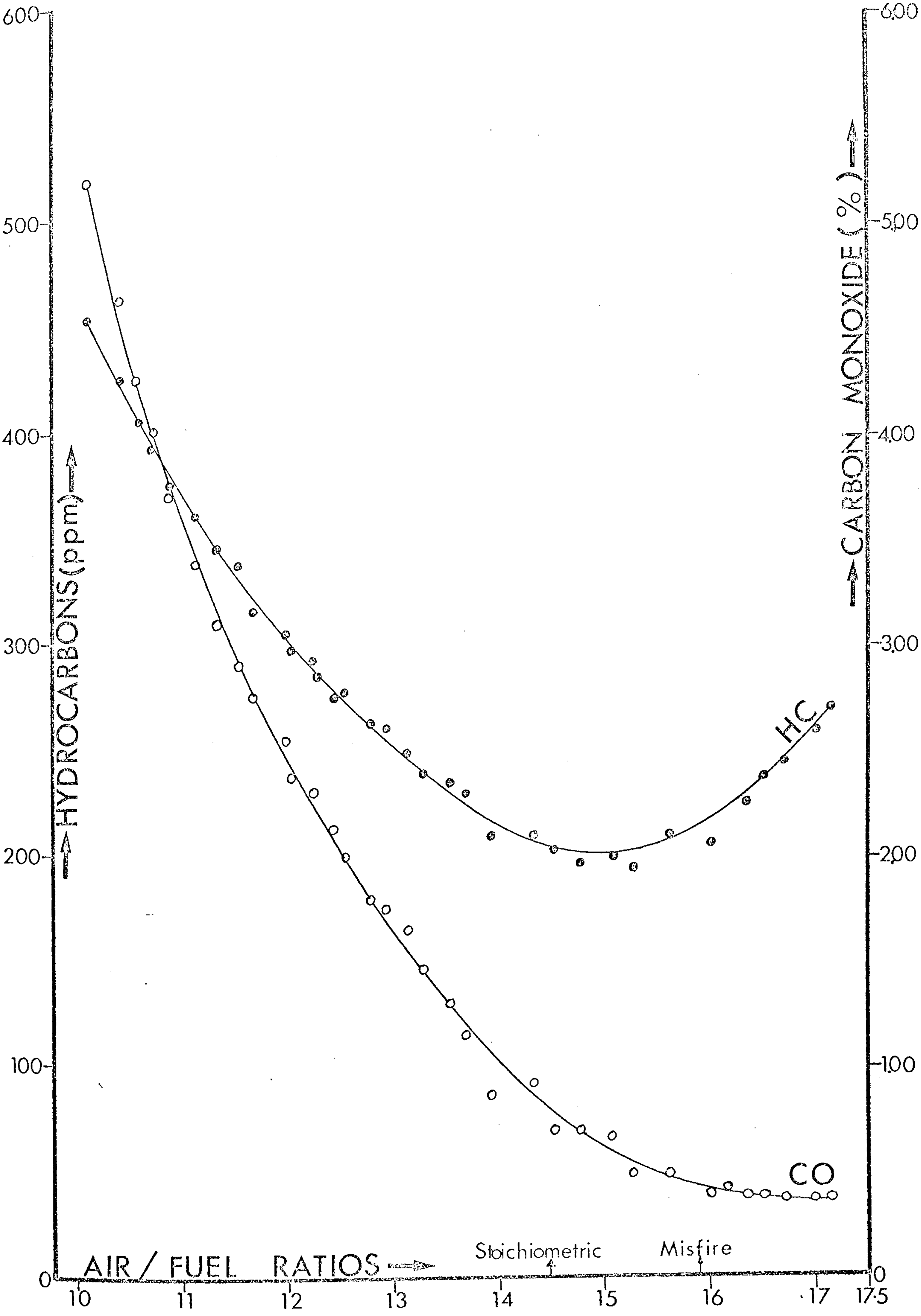


Fig. 4:87. The influence of Air/Fuel ratios on the concentration of Hydrocarbon and Carbon monoxide emissions.

(Fuel = Esso Plus, Engine Speed = 2500, Load = 52 lbs, BHP. = 28.89)

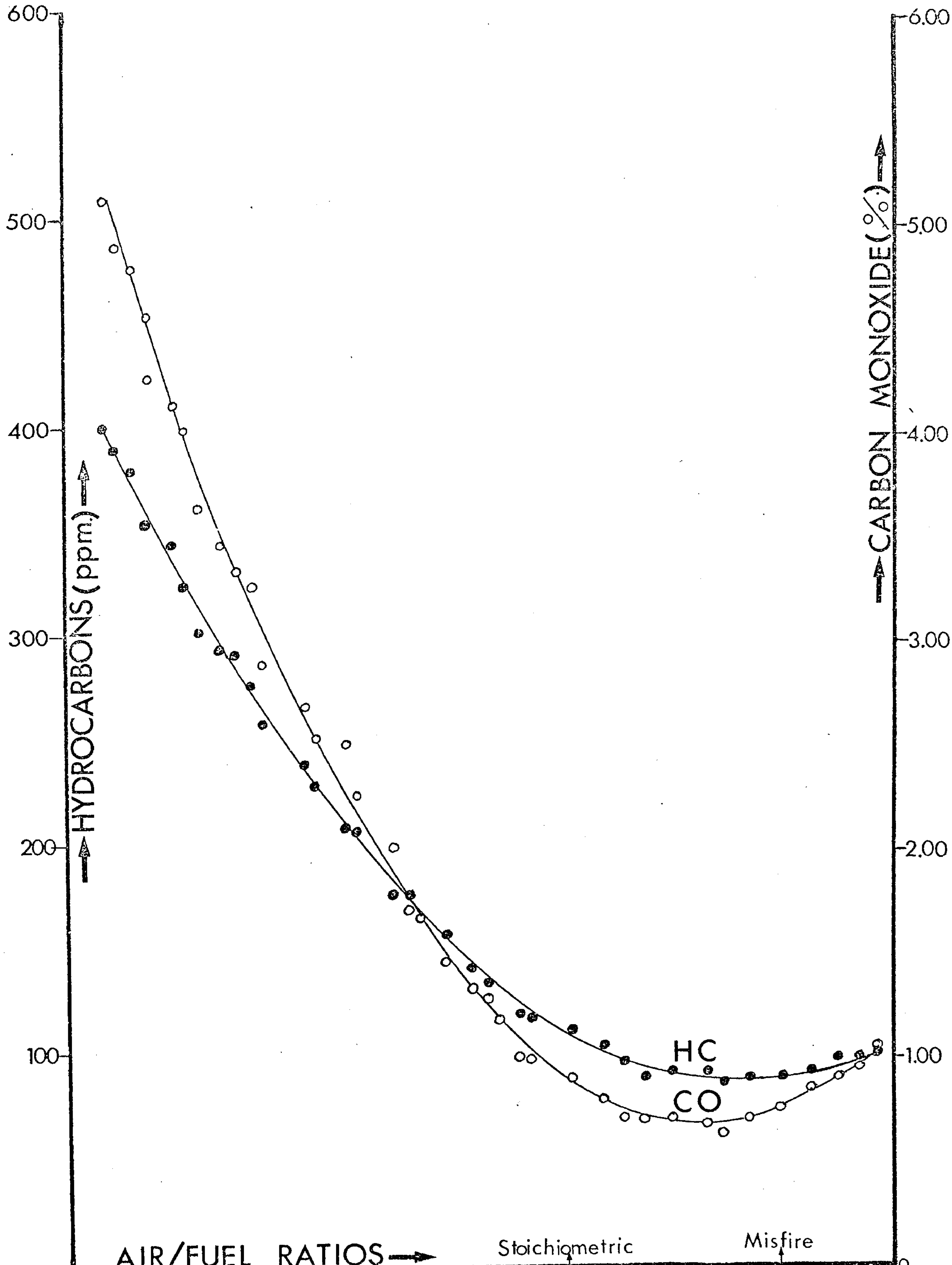


Fig. 4:88. The influence of Air/Fuel ratios on the concentrations of Hydrocarbons and Carbon monoxide emissions.

(Fuel = Esso Plus + F.71 - 600 ppm, Engine Speed = 2500
Load = 52 lbs, BHP. = 28.89)

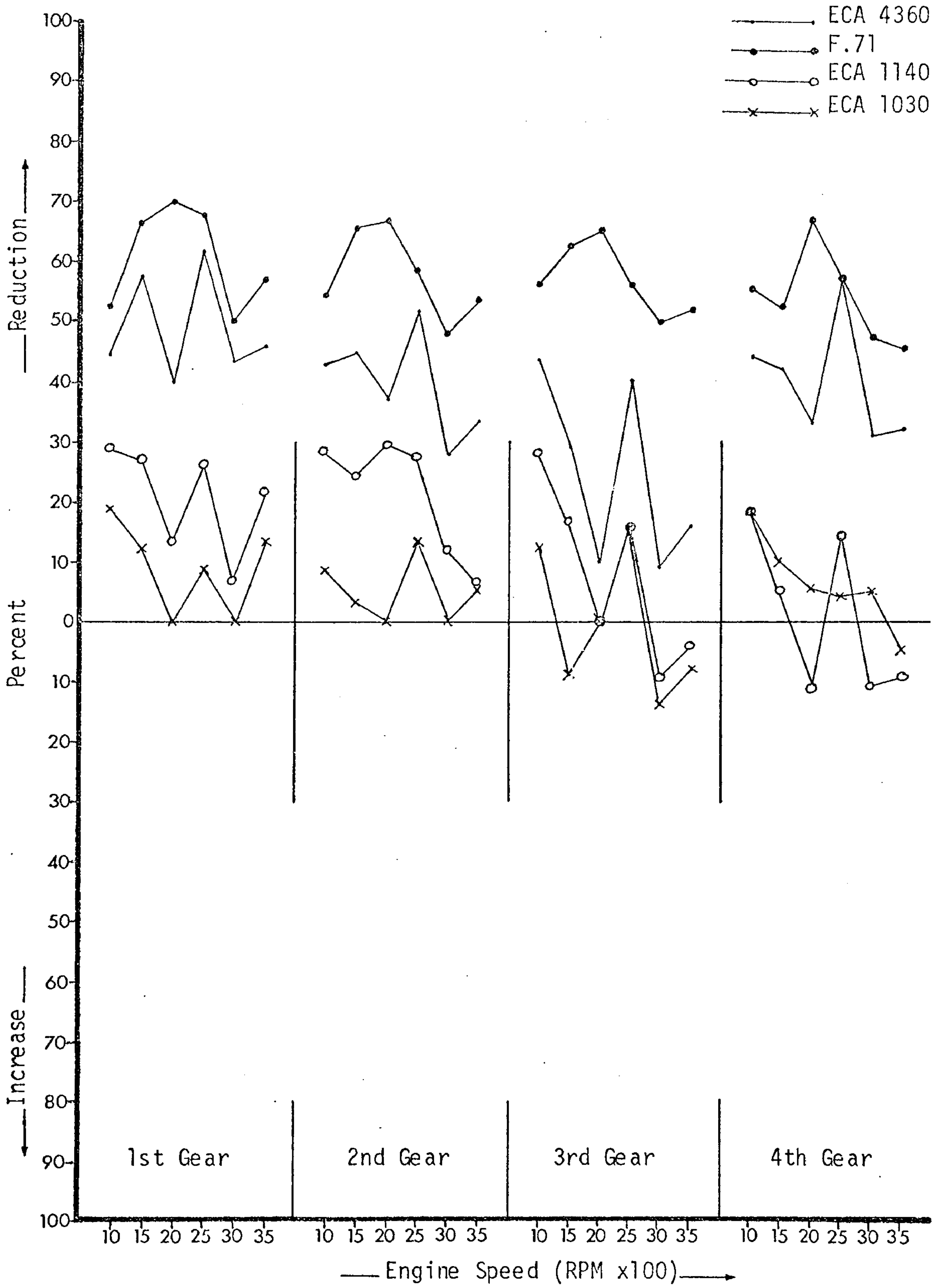


Fig. 4:89. Percentage reduction or increase in Hydrocarbon emissions from mixed exhaust for Esso Plus with best quantities of additives used

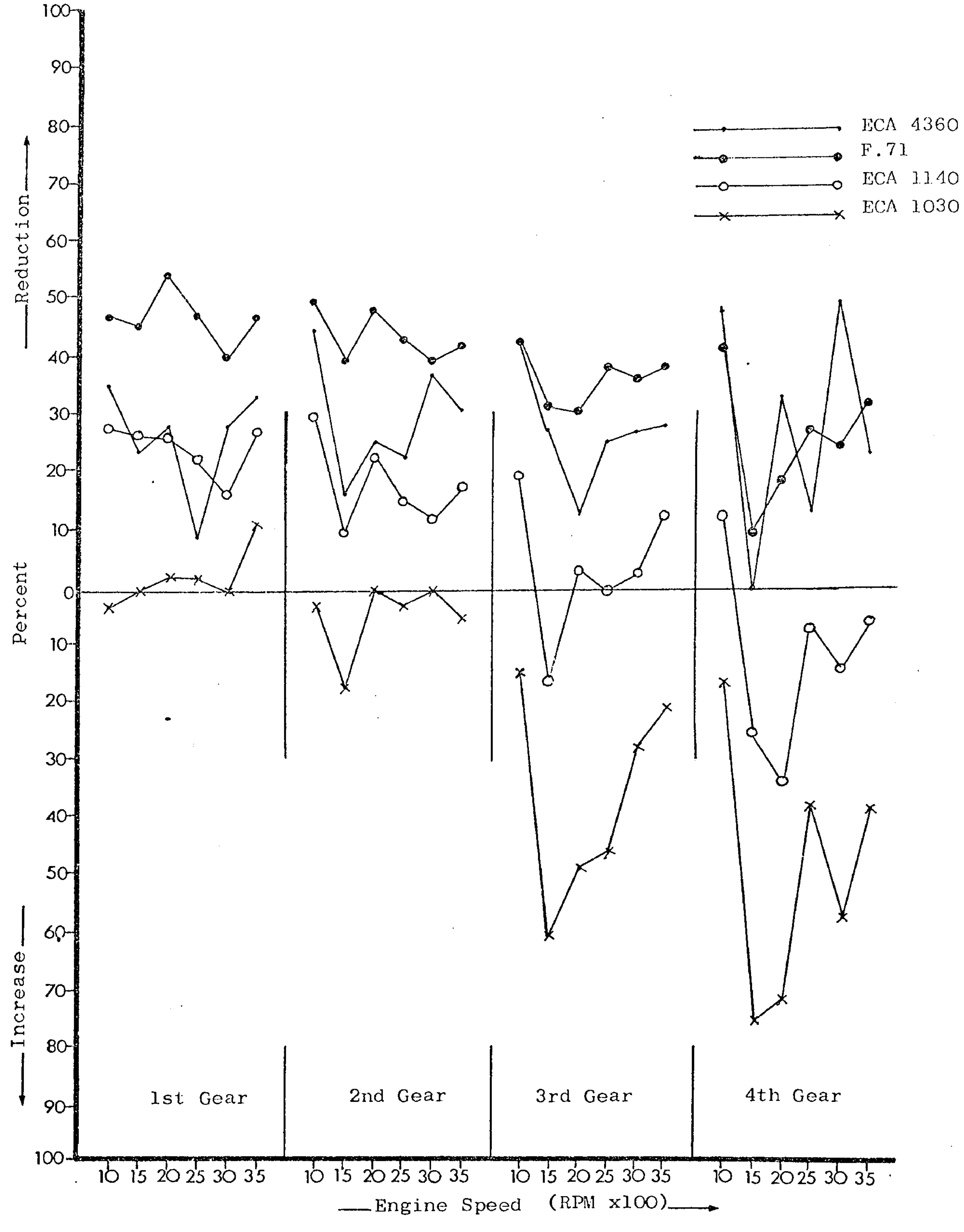


Fig. 4:90. Percentage reduction or increase in Hydrocarbon emissions from best cylinders for Esso Plus with best quantities of additives used

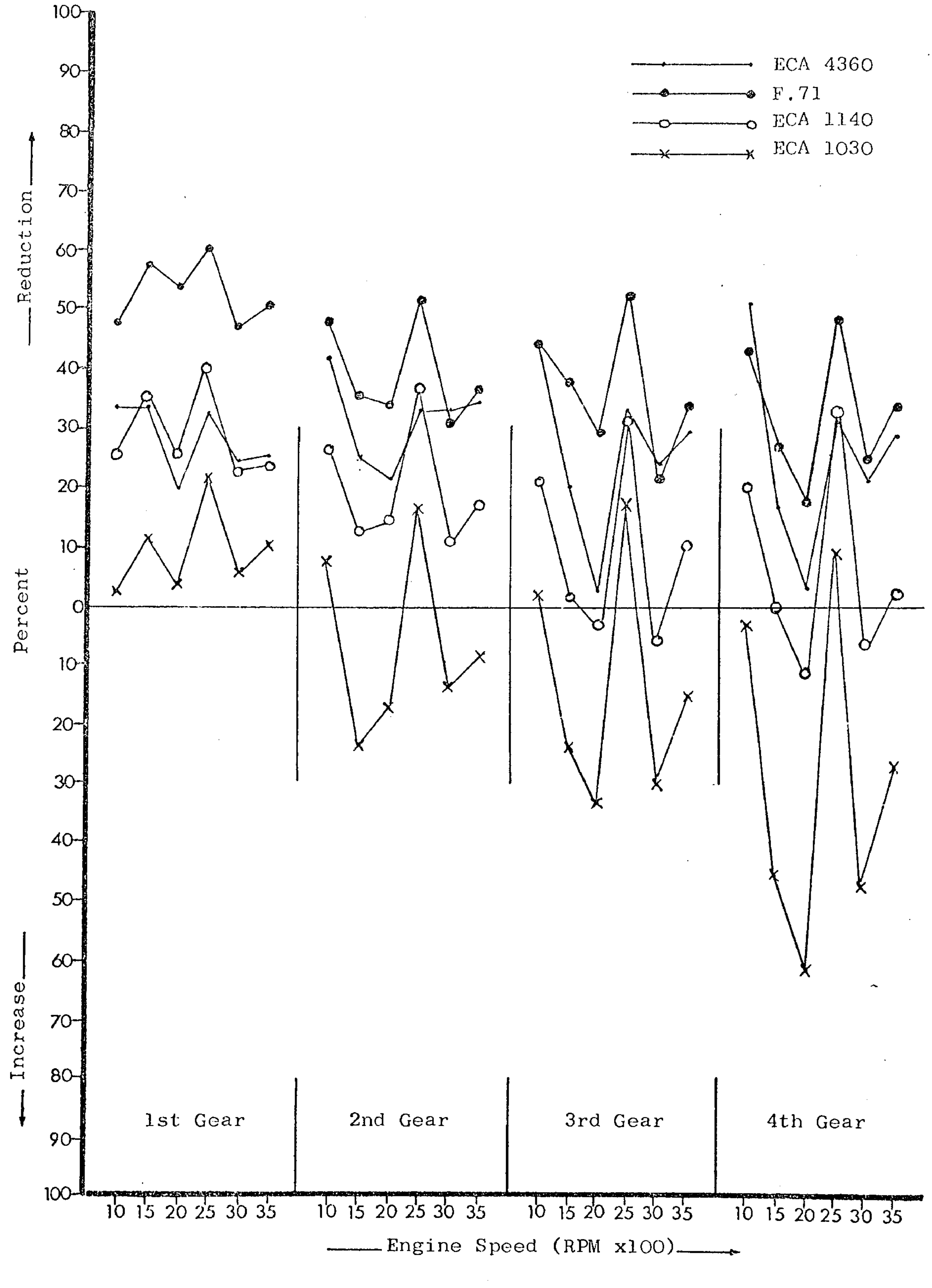


Fig. 4:91. Percentage reduction or increase in Hydrocarbon emissions from worst cylinders for Esso Plus with best quantities of additives used

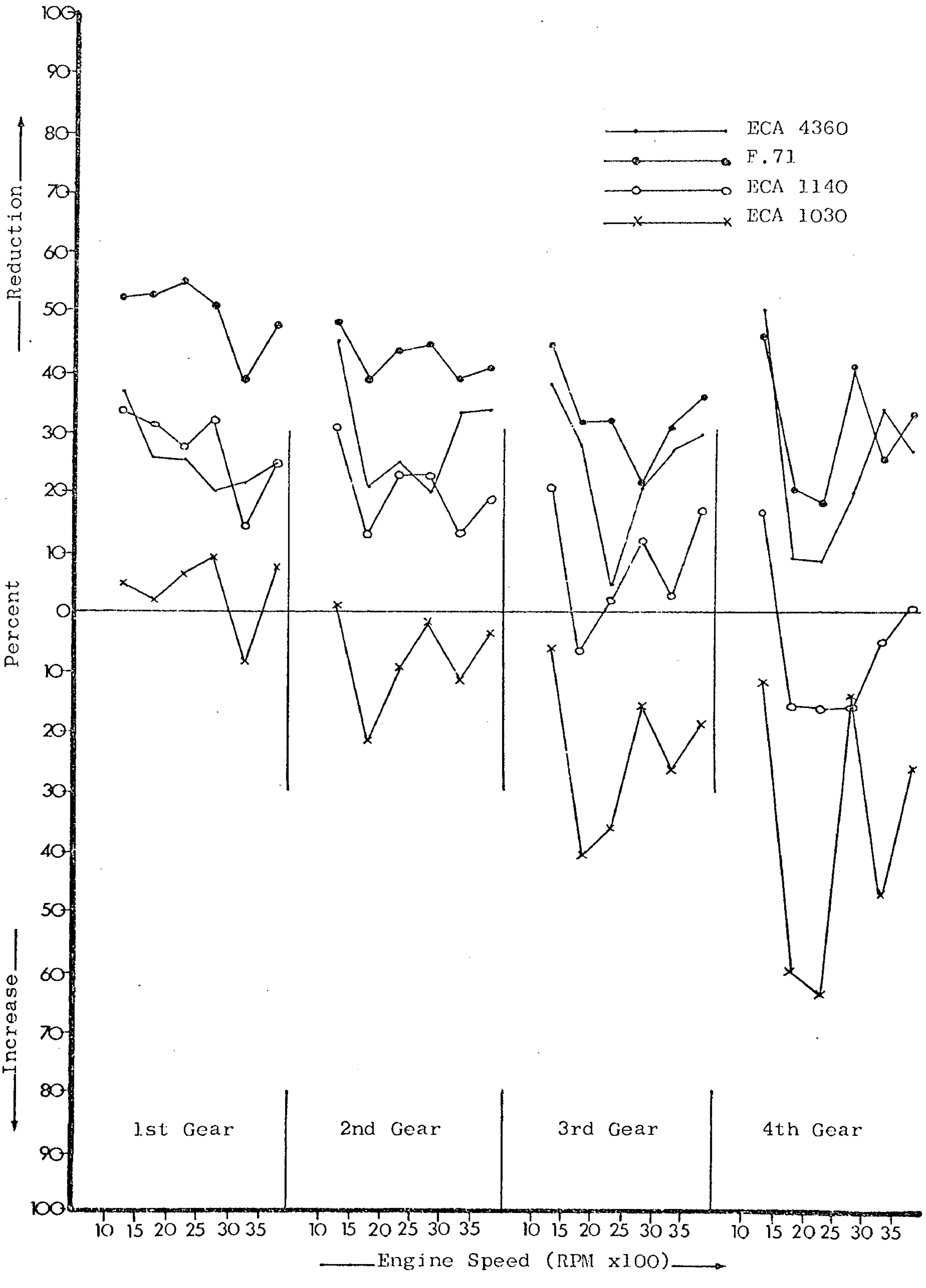


Fig. 4:92. Percentage reduction or increase in Hydrocarbon emissions averages for Esso Plus with best quantities of additives used

Fig. 4:93. Percentage reduction or increase in Carbon monoxide emissions from mixed exhaust for Esso Plus with best quantities of additives used.

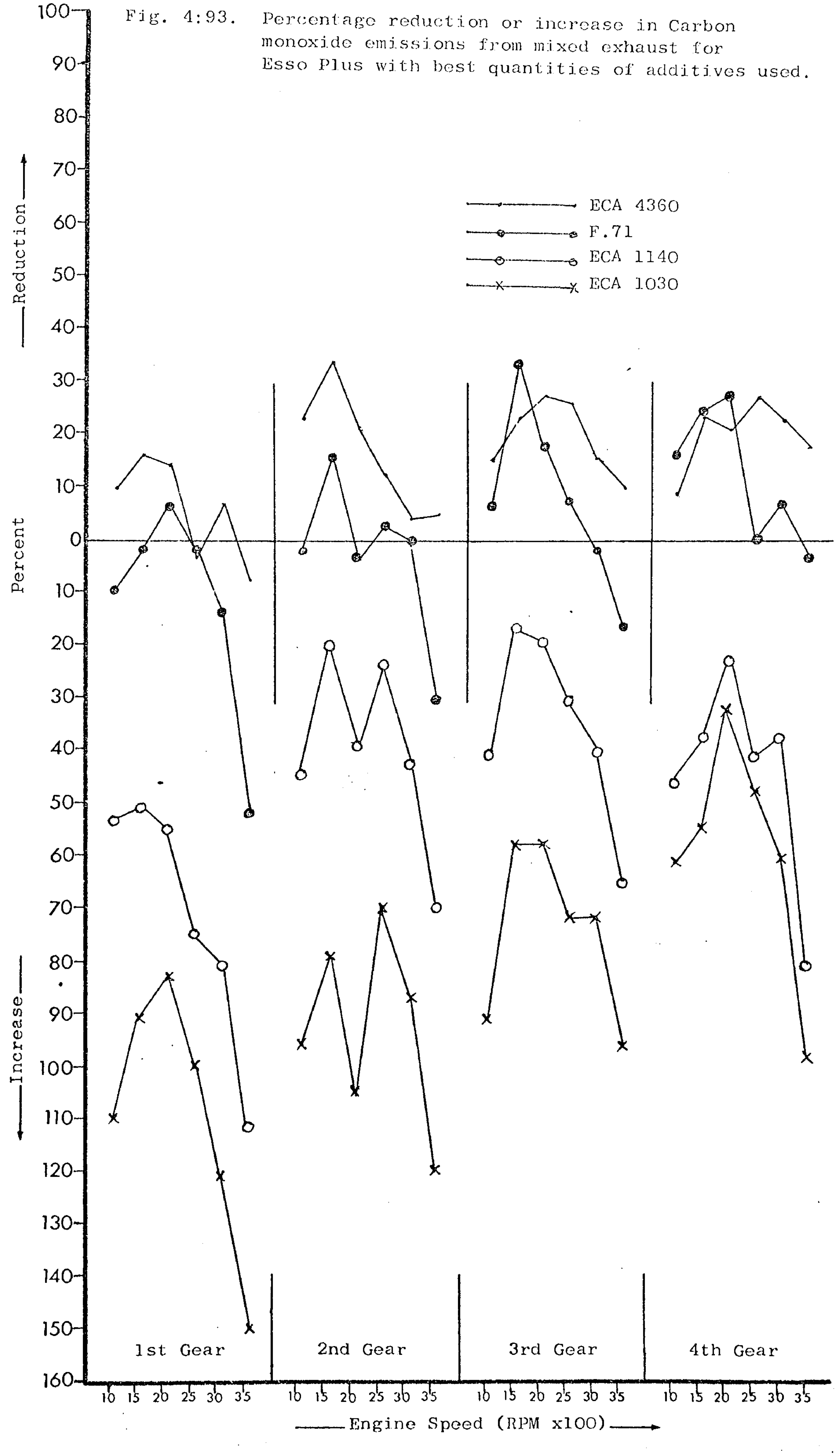


Fig. 4:94. Percentage reduction or increase in Carbon monoxide emissions from best cylinders for Esso Plus with best quantities of additives used.

