THE USE OF EXHAUST GAS FILTERS TO REDUCE LEAD EMISSIONS FROM ROAD VEHICLES

by

K. CAMPBELL
The Associated Octel Co. Ltd England

INTRODUCTION

The addition of very small quantities of lead to petrol increases its octane number. High octane number petrol is essential for today's highly fuel efficient which achieve this efficiency by using high compression ratios.

If lead were to be taken out of petrol completely, then octane quality would fall, compression ratios would have to be decreased and there would be a significant deterioration in vehicle fuel economy. In addition there would be considerable energy penalties in the refinery to produce adequate octane number petrol.

An alternative option to reducing petrol lead content is to use filters in the exhaust system. In this way all the advantages of the use of lead in petrol can be retained whilst the filters prevent its emissions to the atmosphere.

This article deals with the effectiveness, construction, costs and disposal of exhaust gas filters (EGFs).

COLLECTION PRINCIPLES

Lead antiknocks in gasoline are burned in the engine and are emitted as a mixture of lead compounds. These compounds leave the engine as vapours or fine particles in the exhaust gas. As the temperature drops in the exhaust system, the vapours condense to particles. Some of the particles stick to the surfaces of the exhaust system while others stick to each other and by agglomeration grow into larger particles. During normal driving, some of the exhausted particles are very small and become airborne, while others are large and fall to the ground. Most of the large particles are flakes of lead compounds that had previously collected on exhaust system surfaces.

Much of the lead is retained in the exhaust system during normal urban driving, due to low exhaust system temperature and gas velocity. Under these conditions, 20–30% of lead consumed in the gasoline burned in the engine is emitted and the remainder is collected in the exhaust system. During high speed driving, only a small amount of lead is collected in the exhaust system because of the high temperature and gas velocity. Under these conditions, much of the lead burned in the engine is emitted along with some of that collected during urban driving.

The amount of lead collected in the exhaust system can be increased by enhancing the normal collection mechanisms which already occur in the standard exhaust system. Improved collection efficiency can be achieved through the use of properly designed exhaust filters.

The filter element replaces interior components of a standard silencer and consists of alumina-coated stainless steel wire. Externally, there is no difference between filters and standard silencer and both have similar noise-reducing properties.

Filtration systems remove lead from exhaust gas by two mechanisms:-

- mechanical collection
- chemical collection

Mechanical collection occurs as the particles are caught in the matrix of the filter. At temperatures above 350°C, mechanical collection is augmented by chemical collection as the lead particles adsorb on and react with the alumina coating.

Phosphate can be applied to the alumina to further the collection and retention of the lead compounds. The coating processes have been extensively investigated and are suitable for mass production.

Filtration devices can be designed to give the required collection efficiency by using design parameters given in the next section.

DESIGN OF EXHAUST GAS FILTERS

Filter Volume

Filter collection efficiency is related to the ratio of engine maximum power in kW to filter volume in litres (kW/1). This relationship is shown in Figure 1 which gives the collection efficiencies in terms of overall average driving conditions and in terms of urban driving conditions. Also shown is the amount of input lead, consumed in the fuel by the vehicle, which is emitted from the tailpipe during overall average driving conditions.

With knowledge of the collection efficiency required or the maximum amount of lead which can be emitted the ratio of engine power to filter volume can be determined from Figure 1. The filter volume is then calculated from the known or assumed engine maximum power.

Filter Dimensions

The frontal area of the filter can be determined from the relationships shown in Figure 2. These generalised curves relate the filter diameter to engine power. The higher the ratio of filter frontal area to engine power, the lower the pressure drop of the filter unit. A value of 2.4 to 2.9 for the ratio of frontal area to power is preferred as this value will give a pressure drop approximately equivalent to most standard silencer units. Thus, the known value of engine power and the desired value of the ratio defines the effective filter diameter.

