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PROSPECTS FOR THE REDUCTION OF NOXIOUS EMISSIONS FROM DIESEL VEHICLES AND THE ROLE OF ALTERNATIVE FUELS AND POWER SOURCES

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While there has been for many years concern about the emission of nitrogen oxides from diesel engines used in underground mines, it is only relatively recently that the attention which was paid from the early nineteen sixties, initially in California, into exhaust emissions from gasoline engined cars has widened to encompass diesel powered trucks and buses. Exhaust smoke has of course been the subject of legislation for a longer period and this certainly could be called a noxious emission in the quantities which were at one time encountered!

In order to prevent the production of excessive smoke, diesel engines operate under lean conditions and therefore produce low levels of carbon monoxide in their exhaust. In fact a well designed and maintained diesel engine emits lower levels of carbon monoxide and of hydrocarbons than does an uncontrolled gasoline engine. The natural levels of oxides of nitrogen are similar for the two but, due to the heterogeneous nature of diesel combustion, diesels produce particulate material in the exhaust, even when there is no visible trace.

Later papers in the Programme will describe in more detail the steps which can be taken to meet very low levels of diesel exhaust gas legislation but it has to be said that intensive work carried out by the whole engine and component industry over the past few years has produced engines with very much lower levels of pollution than until recently seemed possible.

HEAVY DUTY DIESEL ENGINES

In general this work has indicated the need for lower levels of air swirl in direct injection diesel engines; much higher injection pressures, up to and perhaps exceeding 1200 bar; larger diameter and shallower combustion chamber bowls; higher compression ratios to enable injection timing retard to be carried out without the introduction of misfire with consequent high hydrocarbon levels; and the desirability for using rate shaping of the fuel injection with a very sophisticated map of such timing with both load and speed. Variable geometry turbocharging to reduce emissions under peak torque conditions may be essential to achieve very low limits and in fact, turbocharging and intercooling is probably essential for all low emission heavy duty engines.

The most difficult pollutants to control in a diesel engine are oxides of nitrogen and exhaust particulates. NOx is largely nitric oxide, NO, but with some NO_2, which can give a brown coloration to the exhaust. The particulates are more difficult to define but the average of typical analyses for heavy duty truck engines driven over the U.S. heavy duty test cycle is given in Figure 1.

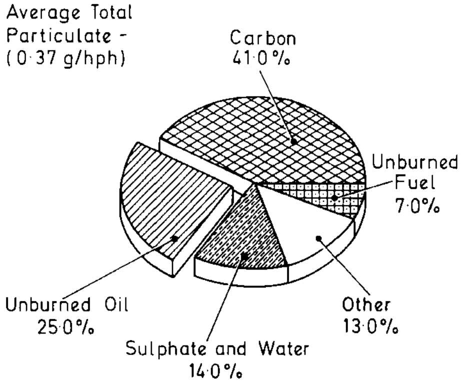

Fig. 1 Typical FTP Particulate Composition [Average of 16 Heavy Duty, TCA DI Engines]

The sulphates come from the sulphur in the fuel and can only be reduced by essentially desulphurising the fuel. In fact if a catalysed particulate trap is fitted into the exhaust, much more of the sulphur is oxidised to SO_3 and appears as increased sulphuric acid in the test, giving yet higher sulphates and hence higher total particulates. The burnt oil is emitted under lighter load conditions when oil, which enters the combustion chamber, is not burnt and can only be reduced by reducing the total engine oil consumption. The "Other" material will contain lubricating oil additives.

At present the U.S. 1991/4 standards are the most stringent worldwide. Currently standards similar to U.S. 1991 are being proposed and discussed in Europe for the mid-90's with the distinct possibility that more stringent standards could follow.

Figure 2 shows the U.S. emission legislation limits, in so far a they concern NOx and particulates together with the band of experimental data produced for the best 1988 natural aspirated and turbocharged engines. The positive effect of turbocharging is clearly indicated.