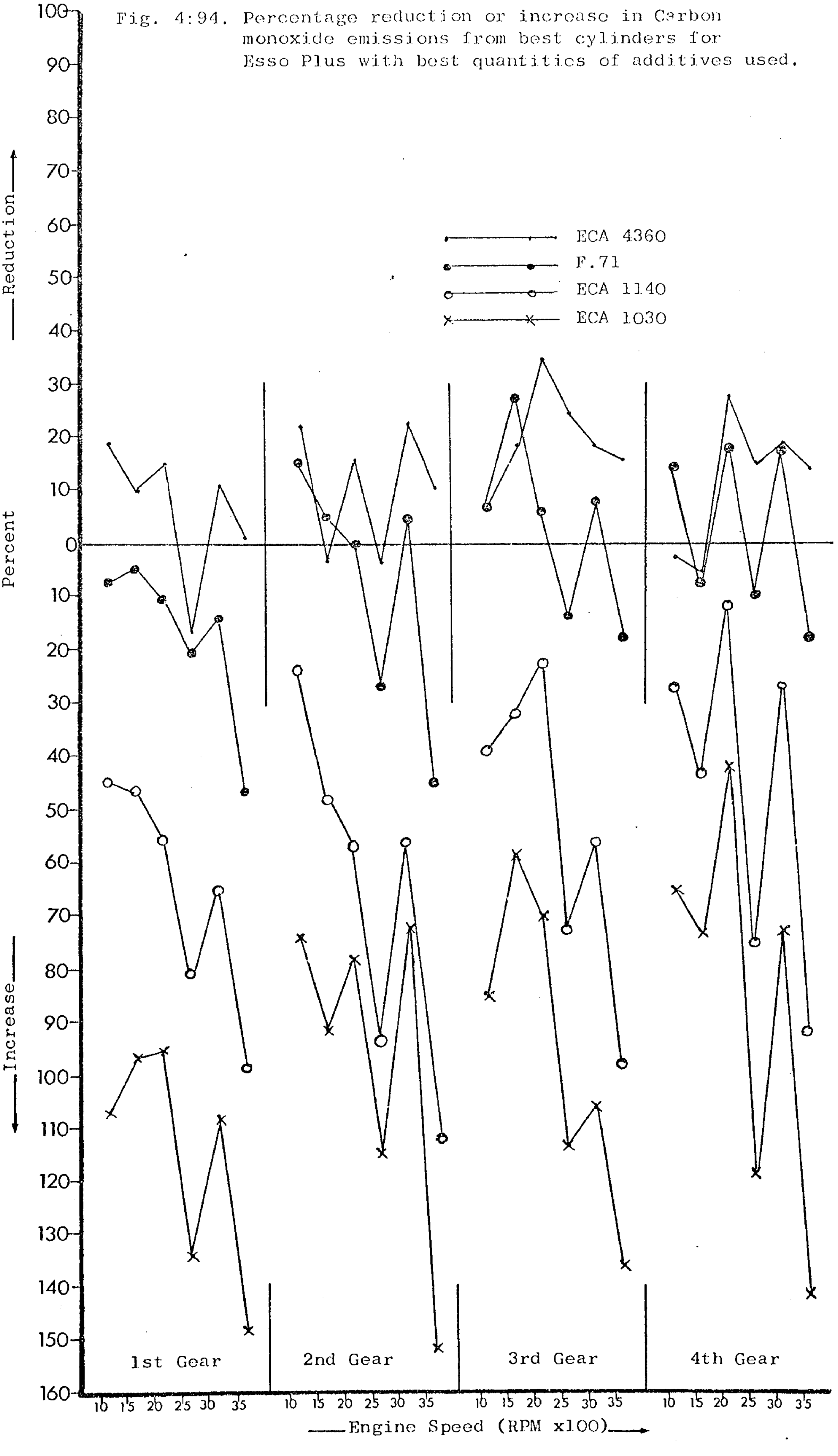


Fig. 4:95. Percentage reduction or increase in Carbon monoxide emissions from worst cylinders for Esso Plus with best quantities of additives used.

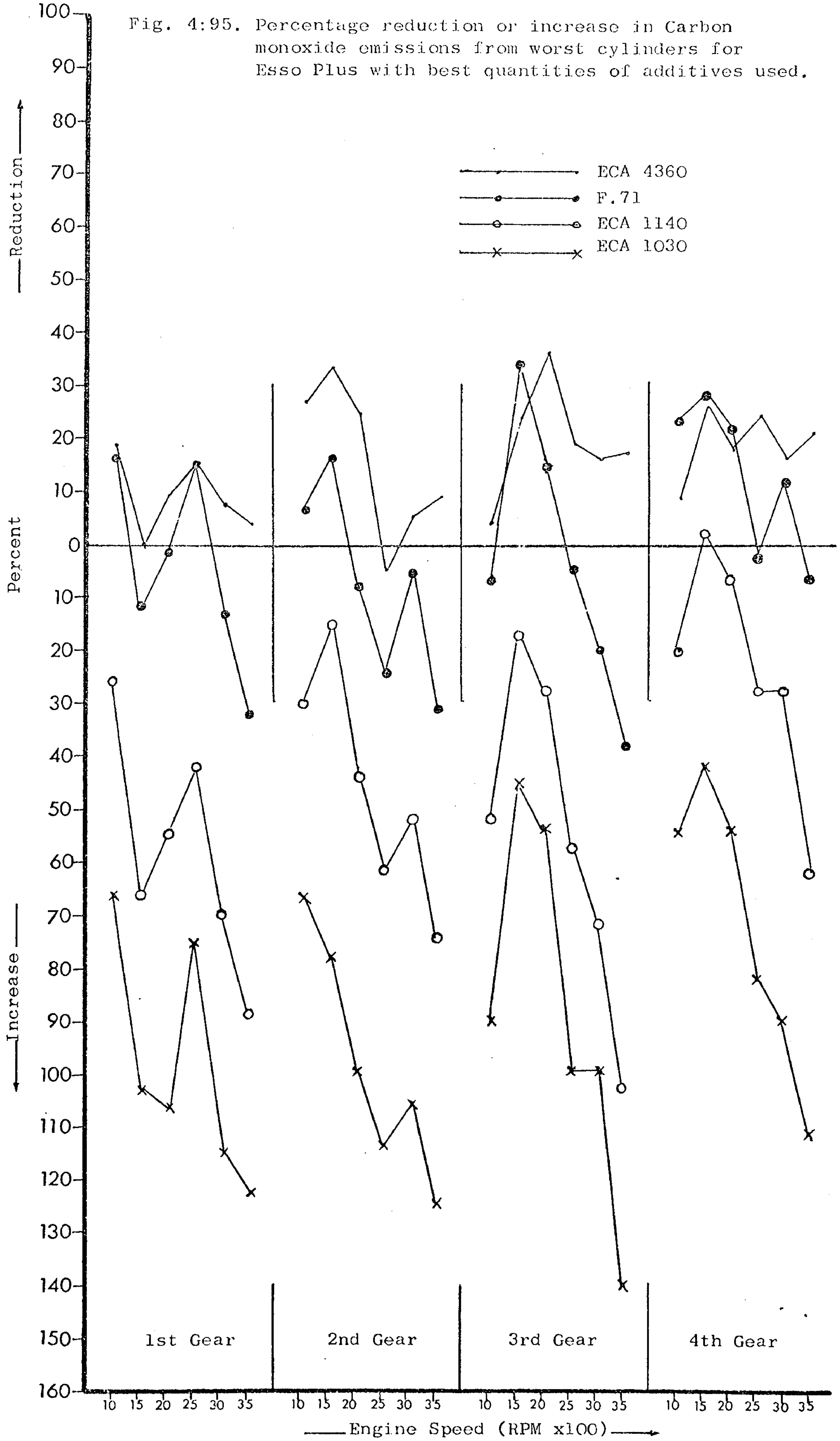
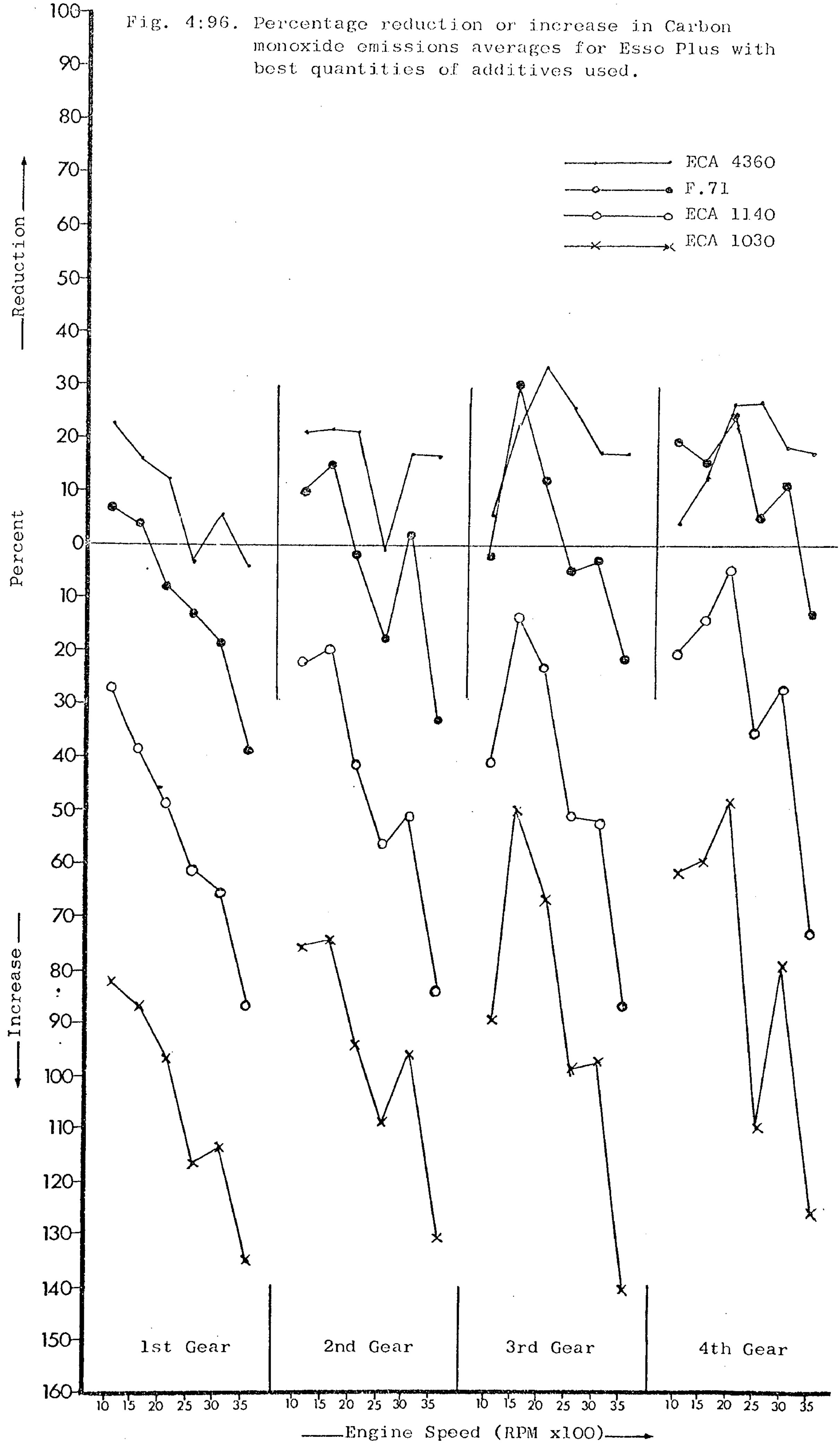


Fig. 4:96. Percentage reduction or increase in Carbon monoxide emissions averages for Esso Plus with best quantities of additives used.



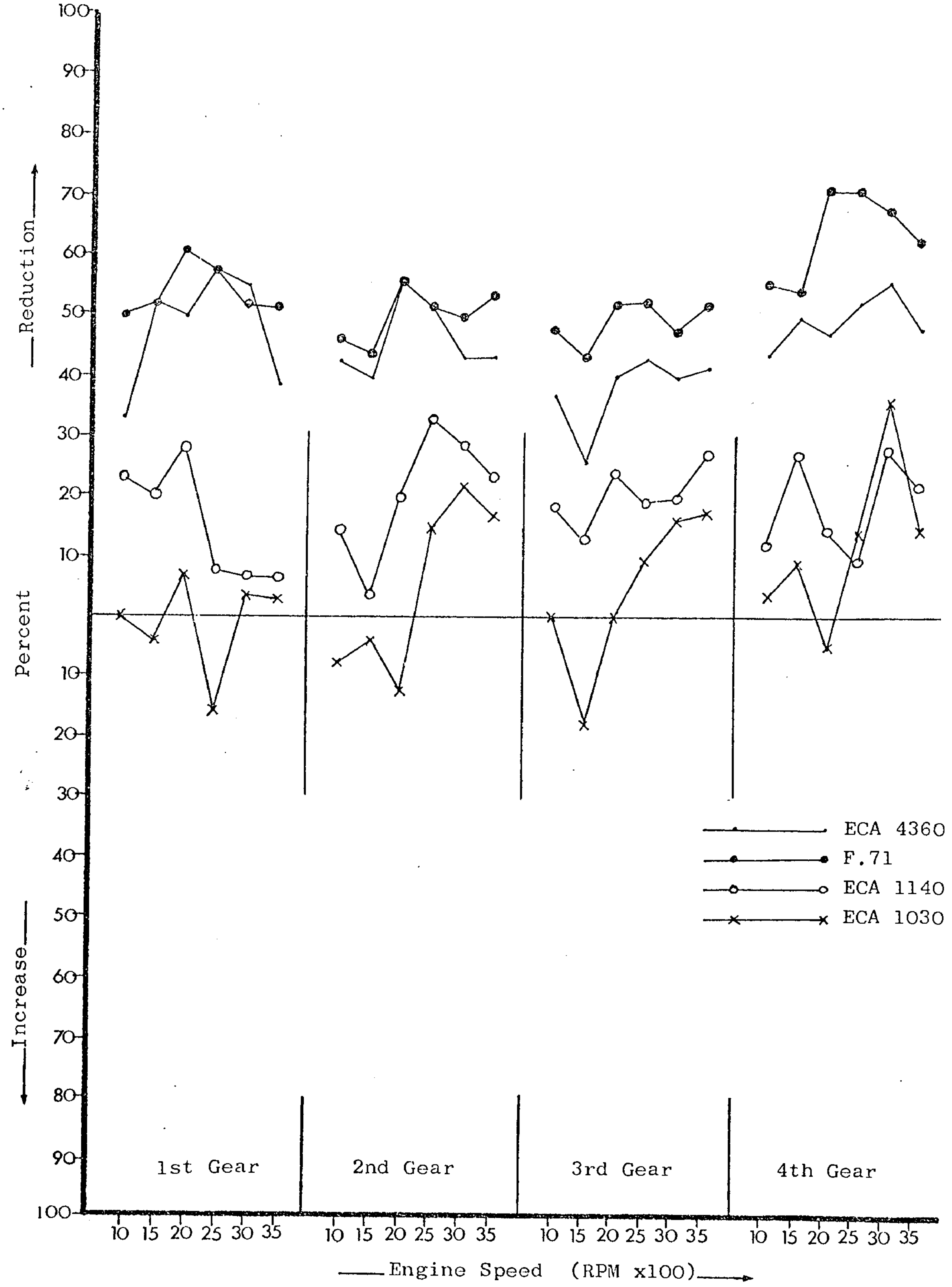


Fig. 4:97. Percentage reduction or increase in Hydrocarbon emissions from mixed exhaust for Reference Gasoline with best quantities of additives used

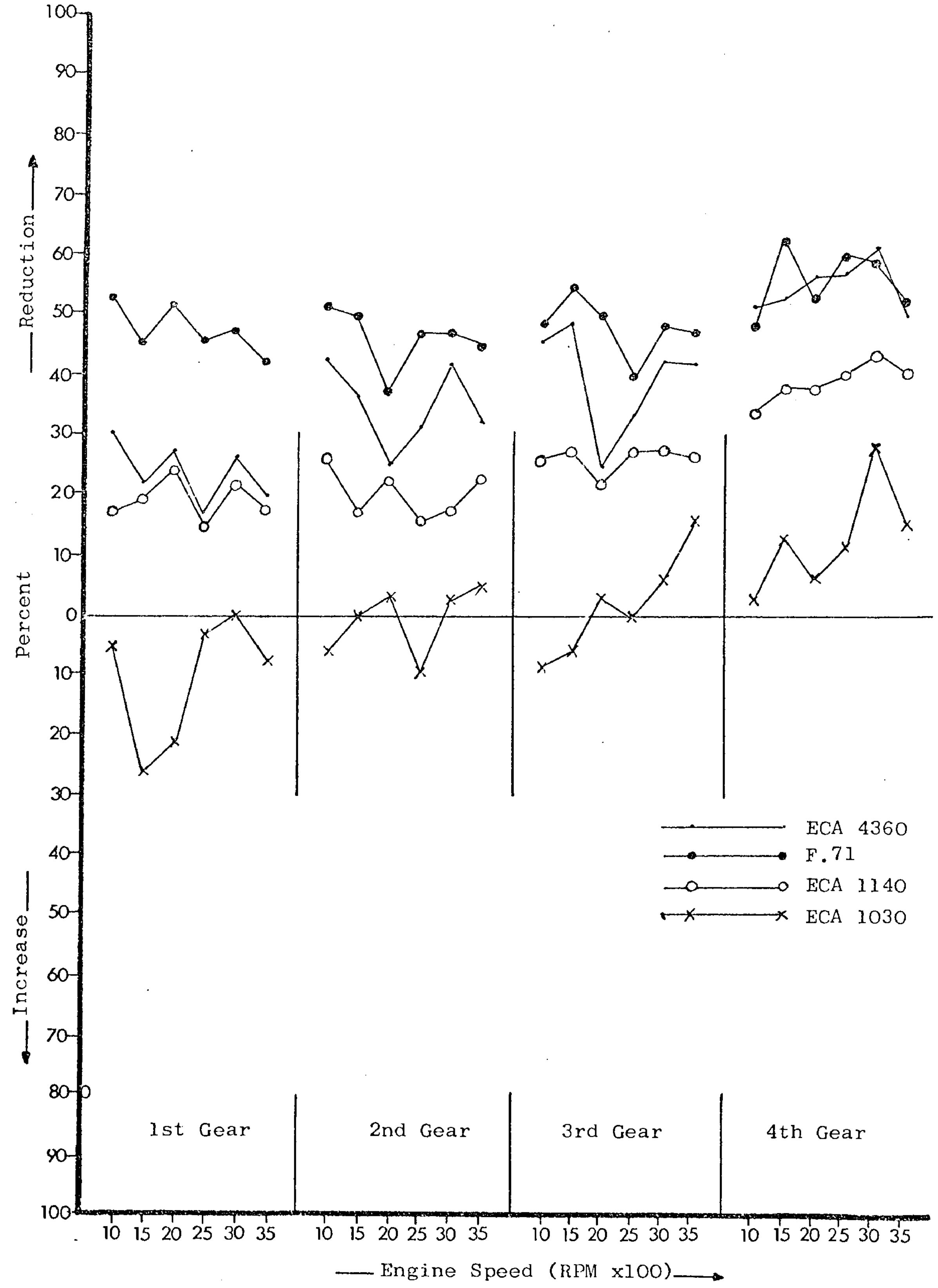


Fig. 4:98. Percentage reduction or increase in Hydrocarbon emissions from best cylinders for Reference Gasoline with best quantities of additives used

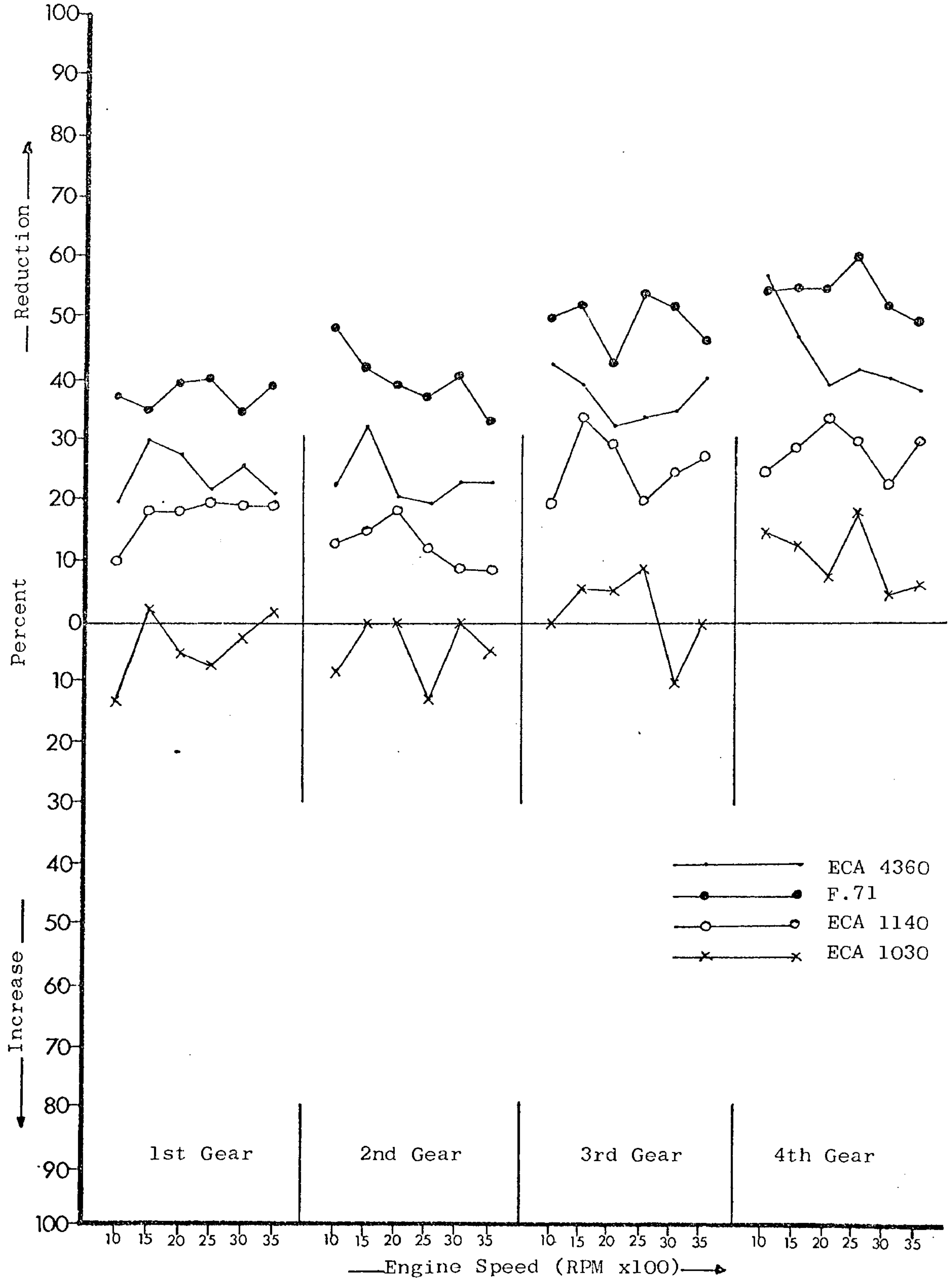


Fig. 4:99. Percentage reduction or increase in Hydrocarbon emissions from worst cylinders for Reference Gasoline with best quantities of additives used.

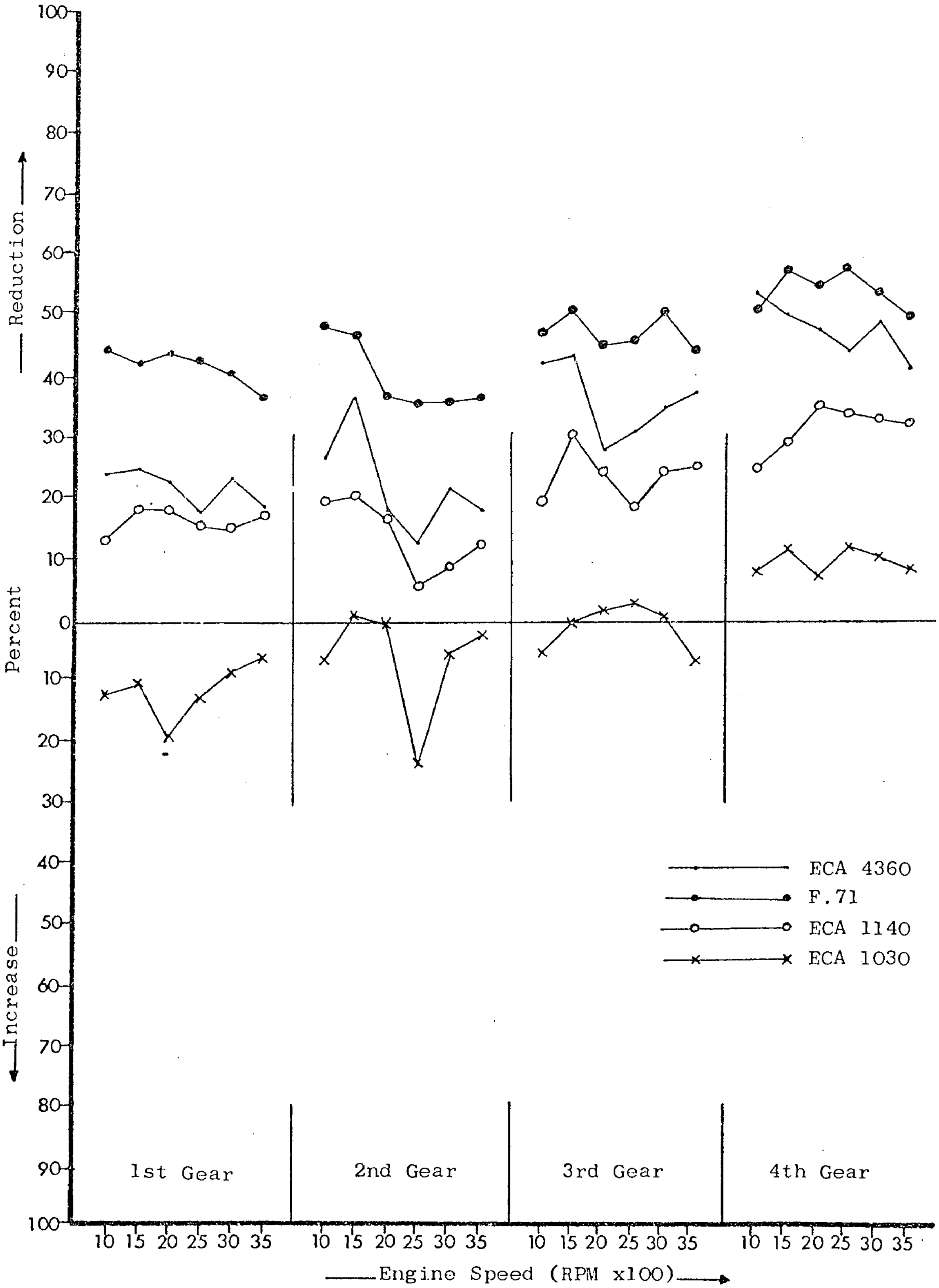


Fig. 4:100. Percentage reduction or increase in Hydrocarbon emissions averages for Reference Gasoline with best quantities of additives used

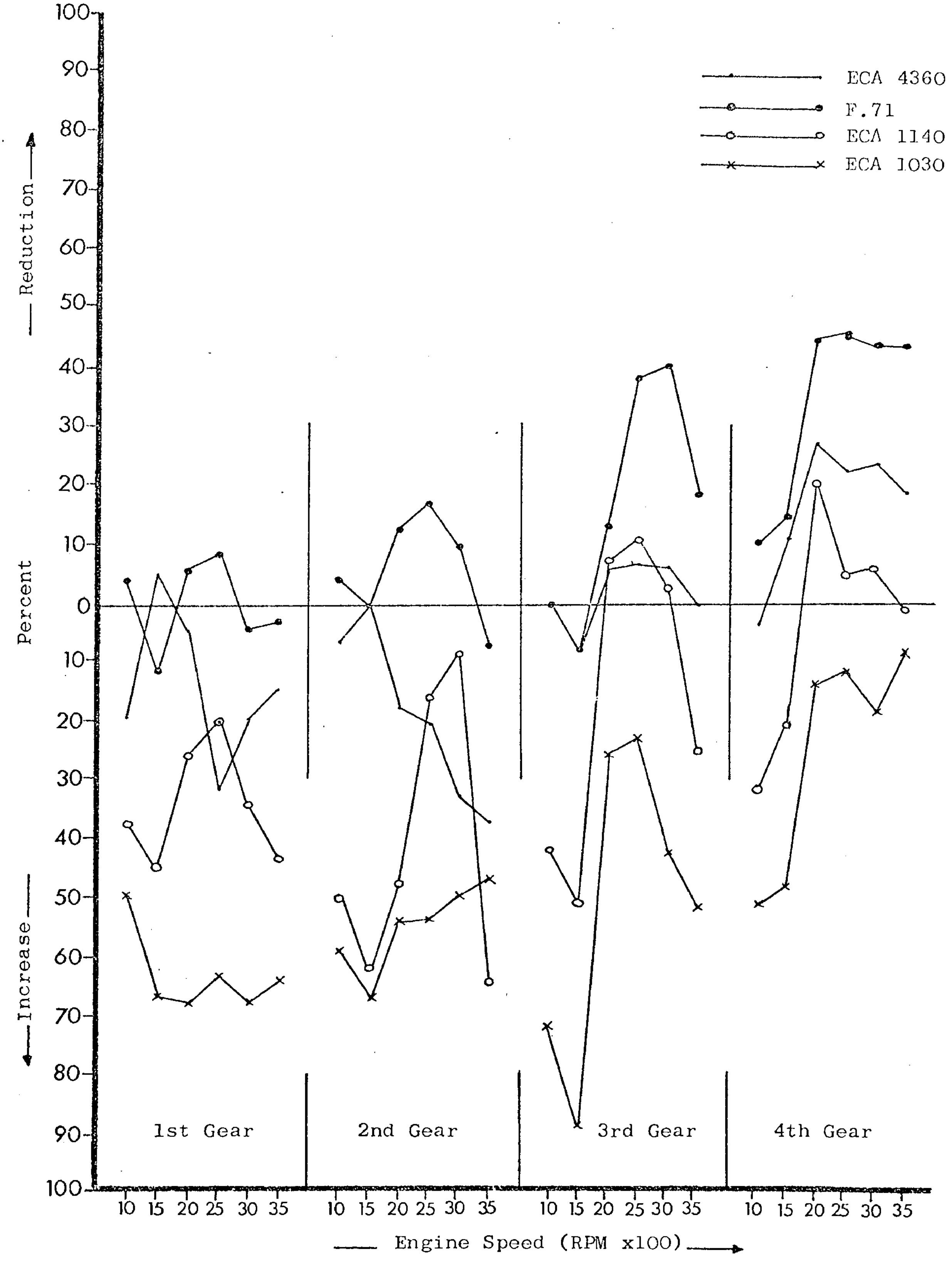


Fig. 4:101. Percentage reduction or increase in Carbon monoxide emissions from mixed exhaust for Reference Gasoline with best quantities of additives used.