The length of the filter unit is determined from Figure 3 using the frontal area to engine power ratio selected in Figure 2 and the ratio of engine power to filter volume determined from Figure 3. The ability to select various values of frontal areas and lengths affords the designer flexibility to choose the dimensions to suit the particular installation while retaining suitable filter collection efficiency and pressure drop characteristics.

THE EFFICACY OF EXHAUST GAS FILTERS

Since 1977 a number of independent studies of filters has been carried out under widely differing climatic conditions.

For example, a fleet test was carried out in Australia (1) using 35 cars composed of nine different models. The report on this work showed:-

- The filters effectively reduced lead emissions up to at least 80,000 kms
- They had no significant effect on gaseous emissions, fuel consumption and exhaust noise.
- The fleet average reduction in lead emissions due to the filters was 66%.

At the other extreme of climatic conditions, a fleet test of filters was carried out in Finland (2) using eight different cars representative of the most popular makes. The cars were driven every day on two test runs of about 200 to 250 km using pre-determined routes along the roads in Southern Finland. During nights and week-ends the cars were parked outdoors and started always at the ambient temperature which ranged from -20° to + 30°C;

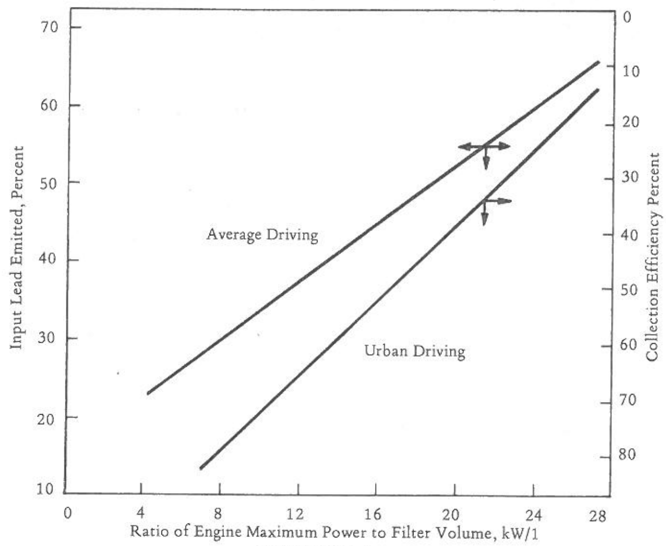

FIGURE 1

Collection efficiencies of filtration devices

The figure below can be used to calculate the filter volume needed to obtain a desired efficiency

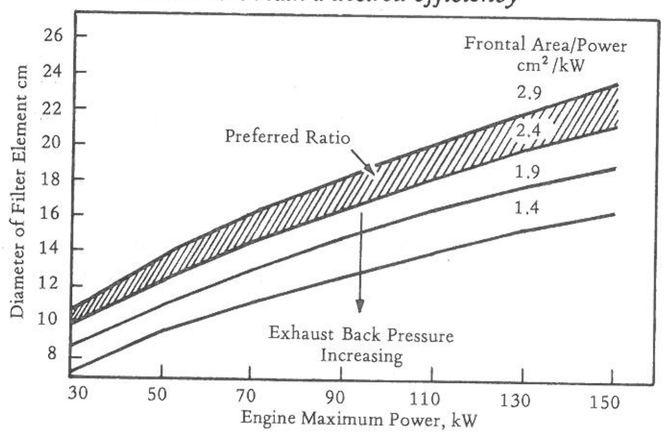

FIGURE 2

Filter element diameter

This figure can be used to calculate the filter diameter for a given engine power level. A preferred ratio is indicated for low exhaust back pressure