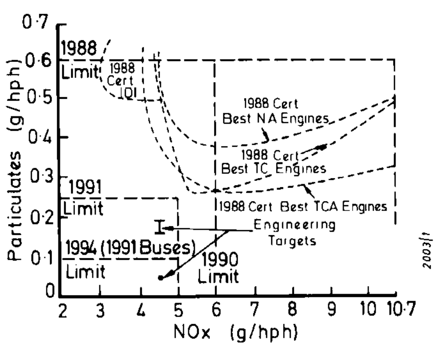

Fig. 2 - Particulate/NOx Trade-offs for 1988 Certification Heavy Duty Diesel Engines over the FTP Cycle

The tighter "Engineering Targets" which are shown on the figure are set by the need to maintain low emission levels over a very long period despite some tendency for emissions to rise with usage.

By means of the steps indicated earlier we can now bring engine emission levels down to the 1991 engine targets. Ways of meeting the 1994 truck and the 1991 bus levels have so far eluded us however, although by applying all the steps and by the use of a special low aromatic, high cetane very low sulphur fuel we can achieve particulate levels approaching or possibly at the legislative level, but with no allowance for service depreciation or for production variability.

It seems likely that by adding an external trap/oxidiser to the exhaust we should finally be able to achieve 1994 levels albeit with substantial additional complexity added to the powerplant and at present unknown effect on vehicle durability and first and maintenance costs. It is certain that a very low sulphur fuel will be required - perhaps as low as 0.02%.

MEDIUM DUTY

If severe emission limits are imposed on all diesel engine vehicles, which appears likely, this will pose a major additional problem for medium duty vehicles where naturally aspirated DI engines are commonly used in many parts of the World including Europe. A switch to turbocharging with aftercooling would involve considerable development and additional cost and there is also likely to be the need for higher pressure and more expensive fuel injection equipment. These costs will bear relatively more heavily on a medium duty vehicle than on a large heavy duty one for which turbocharging is already widely if not universally employed.

LIGHT DUTY DIESEL ENGINES

The majority of the diesel engines used in light duty applications employ indirect injection. Compared with the DI engines, the IDI systems offer superior exhaust emissions and noise whereas the DI has better fuel economy. As fuel prices rise this factor will become more important and it may of course be emphasised by the growing concern over the Greenhouse effect which will emphasise the need to use the engine with the highest thermal efficiency - provided it does not emit other gases of a harmful or a potentially harmful nature.

It is of course difficult to forecast the level at which exhaust emissions legislation will ultimately be stabilised but it clearly is possible to set levels which would effectively debar the use of the diesel engine.

The ability of mid class cars to meet current and possible future EEC limits for exhaust emissions is given in Figure 3. It can be seen that prototype Direct Injection engines have now been produced that give encouragingly low levels of emission such that they may find it possible to meet future legislation.

There is some pressure however, for example within the "Stockholm Group" of countries to employ the U.S. Federal transient test procedure, with tighter limits than are currently being considered within the EEC. Until recently there was little evidence that these limits could be met by a Direct Injection engine. Improvements to the injection equipment, including electronic control have resulted in significant reductions in particulates but meeting HC and NOx limits is still problematic.