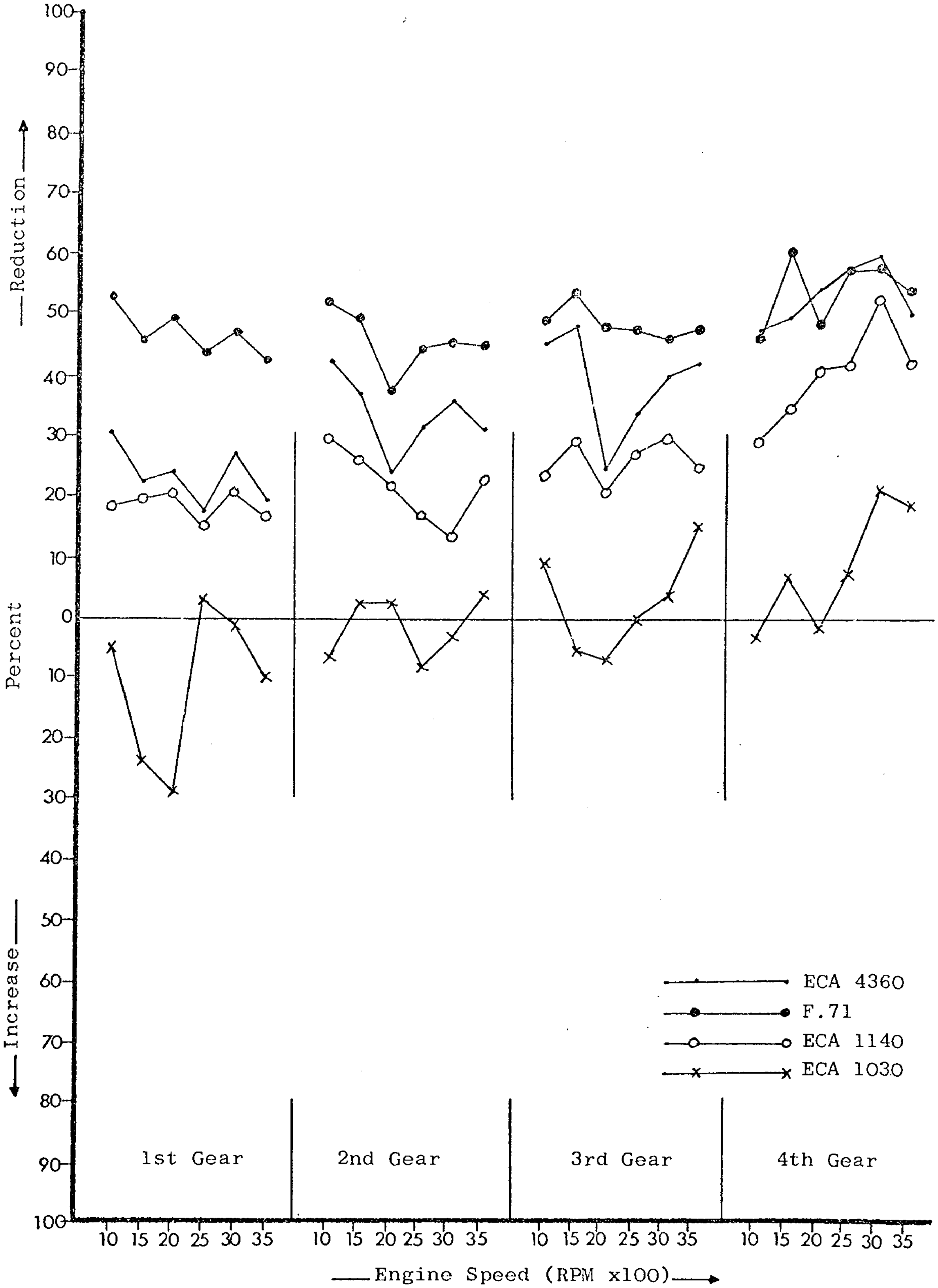


Fig.4:102. Percentage reduction or increase in Carbon monoxide emissions from best cylinders for Reference Gasoline with best quantities of additives used.

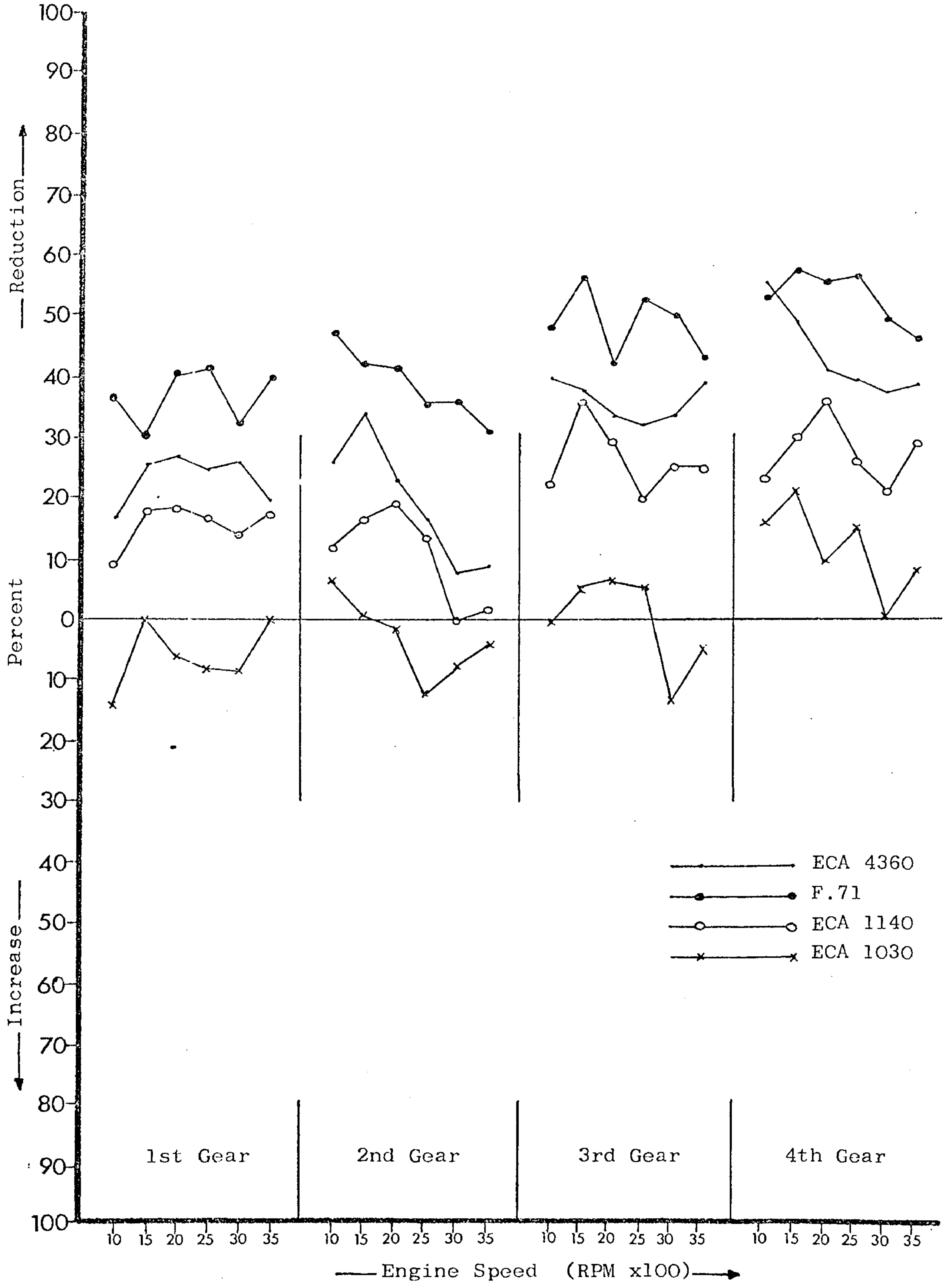


Fig. 4:103. Percentage reduction or increase in Carbon monoxide emissions from worst cylinders for Reference Gasoline with best quantities of additives used.

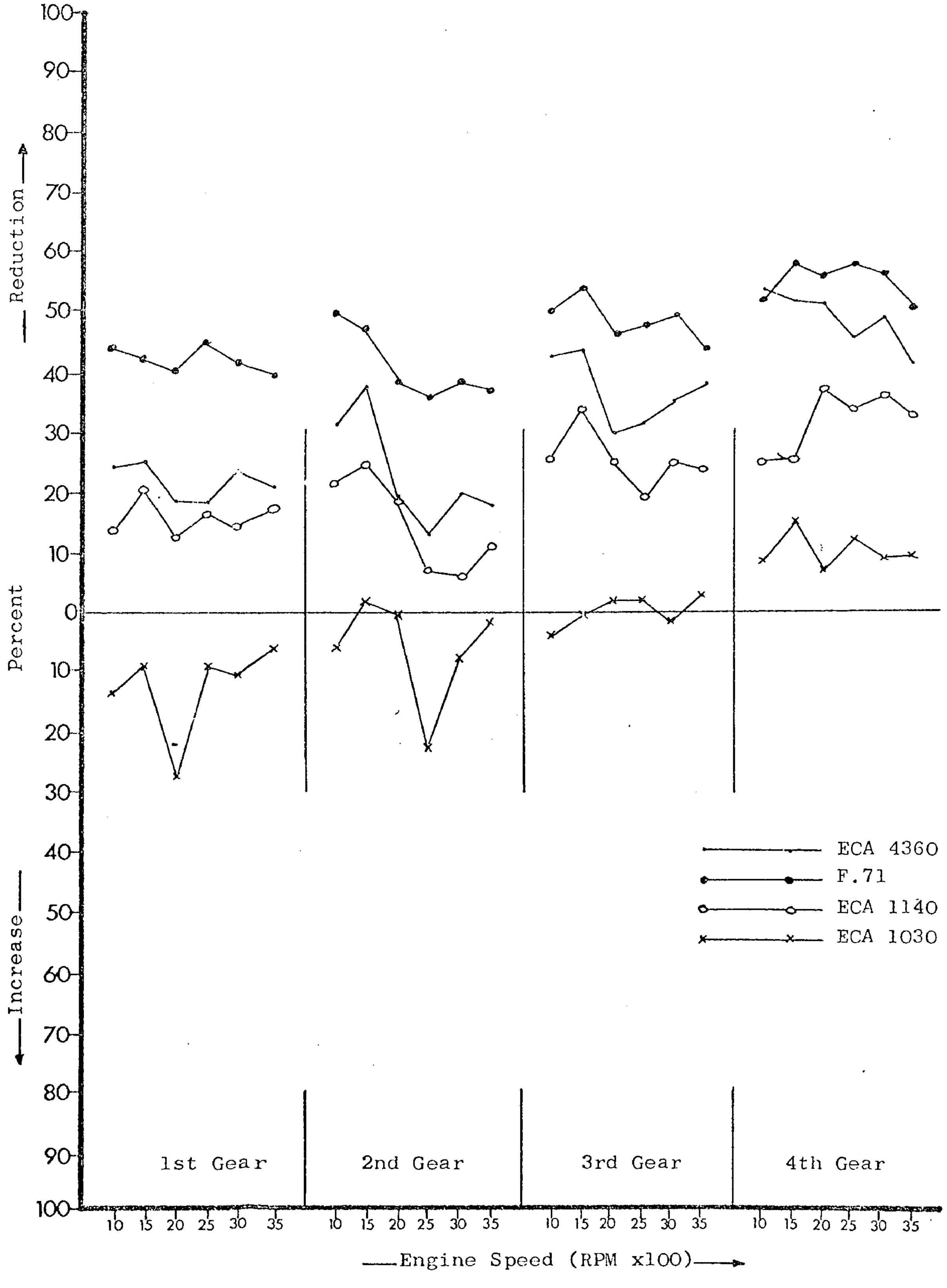
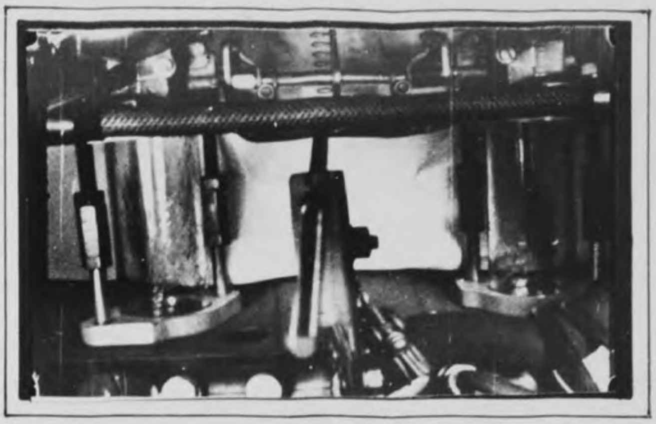
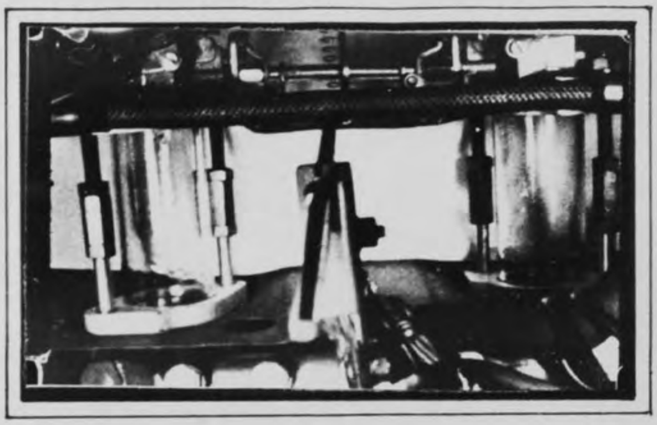


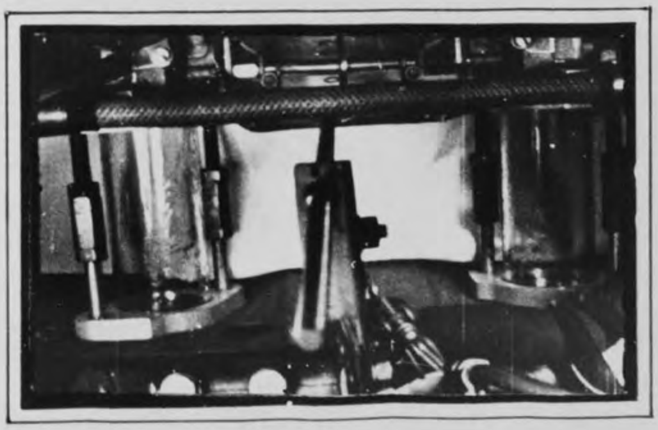
Fig. 4:104. Percentage reduction or increase in Carbon monoxide emissions averages for Reference Gasoline with best quantities of additives used.



Esso Plus

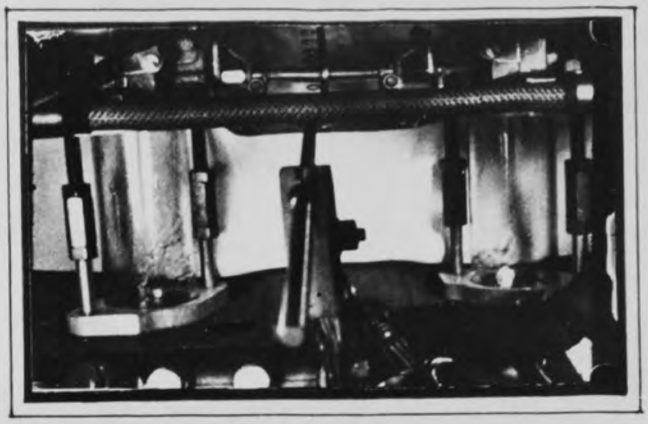


Best Additive (F.71 600ppm.)

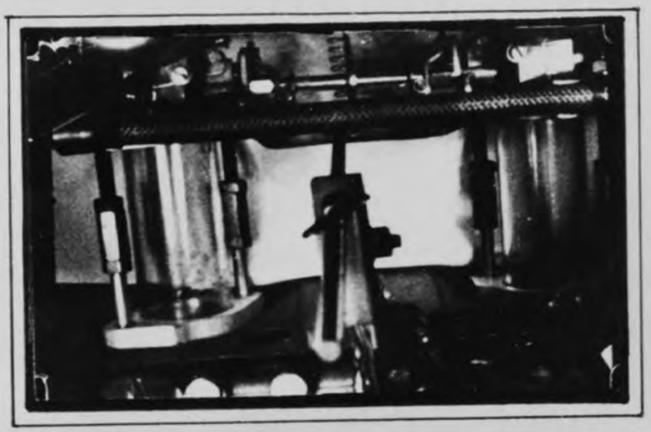


Worst Additive (ECA 1030 100 ppm.)

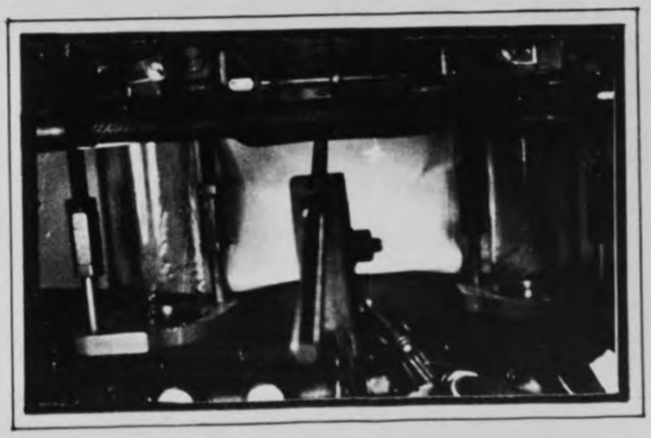
Plate 6. Comparison of flow patterns for 1st. gear. (Gasoline=Esso Plus Engine speed =2500 RPM)



Esso Plus

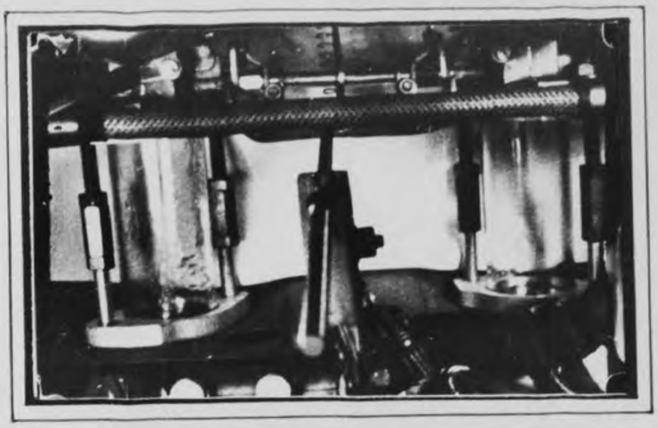


Best Additive (F.71 600 ppm.)

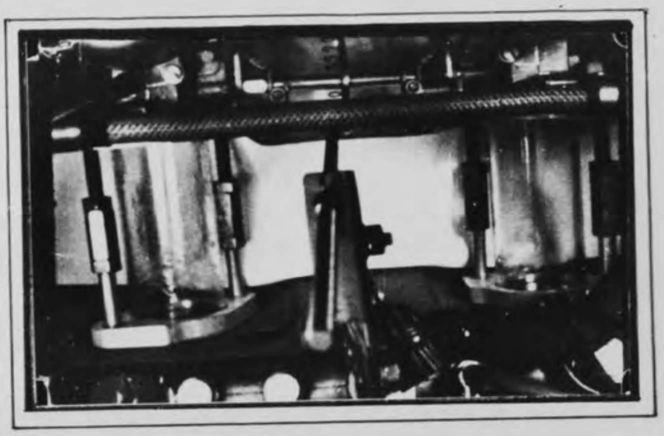


Worst Additive (ECA 1030 100 ppm.)

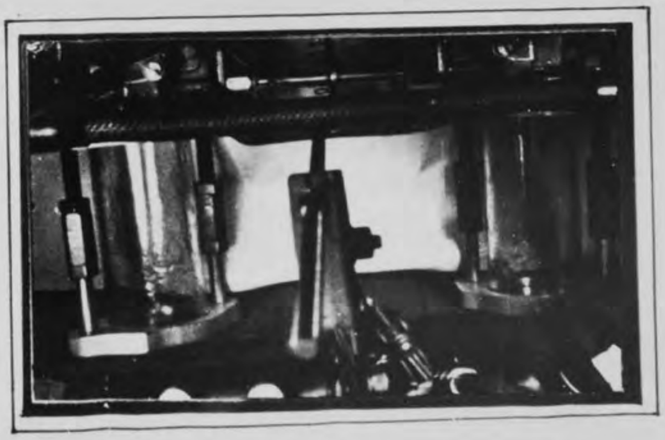
Plate 7. Comparison of flow patterns for 2nd. gear.(Gasoline=Esso Plus Engine speed=2500 RPM)



Esso Plus

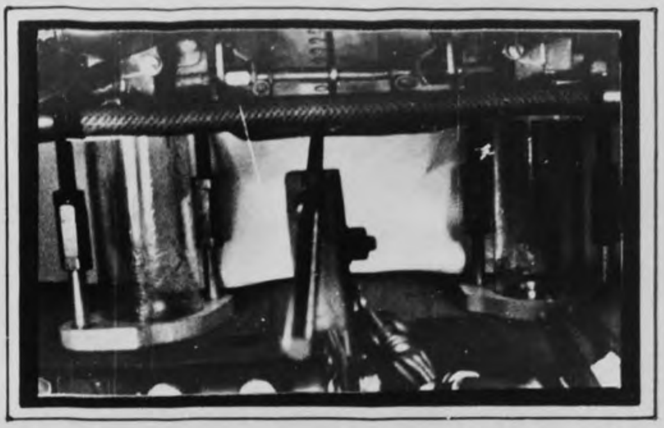


Best Additive (F.71 600 ppm.)

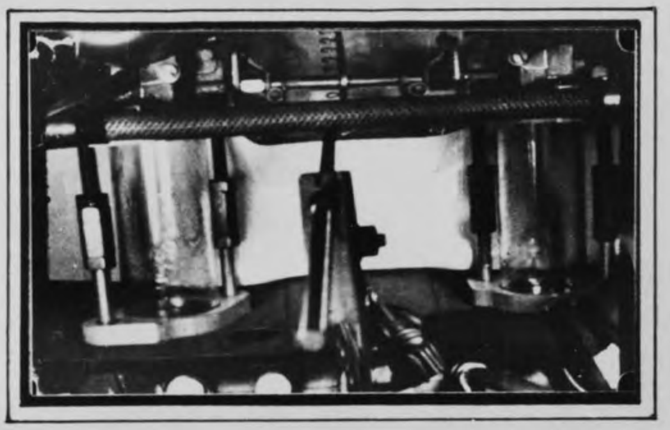


Worst Additive (ECA 1030 100 ppm.)

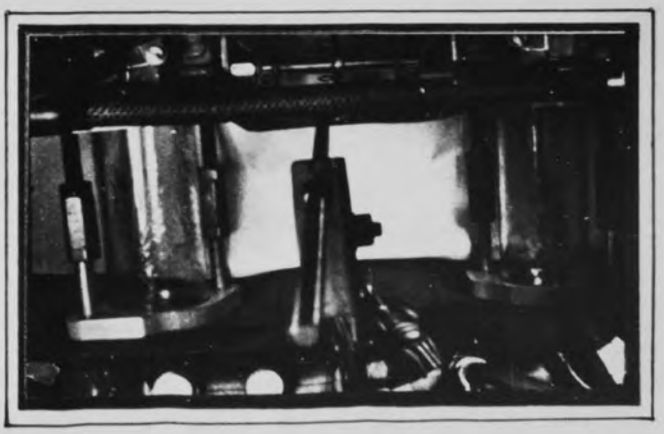
Plate 8. Comparison of flow patterns for 3rd. gear. (Gasoline = Esso Plus Engine speed = 2500 RPM)



Esso Plus

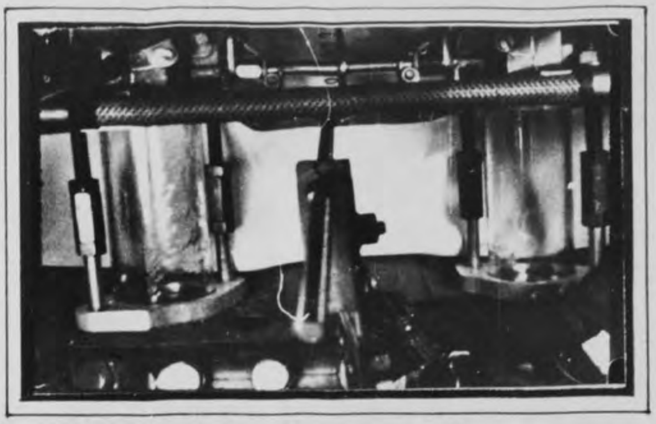


Best Additive (F.71 600 ppm.)

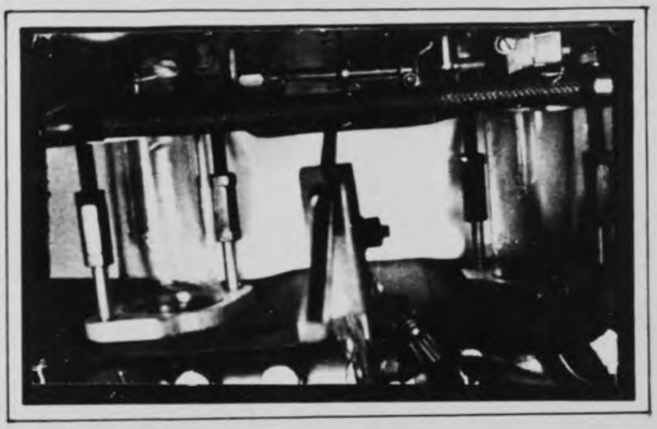


Worst Additive (ECA 1030 100 ppm.)

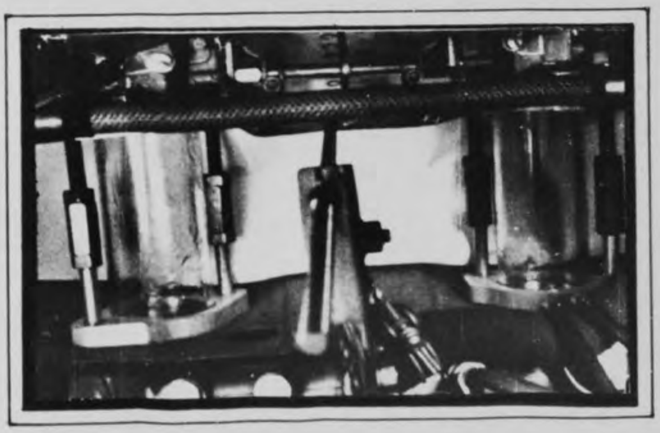
Plate 9. Comparison of flow patterns for 4th. gear. (Gasoline = Esso Plus Engine speed= 2500 RPM)



Reference Gasoline

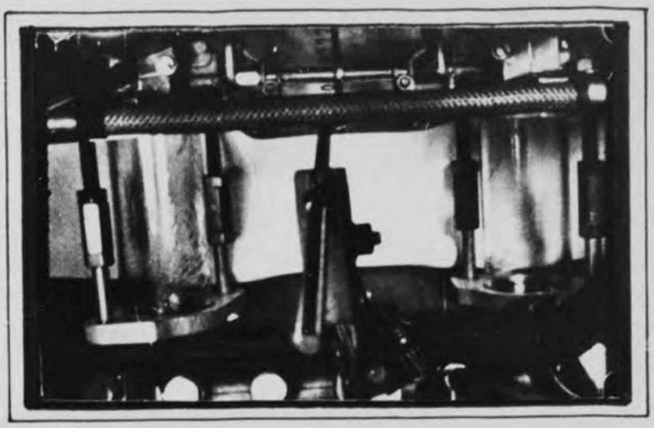


Best Additive (F.71 600 ppm.)

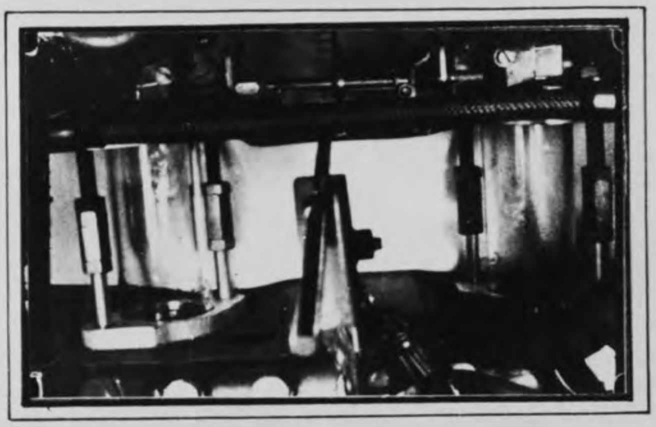


Worst Additive (ECA 1030 100ppm.)