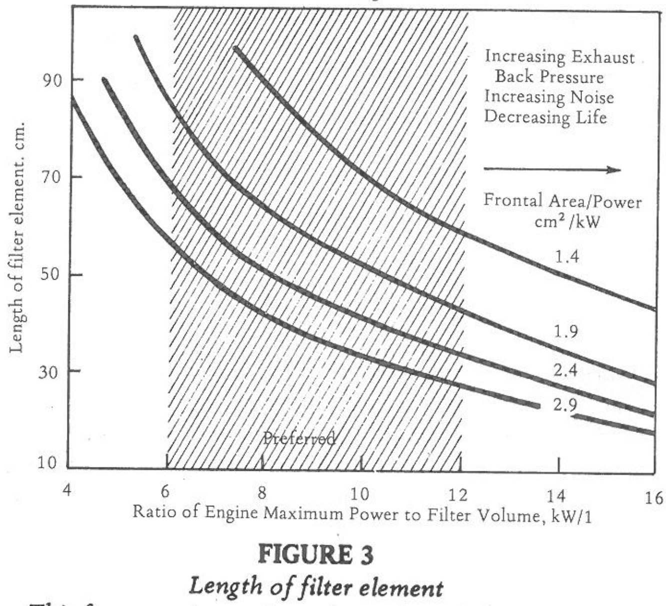

FIGURE 3

Length of filter element

This figure can be used to select a desired filter length

These tests showed:-

- Low ambient temperatures did not affect the operation or efficiency of the filter.
- The filter did not have any significant effect on engine performance, fuel consumption, cold startability or cold driveability.
- The practical lifetime of the filter was at least 60 000 km.
- Filters reduced lead emissions by:

38% over all conditions
54% during city driving
75% during steady speed driving

The effects of lead reduction by filters have been verified by AERE, Harwell (3) which carried out independent tests on filter systems to compare the size distribution of the emitted lead aerosol with that emitted from standard exhaust systems. Their report on this work concluded that the main effects of fitting filters were :-

1. The mean size of the non-impactable particles emitted was not significantly changed but, in mass terms, there was a transfer of lead to larger, impactable sizes.
2. The percentage of input lead emitted from the exhaust was significantly reduced by fitting the filter.

Other independent tests are continuing.

ACCEPTANCE TESTING AND LEGISLATIVE CONTROL OF FILTERS

One question frequently asked about filters is how they would be legislatively controlled. It is suggested this could take one of the following forms:-

Enaction of lead emission standards

or

Device conformation

Lead emission standards

Standards could be introduced limiting the amount of lead emitted from a vehicle's exhaust. These standards could take the form of maximum allowable lead emission in terms of mg per km or mg per test over a particular drive cycle, e.g. the ECE-15 cycle which is used for gaseous emission testing, and for an appropriate distance, e.g. 50,000 km.

Although this would require the formulation of a sui test method and a vehicle homologation procedure, it the advantage that it is familiar to the motor industry has been used for gaseous pollutant emission complia

There would be no practical difficulties because a met has already been drawn up for sampling diesel particula having sufficient flexibility to be used for measuring l emissions.

Device conformation

Here the requirement could be placed on the motor indus to fit vehicles with filters of a specified size, shape a volume and containing a specified matrix.

THE COSTS OF FILTERS

A report commissioned by the UK Government (4) commo ly known as the WOPLIP report arrived at an annual produ tion cost per filter of £20 which included "provision of a exhaust system capable of lasting 50,000 miles (80,000 km)' Inflation and other cost increases probably make this figur nearer £50 in 1983 values.

The overall costs for the introduction of filters also include floor pan changes and the cost of changing the whole exhaust system to stainless steel.

It is envisaged that filters would replace only the silencer so that the remainder of the exhaust system would stay as standard, so again there would be a major reduction in the costs derived in the WOPLIP report.

The method of filter manufacture is also important in deriving costs. For example, if the filter matrices only are produced in one large factory and then forwarded to individual silencer manufacturers for "containerisation" then the price of the matrix could be minimised as a result of the larg volume production. Alternately, commercial competition could reduce filter manufacturing costs as more efficient methods of production are developed.