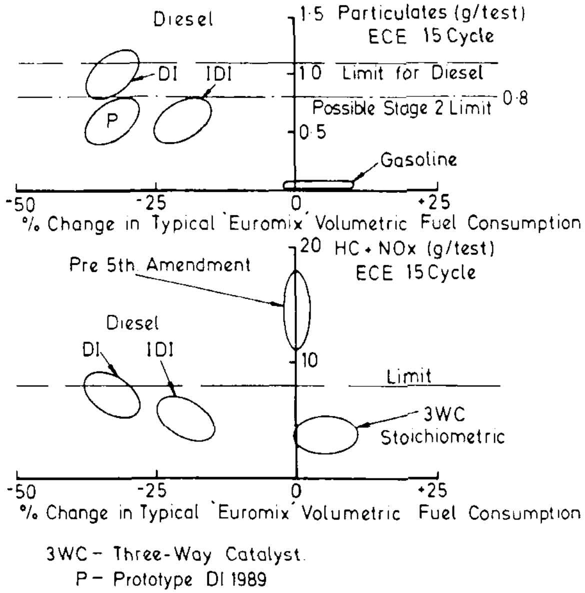

Fig. 3 - Fuel Economy/Exhaust Emissions for Mid-Class Vehicle

Ricardo's research with unit injectors has shown that the combination of high injection pressure and Exhaust Gas Recirculation enables the DI to approach 1987 U.S. Federal limits, although the cost of such a solution will be relatively high. Also the necessary levels of Exhaust Gas Recirculation would result in increased piston ring and liner wear and deposits in the intake system.

Overall, the recent development of improved injection equipment with suitably matched combustion systems gives the DI the potential of meeting U.S. limits but there is no certainty of success and the extra cost is likely to be significant.

ALTERNATIVE FUELS

While it is technically feasible to burn alcohol or gaseous fuels such as natural gas and LPG in a diesel engine either by adding an ignition promoter or by dual fuel operation, these solutions are not attractive. If an ignition promoter is employed it has to be used in relatively large amounts and this is expensive. Dual fuel operation adds expense and complexity to the engine due to the need to have a second injection system. Vehicle range is of course a problem with fuels with a low volumetric calorific value.

All these fuels are better burnt with spark ignition without the production of particulates and a three way catalyst can be employed to achieve very low levels of gaseous emissions. The fuel consumption will be higher than with a compression ignition engine hence giving higher CO_2 emissions however.

ALTERNATIVE ENGINES

While the fuel cells may become a possibility in the long term, giving good fuel economy and potentially very low exhaust emission levels, these devices are today very bulky, heavy and expensive and we are unlikely to see their use in transport applications for many years.

Both Stirling engines and gas turbines employ continuous combustion. Vaporising combustors should give low particulate levels and NOx may be reduced by recirculation of exhaust gas into the combustion chamber and/or by rapid cooling of the combustion gases, although care must be taken not to partially quench the flame or high hydrocarbon levels would result.

At present levels of development however, both types of engines require breakthroughs before they could be considered for use. The Stirling engine tends to be heavy, somewhat bulky and expensive and the fuel consumptions achieved on pre-prototype engine are below that which would be required for truck or bus use. Problems also remain in retaining the charge of gas, be it hydrogen or helium, within the engine for an acceptable time.

Despite its pre-eminent usage in commercial aircraft, the gas turbine has so far been unable to compete in land transport applications. Due to the smaller sizes involved, the use of cooled turbine blades appears to be impossible and it is therefore necessary to provide a material for the "hot parts" of the engine which can accept the high temperatures necessary to achieve adequate efficiency. Metal alloys appear to have reached their limit and attention is now concentrated on the development of engineering ceramic materials.

This development has currently reached 1200°C or so. This is substantially lower than 1300°C which would be necessary to compete on fuel economy with the gasoline car engine. Even higher temperatures would be required to compete with a diesel truck or bus power plant. A breakthrough of this order is unlikely before the end of the century and even then, substantial effort may well be necessary to bring the production costs down to an acceptable level.

SECONDARY POWER PLANTS

While storage batteries may be employed to give a pollution free vehicle, they are currently unable to store enough energy to produce an acceptable power plant for any but a short range, low performance vehicle. Current batteries are very bulky, very heavy and very expensive and have a limited life. There are no indications that this situation will change radically in the near future. Furthermore, electricity for charging the cells must be generated somewhere and this is likely to be an equivalent source of pollution, particularly when transmission and other losses must be allowed for.

Hydrogen for use as an engine fuel is being considered since only water and oxides of nitrogen would be emitted. The hydrogen must of course be generated and hence a hydrogen engine is really only a secondary power plant and the same reservations as above will apply. If however solar cells of adequate efficiency and cost could be produced then hydrogen might be produced by the electrolysis of water and a truly low emissions power plant could result.