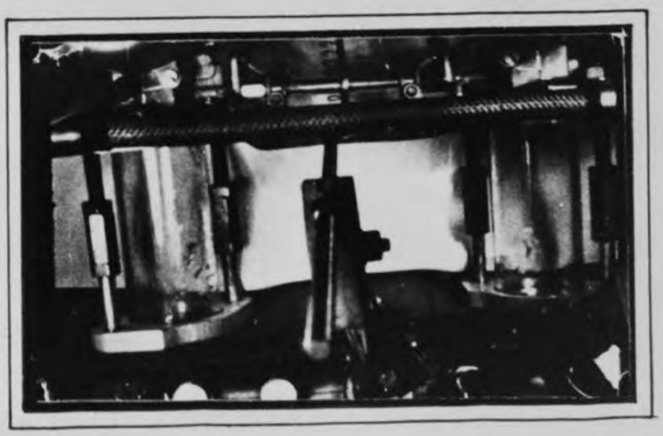
Plate 10. Comparison of flow patterns for 1st. gear. (Gasoline = Reference Engine speed = 2500 RPM)



Reference Gasoline

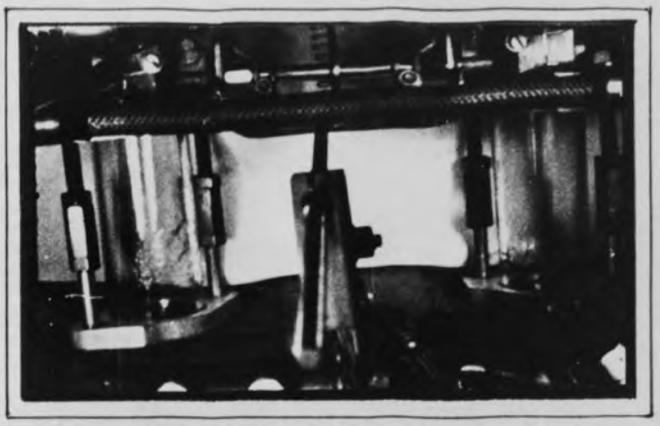


Best Additive (F.71 600 ppm.)

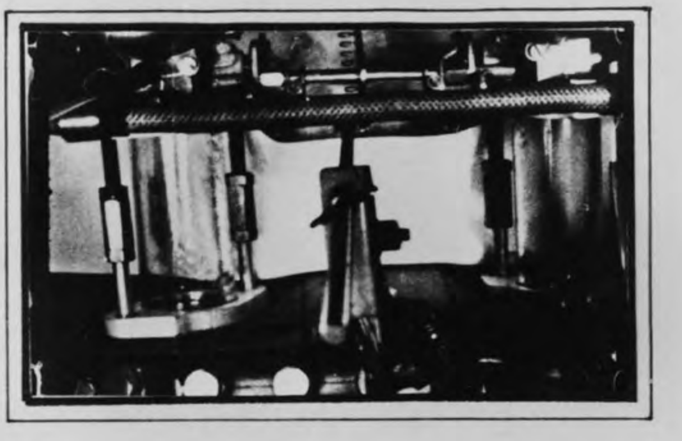


Worst Additive (ECA 1030 100 ppm.)

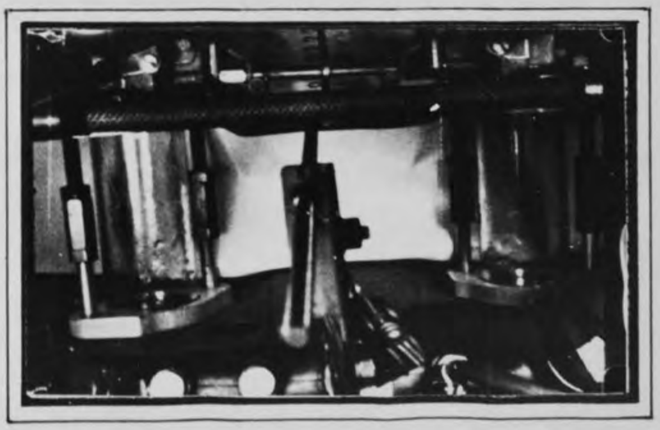
Plate 11. Comparison of flow patterns for 2nd. gear. (Gasoline = Reference
Engine speed = 2500 RPM)



Reference Gasoline

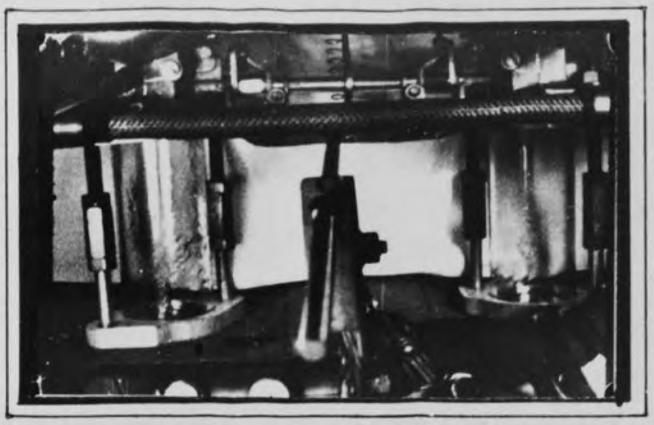


Best Additive(F.71 600ppm.)

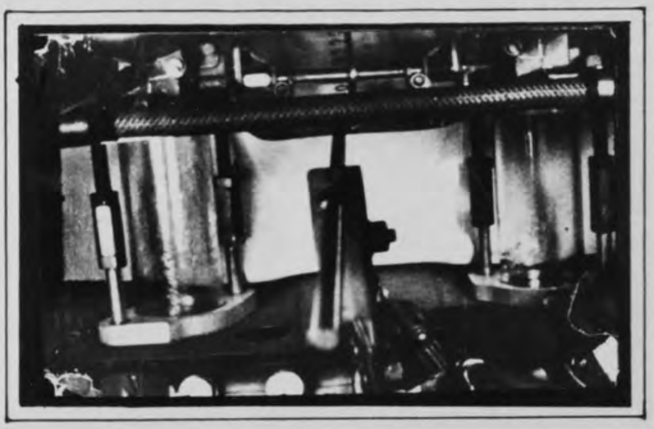


Worst Additive(ECA 1030 100ppm.)

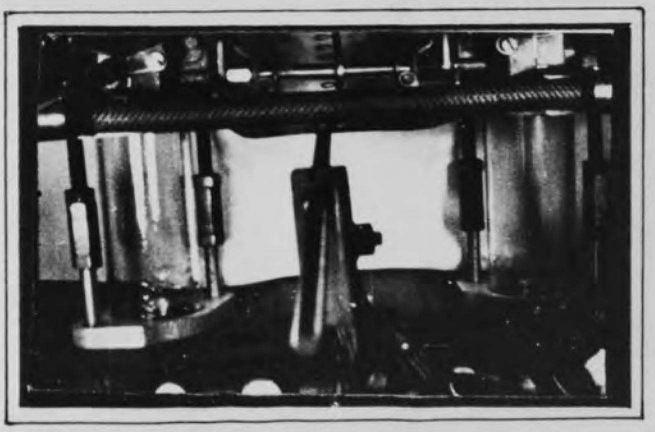
Plate 12. Comparison of flow patterns for 3rd.gear.(Gasoline=Reference
Engine speed 2500RPM)



Reference Gasoline



Best Additive (F.71 600ppm.)



Worst Additive (ECA 1030 100ppm.)

Plate 13. Comparison of flow patterns for 4th. gear. (Gasoline=Reference Engine speed=2500 RPM)

Chapter 5

DISCUSSION and CONCLUSIONS

DISCUSSION

Both types of fuel used, Esso Plus and Reference Gasoline, show a different extent of hydrocarbon and carbon monoxide emissions. Esso Plus - the commercial gasoline - shows higher hydrocarbons and lower carbon monoxide concentrations than the Reference gasoline. (Figs. 4:2, 4:35 and Figs. 4:69, 4:78). The specifications of these fuels, as given in Appendix 1.C. could throw some light on their differing behaviour. In several investigations, the remarkable effects of changes in physical properties and composition of fuel upon extent of emissions have been shown during various engine operational conditions. The specifications of the fuel in terms of volatility defined by Reid Vapour Pressure (R.v.p.), volume distillate at 70°C, and/or temperature difference between 10 and 20 per cent distillation volume has been shown to be of great significance with regard to hydrocarbon and carbon monoxide exhaust gas concentration (152, 153). Variable jet carburettors, as used in present case, show higher values of carbon monoxide emissions. The volatility effect has not altered the hydrocarbon emissions, but did increase the emissions with fixed jet carburettors. Hydrocarbon emissions were more affected by fuel composition e.g. an increase in the aromatic contents of the fuel resulted in an increase in hydrocarbon emissions (118, 153). It also has been asserted that the viscosity of fuel is another factor influencing these emissions, although some authors suggest that the accompanying changes in carbon hydrogen ratio explain such effects. One widely favoured theory is that volatility affects such emissions particularly at idle due to varying degrees of manifold wall wetting with fuels of differing volatility. Such varying factors, as suggested by the above mentioned theories, when combined together could account for the different levels of emissions for the fuels used during present experimental work. Unfortunately, the specifications available for these fuels do not provide conclusive proof of such theories, and to study all the variations in more detail would be beyond the scope of the present work. However, as the present project is more concerned with effects of air-fuel mixture behaviour, it could be safely assumed that these theories will hold under present conditions.

During the present work, a maximum of 70 per cent reduction in the mixed exhaust hydrocarbon emissions has been achieved in the case of commercial gasoline (Esso Plus). On the other hand, the results obtained for the best cylinders do not show this much reduction - maximum reduction achieved is 55 per cent. The worst cylinders show a maximum of 60 per cent reduction, whereas the averages produce maximum reduction of 54.6 per cent. It is noteworthy that the additives used during the course of the present work, show a different degree of effectiveness. The additives can be arranged on the basis of their performance as a whole as F.71 > ECA 4360 > ECA 1140 > ECA>1030. The first two of these additives (F.71 and ECA 4360) show reductions in hydrocarbon emissions throughout the experiments performed. The last two additives (ECA 1140 and ECA 1030) on the other hand, vary in their degree of effectiveness and show an increase in hydrocarbon emissions during higher gears accompanied by high load conditions (Appendix 1:B). Both reduction and increase in emissions follow a pattern showing the additives being more effective during lower gears and high load conditions (Figs. 4:89 - 4:104). Working with various quantities of these additives has strongly indicated that there exists one specific quantity of additive which is more effective than any other amount, i.e. an optimum quantity. This phenomenon is not in accordance with the work reported by others (149), which indicates that an increased quantity of such additives would improve the exhaust emissions. This variance of results is explained in later stages of this discussion. First, it is important to discuss the results achieved with the most successful quantities of the additives used. The most effective quantities of ECA 1140 and ECA 1030 show substantial increases in hydrocarbon emissions during 4th gear. Highest value of increase has been produced in case of best cylinder, in the order of 75 per cent while working with ECA 1030.

It is now understood that incomplete combustion of fuel is mainly responsible for pollutants present in exhaust gases. There are many factors which together determine the concentrations of such pollutants in exhaust gases during various engine operational conditions. It would not be out of place to discuss the most important of these factors in some detail to understand the present work.

Better combustion is much more difficult to realise under low load and slow engine speed. With conventional carburettors this mode of engine operation is accompanied by rich air-fuel mixture required to produce the desired power out-put. Necessity for rich air-fuel mixture arises, primarily from the fact that the maldistribution of the fuel is more marked under these engine conditions. The partly-open throttle producing high inlet manifold vacuum, will result in increased fuel flow rate. The air-fuel mixture under such conditions contains larger fuel droplets which drop out of the mixture stream producing a fuel film. In turn the cylinders receive a weak air-fuel mixture and therefore erratic engine operation occurs. An initially rich supply of air-fuel mixture will help to nullify such discrepancies even after serious fuel precipitation. If the fuel is supplied in more atomized form, it will be mixing with air to a greater degree producing a more homogeneous mixture. This will also reduce the problem of fuel precipitation by decreasing the droplet sizes. The fuel, under such conditions will be supplied more uniformly, reducing the risks of weak air-fuel mixture supply. This will cut down on erratic engine operation as well as the necessity for rich mixture supply. Obviously, a reduction in the pollutants is to be expected. Addition of a surface-active agent, as in the present work, should enable increased air/fuel ratios to be used.

The two basic principles, influencing atomisation and flow rate which are affected by addition of surface active additives, are viscosity and surface tension. These two physical properties of fuel are important, not only because of allowable increase in air/fuel ratios but also in their relation to fuel droplet formation. Viscosity of fuel, apart from affecting the power required to pump the fuel through pipe-lines of fuel supply systems, has marked effects on formation of fuel spray and thus on rate of vaporisation and combustion. The dependency of the co-efficient of discharge of the carburettor jet on density and viscosity clearly indicates that an increase in either of these two functions will reduce the fuel mass flow rate. At high temperatures (as encountered during engine operations) the effects of density become negligible, and only viscosity controls the fuel mass flow rate. Addition of a surface-active agent, if resulting in increased viscosity of the fuel, will alter the fuel flow from the jet orifice. Higher fuel viscosity will result in decreased fuel mass flow rate, thus making it essential to create greater pressure differential inside the choke tube venturi for fuel to flow at the same rate. It is observed during the present work that the addition of an additive resulted in increased air/fuel ratio . This is obviously due to the consequent increase in fuel viscosity, thus requiring an increased air velocity to achieve the same rate of fuel flow without additives. As the velocity of the air is controlled by inlet manifold vacuum, no significant changes in air velocity will occur to counteract the effect of increased viscosity. This results in a lower fuel flow rate producing leaner air-fuel mixture.

The liquid fuel is projected from the orifice of the jet in the form of a continuous ligament. The stability of this ligament depends on the viscosity and the turbulence the liquid fuel experiences during its motion through the fuel supply lines, and on the surface tension. Under certain conditions of viscosity and turbulence, on its projection from the orifice, this ligament breaks down into droplets producing a spray. After this has occured, the further atomisation of droplets depends entirely on surface tension and turbulence. A single droplet is considered to possess an internal pressure balancing the external pressure due to the combined effect of atmosphere and surface tension. When the drops are in flight, they experience a larger value for atmospheric pressure acting on their leading surface, causing a flattening effect, thus reducing the pressure due to surface tension. This effect keeps the drops stable and further atomisation is stopped. However, when surface tension is reduced, the surface tension pressure is reduced as a consequence. Under these conditions the increase in atmospheric pressure exceeds the surface tension pressure drop. In turn the drops split up into two or more droplets each having an increased value of surface tension pressure,hence producing stabilised droplets. Thus reduction of surface tension produces a greater degree of atomisation helping better fuel distribution. Furthermore, smaller droplets, having lower mass and therefore less moment of inertia, will have decreased tendency to hit the manifold walls to produce a fuel film. Geometric distribution is greatly improved due to the fact that the major portion of the fuel entrained by the air stream is homogenised to a greater degree and thus carried to individual cylinders. Under these conditions the cylinders will receive air-fuel mixture in a ratio much nearer to the ratio for which the carburettors are originally set. Although, as the results show, there is a best and worst cylinder performance, the results of the present work also show strong evidence for improved fuel distribution in the form of overall reductions including the other cylinders as well.

Modern petrol engines are provided with such devices as poppet valves accompanied by improved cylinder and piston head design to promote turbulence in air-fuel mixture. The extra turbulence thus created helps in good mixing of fuel and air producing a more homogeneous mixture capable of good combustion resulting in reduction of exhaust hydrocarbons. The effectiveness of the turbulence is enhanced if the fuel exists in smaller droplets to help the eddy currents thus produced to mix air and fuel thoroughly and without causing any fuel precipitation problems. The turbulence level of the air-fuel mixture inside the cylinder is a function of engine speed and is a combined effect of intake manifold turbulence and the turbulence produced by head and combustion chamber design.

From one cycle to the next, depending on engine speed, some 'residual gases' from previous combustion are left inside the cylinders. These 'residual gases' have a significant effect on the air/fuel ratio and combustion of the incoming charge. Sometimes, if containing high concentrations of unburned hydrocarbons, these gases add to the richness of the air-fuel mixture, resulting in excessive pollutants emissions. 'Residual gases' can also interfere with the propagation of flame by forming an inert gas zone. The inlet manifold vacuum is the major factor which controls the degree of dilution of the air-fuel mixture by such 'residual gases'. The increased manifold vacuum produces higher pressure differential causing 'blow-back' of the exhaust gases when the exhaust valve is open. Deceleration of an engine produces a manifold vacuum, approximately in the range of 21-22 inches of Hg. At this value of manifold vacuum, the dilution level of the mixture is a quarter of the total cylinder charge (154). At this dilution level the flame propagation is unduly affected causing an increase in unburned hydrocarbons. During idling, the inlet manifold vacuum ranges between 18-20 inches of Hg, while during low speed and low load conditions, due to part-throttle opening (cruising), it lies between 12-18 inches of Hg. This would explain the high hydrocarbon emissions during low gear and low load obtained during present work. As the emissions are maximum during these conditions, any alterations to improve combustion will show a substantial decrease. Improved mixture condition and higher air/fuel ratio as provided during present experiments show maximum degree of success in reducing pollutants emissions under above mentioned conditions.

The presence of hydrocarbons during low inlet manifold vacuum conditions, as encountered during acceleration and full-open throttle, involve many other conditions posing a more complex analysis. These factors include wall quenching, air-fuel mixture homogeneity and richness, and turbulence at point of combustion. Alterations in these factors to promote better combustion would result in marked reductions in hydrocarbons emissions. The mixing of fuel and air to produce a comparatively more homogeneous mixture not only depends on atomisation of the fuel, but also on good mixing of air and fuel. Turbulence produced during high speed engine operations provides quite an adequate means of achieving good mixing. Although, at high engine speed, the residence time between fuel and air is reduced, the increased turbulence and good atomisation of fuel will produce mixture charge conditions inside a cylinder relatively free of rich zones of bigger droplets. Decreased droplet size results in greater surface area and more of the fuel exists as vapours than as droplets. Obviously one could argue that a fully vaporised mixture is the ultimate solution for this problem but besides having an adverse effect on volumetric efficiency of the engine, previous work has shown that when fuel is present in spray form consisting of smaller droplets, it is possible to obtain a greater degree of heat release and better flame characteristics, as compared to a vaporised mixture of same air/fuel ratio (126). A more homogenised mixture consisting of smaller droplets exposes a greater area for combustion. A relative measure of the amount of combustion surface is given by the ratio of surface area passed by the flame to the volume consumed by the flame - generally known as surface-to-volume ratio of the combustion process. A uniformly distributed mixture of droplets increases this ratio producing enhanced combustion. The flame propagation is also enhanced as the heat loss effect to the colder cylinder walls is also reduced. This reduction of flame quenching results in less hydrocarbons in exhausts. Although flame quenching is mostly responsible for the hydrocarbon emissions in the exhaust, it is well known that a significant portion of hydrocarbons which result from cold combustion chamber walls, are burned during expansion processes.

The effects of leaning the air-fuel mixture must also be considered here. It is well known that the flame speed on the maximum travel line, during the combustion processes of varying mixture strength, is only affected during the first stage - the ignition lag. After the ignition lag there is not much difference in the flame speed as the flame propagation is taken over by surrounding mixture conditions. At this initial stage of combustion the flame speed is somewhat faster for a rich mixture as compared to a leaner one. The generally accepted opinion that a lean mixture burns slowly throughout the combustion processes may be true for combustion bombs where the mixture is stagnant and flame propagation is mainly due to the conduction of heat. However, in the case of a turbulent homogeneous mixture, the combustion rate is much enhanced after the ignition lag. The broken-down flame, producing numerous nuclei of ignition, makes it easier for a lean mixture to burn due to the lower amount of heat required to promote combustion. Again, a homogeneous air-fuel mixture will be more evenly distributed throughout the charge in the cylinder. As mixture characteristics and turbulence in the immediate vicinity of the point of the spark plug determines the ignition lag as well as subsequent flame propagation, the uniformity of the mixture will produce better combustion.

When the mixture is richer, the thickness of the quench zone is probably minimum. However, as the air-fuel mixture is made leaner, more oxygen is available during the expansion and exhaust process to help destroy the surplus hydrocarbons present becuase of increased quench thickness. Thus for lean mixtures, even though the quench zone thickness is increased, very few hydrocarbons survive the expansion and exhaust processes, until the mixture is so lean that erratic flame propagation occurs. High turbulence and turbulent heated manifold will delay this erratic flame for a very lean air-fuel mixture allowing leaner mixtures to be used satisfactorily.

It is now well established that the progressive combustion chamber deposits result in a substantial increase in hydrocarbon emissions. It is understood that these deposits will result in an advanced degree of wall quenching (127). A colder surface due to deposit formation, as compared to a metal surface enhances the chances of wall quenching. This is because the metals are more efficient in absorbing and retaining the heat produced in combustion. On the other hand the build-up of such deposits around the throttle plate of a carburettor upsets the air-fuel mixture preparation (146). These deposits, by restricting the air flow,reduce idle speed and produce a richer air-fuel mixture. The changes in air/fuel ratios due to such deposits, occur throughout the rest of the engine operation causing deterioration in engine performance, and increasing the concentrations of the pollutants emitted. Addition of a surface active agent will produce a detergency effect which will help to reduce and control the build-up of these deposits. Furthermore, continuous use of such additives will not only keep the engine free of unwanted deposits but will also stop any further build-up, thus eliminating one of the causes of increased hydrocarbon emissions.

Reduced effectiveness and/or adverse effects of ECA 1140 and ECA1030 can also be explained by considering this phenomenon. These additives, having comparatively larger molecular structures, may produce or help, in one way or another, in creating such deposits in the engine creating undesirable air-fuel mixture conditions. If these additives undergo cracking processes inside the engine, they will be able to produce high paraffin volumes - a fuel composition producing excessive hydrocarbon emissions (153).

These additives may also be capable of a greater degree of atomisation, but excessive atomisation could also be argued to initiate undesirable phenomenon of coalesence of droplets. Smaller droplets, by increasing their surface area, will require larger volume in order to keep separate from each other. As the volume of the engine manifold space available remains constant, it could be expected that these droplets, under exaggerated degree of motion, will coalesce producing larger droplets. These larger droplets of fuel will increase fuel precipitation tendencies even in earlier stages of mixture formation. This will provide the cylinders with an air fuel mixture ratio in the misfiring region consequently increasing exhaust emissions. The tendencies to fuel precipitation developed by the fuel on addition of such additives is also shown in the photographs present in Plates 6 - 13. The fuel droplets are clearly shown at the base of the glass tubes, confirming that coalescence of droplets starts occuring during even earlier stages.

The formation of carbon monoxide during the combustion of petroleum derivative fuels has been extensively studied in recent years (155, 156). The main conclusion drawn from such studies suggests that the presence of carbon monoxide in exhaust gases is mainly due to oxygen deficiency. This is, of course, also characteristic of continuous combustion processes and has been thoroughly studied. In the I.C. engine carbon monoxide generation at higher air/fuel ratios verifies this fact. On the other hand this is not the only determining factor in internal combustion engine processes. The reason for failure of this principle lies in the fact that a combustion charge inside the spark ignition engine's cylinders, encounters extreme conditions of temperature and pressure. Extent of turbulence, good mixing, mixture temperature etc. are some of the factors which affect carbon monoxide formation.

The most widely accepted principle that the carbon monoxide destruction in combustion processes should correspond to a chemical equilibrium state represented by water-gas equation, presents some satisfactory explanations for this phenomenon. Under this concept, it can be shown that the most probable reaction through which carbon monoxide is oxidised is represented as:

$$CO + OH \rightleftharpoons CO_2 + H_2$$

However, the water-gas equilibrium fails to justify the presence of measured concentrations of carbon monoxide (157, 158). The studies conducted with various air/fuel equivalence ratios and the data thus obtained, relate the actual concentrations of carbon monoxide present to what should be present if the water-gas equilibrium holds true under exhaust gas temperatures. It is shown that as the mixture is made leaner, carbon monoxide, measured at engine exhaust, becomes more abundant than chemical equilibrium would predict (159). During the water-gas reaction, the temperature of the reactants dominates the equilibrium of the reaction. During the initial stages of the combustion process, the temperature of the reacting mixture is continously increasing until a peak temperature is reached. The rate of reaction of this exothermic reaction depends on the mixture strength and its temperature. The peak temperature of the reaction in turn, depends on the composition of the combustion charge. After the initial ignition lag, the reaction rate is considerably increased, producing high temperature conditions. During this process, at high temperatures, carbon monoxide is readily destroyed according to the water-gas equation. At a temperature of 1100°K and above, carbon monoxide oxidation is rapid but as the temperature falls this reaction is slowed down. Fall in temperature is accompanied by the formation of relatively stable HO_2 as compared to the more reactive species of oxygen and hydroxyl radicals. The transition temperature for such reactions is roughly 1016 - 1037°K (160).

During the expansion cycle of engine combustion processes, the time scale involved is in the order of small intervals (20 m.sec. at 1500 RPM). The temperature changes occuring during expansion processes are 2000°R, while the temperature declination is not uniform throughout the expansion. Such declinations of temperatures are recorded to be in the order of 100°R/m.sec. During normal engine speed operations there are little changes in temperature declination during expansion. However, after the expansion, the temperature reduces more rapidly and water-gas equilibrium is shifted. The equilibrium shift as the temperature falls, favours a comparatively large number of hydrogen atoms relative to highly reactive hydroxyl radicals. During the initial stages of the expansion cycle, carbon monoxide is destroyed at a rate corresponding to shifting chemical equilibrium. However with a time scale, an increasing deviation from this equilibrium occurs, until at the end of the expansion cycle the carbon monoxide concentration is as much as ten times the equilibrium value. It has been noticed that at an interval of 4 m.sec. of an expansion cycle, the hydroxyl radicals concentration is four times its equilibrium value, whereas hydrogen atom concentration is over twenty times its original equilibrium value. Therefore during the expansion cycle the ratio of hydrogen atoms to hydroxyl radicals, as dictated by the partial equilibrium, is much greater than it would be in the case of total equilibrium. Thus it can be deduced that the ratio of carbon monoxide to carbon dioxide, contrary to the water-gas equation, must be correspondingly greater than for total equilibrium. As a consequence of this shift in equilibrium, there exists an excess of carbon monoxide. It should be understood that the water-gas reaction is not the only reaction occuring during engine combustion processes. However, research conducted on similar lines shows that the water-gas reaction is the most dominant one. Any other reactions taking place can be neglected on the basis of comparative effects on production of carbon monoxide (161, 162).

Considering the pre-mentioned processes of equilibrium shift, resulting in carbon monoxide concentrations in exhaust gases, the present results can be explained. Introduction of a uniformly distributed fuel among various cylinders, results in improved combustion producing large quantities of carbon monoxide. High temperature conditions prevail during most of the combustion stroke.

This stabilizes the water-gas equilibrium for a longer interval of time, so destroying some of the carbon monoxide generated. This accounts for the reductions in carbon monoxide emissions achieved during the course of the present work.

Another factor which has a marked effect on the air/fuel ratios inside the individual cylinders must also be considered here. It is true that the air/fuel mixture ratio, as it is measured by fuel and air flow rate, indicates that the engine is operating onthe lean side. In practice, it may not be true while considering the individual cylinders. The effects of manifolding the air-fuel mixture can play a significant part in determining the actual air/fuel ratio entering the cylinders. To obtain a stoichiometric or leaner air-fuel mixture, it is essential that the air must also be distributed evenly among various cylinders. Fuel being more highly atomised has increased chances of equal distribution, whereas air, depending on the engine operational speed, could vary in its distributional behaviour. The residence time of air and fuel inside the inlet manifold, along with turbulence and vaporisation of fuel, will determine the degree of mixture homogeneity. Variations among individual cylinders, as encountered during the present work, clearly indicate that these factors are not improved enough to produce the ideal mixture. A cylinder receiving its proper share of fuel but less oxygen could produce reduced hydrocarbon concentrations, but the subsequent oxidation of carbon monoxide will be substantially offset because of insufficient oxygen available for complete oxidation.

As stated before, a substantial reduction in hydrocarbon emissions has been achieved during the course of the present work. Unfortunately, the same degree of success has not been achieved in the case of carbon monoxide emissions. Almost all through the present work, a reduction in hydrocarbon emissions has been accompanied by increased carbon monoxide concentrations (Figs. 4:89 - 4:104). Although ECA 4360 and F.71 have shown carbon monoxide reduction during most of the experiments, still at certain points an increase has been recorded. Corresponding increase in temperature coinciding with increased carbon monoxide concentrations shows marked differences e.g. temperature increase of 107°K at 3500 RPM, first gear, for ECA 4360 (100 ppm) and 110°K under same conditions for F.71 (600 ppm). (During the above mentioned conditions, the maximum increase in carbon monoxide has been measured as 7.7% (ECA 4360) and 51.9% (F.71)). These increases in the temperature indicate that combustion is enhanced, but subsequent increase in carbon monoxide concentrations indicates a condition of oxygen deficit. It must also be considered that enhanced combustion of fuel will produce more carbon monoxide. If the subsequent oxidation of carbon monoxide is inhibited due to one reason or another, an excess of this pollutant will occur in exhaust gases. As no internal combustion engine behaves consistently in an identical manner during various driving cycles, allowances should be made for improved and/or degraded distribution of air-fuel mixture for every cylinder. Such variations could produce some erratic, but occasionally constant, exhaust pollutant levels. It would also mean that changes in various pollutants concentrations can occur at any speed under any load conditions. As the problem of vehicle pollution is always concerned with total air pollution caused by the internal combustion engine, such inconsistencies would not matter in solving the overall problem.

The complexity of the influencing factors poses a great problem in precisely understanding the origin of the pollutants with great accuracy.

The excessively high increase in carbon monoxide emissions during the experimental work with ECA 1040 and ECA 1030 can be explained under similar treatment of results as for hydrocarbons, given earlier in this discussion ie. coalesence of droplets.