THE SAFE DISPOSAL AND RECYCLING OF USED EXHAUST GAS FILTERS

An independent study (5) to show that used filters could be economically and safely disposed of has been carried out by examining:-

- The existing route for disposing of silencer systems in the UK at the end of their life.
- The possibilities of using these routes for the collection of used filters and their disposal by existing or new processes.
- The economics of collection and disposal.

Collection of used filters

The current routes for the disposal of standard exhaust systems have been surveyed to see if filters could be similarly handled.

Silencers can either be loose, having been removed from a car during replacement, or attached to cars when the cars are scrapped.

Loose silencers and exhaust systems on cars which find their way to scrapyards at the end of their lives, are either compressed and baled or, more commonly now, shredded with the car body to be recycled to the steel industry.

It is difficult to assess the ratio of loose to attached systems but it is estimated to be approximately 75% loose to 25% attached.

It is established after visists to scrap-dealers, car dumps, shredders and dismantlers that car dismantling is big business in the UK. Scrap cars are bought at very low prices and dismantled for individual items, which are resold either to the public, metal recovery dealers, or returned to the manufacturer for redeemable premiums.

There is a hierarchy of companies in the UK specialising in particular parts, e.g. alternators, brake-shoes and certain engines or axles, etc.

Car bodies remaining after dismantling are squashed and delivered to the large balers or fragmentisers for return to the steel industry. Fragmentisers are now becoming big business because, once shredded, the metal can be segregated into ferrous and non-ferrous materials, which increases its scrap value.

From the foregoing it is apparent that the nationwide network that exists for dealing with the collection, resale and return to the manufacturer of many car items after scrapping and dismantling, could be used for the collection of used filters. They could be collected in the same way, by the same route and cut off used cars, if the incentives were right.

Although the situation has only been studied in detail for the UK, similar networks probably exist in most countries.

Disposal of used filters

Disposal of used filters falls into two main areas:-

The steel route

The British Steel Corporation produces stainless steel from scrap using the "Duplex" system. This consists of two treatments: the first is an electric arc furnace in an air-rich atmosphere which oxidises the carbon and also oxidises some of the chromium, nickel and other components in the melt. The second stage is operated in an air-lean atmosphere, achieved by the introduction of argon gas, so that the oxides of chromium and nickel are reduced. The fume from the plant contains amongst other things, a small amount of lead oxides (less than 0.6%) and is collected in arrester plants.

The secondary lead smelter route

An alternative method of safely disposing of used filters is the secondary lead smelter route. Dross, slag and process scrap, are fed together with battery scrap, lead sinter, etc. to a coke-fired blast furnace at a smelter. Battery scrap is the main ingredient. Coke, iron-ore scrap iron (frag), limestone and fluxing agents are also used with the feed. The fume from the blast furnace, mainly lead oxides, is passed to a duct cooler, then to a baghouse filter system. The plant recovers 99.99% of the oxides in the flue gas for recycle to the furnace. The outlet gases in the stack contain less than 1.37 mg/m^3 lead oxides.

This route appears to be an ideal one for used filters, when it is considered that it handles lead batteries under high temperature oxidising conditions and has adequate emission control plant.

THE ECONOMICS OF SAFE DISPOSAL OF FILTERS

The economics of collection by the existing routes and safe disposal by the two alternative methods have been extensively examined.

At 1981 prices, collection and disposal through the secondary lead smelters or scrap stainless steel routes would give a credit of between £1.29 and £1.53 per filter.

Therefore the economic incentives exist to support the collection and safe disposal of used filters.

CLOSURE

The benefits of using lead in petrol in terms of energy and cost savings have been well chronicled and accepted.

The viability of filters as a means of reducing vehicle lead emissions has been equally well proved and accepted.

It is logical, therefore, if lead emissions to the atmosphere need to be reduced, to gain the benefits of leaving lead in petrol and preventing its emission from vehicles by the use of filters.

The overall cost effectiveness of this option has been well established.

References on p.24