The first two figures (Fig. 4:87 and Fig. 4:88) of Section'C'of results show the effects of altering the air/fuel ratios controlled by manual adjustment of the carburettors. Esso Plus and Esso Plus with most effective additive (F.71) added in most effective quantity (600 ppm) are used for these experiments. An overall reduction of both pollutants i.e. hydrocarbons and carbon monoxide, is noticed in both cases. In the case of fuel + additive, an increase in carbon monoxide occurs during much higher air/fuel ratios. This is contrary to the previous results reported in the literature. The fact that previous experiments were conducted without additives should also be taken into account. For various reasons as previously mentioned, it can be understood that an increase in carbon monoxide may occur at such lean air fuel mixture ratios.

It was noticed while working with various air/ fuel ratios, that the misfire point shifts towards higher ratios in the case of fuel with surface active additive. A better distribution of fuel to improve atomisation, therefore more homogeneous mixture, provides an explanation for this expected shift of misfire region. Each cylinder receives a combustible air-fuel mixture, even at higher air/ fuel ratios, preventing the misfiring.

Zimmermann et at (147) theory of surface energy of metal and coated surfaces could also be considered here. It is true that initially the reductions in pollutants will occur at a certain degree of increase in air/fuel ratios. Similar results have been obtained in the case of ECA 4360 and F.71 during the present work, but at excessively high air/fuel ratios adverse effects can also occur. Zimmermann's hypothesis of contact angle and increased chance of fuel droplets entrainment off the low energy surfaces would hold true for short driving periods, at part-throttle conditions. Extensive driving under open throttle conditions, on the other hand, could produce conditions where droplets retained on the manifold wall will coalesce together and produce continuous film. Such a film when it acquires sufficient mass would start flowing into various cylinders when inlet valves are open, and will produce similar results as recorded during the present work.

CONCLUSIONS

1. Varied degree of pollutant emissions are shown by both gasolines used - Esso Plus and Reference Gasoline.
2. Hydrocarbon emissions are reduced during most of the experimental work.
3. A decrease in carbon monoxide emissions is also recorded, but most of the work shows an increase in such emissions. The increase in carbon monoxide is usually accompanied by a decrease in hydrocarbon emissions. It is concluded that increase in carbon monoxide emissions is mainly due to maldistribution of air inhibiting further oxidation.
4. Additives used show a varied degree of effectiveness and can be arranged according to their degree of success in reducing pollutants as: F.71 $>$ ECA 4360 $>$ ECA 1140 $>$ ECA 1030.
5. Physio-chemical properties and molecular structure of additives determines the degree of effectiveness. Probable combustion chamber deposits build-up and cracking of larger molecular structure additives could increase hydrocarbon and carbon monoxide emissions.

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APPENDICES

APPENDIX 1:A

Model calculation for air flow measurement

Pressure drop over meter = ΔP = 2.12 in. H_2O = 5.38 cms. H_2O

Depression down-stream = P_d = 2.1 in. H_2O = 0.154 in. Hg.

Temperature at the manometer = 24°C

Barometer Pressure = 29.30 in. Hg.

Meter Calibration Constant = C_c = 9.97 ft.^{3}/cm. H_2O

Temperature correction factor = C_f = 0.99

Volume of the free air leaving the meter =

$$V_d = C_c \times \Delta P \times C_f = 9.97 \times 5.38 \times 0.99 = 53.101 \text{ ft.}^3\text{/min.}$$

Volume flowing at NTP (0°C and 29.9 in. Hg.) =

$$V_{NTP} = 53.101 \frac{273}{273 + 24} \times \frac{29.30 - 0.154}{29.92} = 47.525 \text{ ft.}^3\text{/min.}$$

1 ft.^{3} of air at NTP weighs = 0.0807 x 0.4536 Kg.

Hence the weight of the gas flowing into the carburettor.

$$= \frac{47.525}{60} \times 0.0807 \times 0.4536 = 0.2899 \text{ kg/sec.}$$

APPENDIX 1:B.

LOADS and BREAK HORSE POWER used throughout the experiments

	1st GEAR		2nd GEAR		3rd GEAR		4th GEAR	
	LOAD (lbs)	BHP	LOAD (lbs)	BHP	LOAD (lbs)	BHP	LOAD (lbs)	BHP
1000	30.0	1.94	24.0	2.42	26.0	4.18	30.0	6.66
1500	36.0	3.48	30.0	4.60	32.0	7.72	38.0	12.66
2000	40.0	5.16	38.0	7.78	36.0	11.58	46.0	20.44
2500	48.0	7.74	44.0	11.48	42.0	16.90	52.0	28.89
3000	54.0	10.46	52.0	15.96	50.0	24.16	56.0	37.32
3500	62.0	14.02	60.0	21.50	60.0	33.82	62.0	48.60

$$BHP = \frac{R.P.M. \times Load}{4500 \quad G.R.}$$

where G.R. (Gear Ratio) = Top Gear = 1.0000:1
3rd Gear = 1.3817:1
2nd Gear = 2.1667:1
1st Gear = 3.4440:1

APPENDIX 1:C

Specifications of the fuels used.

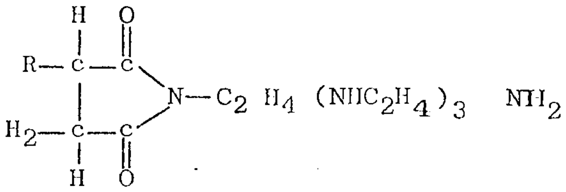
	Esso Plus	Reference Gasoline
Specific Gravity	0.742	0.740
Hydrocarbons (Determined by ASTM D1319)		
Aromatics	30.0%	32.5%
Olefines	20.0%	18.0%
Saturates	50.0%	49.5%
Lead	0.60 gm/litre	0.80 gm/litre
Distillation		
I.B.P.	35°C	30°C
F.B.P.	190°C	193°C
Reid Vapour Pressure	10.0 psi	11.0 psi

APPENDIX 1:D

Additives

1. ECA 4360

a. General Formula =



b. Function = Ashless dispersant and Surface tension modifier

c. Composition = Based on condensation products between Polyisobutenyl Succinic Anhydride and Tetraethylene Pentamine (Differing molar ratios).

2. F.71

a. General Formula = $R—NH_2$

b. Function = Viscosity modifier

c. Composition = 5% - $C_{18}H_{37}NH_2$

16% - $C_{18}H_{37}N(CH_3)_2$

78% - Aromatic solvent (Toluene)

0.5% - Para-flow condensation product of Wax and Naphtha

3. ECA 1030

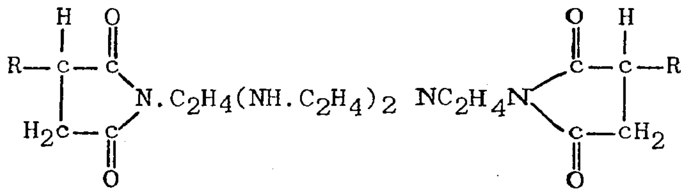
a. General Formula = $R.CH_2CO(NH.C_2H_2)_3\ NHCO.CH_2.R.$

b. Function = Ashless dispersant

c. Composition = Based on condensation product between Polyisobutenyl Propionic Acid and Tetraethylene Pentamine

4. ECA 1140

a. General Formula =



b. Function = Ashless dispersants and surface tension modifier

c. Composition = Based on condensation product between Polyisobutenyl Succinic Anhydride and Tetraethylene Pentamine.

TABLE NO : 1.1

FUEL : Esso Plus

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	648	785	703	806	712	323.2	303.0	318.1
2	1500	653	805	710	812	713	324.5	305.3	323.1
3	2000	666	823	732	833	738	325.9	308.1	330.5
4	2500	684	830	746	844	763	330.0	313.7	335.6
5	3000	738	834	753	862	768	335.3	320.8	338.3
6	3500	738	847	768	866	773	333.1	326.5	343.2

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	480	380	490	510	420	500	3.05	3.10	2.95	3.60	2.50	3.15	0.013	0.146	10.90
2	1500	440	330	440	540	370	410	2.79	3.15	2.60	2.85	2.30	3.40	0.012	0.140	11.38
3	2000	467	300	480	500	420	470	2.76	3.20	2.60	2.90	2.55	3.00	0.016	0.188	11.90
4	2500	517	340	480	650	440	500	2.66	3.00	2.25	3.50	2.25	2.65	0.018	0.209	11.42
5	3000	430	300	500	530	420	470	2.71	2.90	2.65	2.90	2.65	2.65	0.020	0.232	11.71
6	3500	535	370	580	590	510	560	2.59	2.60	2.55	2.85	2.40	2.55	0.022	0.239	11.05

TABLE NO :1.2

FUEL : Esso Plus

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	653	794	712	813	718	330.3	303.1	322.8
2	1500	678	808	713	823	733	333.8	306.5	330.6
3	2000	733	832	738	838	743	336.2	311.7	333.3
4	2500	736	836	758	855	768	335.9	319.2	343.8
5	3000	744	845	770	873	773	338.2	327.4	348.1
6	3500	763	858	773	886	788	338.1	333.9	354.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	442	350	440	500	400	450	3.07	3.25	2.90	3.45	2.85	3.10	0.020	0.123	12.42
2	1500	342	290	310	390	300	370	2.94	3.55	2.80	3.50	2.20	3.25	0.016	0.194	11.91
3	2000	405	270	400	410	390	420	2.71	3.05	2.65	2.90	2.40	2.90	0.015	0.179	11.74
4	2500	452	290	410	600	390	410	2.59	3.60	2.70	2.80	2.10	2.75	0.012	0.143	12.15
5	3000	420	250	410	450	400	420	2.94	3.40	2.85	3.15	2.80	2.95	0.010	0.148	14.11
6	3500	487	300	510	520	450	470	2.66	3.15	2.70	3.00	2.25	2.70	0.016	0.249	14.90

TABLE NO : 1.3

FUEL : Esso Plus

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	660	803	720	823	726	333.1	303.9	323.0
2	1500	688	813	728	832	738	336.3	307.3	231.1
3	2000	743	836	743	844	754	338.5	313.4	336.5
4	2500	762	855	766	863	778	342.2	320.7	351.3
5	3000	770	863	785	888	796	346.9	330.5	353.2
6	3500	783	872	806	904	808	360.4	335.2	360.5

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	395	320	380	450	350	400	2.69	3.20	2.70	2.75	2.60	2.70	0.011	0.132	13.08
2	1500	291	240	250	340	250	320	3.26	3.65	3.10	3.60	2.85	3.50	0.016	0.220	12.23
3	2000	322	200	330	340	290	330	3.15	3.65	3.00	3.50	2.95	3.15	0.016	0.194	12.12
4	2500	392	250	340	570	310	350	2.79	3.45	2.85	3.00	2.35	2.95	0.012	0.157	12.55
5	3000	357	220	360	370	330	370	2.85	3.50	2.80	2.90	2.80	2.90	0.011	0.161	14.63
6	3500	432	250	450	470	390	420	2.57	3.45	2.65	2.70	2.40	2.55	0.017	0.260	15.30

TABLE NO : 1.4

FUEL : Esso Plus

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	686	814	726	836	740	338.5	304.2	326.3
2	1500	696	829	740	842	746	340.3	310.3	333.9
3	2000	750	845	766	866	763	341.4	315.7	340.5
4	2500	768	863	780	873	786	344.9	322.2	348.4
5	3000	780	871	796	900	813	348.5	333.5	355.1
6	3500	796	883	818	918	840	363.7	338.9	365.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	345	270	330	390	310	350	2.91	3.30	3.00	3.10	2.65	2.9	0.013	0.178	13.70
2	1500	241	190	210	290	200	260	2.91	3.60	2.65	3.55	2.35	3.10	0.015	0.199	13.10
3	2000	251	180	230	280	210	280	3.39	3.80	3.25	3.50	3.15	3.65	0.012	0.185	13.31
4	2500	384	210	360	510	290	290	2.84	3.50	3.10	3.15	2.20	2.90	0.019	0.274	14.59
5	3000	307	190	310	320	280	310	3.09	3.70	3.10	3.15	3.05	3.05	0.017	0.262	14.90
6	3500	378	220	390	410	340	370	2.61	3.60	2.70	2.95	2.35	2.5	0.018	0.274	15.30

TABLE NO : 2.1

FUEL : Esso Plus + ECA 4360 (100 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K						Water	
		Ex	CY1	CY2	CY3	CY4	Sump Oil	In	Out
1	1000	693	873	788	773	783	324.2	304.2	321.3
2	1500	703	903	808	788	798	325.4	305.1	326.4
3	2000	720	938	833	842	813	327.7	310.5	333.0
4	2500	765	944	843	860	828	329.0	314.6	336.3
5	3000	798	970	858	873	851	332.2	323.7	339.9
6	3500	838	981	871	888	862	334.3	330.3	345.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	309	210	270	300	340	320	2.35	2.80	2.00	2.15	2.95	2.30	0.010	0.132	12.70
2	1500	330	140	280	320	360	360	2.31	2.65	2.05	2.10	2.85	2.25	0.013	0.180	12.08
3	2000	342	180	300	350	400	320	2.40	2.75	2.15	2.55	2.65	2.25	0.014	0.169	11.90
4	2500	416	130	400	410	440	420	2.74	3.10	2.60	2.70	3.00	2.65	0.013	0.167	12.46
5	3000	340	170	300	350	400	310	2.55	2.70	2.35	2.65	2.70	2.60	0.013	0.197	14.60
6	3500	402	200	340	410	440	420	2.50	2.80	2.35	2.50	2.75	2.40	0.014	0.200	13.80

TABLE NO : 2.2

FUEL : Esso Plus + ECA 4360 (100 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	698	878	794	786	798	324.2	304.0	323.0
2	1500	715	910	811	794	811	325.0	305.4	327.6
3	2000	726	943	840	853	826	329.4	311.0	334.2
4	2500	772	951	851	872	835	330.4	314.7	337.5
5	3000	811	969	870	894	862	333.7	324.2	340.7
6	3500	845	975	883	916	868	336.9	332.7	346.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	242	200	220	240	290	220	2.41	2.50	2.20	2.45	2.55	2.45	0.013	0.171	13.05
2	1500	270	160	250	260	290	280	2.30	2.35	2.25	2.20	2.35	2.35	0.014	0.186	13.69
3	2000	305	170	290	300	320	310	2.12	2.40	2.00	2.10	2.20	2.20	0.015	0.198	13.48
4	2500	362	140	300	350	400	390	2.62	3.15	2.15	2.65	2.95	2.75	0.014	0.195	13.95
5	3000	285	180	250	290	300	280	2.44	3.25	2.15	2.40	3.00	2.20	0.018	0.236	13.26
6	3500	325	200	310	330	340	320	2.21	3.00	2.00	2.10	2.75	2.00	0.018	0.225	12.49

TABLE NO : 2.3

FUEL : Esso Plus + ECA 4360 (100 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^oK						Water	
		Ex	CY1	CY2	CY3	CY4	Sump Oil	In	Out
1	1000	704	886	805	800	810	325.7	305.3	324.2
2	1500	720	917	820	810	819	326.5	306.0	328.2
3	2000	738	946	846	816	841	328.3	310.5	333.0
4	2500	786	953	862	883	844	330.7	313.9	338.3
5	3000	816	976	873	902	866	332.9	325.0	341.0
6	3500	861	985	896	925	880	335.8	332.9	345.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	247	180	200	210	250	230	2.52	2.70	2.40	2.50	2.65	2.55	0.014	0.181	13.31
2	1500	215	170	180	220	270	190	2.52	2.80	2.30	2.35	2.75	2.70	0.015	0.200	13.70
3	2000	307	180	250	320	330	330	2.07	2.65	1.90	2.00	2.25	2.15	0.015	0.198	13.20
4	2500	312	150	230	370	380	270	2.05	2.55	1.75	2.20	2.45	1.80	0.015	0.208	13.95
5	3000	262	200	240	270	280	260	2.34	2.95	2.25	2.35	2.45	2.30	0.019	0.242	12.73
6	3500	305	210	280	300	330	310	2.12	3.10	2.00	2.10	2.25	2.15	0.020	0.291	12.45

TABLE NO : 2.4

FUEL : Esso Plus + ECA 4360 (100 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	710	888	816	805	822	326.1	304.9	323.7
2	1500	725	922	829	818	825	327.2	305.0	326.6
3	2000	741	955	860	871	844	329.6	311.0	333.1
4	2500	792	963	893	895	860	331.0	314.1	335.0
5	3000	824	982	896	911	874	333.1	323.3	340.5
6	3500	865	996	905	940	893	336.1	332.8	345.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	172	150	160	170	190	170	2.77	3.00	2.70	2.80	2.85	2.75	0.015	0.208	13.97
2	1500	220	110	200	210	240	230	2.55	2.75	2.45	2.50	2.65	2.60	0.014	0.208	14.61
3	2000	230	120	140	250	270	260	2.47	3.00	2.25	2.35	2.90	2.40	0.015	0.216	14.22
4	2500	310	90	250	300	350	340	2.06	2.55	1.85	1.90	2.40	2.10	0.018	0.272	15.11
5	3000	205	130	140	200	250	230	2.51	2.85	2.45	2.45	2.65	2.50	0.017	0.240	13.95
6	3500	275	150	260	280	290	270	2.16	2.95	2.00	2.25	2.35	2.05	0.019	0.258	13.65

TABLE NO : 3.1

FUEL : Esso Plus + ECA 4360 (500 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	685	773	758	848	763	323.0	303.1	314.0
2	1500	693	783	765	856	771	324.3	304.7	316.3
3	2000	705	798	782	870	784	325.9	306.0	319.7
4	2500	743	821	796	885	796	327.9	309.1	322.9
5	3000	768	836	813	900	813	329.8	312.7	329.0
6	3500	792	852	830	912	832	332.0	319.8	333.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	370	240	340	440	320	380	2.49	2.60	2.40	2.55	1.95	2.25	0.012	0.142	12.03
2	1500	358	220	330	420	320	360	2.26	2.55	2.35	2.50	2.05	2.55	0.013	0.158	12.34
3	2000	305	200	390	430	340	480	2.10	2.30	2.20	2.25	1.95	2.00	0.011	0.148	12.96
4	2500	440	180	450	460	390	460	1.95	2.00	1.85	2.20	1.85	1.90	0.014	0.196	13.80
5	3000	457	190	480	490	410	450	1.85	1.95	1.90	2.05	1.70	1.75	0.015	0.210	13.55
6	3500	490	200	500	520	470	470	1.66	1.90	1.75	1.80	1.45	1.65	0.016	0.218	13.21

TABLE NO : 3.2

FUEL : Esso Plus + ECA 4360 (500 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	690	778	765	852	772	323.5	303.0	315.1
2	1500	702	796	780	878	783	324.9	305.1	316.0
3	2000	723	812	806	886	802	326.0	306.8	320.3
4	2500	752	836	816	892	830	328.2	307.9	323.7
5	3000	783	853	835	908	836	331.9	311.8	326.2
6	3500	603	866	843	916	845	333.2	314.5	335.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	353	240	360	360	340	350	2.37	2.55	2.30	2.45	2.30	2.35	0.013	0.160	12.50
2	1500	355	200	330	390	350	350	2.39	2.45	2.30	2.50	2.30	2.45	0.013	0.168	12.92
3	2000	405	180	430	450	360	380	2.17	2.60	2.25	2.35	2.00	2.10	0.013	0.171	13.38
4	2500	460	190	480	490	420	450	1.87	2.00	2.00	2.05	1.70	1.75	0.013	0.176	13.02
5	3000	490	200	490	520	440	510	1.74	1.95	1.75	1.95	1.55	1.70	0.015	0.195	12.83
6	3500	510	210	510	520	480	530	1.70	1.80	1.75	1.75	1.50	1.80	0.017	0.212	12.70

TABLE NO : 3.3

FUEL : Esso Plus + ECA 4360 (500 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	696	785	774	866	782	324.2	304.5	316.2
2	1500	710	810	793	883	794	325.2	305.0	317.0
3	2000	735	823	805	893	905	325.7	307.0	321.2
4	2500	761	848	833	914	936	327.9	308.2	322.9
5	3000	792	871	851	925	953	330.9	312.0	327.3
6	3500	820	883	874	942	965	334.0	314.0	335.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	355	230	370	440	330	380	2.29	2.45	2.15	2.50	2.15	2.35	0.013	0.168	12.54
2	1500	390	190	410	440	340	370	2.32	2.40	2.40	2.45	2.20	2.25	0.013	0.175	13.16
3	2000	457	180	480	490	410	450	1.94	2.00	2.00	2.10	1.80	1.85	0.013	0.172	13.34
4	2500	475	200	470	510	440	480	1.76	2.15	1.75	1.95	1.45	1.90	0.018	0.220	12.15
5	3000	502	220	490	530	490	500	1.61	1.95	1.60	1.70	1.50	1.65	0.020	0.234	11.88
6	3500	535	250	520	550	530	540	1.34	1.80	1.25	1.50	1.15	1.40	0.028	0.240	11.54

TABLE NO : 3.4

FUEL : Esso Plus + ECA 4360 (500 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	432	520	510	612	523	52.0	30.0	42.2
2	1500	445	549	529	621	540	52.9	31.9	43.6
3	2000	473	562	545	632	559	53.8	33.8	47.0
4	2500	495	592	572	660	571	55.6	35.0	48.6
5	3000	532	610	593	672	593	58.0	39.6	51.0
6	3500	573	629	600	681	610	62.3	42.3	67.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	375	230	350	440	320	370	2.35	2.50	2.30	2.55	2.10	2.40	0.016	0.190	12.10
2	1500	380	220	380	450	340	350	2.36	2.45	2.40	2.45	2.25	2.35	0.017	0.202	11.89
3	2000	404	180	430	450	350	380	2.20	2.30	2.25	2.45	2.00	2.10	0.017	0.224	12.86
4	2500	443	180	470	480	400	420	1.90	2.25	2.00	2.15	1.65	1.80	0.019	0.240	12.70
5	3000	515	190	520	550	460	530	1.74	2.35	1.55	2.25	1.50	1.65	0.022	0.244	12.09
6	3500	535	210	540	560	490	550	1.50	2.20	1.40	1.75	1.35	1.50	0.024	0.278	11.79

TABLE NO : 4.1

FUEL :Esso Plus + ECA 4360 (1000 ppm)

GEAR :1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	663	751	743	834	754	323.3	303.3	314.7
2	1500	674	758	760	845	766	325.1	304.0	317.0
3	2000	698	770	772	853	775	326.3	305.7	318.3
4	2500	726	783	783	868	789	327.9	308.2	320.9
5	3000	751	792	804	886	805	329.3	310.9	323.3
6	3500	766	796	813	900	823	330.8	313.5	332.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	315	250	320	330	300	310	2.09	2.75	2.15	2.15	2.00	2.05	0.013	0.150	11.20
2	1500	320	190	350	350	260	300	2.06	2.20	2.05	2.35	1.90	1.95	0.014	0.173	12.36
3	2000	322	170	360	360	250	320	2.04	2.10	2.10	2.40	1.80	1.85	0.016	0.202	12.95
4	2500	420	230	410	460	390	420	1.66	2.65	1.60	2.00	1.35	1.70	0.019	0.224	11.54
5	3000	435	230	420	470	400	450	1.49	2.50	1.40	1.65	1.35	1.55	0.020	0.216	11.01
6	3500	487	260	470	500	470	510	1.21	2.55	1.15	1.35	1.05	1.30	0.022	0.242	11.10

TABLE NO :4.2

FUEL : Esso Plus + ECA 4360 (1000 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	670	759	754	853	766	324.2	304.3	315.0
2	1500	685	773	778	871	780	326.0	306.2	318.1
3	2000	710	793	800	888	793	327.7	307.0	319.7
4	2500	733	802	812	896	812	328.6	310.3	322.8
5	3000	760	811	818	912	821	331.3	314.2	326.7
6	3500	776	822	836	925	832	333.3	318.0	335.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	298	240	320	320	240	310	2.30	2.50	2.10	2.95	2.05	2.10	0.014	0.167	11.60
2	1500	318	210	340	340	270	320	2.04	2.10	2.00	2.30	1.90	1.95	0.015	0.172	11.45
3	2000	348	180	350	410	280	350	1.94	2.10	1.90	2.25	1.60	1.90	0.016	0.200	12.65
4	2500	402	200	360	490	350	410	1.64	1.95	1.60	1.90	1.20	1.85	0.016	0.198	12.21
5	3000	420	220	400	470	390	420	1.30	2.00	1.55	1.70	1.30	1.65	0.016	0.198	12.00
6	3500	476	290	410	480	400	450	1.42	2.70	1.35	1.65	1.15	1.55	0.022	0.248	11.27

TABLE NO : 4.3

FUEL :Esso Plus + ECA 4360 (1000 ppm)

GEAR :3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	682	766	770	866	772	324.0	303.7	313.1
2	1500	694	783	794	886	792	325.7	304.5	316.7
3	2000	716	805	815	900	808	326.9	305.2	319.5
4	2500	746	818	826	913	820	328.0	308.0	321.7
5	3000	766	826	835	925	833	330.9	309.3	322.9
6	3500	790	840	848	945	846	333.0	314.0	325.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	308	230	330	340	260	300	2.44	2.55	2.15	2.50	2.00	2.10	0.015	0.182	12.12
2	1500	363	200	340	400	330	380	2.06	2.10	1.95	2.35	1.90	2.05	0.016	0.199	12.42
3	2000	375	190	360	450	330	360	1.89	1.95	1.80	2.40	1.50	1.85	0.019	0.250	12.94
4	2500	400	200	390	450	360	400	1.90	2.15	1.70	2.25	1.65	2.00	0.018	0.236	12.75
5	3000	415	230	410	430	400	420	1.74	2.30	1.65	1.95	1.55	1.80	0.021	0.260	12.25
6	3500	500	300	480	550	470	500	1.35	2.65	1.70	1.55	1.35	1.80	0.024	0.264	10.82

TABLE NO :4.4

FUEL :Esso Plus + ECA 4360 (1000 ppm)

GEAR :4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	694	773	783	873	793	325.1	303.0	314.0
2	1500	705	792	810	892	812	325.0	303.9	315.7
3	2000	724	819	834	908	818	327.7	305.1	315.9
4	2500	752	832	852	930	836	328.9	306.8	319.0
5	3000	772	843	860	941	853	332.0	308.1	321.7
6	3500	803	858	872	956	871	334.1	312.6	324.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	315	220	330	340	280	310	2.15	2.20	2.05	2.25	2.00	2.00	0.017	0.214	12.96
2	1500	367	180	350	450	300	370	1.91	2.15	1.80	2.15	1.80	1.90	0.019	0.266	14.00
3	2000	412	210	390	470	380	410	1.91	2.00	1.75	2.30	1.70	1.90	0.020	0.248	12.40
4	2500	415	230	400	450	400	400	1.80	2.15	1.65	2.35	1.60	1.60	0.022	0.286	12.75
5	3000	455	280	440	490	420	470	1.41	1.95	1.30	1.55	1.15	1.65	0.024	0.296	12.12
6	3500	490	310	510	500	460	490	1.49	2.35	1.35	1.65	1.20	1.75	0.029	0.316	10.81

TABLE NO :5.1

FUEL : Esso Plus + 0.6ml/l F71
(600 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	723	898	773	795	763	323.0	303.0	320.6
2	1500	732	911	803	813	780	324.0	303.7	321.3
3	2000	746	943	818	840	801	324.7	304.5	323.0
4	2500	772	955	840	855	823	325.3	309.0	330.7
5	3000	810	966	870	870	836	327.0	313.0	335.0
6	3500	848	975	873	883	853	328.7	316.7	343.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	235	180	220	240	230	270	2.82	3.40	2.65	2.85	2.75	3.05	0.015	0.224	14.10
2	1500	210	110	200	210	200	230	2.64	3.20	2.40	2.50	2.45	3.20	0.018	0.272	15.11
3	2000	212	90	190	210	220	230	2.96	3.00	2.80	3.15	2.95	2.95	0.019	0.298	15.45
4	2500	255	110	230	280	250	260	3.00	3.05	2.70	3.35	2.95	3.00	0.020	0.292	14.82
5	3000	267	150	250	270	270	280	3.21	3.30	3.00	3.30	3.25	3.30	0.022	0.320	13.85
6	3500	282	160	270	280	290	290	3.61	3.95	3.50	3.50	3.65	3.80	0.024	0.320	13.21

TABLE NO : 5.2

FUEL : Esso Plus + 0.6 ml/l F71
(600 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	735	903	782	803	772	324.0	304.0	322.7
2	1500	743	915	806	825	794	325.3	304.9	323.0
3	2000	756	954	826	850	810	327.7	306.2	327.2
4	2500	783	963	851	873	836	329.0	308.6	331.7
5	3000	821	978	880	888	851	330.9	313.3	334.8
6	3500	863	988	892	905	868	335.2	317.0	345.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	230	160	200	240	220	260	2.77	3.30	2.40	2.80	2.65	3.25	0.018	0.268	14.57
2	1500	210	100	180	210	200	250	2.49	3.00	2.05	2.55	2.40	2.95	0.017	0.268	15.31
3	2000	230	90	200	230	220	270	2.74	3.15	2.40	2.75	2.65	3.15	0.019	0.300	15.54
4	2500	252	120	220	260	240	290	3.05	3.50	2.65	3.25	2.80	3.50	0.021	0.284	13.65
5	3000	257	130	240	240	240	310	2.90	3.40	2.65	2.80	2.80	3.35	0.022	0.320	13.99
6	3500	290	140	260	300	270	330	3.52	4.10	3.25	3.60	3.30	3.95	0.023	0.296	12.87

TABLE NO : 5.3

FUEL : Esso Plus + 0.6 ml/l F71
(600 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	740	910	792	815	782	324.0	303.0	321.3
2	1500	752	922	816	843	811	325.7	304.2	324.2
3	2000	768	963	833	860	826	326.9	307.0	327.9
4	2500	790	970	862	883	843	330.0	307.9	333.0
5	3000	831	983	891	900	876	332.6	310.8	336.0
6	3500	873	995	905	918	890	333.9	313.2	346.5

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	220	140	200	230	200	250	2.62	3.00	2.40	2.75	2.40	2.95	0.016	0.246	14.90
2	1500	197	90	170	220	190	210	2.27	2.40	2.05	2.35	2.30	2.40	0.016	0.238	15.15
3	2000	220	70	200	240	200	240	2.74	3.00	2.75	2.80	2.40	3.00	0.019	0.300	15.95
4	2500	232	110	190	260	210	270	2.90	3.20	2.65	3.25	2.55	3.15	0.020	0.298	14.90
5	3000	250	110	210	280	220	290	2.92	3.55	2.55	3.30	2.35	3.50	0.022	0.320	14.54
6	3500	272	120	240	300	240	310	3.72	4.00	2.80	3.60	2.35	3.75	0.024	0.330	13.96

TABLE NO : 5.4

FUEL : Esso Plus + 0.6 ml/1 F71
(600 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	746	916	801	832	793	323.8	304.6	326.1
2	1500	758	931	829	854	825	324.6	305.0	328.3
3	2000	773	973	845	872	836	325.9	306.7	330.9
4	2500	798	983	870	892	855	328.3	308.8	333.7
5	3000	835	996	900	908	882	330.9	312.9	338.0
6	3500	878	1010	922	932	905	332.7	315.1	348.2

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	195	120	180	200	180	220	2.32	2.75	2.25	2.35	2.25	2.40	0.017	0.236	14.12
2	1500	195	90	180	200	190	210	2.45	2.70	2.50	2.40	2.35	2.55	0.015	0.224	14.64
3	2000	207	60	170	220	210	230	2.55	2.75	2.55	2.35	2.55	2.75	0.017	0.280	16.18
4	2500	227	90	200	230	220	260	2.69	3.50	2.40	2.75	2.35	3.25	0.018	0.280	15.42
5	3000	230	100	210	240	230	240	2.71	3.45	2.50	2.80	2.75	2.80	0.021	0.310	14.61
6	3500	252	120	230	270	240	270	2.96	3.70	2.75	3.15	2.80	3.15	0.024	0.330	13.98

TABLE NO : 6.1

FUEL : Esso Plus + 1 ml/l F.71
(1000 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K						Water	
		Ex	CY1	CY2	CY3	CY4	Sump Oil	In	Out
1	1000	711	740	755	773	873	315.7	303.0	319.2
2	1500	723	752	762	793	886	316.0	304.2	320.0
3	2000	732	763	773	812	915	317.9	305.7	324.0
4	2500	745	772	792	823	923	320.3	309.5	329.3
5	3000	754	793	811	840	932	322.0	314.0	333.0
6	3500	770	810	825	852	951	323.7	318.1	340.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	255	190	290	260	240	230	3.09	3.65	3.50	3.25	2.85	2.75	0.017	0.240	14.12
2	1500	225	140	250	220	220	210	2.77	3.35	3.25	2.65	2.65	2.55	0.019	0.272	14.50
3	2000	237	130	250	240	230	230	2.76	3.00	2.95	2.85	2.75	2.50	0.017	0.248	14.75
4	2500	250	110	270	260	250	220	2.84	2.95	2.95	2.80	2.95	2.65	0.020	0.286	15.19
5	3000	272	150	290	290	260	250	3.22	3.55	3.40	3.50	3.25	2.75	0.021	0.286	13.48
6	3500	297	170	310	300	290	290	3.65	4.30	4.00	3.60	3.50	3.50	0.025	0.324	13.05

TABLE NO :6.2

FUEL : Esso Plus + 1.00 ml/l F71
(1000 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	718	746	770	788	888	316.0	303.7	320.9
2	1500	732	761	773	811	902	317.7	304.8	321.0
3	2000	740	774	796	833	915	318.9	306.5	325.3
4	2500	752	796	822	846	940	321.0	307.9	330.8
5	3000	768	811	833	858	946	322.8	313.0	332.3
6	3500	776	818	846	870	955	324.9	316.7	335.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	245	170	290	250	230	210	2.94	3.55	3.50	2.95	2.75	2.55	0.018	0.242	13.60
2	1500	252	140	290	260	240	220	2.88	3.15	3.00	3.25	2.85	2.40	0.019	0.282	14.91
3	2000	250	100	280	270	250	200	3.06	3.50	3.50	3.40	2.95	2.40	0.016	0.260	15.85
4	2500	277	140	320	280	260	250	3.32	4.00	3.85	3.25	3.25	2.95	0.019	0.276	14.15
5	3000	287	150	330	290	270	260	3.47	4.15	3.75	3.50	3.40	3.25	0.022	0.280	13.30
6	3500	317	170	370	310	300	290	3.84	4.65	4.50	3.75	3.60	3.50	0.025	0.346	13.82

TABLE NO : 6.3

FUEL : Esso Plus + 1 ml/l F71
(1000 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	725	760	770	798	896	327.0	303.0	321.0
2	1500	741	765	793	823	910	318.7	304.8	322.9
3	2000	755	783	808	842	932	319.8	305.7	323.9
4	2500	773	798	840	862	951	322.3	307.0	337.3
5	3000	786	816	852	872	963	324.0	312.7	332.9
6	3500	798	832	861	863	973	325.7	317.3	338.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	232	150	280	230	220	200	2.76	3.30	3.25	2.75	2.65	2.40	0.019	0.268	14.10
2	1500	230	100	250	230	230	210	2.61	3.00	2.95	2.75	2.75	2.00	0.018	0.278	15.35
3	2000	252	100	290	260	250	210	2.99	3.55	3.10	3.15	2.95	2.75	0.019	0.304	15.67
4	2500	257	120	280	280	250	200	2.36	3.35	3.25	3.25	2.95	2.40	0.021	0.320	15.25
5	3000	282	130	330	310	270	220	3.23	3.45	3.50	3.75	3.40	2.50	0.023	0.350	14.95
6	3500	320	130	390	320	300	270	3.65	3.80	3.75	3.85	3.60	3.40	0.026	0.368	14.75

TABLE NO : 6.4

FUEL : Esso Plus + 1 ml/l F71
(1000 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	733	772	791	806	908	317.0	304.0	321.3
2	1500	750	786	805	834	920	318.8	305.5	323.1
3	2000	771	803	822	852	943	320.7	306.9	326.9
4	2500	790	818	846	870	962	323.2	307.8	328.9
5	3000	802	835	862	886	971	326.0	310.7	335.0
6	3500	812	847	873	898	986	327.1	316.2	338.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	212	120	220	220	210	200	2.56	2.85	2.65	2.65	2.55	2.40	0.021	0.312	14.83
2	1500	210	110	230	210	200	200	2.45	2.75	2.60	2.55	2.40	2.25	0.020	0.288	14.40
3	2000	235	70	260	250	220	210	2.82	3.15	3.15	2.95	2.65	2.55	0.021	0.342	16.12
4	2500	250	90	270	260	240	230	3.01	3.50	3.40	3.15	2.75	2.75	0.023	0.364	15.81
5	3000	262	120	290	280	250	230	2.92	3.10	3.60	3.25	2.95	2.50	0.025	0.350	14.15
6	3500	310	140	350	310	300	280	3.70	3.95	4.20	3.75	3.60	3.25	0.022	0.292	13.27

TABLE NO : 7.1

FUEL : Esso Plus + 2 ml/1 F71
(2000 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature $^{\circ}$K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	693	753	730	832	712	316.3	302.0	319.1
2	1500	705	766	741	840	728	317.0	303.0	320.0
3	2000	713	783	762	856	735	319.7	304.7	323.0
4	2500	726	796	770	871	753	322.8	307.5	327.9
5	3000	740	808	786	882	766	324.7	310.9	331.8
6	3500	758	813	802	903	783	327.8	314.0	335.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	277	220	270	280	260	300	3.35	4.00	3.40	3.25	3.15	3.60	0.016	0.195	12.50
2	1500	252	160	240	250	230	290	3.01	3.50	2.85	2.95	3.00	3.25	0.018	0.240	13.19
3	2000	262	150	280	280	260	330	3.36	4.00	3.25	3.25	3.00	3.95	0.016	0.220	13.50
4	2500	297	130	290	280	270	350	3.47	4.00	3.50	3.25	3.40	3.75	0.019	0.270	14.05
5	3000	317	170	330	300	290	350	3.81	4.25	3.95	3.60	3.50	4.20	0.024	0.314	12.97
6	3500	362	210	350	340	350	410	4.35	4.50	4.20	4.05	4.20	4.95	0.027	0.328	12.05

TABLE NO : 7.2

FUEL : Esso Plus + 2 ml/l F71
(2000 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	702	763	740	843	722	316.0	303.0	321.1
2	1500	713	780	746	851	739	318.3	304.2	322.0
3	2000	730	801	771	862	743	319.6	304.9	323.3
4	2500	742	810	792	873	756	323.9	305.2	326.1
5	3000	751	822	804	886	773	325.0	308.7	328.0
6	3500	763	836	813	913	804	328.7	313.0	333.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	262	210	270	260	240	280	3.24	3.75	3.40	3.15	2.85	3.55	0.016	0.204	12.73
2	1500	247	190	250	240	230	270	3.15	3.75	3.05	3.00	3.00	3.55	0.017	0.218	12.80
3	2000	265	200	310	250	210	290	2.96	3.15	3.15	2.95	2.50	3.25	0.018	0.224	12.11
4	2500	300	170	320	290	260	330	3.61	3.80	3.85	3.50	3.15	3.95	0.018	0.236	13.32
5	3000	312	200	330	290	280	350	3.72	4.30	3.95	3.50	3.25	4.20	0.021	0.262	12.37
6	3500	367	230	380	360	340	390	4.27	4.40	4.55	4.35	4.05	4.55	0.025	0.304	11.98

TABLE NO : 7.3

FUEL : Esso Plus + 2 ml/l F.71
(2000 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	708	776	753	855	733	315.0	303.5	322.0
2	1500	722	789	765	870	746	315.9	304.7	323.1
3	2000	735	810	772	876	763	316.5	305.3	325.0
4	2500	753	821	800	890	781	318.0	306.9	328.0
5	3000	762	832	813	900	796	321.3	309.0	332.3
6	3500	773	843	825	908	813	325.7	312.3	333.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratic
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	287	210	300	270	230	350	3.42	4.00	3.60	3.15	2.75	4.20	0.019	0.240	12.30
2	1500	270	160	280	250	210	340	3.34	4.25	3.25	2.85	2.75	4.50	0.018	0.246	13.66
3	2000	300	170	320	260	250	370	3.52	4.25	3.85	3.05	2.85	4.35	0.020	0.266	13.50
4	2500	325	130	370	340	290	300	3.55	4.00	3.55	3.55	3.50	3.60	0.022	0.316	14.36
5	3000	340	160	340	330	300	390	4.04	4.75	4.05	3.95	3.60	4.55	0.024	0.336	14.00
6	3500	370	200	370	360	310	440	4.60	5.00	4.50	4.35	4.25	5.30	0.023	0.272	12.03

TABLE NO : 7.4

FUEL : Esso Plus + 2 ml/1 F 71
(2000 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	615	784	760	863	746	314.0	303.0	322.0
2	1500	730	800	772	873	758	315.0	305.0	324.7
3	2000	743	818	788	884	773	317.1	306.7	327.8
4	2500	666	832	800	896	793	320.0	308.9	331.7
5	3000	775	846	818	910	812	322.3	310.9	334.9
6	3500	788	853	833	923	826	326.1	313.0	338.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	245	180	260	240	210	270	3.01	4.00	3.15	2.85	2.55	3.50	0.020	0.260	13.00
2	1500	230	150	230	230	210	250	2.65	3.75	2.75	2.75	2.25	2.85	0.022	0.308	13.75
3	2000	252	160	260	240	240	270	3.15	3.60	3.15	2.85	2.85	3.75	0.018	0.252	13.61
4	2500	277	110	280	270	270	290	3.25	3.75	3.25	3.25	3.00	3.50	0.020	0.288	14.62
5	3000	290	170	290	290	280	300	3.49	4.00	3.50	3.50	3.35	3.60	0.025	0.314	12.76
6	3500	315	240	320	300	310	330	3.86	4.40	3.85	3.60	3.75	4.25	0.029	0.342	11.80

TABLE NO : 8.1

FUEL : Esso Plus + ECA 1140
(100 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	663	803	743	655	709	323.0	303.1	319.3
2	1500	678	815	755	763	713	323.9	305.0	321.1
3	2000	686	824	763	770	715	325.3	306.9	322.8
4	2500	694	838	771	783	720	327.7	308.7	325.0
5	3000	703	852	870	798	726	329.0	311.0	328.1
6	3500	712	865	793	810	733	331.3	315.1	333.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	355	270	320	350	330	420	4.26	5.50	3.85	4.20	3.95	5.05	0.019	0.218	11.60
2	1500	335	250	290	340	300	410	4.02	5.25	3.50	4.05	3.60	4.95	0.017	0.204	12.00
3	2000	370	260	330	380	340	430	4.40	5.35	3.75	4.55	4.05	5.25	0.019	0.228	11.69
4	2500	390	270	350	410	370	430	4.61	5.50	3.75	4.95	4.50	5.25	0.022	0.256	11.63
5	3000	395	290	360	390	380	450	4.78	5.50	4.35	4.75	4.55	5.50	0.022	0.250	11.26
6	3500	432	310	390	430	420	490	5.23	6.00	4.75	5.25	5.05	5.90	0.024	0.266	10.90

TABLE NO : 8.2

FUEL : Esso Plus + ECA 1140
(100 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	660	714	751	768	721	323.3	301.0	318.0
2	1500	683	823	765	783	726	324.2	302.1	320.0
3	2000	693	835	774	800	733	325.1	304.0	323.1
4	2500	704	847	786	813	745	327.0	307.1	327.0
5	3000	716	863	803	820	753	330.3	310.7	329.3
6	3500	730	874	812	833	764	333.0	314.3	333.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	337	250	300	330	320	400	4.05	5.00	3.60	3.95	3.85	4.8	0.020	0.248	12.13
2	1500	330	220	310	310	320	380	3.92	4.75	3.50	3.75	3.85	4.60	0.018	0.222	12.53
3	2000	345	230	310	320	340	410	4.22	5.00	3.75	3.85	4.05	5.25	0.019	0.240	12.30
4	2500	372	230	350	360	380	400	4.46	5.00	4.20	4.35	4.55	4.75	0.020	0.254	12.70
5	3000	390	250	370	390	380	420	4.58	4.75	4.00	4.75	4.55	5.05	0.023	0.280	11.95
6	3500	432	300	410	420	430	470	5.22	5.75	4.95	5.05	5.25	5.65	0.026	0.296	11.21

TABLE NO : 8.3

FUEL : Esso Plus + ECA 1140 (100 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	676	823	769	781	732	324.2	302.0	318.7
2	1500	680	832	777	793	740	326.0	302.9	320.0
3	2000	705	843	786	805	746	327.3	305.0	322.0
4	2500	718	854	800	818	758	329.7	306.7	324.3
5	3000	733	866	813	833	770	332.9	311.0	329.7
6	3500	742	880	826	832	786	335.3	316.1	335.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	345	240	300	320	360	400	4.15	5.00	3.60	3.85	4.35	4.80	0.020	0.238	11.79
2	1500	315	220	280	280	340	360	3.72	4.50	3.25	3.25	4.05	4.35	0.019	0.232	12.14
3	2000	340	210	320	330	350	360	4.00	4.40	3.35	3.95	4.20	4.50	0.021	0.270	12.79
4	2500	342	220	290	330	370	380	4.24	4.75	3.50	3.95	4.50	5.00	0.026	0.312	11.90
5	3000	382	230	340	380	390	420	4.60	5.00	4.05	4.55	4.75	5.05	0.028	0.330	11.74
6	3500	412	280	380	400	430	440	4.95	5.35	4.55	4.80	5.20	5.25	0.028	0.302	10.94

TABLE NO : 8.4

FUEL : Esso Plus + ECA 1140
(100 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	683	830	768	789	738	325.0	303.0	318.0
2	1500	702	842	783	804	749	325.8	304.0	319.7
3	2000	713	852	797	816	761	327.0	304.7	320.3
4	2500	730	863	808	832	772	329.4	306.0	322.7
5	3000	738	872	823	842	784	332.0	310.6	337.5
6	3500	746	892	835	852	800	336.0	317.0	335.1

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	305	230	290	300	300	330	3.66	4.75	3.50	3.60	3.60	3.95	0.025	0.300	12.00
2	1500	302	210	270	300	310	330	3.72	4.50	3.05	3.60	3.75	4.50	0.021	0.236	11.28
3	2000	315	210	300	300	320	340	3.77	4.25	3.60	3.60	3.85	4.05	0.023	0.268	11.80
4	2500	355	220	340	350	360	370	4.14	4.40	3.50	4.20	4.35	4.50	0.026	0.292	11.40
5	3000	362	230	340	350	380	380	4.39	4.50	4.05	4.20	4.55	4.75	0.028	0.310	11.10
6	3500	397	280	380	390	410	410	4.80	4.90	4.55	4.75	4.95	4.95	0.030	0.338	11.25

TABLE NO : 9.1

FUEL : Esso Plus + ECA 1140
(500 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	665	763	755	812	723	316.1	301.7	312.6
2	1500	682	773	766	825	735	316.9	302.7	314.9
3	2000	688	782	774	833	743	317.8	303.9	316.0
4	2500	697	795	783	850	750	318.8	305.2	322.0
5	3000	714	813	796	863	762	319.3	307.0	326.7
6	3500	723	825	808	875	773	320.9	312.0	332.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	322	270	300	310	300	380	3.87	4.75	3.60	3.75	3.60	4.55	0.016	0.180	10.99
2	1500	307	240	280	330	270	350	3.82	4.75	3.35	3.95	3.25	4.75	0.018	0.206	11.70
3	2000	340	260	330	350	310	370	4.10	4.95	3.95	4.20	3.75	4.50	0.019	0.224	11.50
4	2500	357	250	340	360	340	390	4.29	5.25	4.05	4.35	3.75	5.00	0.020	0.248	12.15
5	3000	372	280	360	370	350	410	4.50	5.25	4.35	4.50	4.20	4.95	0.025	0.264	10.62
6	3500	402	290	390	400	370	450	4.86	5.50	4.75	4.80	4.50	5.40	0.028	0.290	10.50

TABLE NO : 9.2

FUEL : Esso Plus + ECA 1140
(500 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	663	771	763	820	733	315.0	302.0	314.3
2	1500	685	783	776	834	746	316.1	303.2	315.9
3	2000	693	791	787	846	755	317.7	304.6	317.3
4	2500	704	805	798	861	768	319.2	306.0	320.1
5	3000	725	824	809	873	786	321.1	307.1	321.8
6	3500	736	836	821	886	803	322.0	312.8	327.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	310	250	290	300	280	370	3.74	4.70	3.50	3.60	3.35	4.50	0.018	0.202	11.22
2	1500	297	220	270	310	270	340	3.51	4.25	3.25	3.75	3.00	4.05	0.017	0.208	12.10
3	2000	317	190	310	310	300	350	3.82	4.25	3.75	3.75	3.60	4.20	0.020	0.246	12.35
4	2500	350	210	340	350	330	380	4.07	4.45	4.05	4.20	3.50	4.55	0.021	0.242	11.51
5	3000	370	220	360	370	350	400	4.46	4.35	4.35	4.50	4.20	4.80	0.023	0.260	11.30
6	3500	397	280	390	400	370	430	4.89	5.35	4.75	4.80	4.75	5.25	0.027	0.290	10.65

TABLE NO : 9.3

FUEL :Esso Plus + ECA 1140
(500 ppm)

GEAR :3rd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	681	780	773	829	741	316.1	303.0	315.3
2	1500	694	792	787	843	753	317.0	303.8	316.6
3	2000	705	808	800	860	770	318.1	305.0	318.0
4	2500	718	823	813	871	793	319.3	306.5	320.8
5	3000	733	838	826	887	810	321.9	307.9	322.8
6	3500	751	852	837	902	829	324.8	311.1	326.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	315	230	300	330	280	350	3.77	4.50	3.60	3.95	3.35	4.20	0.020	0.240	12.00
2	1500	312	200	310	320	290	330	3.71	4.25	3.75	3.85	3.00	4.25	0.019	0.238	12.65
3	2000	315	200	300	330	280	350	3.85	4.35	3.60	3.95	3.35	4.50	0.020	0.262	12.96
4	2500	347	210	340	350	310	390	4.19	4.50	4.05	4.20	3.75	4.75	0.023	0.282	12.10
5	3000	365	240	360	370	320	390	4.34	4.90	4.35	4.50	4.00	5.00	0.025	0.288	11.60
6	3500	360	260	390	410	340	420	4.81	5.70	4.75	4.95	4.05	5.50	0.033	0.338	11.00

TABLE NO : 9.4

FUEL : Esso Plus + ECA 1140
(500 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	688	789	783	839	752	317.0	303.0	315.7
2	1500	703	801	798	854	772	317.9	304.0	317.1
3	2000	716	819	812	873	790	319.3	306.2	320.5
4	2500	733	835	828	890	808	321.0	308.0	324.2
5	3000	753	851	842	903	819	323.3	310.6	326.7
6	3500	768	863	853	919	845	326.0	313.1	331.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	290	220	280	300	270	310	3.49	4.25	3.35	3.60	3.25	3.75	0.021	0.268	12.45
2	1500	277	180	280	290	250	290	3.32	4.00	3.35	3.50	2.95	3.50	0.020	0.259	13.14
3	2000	292	200	290	290	280	310	3.52	4.15	3.50	3.50	3.35	3.75	0.023	0.285	12.61
4	2500	325	180	320	330	310	340	3.84	4.00	3.85	3.95	3.50	4.05	0.025	0.310	13.20
5	3000	327	210	320	330	320	340	3.90	4.25	3.85	3.95	3.75	4.05	0.029	0.345	12.05
6	3500	377	240	370	380	360	400	4.55	5.15	4.50	4.55	4.35	4.80	0.033	0.362	11.10

TABLE NO : 10.1

FUEL : Esso Plus + ECA 1140
(1000 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	653	773	753	745	673	313.1	301.0	310.5
2	1500	660	779	770	753	680	314.2	302.2	312.9
3	2000	665	788	779	766	686	316.5	303.9	314.2
4	2500	667	798	792	777	698	317.3	305.8	317.9
5	3000	673	810	808	788	709	319.7	307.0	318.7
6	3500	683	843	823	804	720	322.0	310.6	322.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	367	280	310	360	370	430	4.46	5.50	3.75	4.35	4.50	5.25	0.018	0.194	10.90
2	1500	350	260	310	330	350	410	4.22	5.35	3.50	3.95	4.20	5.25	0.017	0.193	11.55
3	2000	352	270	330	350	380	450	4.42	5.10	3.95	4.20	4.55	5.00	0.019	0.214	11.20
4	2500	387	290	350	360	410	430	4.57	5.25	3.75	4.35	4.95	5.25	0.022	0.240	11.00
5	3000	415	300	380	380	410	490	4.99	5.75	4.55	4.55	4.95	5.90	0.025	0.271	10.65
6	3500	460	320	420	450	460	510	5.45	5.90	5.65	5.20	5.55	6.00	0.029	0.289	10.10

TABLE NO : 10.2

FUEL : Esso Plus + ECA 1140
(1000 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	658	779	764	743	683	313.0	302.1	312.6
2	1500	669	781	773	754	698	314.3	303.0	314.8
3	2000	676	790	783	778	707	315.4	304.3	317.0
4	2500	685	801	786	788	708	316.9	305.6	318.3
5	3000	694	808	803	790	719	320.0	306.9	319.0
6	3500	703	823	813	803	723	323.7	309.7	322.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	345	280	310	320	350	400	4.15	5.40	3.75	3.85	4.20	4.80	0.019	0.222	11.50
2	1500	347	250	320	330	350	390	4.16	5.10	3.50	3.95	4.20	5.00	0.017	0.210	12.32
3	2000	365	260	330	340	370	420	4.39	5.00	3.95	4.05	4.50	5.05	0.020	0.238	11.95
4	2500	400	240	380	390	400	430	4.82	5.25	4.25	4.75	4.80	5.50	0.019	0.250	13.00
5	3000	415	270	400	400	410	450	5.02	5.65	4.80	4.80	4.95	5.55	0.024	0.286	12.10
6	3500	457	310	430	450	460	490	5.31	5.85	5.25	5.55	5.55	5.90	0.026	0.303	11.65

TABLE NO : 10.3

FUEL : Esso Plus + ECA 1140
(1000 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	665	780	770	758	723	314.7	303.0	313.8
2	1500	680	783	781	762	728	316.1	303.7	315.9
3	2000	693	791	787	780	743	318.0	305.0	317.7
4	2500	703	800	793	791	755	319.9	306.7	319.8
5	3000	716	813	805	793	763	322.0	308.6	322.3
6	3500	723	832	818	810	776	326.7	311.8	326.6

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	335	250	310	320	340	370	4.04	5.15	3.75	3.85	4.05	4.50	0.017	0.187	11.00
2	1500	357	230	330	340	360	400	4.22	4.90	3.50	4.05	4.35	5.00	0.017	0.200	11.42
3	2000	360	230	330	350	370	390	4.41	5.25	3.95	4.20	4.50	5.00	0.017	0.193	11.55
4	2500	385	240	350	380	400	410	4.54	5.00	4.20	4.55	4.65	4.75	0.020	0.224	11.37
5	3000	420	260	400	410	430	440	5.00	5.25	4.50	4.95	5.25	5.30	0.024	0.263	10.95
6	3500	445	300	410	430	470	470	5.37	5.75	4.95	5.25	5.65	5.65	0.031	0.331	10.60

TABLE NO : 10.4

FUEL : Esso Plus + ECA 1140
(1000 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	673	783	773	770	736	315.0	301.0	311.7
2	1500	686	794	793	773	748	316.7	301.3	312.8
3	2000	694	803	795	792	753	317.3	302.0	314.7
4	2500	715	811	808	799	766	319.5	302.8	316.5
5	3000	743	830	820	816	783	322.0	303.9	319.0
6	3500	760	846	833	830	800	326.7	308.7	322.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	327	230	310	320	330	350	3.94	4.50	3.75	3.85	3.95	4.20	0.019	0.223	11.50
2	1500	335	220	300	310	360	370	3.90	4.25	3.50	3.75	4.35	4.00	0.017	0.218	12.75
3	2000	365	230	290	350	340	380	4.07	4.50	3.50	4.20	4.05	4.55	0.020	0.250	12.50
4	2500	365	250	340	360	370	390	4.34	4.60	3.75	4.35	4.50	4.75	0.023	0.284	12.05
5	3000	390	250	370	390	400	400	4.76	5.00	4.50	4.75	4.80	5.00	0.026	0.312	12.00
6	3500	407	270	380	400	420	430	4.97	5.75	4.55	4.80	5.05	5.50	0.030	0.337	11.15

TABLE NO : 11.1

FUEL : Esso Plus + ECA 1030
(100 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	588	756	713	768	743	316.0	303.0	314.3
2	1500	651	750	735	783	758	316.7	304.3	317.0
3	2000	556	765	731	786	764	317.5	305.7	319.5
4	2500	663	730	733	793	773	319.0	317.1	310.2
5	3000	670	789	740	804	784	320.8	344.3	333.2
6	3500	672	796	748	813	793	322.9	313.1	336.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	460	310	450	500	430	460	5.57	6.50	5.40	6.00	5.15	5.75	0.017	0.183	10.70
2	1500	432	290	430	480	370	450	5.16	6.00	5.15	5.80	4.50	5.20	0.016	0.176	11.05
3	2000	440	300	410	480	410	460	5.41	5.85	4.95	6.00	4.95	5.75	0.020	0.227	11.32
4	2500	472	310	460	510	430	490	5.76	6.00	5.75	6.15	5.25	5.90	0.024	0.271	11.10
5	3000	467	300	470	500	420	480	5.80	6.40	5.65	6.25	5.50	5.80	0.024	0.276	11.55
6	3500	497	320	500	530	450	510	6.11	6.50	6.00	6.35	5.95	6.15	0.028	0.292	10.50

TABLE NO : 11.2

FUEL : Esso Plus + ECA 1030
(100 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	633	762	735	776	738	315.7	303.1	314.2
2	1500	655	773	743	803	756	316.5	304.7	318.0
3	2000	670	780	746	810	763	317.6	305.9	320.3
4	2500	683	783	753	815	974	324.0	307.1	321.0
5	3000	689	891	763	823	780	322.9	310.0	334.0
6	3500	700	803	771	832	786	323.2	312.8	327.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	440	320	430	450	410	460	5.40	6.35	5.15	5.75	4.95	5.75	0.019	0.210	10.99
2	1500	417	280	410	480	350	430	5.14	6.35	4.95	6.25	4.20	5.15	0.020	0.238	11.90
3	2000	445	270	440	480	390	470	5.24	6.25	5.25	5.80	4.25	5.65	0.018	0.228	12.45
4	2500	460	250	450	500	400	490	5.44	6.10	5.40	6.00	4.50	5.85	0.021	0.271	12.90
5	3000	470	250	460	510	400	510	5.80	6.35	5.75	6.50	4.80	6.15	0.024	0.298	12.62
6	3500	507	280	480	560	470	520	6.11	6.90	5.80	6.75	5.65	6.25	0.026	0.309	11.70

TABLE NO : 11.3

FUEL : Esso Plus + ECA 1030
(100 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water	
								In	Out
1	1000	663	768	751	783	763	316.0	303.0	315.5
2	1500	674	783	763	789	780	317.9	305.1	318.0
3	2000	703	780	768	793	787	319.7	307.0	319.7
4	2500	708	793	773	799	791	322.5	311.8	324.0
5	3000	720	804	781	816	797	335.7	313.2	321.7
6	3500	731	813	780	827	806	329.0	317.6	329.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	422	280	420	440	400	430	5.06	6.10	5.05	5.25	4.80	5.15	0.023	0.264	11.68
2	1500	410	260	410	420	400	410	4.91	5.75	4.95	5.25	4.50	4.95	0.020	0.238	12.13
3	2000	440	200	440	450	430	440	5.22	5.75	5.25	5.40	5.00	5.25	0.023	0.311	13.40
4	2500	455	210	440	470	450	460	5.50	5.90	5.25	6.00	5.00	5.75	0.027	0.350	13.11
5	3000	452	250	430	480	420	480	5.62	6.00	5.15	5.80	5.75	5.80	0.028	0.355	12.71
6	3500	515	270	500	540	470	550	6.19	6.75	6.00	6.50	5.65	6.60	0.029	0.322	11.05

TABLE NO : 11.4

FUEL : Esso Plus + ECA 1030
(100 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	781	883	778	723	781	318.0	304.0	316.4
2	1500	708	880	783	836	797	319.9	305.8	319.8
3	2000	713	803	886	841	794	322.3	311.1	320.3
4	2500	710	811	893	846	803	326.6	309.9	321.0
5	3000	722	819	898	852	813	331.0	312.8	327.3
6	3500	739	826	803	858	826	336.1	317.2	332.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	387	220	390	400	360	400	4.67	5.30	4.75	4.80	4.35	4.80	0.020	0.264	13.20
2	1500	387	170	390	420	350	390	4.65	5.55	4.75	5.05	4.05	4.75	0.019	0.276	14.15
3	2000	412	170	410	450	360	430	4.99	5.00	4.95	5.40	4.45	5.15	0.024	0.341	14.39
4	2500	440	200	450	460	400	450	5.34	5.15	5.40	5.75	4.80	5.40	0.026	0.332	12.95
5	3000	452	180	450	470	440	450	5.51	5.90	5.40	6.00	5.25	5.40	0.028	0.367	13.10
6	3500	490	230	480	520	470	500	5.92	6.50	5.80	6.25	5.65	6.00	0.033	0.394	11.93

TABLE NO : 12.1

FUEL : Esso Plus + ECA 1030
(500 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	623	708	702	773	714	316.0	301.0	311.1
2	1500	643	723	713	796	728	316.6	302.3	312.7
3	2000	649	728	717	803	734	317.6	303.7	314.9
4	2500	653	736	723	808	732	319.7	305.6	317.5
5	3000	663	743	730	811	750	321.0	307.7	320.0
6	3500	671	750	741	818	771	323.3	310.8	324.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	487	350	500	520	450	480	5.86	6.50	6.00	6.25	5.40	5.80	0.019	0.200	10.47
2	1500	445	300	440	510	400	430	5.30	6.15	5.25	6.00	4.80	5.15	0.020	0.219	11.12
3	2000	442	300	470	510	430	460	5.59	6.25	5.65	6.15	5.00	5.55	0.018	0.216	11.43
4	2500	497	310	510	550	460	470	5.96	6.40	6.15	6.50	5.55	5.65	0.020	0.224	11.25
5	3000	510	300	530	560	460	490	6.27	6.65	6.35	6.75	6.00	6.00	0.022	0.251	11.20
6	3500	555	340	570	580	530	540	6.67	6.80	6.85	7.00	6.35	6.50	0.024	0.260	10.82

TABLE NO : 12.2

FUEL : Esso Plus + ECA1030
(500 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	649	714	713	879	723	316.7	302.0	313.6
2	1500	662	726	720	803	728	317.4	306.9	313.8
3	2000	670	732	729	806	730	318.5	304.3	316.9
4	2500	778	743	736	813	748	320.9	306.0	318.5
5	3000	786	749	743	820	756	322.8	307.7	310.8
6	3500	793	753	750	826	886	325.0	310.9	324.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	475	320	500	500	450	450	5.70	6.25	6.00	6.00	5.40	5.40	0.019	0.203	10.80
2	1500	442	290	450	470	400	450	5.24	6.00	5.40	5.65	4.50	5.40	0.020	0.232	11.65
3	2000	475	250	510	510	400	480	5.72	6.25	6.15	6.15	4.80	5.80	0.021	0.271	12.60
4	2500	487	270	500	510	440	500	5.91	6.40	6.00	6.50	5.15	6.00	0.023	0.280	12.11
5	3000	507	300	530	530	460	510	6.19	6.90	6.35	6.75	5.50	6.15	0.025	0.294	11.65
6	3500	550	310	580	590	510	520	6.56	7.00	6.95	7.05	6.00	6.25	0.028	0.307	10.92

TABLE NO : 12.3

FUEL : Essc Plus + ECA 1030
(500 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	665	743	736	790	755	317.0	302.1	315.0
2	1500	686	756	738	801	768	317.8	303.0	316.7
3	2000	700	780	743	812	776	318.9	304.3	318.6
4	2500	705	763	750	828	783	319.9	306.0	320.3
5	3000	713	768	754	832	796	321.8	308.3	323.0
6	3500	720	773	763	841	803	324.5	311.0	326.2

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	440	300	450	470	400	440	5.27	6.05	5.40	5.65	4.80	5.25	0.012	0.222	11.15
2	1500	440	260	440	470	430	420	5.24	5.75	5.25	5.50	5.15	5.05	0.022	0.267	12.22
3	2000	472	220	480	490	470	450	5.52	6.00	5.80	5.90	5.00	5.40	0.019	0.246	13.15
4	2500	470	230	480	500	440	460	5.71	6.00	5.80	6.25	5.25	5.55	0.022	0.289	12.90
5	3000	480	240	480	500	470	470	5.77	6.25	5.80	6.00	5.65	5.65	0.024	0.303	12.55
6	3500	542	280	560	570	530	510	6.52	6.70	6.75	6.85	6.35	6.15	0.028	0.324	11.72

TABLE NO : 12.4

FUEL : Esso Plus + ECA 1030
(500 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	688	758	749	801	773	317.3	303.0	316.1
2	1500	700	763	753	806	776	318.4	304.3	317.9
3	2000	711	770	760	809	783	320.0	305.9	321.0
4	2500	716	776	763	814	788	322.3	307.3	322.4
5	3000	723	783	773	823	791	325.6	311.0	314.7
6	3500	734	790	784	831	802	328.3	313.3	318.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	402	240	410	420	370	410	4.86	5.90	4.95	5.05	4.50	4.95	0.018	0.237	12.90
2	1500	410	200	410	450	380	400	4.85	5.75	4.95	5.40	4.25	4.80	0.022	0.300	13.45
3	2000	440	190	450	480	390	440	5.30	5.90	5.40	5.80	4.75	5.25	0.020	0.275	13.88
4	2500	457	220	460	480	430	460	5.65	6.40	5.55	6.50	5.00	5.55	0.025	0.310	12.50
5	3000	480	250	490	500	450	480	5.77	6.25	5.90	6.00	5.40	5.80	0.031	0.376	11.95
6	3500	522	250	530	550	500	510	6.27	6.75	6.35	6.60	6.00	6.15	0.035	0.406	11.62

TABLE NO : 13.1

FUEL : Esso Plus + ECA 1030
(1000 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	610	693	686	768	673	313.0	303.0	313.3
2	1500	618	703	705	774	694	313.5	303.9	314.7
3	2000	633	709	713	783	702	314.4	304.9	316.9
4	2500	640	714	717	789	702	316.5	306.7	319.2
5	3000	643	722	727	600	713	318.8	309.2	323.1
6	3500	650	725	732	608	716	322.0	312.8	326.6

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	522	370	520	550	450	570	6.25	6.85	6.25	6.60	5.40	6.75	0.020	0.203	10.15
2	1500	482	330	470	480	440	540	5.74	6.60	5.65	5.80	5.00	6.50	0.022	0.224	10.82
3	2000	507	320	500	510	470	550	5.97	6.00	6.00	6.15	5.50	6.25	0.020	0.220	11.16
4	2500	522	340	500	540	480	570	6.30	6.75	6.00	6.50	5.85	6.86	0.025	0.283	11.40
5	3000	547	350	530	560	500	600	6.56	6.80	6.35	6.75	6.16	7.00	0.027	0.294	11.04
6	3500	590	390	570	590	570	630	6.94	7.25	6.85	7.05	6.50	7.35	0.028	0.286	10.35

TABLE NO : 13.2

FUEL : Esso Plus +ECA 1030
(1000 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	623	725	700	782	688	314.0	303.3	314.1
2	1500	638	733	715	794	702	314.7	305.0	315.5
3	2000	648	740	723	801	708	315.6	307.5	319.7
4	2500	663	743	730	803	719	317.7	310.6	323.9
5	3000	668	751	733	810	724	321.0	313.0	326.3
6	3500	671	756	744	823	733	324.8	315.9	329.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	485	340	460	520	430	530	5.91	6.75	5.75	6.25	5.15	6.50	0.020	0.212	10.75
2	1500	472	300	460	490	430	510	5.60	6.50	5.75	5.90	4.75	6.00	0.023	0.269	11.42
3	2000	502	390	480	540	440	550	6.04	6.50	5.80	6.50	5.25	6.60	0.020	0.206	10.30
4	2500	502	300	500	510	470	530	6.16	7.00	6.00	6.15	5.75	6.75	0.023	0.286	12.54
5	3000	530	300	510	550	500	560	6.37	6.60	5.15	6.60	6.00	6.75	0.024	0.281	12.05
6	3500	562	350	540	580	540	590	6.69	7.25	6.50	6.95	6.25	7.05	0.024	0.268	10.99

TABLE NO : 13.3

FUEL : Esso Plus + ECA 1030
(1000 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	630	733	726	787	700	314.7	303.0	314.9
2	1500	643	740	733	793	712	315.9	304.9	317.0
3	2000	648	743	736	797	724	317.6	309.0	321.3
4	2500	662	750	743	803	728	319.7	311.3	324.3
5	3000	665	756	747	812	741	322.9	314.0	327.2
6	3500	672	763	754	821	746	327.7	317.3	331.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	455	340	440	450	430	500	5.45	6.25	5.25	5.40	5.15	6.00	0.020	0.219	11.00
2	1500	452	270	450	450	430	480	5.40	6.00	5.40	5.40	5.00	5.80	0.021	0.240	11.65
3	2000	472	270	460	480	460	490	5.80	6.00	5.75	5.80	5.75	5.90	0.020	0.233	11.82
4	2500	510	250	500	510	490	540	6.01	6.25	6.00	6.15	5.90	6.00	0.020	0.278	12.62
5	3000	515	270	510	520	560	530	6.19	6.50	6.15	6.25	6.00	6.35	0.025	0.300	11.90
6	3500	577	300	570	580	560	600	6.94	7.05	6.85	6.95	6.75	7.20	0.029	0.329	11.25

TABLE NO : 13.4

FUEL : Esso Plus +ECA 1030
(1000 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	643	737	728	803	723	315.0	303.3	315.7
2	1500	655	756	742	807	730	316.0	304.9	317.8
3	2000	663	763	748	813	735	317.7	307.0	320.3
4	2500	670	770	763	820	743	319.8	310.1	323.8
5	3000	676	783	771	827	750	322.9	314.3	327.2
6	3500	683	796	783	834	773	327.0	318.7	332.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	442	300	440	460	400	470	5.39	6.25	5.25	5.75	4.80	5.75	0.026	0.206	11.50
2	1500	427	280	410	440	400	460	5.06	5.75	4.95	5.25	4.50	5.55	0.020	0.238	12.14
3	2000	455	280	450	460	430	480	5.77	6.00	5.60	5.75	5.50	6.25	0.024	0.288	12.10
4	2500	497	290	500	500	490	500	5.97	6.25	6.00	6.00	5.90	6.00	0.025	0.299	11.95
5	3000	535	310	520	550	520	550	6.42	6.50	6.25	6.60	6.25	6.60	0.028	0.326	11.48
6	3500	560	320	550	570	540	580	6.84	7.10	6.80	6.85	6.75	6.95	0.030	0.340	11.15

TABLE NO : 14.1

FUEL : REFERENCE

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	673	821	759	773	805	323.0	303.0	319.3
2	1500	698	853	766	784	824	325.3	304.9	321.8
3	2000	710	850	781	803	833	328.0	307.8	323.3
4	2500	726	862	786	812	845	331.7	310.0	326.7
5	3000	733	868	795	807	853	335.3	312.9	329.3
6	3500	740	873	803	813	861	339.4	315.0	332.5

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	380	300	360	400	390	370	4.49	3.65	4.35	4.75	4.60	4.25	0.017	0.182	11.40
2	1500	367	250	310	430	390	340	4.35	3.15	3.70	5.00	4.55	4.15	0.019	0.240	12.31
3	2000	365	280	330	430	360	340	4.10	3.35	3.85	5.15	3.30	4.10	0.022	0.264	12.00
4	2500	397	260	350	450	410	380	4.76	3.55	4.20	5.35	4.95	4.55	0.019	0.241	12.95
5	3000	412	290	380	460	410	400	4.87	3.55	4.55	5.35	4.80	4.80	0.023	0.267	11.71
6	3500	447	310	400	510	450	430	5.36	3.75	4.80	6.00	5.40	5.25	0.025	0.278	11.90

TABLE NO : 14.2

FUEL : Reference Gasoline

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	690	834	763	782	813	325.3	303.2	319.8
2	1500	710	851	773	796	830	326.2	304.0	321.7
3	2000	723	858	798	813	843	328.6	305.9	323.7
4	2500	732	866	804	829	851	331.4	307.6	325.2
5	3000	743	875	813	833	863	333.0	309.9	327.8
6	3500	754	893	820	840	870	338.9	312.8	331.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	370	280	350	390	380	360	4.45	3.30	4.20	4.70	4.55	4.35	0.018	0.221	12.06
2	1500	355	250	300	400	380	340	4.22	3.00	3.60	4.80	4.45	4.05	0.017	0.214	12.59
3	2000	345	250	320	380	360	320	4.17	3.15	3.85	4.65	4.40	3.80	0.020	0.256	12.80
4	2500	332	270	320	400	310	300	3.99	3.45	3.90	4.70	3.75	3.60	0.023	0.273	11.96
5	3000	387	280	360	440	380	370	4.51	3.55	4.15	4.95	4.50	4.45	0.025	0.290	11.60
6	3500	427	300	400	450	440	420	5.02	3.65	4.75	5.25	5.20	4.90	0.027	0.294	11.03

TABLE NO : 14.3.

FUEL : REFERENCE

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	702	843	773	894	835	327.1	304.0	322.1
2	1500	723	866	790	803	857	328.2	304.9	323.6
3	2000	710	873	801	826	863	330.0	306.2	325.0
4	2500	743	886	813	833	876	332.2	308.0	327.3
5	3000	752	802	830	844	883	335.9	311.3	330.3
6	3500	755	903	842	853	887	339.0	314.5	332.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	370	270	350	400	370	360	4.46	3.00	4.15	4.80	4.50	4.40	0.018	0.220	12.15
2	1500	355	230	330	380	400	310	4.26	2.65	3.90	4.65	4.75	3.75	0.020	0.258	13.01
3	2000	345	250	320	370	350	340	4.14	3.35	3.80	4.50	4.25	4.00	0.022	0.272	12.59
4	2500	360	210	300	440	400	300	4.27	3.75	3.65	5.15	4.75	3.55	0.019	0.260	13.40
5	3000	375	250	330	400	420	350	4.41	3.90	3.85	4.80	4.75	4.25	0.025	0.315	12.39
6	3500	422	290	380	470	440	400	5.00	4.00	4.50	5.65	5.15	4.70	0.028	0.324	11.32

TABLE NO : 14.4

FUEL : REFERENCE

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	723	856	781	798	848	327.0	304.7	323.0
2	1500	740	867	793	812	863	328.6	305.8	324.9
3	2000	747	873	803	833	871	330.5	307.0	326.1
4	2500	753	892	837	841	883	333.0	309.5	329.1
5	3000	761	901	834	855	891	335.7	312.4	331.9
6	3500	772	910	853	867	900	338.6	316.8	335.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	365	250	330	400	380	350	4.34	2.85	3.75	4.80	4.75	4.05	0.019	0.239	12.85
2	1500	342	220	320	380	350	320	4.04	2.70	3.60	4.70	4.05	3.80	0.021	0.288	13.71
3	2000	355	210	320	380	370	350	4.32	3.65	3.65	4.75	4.75	4.15	0.019	0.268	14.02
4	2500	387	210	350	430	400	370	4.67	3.90	4.15	5.05	4.80	4.70	0.023	0.308	13.50
5	3000	405	250	390	420	410	400	4.84	4.15	4.65	4.95	4.95	4.80	0.026	0.331	12.92
6	3500	437	270	400	470	450	430	5.27	4.95	4.95	5.70	5.50	4.95	0.030	0.358	11.85

TABLE NO :15.1

FUEL :REFERENCE + ECA 4360
(100 ppm)

GEAR :1st

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	705	883	865	823	846	321.0	303.0	319.8
2	1500	723	896	872	845	860	322.9	304.7	321.2
3	2000	731	897	876	853	866	325.6	306.0	323.4
4	2500	744	905	888	857	873	328.5	308.2	326.0
5	3000	753	913	896	868	878	331.9	311.3	329.0
6	3500	754	920	703	873	891	335.8	314.7	332.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	285	200	250	270	320	300	3.41	4.35	3.00	3.25	3.95	3.45	0.017	0.230	13.69
2	1500	272	120	240	270	300	280	3.26	3.00	2.85	3.15	3.70	3.35	0.017	0.254	14.51
3	2000	280	140	240	280	310	290	3.34	3.50	2.90	3.30	3.75	3.40	0.017	0.252	13.90
4	2500	322	110	290	320	350	350	3.89	4.65	3.45	3.90	4.00	4.20	0.019	0.293	15.10
5	3000	312	130	280	300	340	330	3.71	4.25	3.30	3.60	3.95	4.00	0.022	0.322	14.50
6	3500	360	190	320	350	400	370	4.24	4.30	3.85	4.15	4.80	4.15	0.025	0.333	13.20

TABLE NO : 15.2

FUEL : REFERENCE + ECA 4360
(100 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	727	920	873	853	862	323.3	303.1	320.5
2	1500	752	933	905	873	890	325.4	304.9	323.0
3	2000	763	937	912	883	898	327.0	306.6	326.2
4	2500	773	945	916	889	907	329.7	308.5	328.0
5	3000	780	953	918	893	913	332.4	311.0	332.0
6	3500	785	957	927	900	919	336.7	316.5	337.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	267	160	200	280	300	290	3.06	3.50	2.40	3.30	3.45	3.40	0.017	0.246	14.05
2	1500	222	150	190	200	270	230	2.64	3.00	2.25	2.35	3.15	2.80	0.016	0.233	14.30
3	2000	280	110	240	290	300	290	3.37	3.70	2.90	3.55	3.55	3.50	0.018	0.274	14.80
4	2500	287	130	220	300	320	310	3.47	4.15	2.65	3.60	3.90	3.75	0.021	0.294	14.00
5	3000	300	160	210	300	380	310	3.62	4.70	2.65	3.60	4.55	3.80	0.024	0.329	13.60
6	3500	345	170	270	330	390	390	4.12	5.00	3.25	3.85	4.75	4.65	0.026	0.346	13.22

TABLE NO :15.3

FUEL : REFERENCE + ECA 4360
(100 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	733	927	908	866	873	323.7	302.7	320.0
2	1500	753	944	923	873	904	326.0	303.9	321.4
3	2000	764	951	930	886	913	328.1	305.7	323.8
4	2500	780	963	941	893	925	331.0	308.5	327.0
5	3000	785	972	947	904	933	334.1	312.0	331.3
6	3500	793	976	953	918	940	337.8	317.3	337.2

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	210	170	190	200	230	220	2.55	3.00	2.25	2.50	2.85	2.60	0.018	0.256	13.83
2	1500	197	170	170	190	230	200	2.40	2.85	2.00	2.30	2.85	2.45	0.017	0.241	13.94
3	2000	245	150	240	240	250	250	2.90	3.15	2.85	2.90	2.95	2.90	0.020	0.287	14.20
4	2500	245	120	200	230	290	260	2.91	3.50	2.40	2.75	3.45	3.05	0.022	0.324	14.45
5	3000	240	150	190	250	260	260	2.86	3.65	2.30	3.00	3.15	3.00	0.025	0.353	14.00
6	3500	260	170	220	270	280	270	3.10	4.00	2.60	3.25	3.40	3.15	0.028	0.369	13.28

TABLE NO : 15.4

FUEL : REFERENCE + ECA 4360
(100 ppm)

GEAR : 4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	748	943	923	905	919	324.3	304.3	322.0
2	1500	763	956	931	913	923	327.0	305.9	324.0
3	2000	771	973	943	920	930	329.4	306.0	324.9
4	2500	783	977	955	923	943	333.7	309.1	328.2
5	3000	791	983	963	927	951	338.0	313.0	334.0
6	3500	798	989	970	936	963	342.3	318.2	340.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	165	140	160	160	170	170	2.01	2.95	1.95	2.00	2.10	2.00	0.018	0.261	14.41
2	1500	167	110	150	160	200	160	1.95	2.40	1.80	1.90	2.35	1.85	0.016	0.246	15.00
3	2000	182	110	140	170	230	190	2.09	2.65	1.65	2.05	2.75	1.90	0.019	0.285	14.84
4	2500	212	100	150	200	250	250	2.52	3.00	1.75	2.40	3.00	2.95	0.023	0.354	15.25
5	3000	202	110	150	180	250	230	2.46	3.15	1.85	2.15	3.05	2.80	0.026	0.378	14.70
6	3500	252	140	200	240	290	280	3.07	4.00	2.45	2.95	3.50	3.40	0.029	0.400	13.79

TABLE NO : 16.1

FUEL : Reference F.71 (600 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	763	903	887	863	844	318.3	300.9	316.0
2	1500	789	912	893	877	853	320.4	302.8	319.7
3	2000	801	923	901	883	867	323.9	305.0	323.1
4	2500	808	930	905	888	873	327.5	308.6	327.8
5	3000	813	933	913	894	876	331.4	312.3	330.1
6	3500	821	938	920	903	883	336.0	317.4	335.6

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	207	150	170	190	220	250	2.50	3.50	2.05	2.30	2.65	3.00	0.019	0.265	13.90
2	1500	207	120	170	180	200	280	2.50	3.50	2.00	2.15	2.40	3.45	0.017	0.251	14.60
3	2000	202	110	160	180	210	260	2.44	3.15	1.95	2.20	2.55	3.05	0.016	0.246	15.00
4	2500	222	110	190	200	230	270	2.61	8.25	2.35	2.40	2.60	3.10	0.020	0.300	15.21
5	3000	242	140	200	230	240	300	2.85	3.70	2.40	2.80	2.60	3.60	0.022	0.312	13.92
6	3500	277	150	230	270	300	310	3.25	3.85	2.75	3.05	3.60	3.60	0.025	0.335	13.50

TABLE NO : 16.2

FUEL : REFERENCE + 600 ppm E.71

GEAR : 2nd

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	768	908	898	873	860	319.1	301.3	316.9
2	1500	783	921	911	886	868	321.8	303.9	320.0
3	2000	809	926	918	892	873	325.0	307.0	325.2
4	2500	816	937	932	903	877	328.9	310.9	328.8
5	3000	823	943	936	910	883	333.3	315.0	333.3
6	3500	833	951	941	922	888	337.8	319.7	337.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	187	150	170	180	200	200	2.24	3.15	2.00	2.15	2.35	2.45	0.020	0.277	13.70
2	1500	185	140	150	170	190	230	2.21	3.00	1.80	2.05	2.25	2.75	0.019	0.263	13.97
3	2000	215	110	200	210	220	230	2.57	2.75	2.40	2.55	2.65	2.70	0.019	0.280	14.58
4	2500	210	130	170	200	220	250	2.56	2.85	2.15	2.40	2.70	3.00	0.024	0.337	13.81
5	3000	230	140	190	230	240	260	2.77	3.20	2.25	2.75	2.95	3.15	0.028	0.370	13.40
6	3500	267	140	220	260	290	300	3.17	3.90	2.60	3.05	3.45	3.60	0.029	0.386	13.05

TABLE NO : 16.3

FUEL : REFERENCE + 600 ppm F.71

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	773	914	903	887	868	320.0	302.1	318.2
2	1500	789	936	916	893	879	323.1	305.5	321.8
3	2000	813	942	923	908	883	327.8	309.0	326.2
4	2500	830	948	941	923	905	330.5	312.8	330.3
5	3000	837	957	948	929	923	334.4	317.7	335.6
6	3500	845	963	956	938	931	338.5	322.9	342.8

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	190	140	180	190	190	200	2.22	3.00	2.10	2.25	2.30	2.45	0.021	0.320	14.03
2	1500	170	130	150	170	180	180	1.96	2.85	1.80	2.00	2.05	2.00	0.019	0.279	14.45
3	2000	185	120	160	170	200	210	2.21	2.90	1.95	1.95	2.40	2.55	0.020	0.294	14.70
4	2500	190	100	180	190	190	200	2.21	2.30	1.90	2.30	2.25	2.40	0.023	0.348	15.40
5	3000	182	130	170	180	190	190	2.22	2.30	2.05	2.25	2.25	2.35	0.026	0.365	14.12
6	3500	230	140	200	230	240	250	2.79	3.25	2.35	2.85	2.80	3.15	0.029	0.398	13.55

TABLE NO : 16.4

FUEL : REFERENCE + 600 ppm F.71

GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	773	823	915	903	873	320.9	292.8	309.7
2	1500	816	848	933	912	880	323.0	305.7	310.8
3	2000	843	956	945	918	888	326.1	308.8	326.6
4	2500	851	963	960	923	893	329.7	313.0	331.2
5	3000	855	968	964	930	900	333.4	318.3	336.8
6	3500	863	973	967	943	912	337.9	334.0	343.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	175	110	170	170	180	180	2.07	2.55	2.00	1.95	2.15	2.20	0.022	0.330	14.04
2	1500	142	100	120	130	150	170	1.69	2.30	1.40	1.55	1.85	1.95	0.016	0.253	15.90
3	2000	157	60	150	150	160	170	1.91	2.00	1.85	1.75	2.00	2.05	0.018	0.300	16.30
4	2500	160	60	140	160	170	170	1.96	2.10	1.75	1.95	2.00	2.15	0.021	0.338	16.09
5	3000	182	80	160	180	190	200	2.11	2.30	1.95	1.90	2.15	2.45	0.025	0.383	15.20
6	3500	215	100	190	200	230	240	2.60	2.75	2.25	2.40	2.75	3.00	0.028	0.405	14.35

TABLE NO : 17.1

FUEL : REFERENCE + ECA 1140
(500 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	684	725	713	673	664	321.3	304.0	319.1
2	1500	703	738	726	707	674	322.9	304.9	320.8
3	2000	708	743	732	713	682	324.8	306.1	322.7
4	2500	711	748	757	724	691	327.0	308.9	325.5
5	3000	717	752	742	731	698	330.8	312.0	329.3
6	3500	723	760	748	739	703	333.9	316.5	334.2

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	327	230	300	300	350	360	3.91	5.00	3.55	3.65	4.15	4.30	0.018	0.222	12.00
2	1500	297	200	250	290	300	350	3.46	4.55	3.00	3.30	3.45	4.10	0.019	0.245	12.75
3	2000	295	200	250	280	300	350	3.59	4.20	3.05	3.45	3.65	4.20	0.018	0.226	12.50
4	2500	332	240	300	330	340	360	3.99	4.25	3.55	3.95	4.00	4.45	0.021	0.249	11.95
5	3000	347	270	300	360	360	370	4.19	4.75	3.60	4.25	4.30	4.60	0.025	0.288	11.42
6	3500	367	290	330	350	380	410	4.45	5.35	4.00	4.20	4.65	4.95	0.029	0.323	11.21

TABLE NO : 17.2

FUEL : REFERENCE + ECA 1140
(500 ppm)

GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	690	743	735	718	673	321.7	304.7	320.2
2	1500	706	758	753	733	676	323.8	305.1	321.9
3	2000	713	763	757	742	693	325.9	307.0	322.9
4	2500	724	767	763	748	702	328.1	309.7	326.8
5	3000	730	773	765	755	708	331.0	313.3	330.9
6	3500	738	783	773	760	726	335.6	317.7	336.0

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	295	240	260	280	300	340	3.49	4.95	2.95	3.35	3.50	4.15	0.020	0.233	11.70
2	1500	279	240	250	250	280	340	3.19	4.85	2.65	2.95	3.15	4.00	0.021	0.250	12.12
3	2000	285	200	250	290	290	310	3.40	4.65	3.00	3.35	3.50	3.75	0.018	0.234	12.71
4	2500	310	180	270	300	320	350	3.71	4.00	3.25	3.70	3.85	4.05	0.020	0.270	13.36
5	3000	350	200	300	350	350	400	4.25	3.85	3.60	4.20	4.25	4.95	0.025	0.312	12.48
6	3500	372	230	310	370	400	410	4.49	6.00	3.65	4.35	4.80	5.15	0.027	0.321	11.98

TABLE NO :17.3

FUEL: REFERENCE + ECA 1140
(500 ppm)

GEAR :3rd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	703	748	737	722	688	322.3	305.0	321.7
2	1500	722	766	763	738	705	324.7	306.9	322.8
3	2000	736	773	768	744	713	326.0	308.7	324.0
4	2500	743	781	773	753	719	329.9	310.9	328.3
5	3000	751	797	776	768	733	332.5	314.6	332.1
6	3500	757	803	783	774	744	336.8	318.9	337.7

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	295	220	260	290	310	320	3.32	4.25	3.15	3.45	3.60	3.70	0.023	0.280	12.28
2	1500	245	200	240	240	250	250	2.82	4.00	2.75	2.60	3.00	2.95	0.019	0.254	13.01
3	2000	257	190	250	260	260	260	3.10	3.10	3.00	3.15	3.10	3.15	0.022	0.294	13.42
4	2500	290	170	220	290	300	350	3.45	3.35	2.65	3.50	3.55	4.10	0.023	0.322	14.00
5	3000	280	200	240	290	290	300	3.31	4.00	2.70	3.55	3.45	3.55	0.029	0.370	12.90
6	3500	312	210	280	310	320	340	3.79	5.00	3.35	3.75	3.85	4.20	0.032	0.396	12.45

TABLE NO :17.4

FUEL : REFERENCE + ECA 1140
(500 ppm)

GEAR :4th

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	711	763	746	728	694	322.5	303.3	320.0
2	1500	723	776	768	751	713	325.1	305.8	323.0
3	2000	743	783	773	763	727	327.8	306.4	326.6
4	2500	756	790	780	770	733	330.9	309.7	328.9
5	3000	763	800	783	777	742	333.8	314.9	333.0
6	3500	771	803	786	783	753	337.1	320.2	338.4

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	270	220	220	260	300	300	3.24	3.75	2.65	3.15	3.50	3.65	0.024	0.295	12.50
2	1500	240	160	200	230	260	270	2.89	3.25	2.35	2.90	3.05	3.25	0.019	0.270	14.35
3	2000	227	180	200	220	240	250	2.72	2.90	2.15	2.85	2.90	3.00	0.022	0.298	13.65
4	2500	252	190	210	250	250	300	3.04	3.70	2.40	3.00	3.05	3.70	0.025	0.330	13.20
5	3000	267	180	220	260	270	320	3.10	3.90	2.20	3.05	3.30	3.85	0.028	0.377	13.36
6	3500	292	210	240	300	300	330	3.54	5.00	2.85	3.60	3.70	4.00	0.034	0.410	12.20

TABLE NO : 18.1

FUEL : REFERENCE + ECA 1030 (100 ppm)

GEAR : 1st

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	671	773	756	793	753	321.0	303.2	318.4
2	1500	690	795	773	808	760	322.3	305.7	321.5
3	2000	693	799	786	813	773	323.7	307.5	323.3
4	2500	700	803	798	832	782	325.3	310.8	326.9
5	3000	708	816	804	837	796	327.9	315.0	332.3
6	3500	713	823	813	848	800	331.0	318.7	335.5

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	422	300	430	450	380	450	5.10	5.45	5.05	5.40	4.55	5.40	0.023	0.260	11.30
2	1500	402	260	400	400	390	420	4.75	5.25	4.80	4.65	4.55	5.00	0.019	0.235	12.15
3	2000	432	260	440	440	400	450	5.22	5.60	5.35	5.15	4.95	5.45	0.022	0.273	12.30
4	2500	445	300	470	470	360	480	5.21	5.80	5.50	5.55	4.05	5.75	0.028	0.310	10.99
5	3000	445	280	460	470	380	470	5.39	5.95	5.50	5.70	4.60	5.75	0.029	0.338	11.72
6	3500	472	300	470	490	430	500	5.71	6.15	5.75	5.85	5.25	6.00	0.035	0.378	10.80

TABLE NO : 18.2

FUEL : REFERENCE + ECA1030
(100 ppm)
GEAR : 2nd

No.	Engine Rev. RPM	Temperature ^{o}K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	673	786	773	798	760	322.1	304.1	319.6
2	1500	693	803	790	813	773	323.7	305.8	321.6
3	2000	697	818	793	833	786	325.6	308.3	324.4
4	2500	708	823	802	837	793	327.8	311.5	329.2
5	3000	723	838	808	851	803	330.9	315.0	333.2
6	3500	730	843	817	863	807	335.0	319.7	338.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	392	300	380	400	370	420	4.72	5.25	4.65	4.75	4.45	5.05	0.024	0.281	11.60
2	1500	350	260	320	380	300	400	4.15	5.00	3.85	4.50	3.50	4.75	0.021	0.258	12.52
3	2000	345	280	310	380	310	380	4.20	4.85	3.75	4.60	3.75	4.70	0.023	0.281	12.11
4	2500	407	230	400	430	350	450	4.90	5.30	4.95	5.20	4.20	5.25	0.027	0.350	12.95
5	3000	405	220	390	440	350	440	4.86	5.30	4.65	5.25	4.25	5.30	0.029	0.383	13.12
6	3500	432	250	430	450	380	470	5.11	5.35	5.15	5.30	4.55	5.45	0.032	0.400	12.55

TABLE NO : 18.3

FUEL : REFERENCE + ECA1030
(100 ppm)

GEAR : 3rd

No.	Engine Rev. RPM	Temperature ^oK							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	688	793	786	810	773	322.7	305.0	320.8
2	1500	698	804	793	821	788	324.4	307.1	323.3
3	2000	709	821	800	843	793	327.3	309.9	326.8
4	2500	723	835	808	845	797	331.2	312.8	329.9
5	3000	732	843	822	863	803	335.2	315.1	333.6
6	3500	738	860	843	873	815	340.0	319.9	337.3

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	387	270	380	390	380	400	4.64	5.15	4.55	4.65	4.55	4.80	0.024	0.303	12.42
2	1500	355	270	360	350	350	360	4.24	5.00	4.15	4.30	4.10	4.40	0.023	0.282	12.20
3	2000	337	250	330	340	330	350	4.07	4.20	3.95	4.10	4.05	4.20	0.024	0.306	12.72
4	2500	347	190	340	350	300	400	4.20	4.60	4.05	4.25	3.65	4.85	0.026	0.337	13.05
5	3000	370	210	360	370	310	440	4.49	5.55	4.35	4.50	3.70	5.40	0.030	0.389	12.45
6	3500	447	240	400	400	320	470	4.87	6.05	4.85	4.95	3.80	5.90	0.033	0.394	11.92

TABLE NO : 18.4

FUEL : REFERENCE + ECA 1030
(100 ppm)
GEAR : 4th

No.	Engine Rev. RPM	Temperature °K							
		Ex	CY1	CY2	CY3	CY4	Sump Oil	Water In	Water Out
1	1000	700	814	798	823	783	322.6	305.5	321.7
2	1500	713	830	813	843	796	325.4	308.0	324.9
3	2000	721	836	818	848	803	327.9	311.0	327.9
4	2500	734	843	826	858	810	332.1	314.2	330.0
5	3000	751	847	833	871	813	335.0	317.9	335.1
6	3500	762	868	846	883	828	341.9	321.2	338.9

No.	Engine Rev. RPM	Hydrocarbons (ppm.)						Carbonmonoxide (%)						Fuel Flow Rate Kg/Sec	Air Flow Rate Kg/Sec	Air/ Fuel Ratio
		Ave	Exh	CY1	CY2	CY3	CY4	Ave	Exh	CY1	CY2	CY3	CY4			
1	1000	332	240	330	340	320	340	3.97	4.30	3.95	4.10	3.85	4.00	0.025	0.329	13.04
2	1500	300	200	290	300	280	330	3.44	4.00	3.30	3.45	3.35	3.65	0.021	0.290	13.48
3	2000	327	220	330	330	300	350	4.02	4.15	4.05	4.10	3.70	4.25	0.025	0.335	13.22
4	2500	337	180	340	350	310	350	4.11	4.35	4.15	4.20	3.85	4.25	0.026	0.356	13.90
5	3000	360	160	370	390	280	400	4.41	4.90	4.45	4.65	3.65	4.90	0.026	0.373	14.41
6	3500	397	230	400	410	340	440	4.77	5.35	4.85	4.95	4.00	5.20	0.031	0.410	13.10

Table No. 21:1. The influence of air/fuel ratios on the concentrations of hydrocarbons and carbon monoxide emitted. (Fuel = Esso Plus, Engine Speed = 2500, Load = 28.89)

Air/Fuel ratio	Hydrocarbons (ppm)	Carbon monoxide (%)
10.10	452	5.17
10.40	425	4.62
10.55	405	4.25
10.70	392	4.00
10.85	375	3.70
11.10	360	3.37
11.30	350	3.10
11.50	337	2.90
11.65	315	2.75
11.95	305	2.55
12.00	297	2.37
12.25	285	2.30
12.40	275	2.12
12.50	277	2.00
12.75	262	1.80
12.90	260	1.75
13.10	250	1.65
13.25	240	1.45
13.50	235	1.30
13.65	230	1.15
13.95	210	0.85
14.30	210	0.92
14.50	202	0.70
14.75	198	0.70
15.05	200	0.68
15.25	195	0.50
15.60	205	0.50
16.00	207	0.40
16.15	213	0.43
16.35	225	0.37
16.50	238	0.37
16.70	245	0.37
17.00	260	0.37
17.15	270	0.37

Table No. 21:2. The influence of air/fuel ratios on the concentrations of hydrocarbons and carbon monoxide emitted. (Fuel = Esso Plus + F.71 - 600 ppm, Engine Speed + 2500, Load = 28.89)

Air/Fuel ratio	Hydrocarbons (ppm)	Carbon monoxide (%)
10.00	400	5.10
10.10	390	4.87
10.25	380	4.78
10.40	355	4.25
10.65	345	4.13
10.75	325	4.00
10.90	290	3.62
11.10	295	3.45
11.25	292	3.33
11.40	277	3.25
11.50	260	2.88
11.90	240	2.67
12.00	230	2.53
12.30	210	2.50
12.40	207	2.25
12.75	177	2.00
12.90	170	1.78
13.00	165	1.65
13.25	157	1.45
13.50	143	1.33
13.65	135	1.27
13.75	130	1.15
13.95	120	1.00
14.05	117	0.97
14.45	112	0.90
14.75	105	0.80
14.95	115	0.70
15.15	90	0.70
15.40	93	0.70
15.75	93	0.67
15.90	88	0.63
16.15	90	0.70
16.45	90	0.75
16.75	93	0.85
17.00	100	0.90
17.20	100	0.95
17.35	105	1.03

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	44.7	42.8	43.7	44.4	52.6	54.3	56.3	55.6	28.9	28.6	28.1	18.5	18.4	8.6	12.5	18.5
1500	57.6	44.8	29.2	42.1	66.7	65.5	62.5	52.6	27.3	24.1	16.7	5.3	12.1	3.4	-8.3	10.5
2000	40.0	37.0	10.0	33.3	70.0	66.7	65.0	66.7	13.3	29.6	00.0	-11.1	00.0	00.0	00.0	5.6
2500	61.8	51.7	40.0	57.1	67.6	58.6	56.0	57.1	26.5	27.6	16.0	14.3	8.8	13.8	16.0	4.8
3000	43.3	28.0	9.1	31.6	50.0	48.0	50.0	47.4	6.7	12.0	-9.1	-10.5	00.0	00.0	-13.6	5.3
3500	45.9	33.3	16.0	31.8	56.8	53.3	52.0	45.5	21.6	6.7	-4.0	-9.1	13.5	6.7	-8.0	-4.5

Table 19:1. Percentage reductions or increase in Hydrocarbon emissions from mixed exhaust for best quantities of various additives used with Esso Plus.

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	35.7	45.0	42.9	48.4	47.6	50.0	42.9	41.9	28.6	30.0	20.0	12.9	-2.4	-2.5	-14.3	-16.1
1500	24.3	16.7	28.0	00.0	45.9	40.0	32.0	10.0	27.0	10.0	-16.0	-25.0	0.0	-16.7	-60.0	-75.0
2000	28.6	25.6	13.8	33.3	54.7	48.7	31.0	19.0	26.2	23.1	3.4	-33.3	2.4	0.0	-48.3	-71.4
2500	9.1	23.1	25.8	13.8	47.7	43.6	38.7	27.6	22.7	15.4	0.0	-6.9	2.3	-2.6	-45.2	-37.9
3000	28.6	37.5	27.3	50.0	40.5	40.0	36.4	25.0	16.7	12.5	3.0	-14.3	0.0	0.0	-27.3	-57.1
3500	33.3	31.1	28.2	23.5	47.1	42.2	38.5	32.4	27.5	17.8	12.8	-5.9	11.8	-4.4	-20.5	-38.2

Table 19:2. Percentage reductions or increase in Hydrocarbon emissions from best cylinders for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	33.3	42.0	44.4	51.3	47.1	48.0	44.4	43.6	25.5	26.0	22.2	20.5	2.0	8.0	2.2	-2.6
1500	33.3	25.6	20.6	17.2	57.4	35.9	38.2	27.6	35.2	12.8	2.9	0.0	11.1	-23.1	-23.5	-44.8
2000	20.0	21.9	2.9	3.6	54.0	34.1	29.4	17.9	26.0	14.6	-2.9	-10.7	4.0	-17.1	-32.4	-60.7
2500	32.3	33.3	33.3	31.4	60.0	51.7	52.6	49.0	40.0	36.7	31.6	33.3	21.5	16.7	17.5	9.8
3000	24.5	33.3	24.3	21.9	47.2	31.1	21.6	25.0	22.6	11.1	-5.4	-6.3	5.7	-13.3	-29.3	-46.9
3500	25.4	34.6	29.8	29.3	50.8	36.5	34.0	34.1	23.7	17.3	10.6	2.4	10.2	-7.7	-14.9	-26.8

Table 19:3. Percentage reductions or increase in Hydrocarbon emission from worst cylinders for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	36.5	44.9	37.7	50.1	52.1	48.0	44.3	45.6	32.9	30.3	20.3	16.6	4.2	0.5	-6.8	-12.2
1500	25.3	20.5	27.1	8.7	52.3	38.4	31.5	20.2	30.8	12.6	-7.2	-15.8	1.8	-21.9	-40.9	-60.6
2000	25.1	24.7	4.4	8.1	54.6	43.2	31.5	18.0	27.2	22.3	1.6	-16.3	5.8	-9.9	-36.6	-64.1
2500	19.9	18.9	20.4	19.5	50.8	44.2	20.8	40.9	31.5	22.2	11.5	16.1	8.7	-1.8	-16.1	-14.6
3000	20.8	32.9	26.6	33.4	38.1	38.8	30.4	25.3	13.9	12.4	-2.0	-5.5	-8.6	-11.9	-26.6	-47.2
3500	24.3	33.1	29.4	26.7	47.1	40.2	36.9	32.8	24.3	18.6	16.5	0.2	7.1	-4.1	-19.2	-26.6

Table 19:4. Percentage reductions or increase in Hydrocarbon emissions for averages for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	9.7	23.1	15.6	9.1	-9.7	-1.5	6.3	16.7	-53.2	-44.6	-40.6	-46.0	-109.7	-95.4	-90.6	-60.6
1500	15.9	33.8	23.3	23.6	-1.6	15.5	34.2	25.0	-50.8	-19.7	-16.4	-37.5	-90.5	-78.9	-57.5	-54.2
2000	14.1	21.3	27.4	21.1	6.3	-3.3	17.8	27.6	-54.7	-39.3	-19.2	-22.4	-82.8	-104.9	-57.5	-31.6
2500	-3.3	12.5	26.1	27.1	-1.7	2.8	7.2	0.0	-75.0	-23.6	-30.4	-40.8	-100.0	-69.4	-71.0	-47.1
3000	6.9	4.4	15.7	23.0	-13.8	0.0	-1.4	6.8	-81.0	-42.6	-40	-37.5	-120.7	-86.8	-71.4	-59.5
3500	-7.7	4.8	10.1	18.1	-51.9	-30.2	-15.9	-2.8	-111.5	-69.8	-65.2	-97.3	-150.0	-119.0	-95.7	-80.6

Table 19:5. Percentage reductions or increase in Carbon monoxide emissions from mixed exhaust for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	20.0	22.8	7.7	-1.9	-6.0	15.8	7.7	15.1	-44.0	-22.8	-38.5	-26.4	-106.0	-73.7	-84.6	-64.2
1500	10.9	-2.3	19.3	-4.3	-4.3	6.8	28.1	-6.4	-45.7	-47.7	-31.6	-42.6	-95.7	-90.9	-57.9	-72.3
2000	15.7	16.7	35.6	28.6	-9.8	0.0	6.8	19.0	-54.9	-56.3	-22.0	-11.1	-94.1	-77.1	-69.5	-41.3
2500	-15.6	-2.4	25.5	15.9	-20.0	-26.2	-12.8	-9.1	-80.0	-92.9	-72.3	-75.0	-133.3	-114.3	-112.8	-118.2
3000	11.3	23.2	19.6	19.7	-13.2	5.4	8.9	18.0	-64.2	-55.4	-55.4	-26.2	-107.5	-71.4	-105.4	-72.1
3500	2.1	11.1	16.7	14.9	-45.8	-44.4	-16.7	-17.0	-97.9	-111.1	-97.9	-91.5	-147.9	-151.1	-135.4	-140.4

Table 19:6. Percentage reductions or increase in Carbon monoxide emissions from best cylinders for best quantities of various additives used with Esso Plus.

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	18.1	26.1	3.6	8.1	15.3	5.8	-7.3	22.6	-26.4	-30.4	-52.7	-21.0	-66.7	-66.7	-90.9	-54.8
1500	0.0	32.9	23.6	25.4	-12.3	15.7	33.3	28.2	-66.7	-15.7	-18.1	1.4	-103.5	-78.6	-45.8	-42.3
2000	8.6	24.1	35.7	17.1	-1.7	-8.6	14.3	21.4	-55.2	-44.8	-28.6	-7.1	-106.9	-100.0	-54.3	-54.3
2500	14.3	-5.4	18.3	23.8	14.3	-25.0	-5.0	-3.2	-42.9	-62.5	-58.3	-28.6	-75.7	-114.3	-100.0	-82.5
3000	6.9	4.8	15.5	15.9	-13.8	-6.3	-20.7	11.1	-70.7	-52.4	-72.4	-28.6	-115.7	-106.3	-100.0	-90.5
3500	3.5	8.3	16.7	20.3	-33.3	-31.7	-38.9	-6.8	-89.5	-75.0	-103.7	-62.7	-112.8	-125.0	-140.7	-111.9

Table 19:7. Percentage reductions or increase in Carbon monoxide emissions from worst cylinders for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	23.0	21.5	5.7	4.5	7.5	9.8	-2.0	20.1	-26.9	-21.8	-41.2	-20.3	-82.6	-75.9	-89.5	-61.1
1500	16.5	21.8	23.1	12.4	4.4	15.3	30.6	15.8	-38.4	-19.4	-13.5	-14.1	-87.0	-74.8	-50.2	-59.8
2000	12.8	21.6	34.0	26.9	-7.7	-1.5	12.6	24.4	-49.1	-41.5	-23.0	-4.5	-96.7	-94.1	-66.7	-48.2
2500	-3.0	-0.8	26.0	27.5	-12.8	-17.3	-4.7	5.3	-61.3	-56.5	-51.3	-35.2	-116.5	-109.2	-98.6	-110.2
3000	5.9	17.3	17.9	18.7	-18.5	1.7	-2.5	11.8	-66.1	-51.2	-52.3	-27.1	-114.0	-96.6	-97.2	-79.6
3500	3.9	16.7	17.5	17.5	-38.8	-32.8	-21.4	-12.9	-86.9	-84.5	-87.2	-73.6	-135.0	-130.6	-140.9	-125.9

Table 19:8. Percentage reductions or increase in Carbon monoxide emissions for averages for best quantities of various additives used with Esso Plus

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	33.3	42.9	37.0	44.0	50.0	46.4	48.1	56.0	23.3	14.3	18.5	12.0	0.0	-7.1	0.0	4.0
1500	52.0	40.0	26.1	50.0	52.0	44.0	43.5	54.4	20.0	4.0	13.0	27.3	-4.0	-4.0	-17.4	9.1
2000	50.0	56.0	40.0	47.6	60.7	56.0	52.0	71.4	28.6	20.0	24.0	14.3	7.1	-12.0	0.0	-4.8
2500	57.7	51.9	42.9	52.4	57.7	51.9	52.4	71.4	7.7	33.3	19.0	9.5	-15.4	14.8	9.5	14.3
3000	55.2	42.9	40.0	56.0	51.7	50.0	48.0	68.0	6.9	28.6	20.0	28.0	3.4	21.4	16.0	36.0
3500	38.7	43.3	41.4	48.1	51.6	53.3	51.7	63.0	6.5	23.3	27.6	22.2	3.2	16.7	17.2	14.8

Table 20:1. Percentage reductions or increase in Hydrocarbon emissions from mixed exhaust for best quantities of additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	30.6	42.9	45.7	51.5	52.8	51.4	48.6	48.5	16.7	25.7	25.7	33.3	-5.6	-5.7	-8.6	3.0
1500	22.6	36.7	48.5	53.1	45.2	50.0	54.5	62.5	19.4	16.7	27.3	37.5	-25.8	0.0	-6.1	12.5
2000	27.3	25.0	25.0	56.3	51.5	37.5	50.0	53.1	24.2	21.9	21.9	37.5	-21.2	3.1	-3.1	6.3
2500	17.1	31.3	33.3	57.1	45.7	46.9	40.0	60.0	14.3	15.6	26.7	40.0	-2.9	-9.4	0.0	11.4
3000	26.3	41.7	42.4	61.5	47.4	47.2	48.5	59.0	21.1	16.7	27.3	43.6	0.0	2.8	6.1	28.2
3500	20.0	32.5	42.1	50.0	42.5	45.0	47.4	52.5	17.5	22.5	26.3	40.0	-7.5	5.0	15.8	15.0

Table 20:2. Percentage reductions or increase in Hydrocarbon emissions from best cylinders for best quantities of additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	20.0	23.1	42.5	57.5	37.5	48.7	50.0	55.0	10.0	12.8	20.0	25.0	-12.5	-7.7	0.0	15.0
1500	30.2	32.5	39.5	47.4	34.9	42.5	52.6	55.3	18.6	15.0	34.2	28.9	2.3	0.0	5.3	13.2
2000	27.9	21.1	32.4	39.5	39.5	39.5	43.2	55.3	18.6	18.4	29.7	34.2	-4.7	0.0	5.4	7.9
2500	22.2	20.0	34.1	41.9	40.0	37.5	54.5	60.5	20.0	12.5	20.5	30.2	-6.7	-12.5	9.1	18.6
3000	26.1	13.6	35.0	40.5	34.8	40.9	52.5	52.4	19.6	9.1	25.0	23.8	-2.2	0.0	-10.0	4.8
3500	21.6	13.3	40.4	38.3	39.2	33.3	46.8	48.9	19.6	8.9	27.7	29.8	2.0	-4.4	0.0	6.4

Table 20:3. Percentage reductions or increase in Hydrocarbon emissions from worst cylinders for best quantities of additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	25.0	27.8	43.2	54.8	45.5	49.5	48.6	52.1	13.9	20.3	20.3	26.0	-11.1	-5.9	-4.6	9.0
1500	25.9	37.5	44.5	51.2	43.6	47.9	52.1	58.5	19.1	21.4	31.0	29.8	-9.5	1.4	0.0	12.3
2000	23.9	18.8	29.0	48.7	44.7	37.7	46.4	55.8	19.2	17.4	25.5	36.1	-18.4	0.0	2.3	7.9
2500	18.9	13.6	31.9	45.2	44.1	36.7	47.2	58.7	16.4	6.6	19.4	34.9	-12.1	-22.6	3.6	12.9
3000	24.3	22.5	36.0	50.1	41.3	36.7	51.5	55.1	15.8	9.6	25.3	34.1	-8.0	-4.7	1.3	11.1
3500	19.5	19.2	38.4	42.3	38.0	37.5	45.5	50.8	17.9	12.9	26.1	33.2	-5.6	-1.2	-5.9	9.2

Table 20:4. Percentage reductions or increase in Hydrocarbon emissions for averages for best quantities of additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	16.8	26.6	40.6	56.3	36.8	47.9	49.0	54.2	9.5	11.7	22.9	24.0	-13.7	6.9	0.0	16.7
1500	26.0	34.4	38.7	50.0	31.0	42.7	57.0	58.5	18.0	16.7	36.6	30.9	0.0	1.0	5.4	22.3
2000	27.2	23.7	34.4	42.1	40.8	41.9	43.3	56.8	18.4	19.4	30.0	36.8	-5.8	-1.1	6.7	10.5
2500	25.2	17.0	33.0	40.6	42.1	36.2	53.4	57.4	16.8	13.8	20.4	26.8	-7.5	-11.7	5.8	15.8
3000	26.1	8.1	34.4	38.4	32.7	36.4	51.0	50.5	14.0	0.0	26.0	22.2	-7.5	-7.1	-12.5	1.0
3500	20.0	9.5	39.8	38.6	40.0	31.4	44.2	47.4	17.5	1.9	25.7	29.8	0.0	-3.8	-4.4	8.8

Table 20:5. Percentage reductions or increase in Carbon monoxide emissions from worst cylinders for best quantities of various additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360 GEAR				F71 GEAR				ECA 1140 GEAR				ECA 1030 GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	24.1	31.2	42.8	53.7	44.3	49.7	50.2	52.3	12.9	21.6	25.6	25.3	-13.6	-6.1	-4.0	8.5
1500	25.1	37.4	43.7	51.7	42.5	47.6	54.0	58.2	20.5	24.4	33.8	26.5	-9.2	1.7	— 0.5	14.9
2000	18.5	19.2	30.0	51.6	40.5	38.4	46.6	55.8	12.4	18.5	25.1	37.0	-27.3	-0.7	1.7	6.9
2500	18.3	13.0	31.9	46.0	45.2	35.8	48.2	58.0	16.2	7.0	19.2	34.9	-9.5	-22.8	1.6	12.0
3000	23.8	19.7	35.1	49.2	41.5	38.6	49.7	56.4	14.0	5.8	24.9	36.0	-10.7	-7.8	-1.8	8.9
3500	20.9	17.9	38.0	41.7	39.4	36.9	44.2	50.7	17.0	10.6	24.2	32.8	-6.5	-1.8	2.6	9.5

Table 20:6. Percentage reductions or increase in carbon monoxide emissions for averages for best quantities of various additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	-19.2	-6.1	0.0	-3.5	4.1	4.5	0.0	10.5	-37.0	-50.0	-41.7	-31.6	-49.3	-59.1	-71.7	-50.9
1500	4.8	0.0	-7.5	11.1	-11.1	0.0	-7.5	14.8	-44.4	-61.7	-50.9	-20.4	-66.7	-66.7	-88.7	-48.1
2000	-4.5	-17.5	6.0	27.4	6.0	12.7	13.4	45.2	-25.4	-47.6	7.5	20.5	-67.2	-54.0	-25.4	-13.7
2500	-31.0	-20.3	6.7	23.1	8.5	17.4	38.7	46.2	-19.7	-15.9	10.7	5.1	-63.4	-53.6	-22.7	-11.5
3000	-19.7	-32.4	6.4	24.1	-4.2	9.9	41.0	44.6	-33.8	-8.5	-2.7	6.0	-67.6	-49.3	-42.3	-18.1
3500	-14.7	-37.0	0.0	19.2	-2.7	-6.8	18.8	44.4	-42.7	-64.4	-25.0	-1.0	-64.0	-46.6	-51.3	-8.1

Table 20:7. Percentage reductions or increase in Carbon monoxide emissionsfrom exhaust for best quantities of various additives used with Reference Gasoline

Engine Speed R.P.M.	ECA 4360				F71				ECA 1140				ECA 1030			
	GEAR				GEAR				GEAR				GEAR			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1000	31.0	42.9	45.8	48.0	52.9	52.4	49.4	46.7	18.4	29.8	24.1	29.3	-4.6	-6.0	-9.6	-2.7
1500	23.0	37.5	48.7	50.0	45.9	50.0	53.8	61.1	18.9	26.4	29.5	34.7	-23.0	2.8	-5.1	6.9
2000	24.7	24.7	25.0	54.8	49.4	37.7	48.7	49.3	20.8	22.1	21.1	41.1	-28.6	2.6	-6.6	-1.4
2500	17.9	32.1	34.2	57.8	44.0	44.9	47.9	57.8	15.5	16.7	27.4	42.2	3.6	-7.7	0.0	7.2
3000	27.5	36.1	40.3	60.2	47.3	45.8	46.8	58.1	20.9	13.3	29.9	52.7	-1.1	-2.4	3.9	21.5
3500	19.8	31.6	42.2	50.5	42.7	45.3	47.8	54.5	16.7	23.2	25.6	42.4	-9.4	4.2	15.6	19.2

Table 20:8. Percentage reductions or increase in Carbon monoxide emissions from best cylinders for best quantities of various additives used with Reference Gasoline