CONTRACTORS TO GOVERNMENT DEPARTMENTS AND NATIONAL UNDERTAKINGS

MANUFACTURERS OF FUEL INJECTION AND ELECTRICAL EQUIPMENT

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YOUR REF.

PLEASE QUOTE OUR REF. Au/MP/ee

8th October, 1958.

Sir Ronald A. Fisher,
Department of Genetics,
University of Cambridge.

Dear Sir Ronald Fisher,

Many thanks for your letter of the 25th September about smoking and cancer etc. and the enclosed article.

It would be very easy to write to you at length about the diesel engine and cancer hypothesis but I will resist the temptation to do so.

You might, however, be interested in a short review of the situation we made some time ago.

Yours sincerely,

A.E.W. Austen

A.E.W. Austen
Chief Research Engineer.

The contribution of

ENGINE EXHAUST to AIR POLLUTION

and its possible relation to Lung Cancer

WITH the increasing public concern about air pollution it is appropriate to consider the fraction of the overall pollution contributed by the exhausts of internal combustion engines. In the first part of this article the amounts of undesirable solids and gases emitted into the atmosphere of Greater London by internal combustion engines, both diesel and petrol, are estimated and compared with the amounts contributed from other sources, chiefly coal burning.

The possibility of a relation between engine exhaust and lung cancer has also come to the fore owing to the rapid increase in the number of deaths from this disease. Unfortunately, a number of statements have been made (and reported in the public press) which were uninformed or inaccurate. So far the whole nature of the problem is not at all clear and the final verdict should come from an authoritative source after extensive research. Nevertheless, there is available sufficiently reliable information on various aspects of this problem to justify collecting it together in order to put the matter into reasonable perspective and to indicate with what urgency investigation should be considered. The purpose of the second part of this article is to summarize our knowledge on this subject, and to attempt to assess its significance.

AIR POLLUTION AND ENGINE EXHAUST

Air pollution is caused mainly by the combustion of fuels, with small contributions from other industrial processes. The polluting agents discharged during combustion can be divided broadly into three groups: —

(*a*) The finest particles, mostly 'smoke,' which are produced when fuels are incompletely burned. They remain airborne for long periods and are deposited ultimately as dirt on walls and other surfaces.

(*b*) Relatively coarse particles, which soon settle, and which consist mostly of mineral matter and grit from the fuel but may also contain partly burnt fuel.

(*c*) Reactive gases. This group is dominated by oxides of sulphur produced from any fuel containing sulphur. Also present are carbon monoxide, ammonia, hydrochloric acid, and other gases, but sulphur dioxide presents by far the biggest problem.

When determining the atmospheric pollution of a given district it is necessary first to determine the rate of consumption of the various fuels used in that district and their mode of combustion. The conditions may vary widely from city to city and may change with the seasons, depending on the pattern of fuel needs. For instance, in Los Angeles, U.S.A., where the problem of 'smog' formation has become a classical example in the study of atmospheric pollution, the chief offender is the petrol-engined automobile.[1] Solid fuels burnt amount to less than 0·5% of the total fuel consumption and diesel fuel slightly more than that. Consequently, emphasis is placed there on petrol engine exhaust and a large amount of research has been concentrated on it.

However, these conditions may not apply to other parts of the world, and it is the intention of this article to show what proportion of the pollution in British cities is contributed by road vehicles, particularly diesel-engined vehicles, and to what extent a large increase in the number of these latter vehicles would alter the present position.

Greater London has been chosen as an example and estimates (summarized in Table 1) have been made of the pollution caused by petrol and diesel engined vehicles, and by all other fuel-consuming sources. In these estimates the pollution by petrol and diesel engines has been

	COAL AND OTHER FUELS	PETROL		GAS OIL	
Total consumption... ...	34700	990		190	
		Chemically Correct	20% Rich	All Engines Normal	All Engines Neglected
Smoke	350	—	—	0·8	4·7
Grit	100	—	—	—	—
Sulphur dioxide	880	2	2	2·7	2·7
Carbon monoxide	3300	67	730	6·8	12·3
Hydrochloric acid, etc. ...	50	4·6	26	7·2	10·3

Table 1. Pollution caused by solid fuels, petrol, and gas oil burnt in Greater London (All figures in 1000 ton/year)

appraised for two engine conditions each: for petrol engines these were air-fuel ratios of 14·75 : 1 (chemically correct) and 12 : 1 (rich); and for diesel engines they were for a well-maintained engine (invisible exhaust to slight haze) and for a neglected engine (black exhaust), both with an air-fuel ratio of 20 : 1. In each case it has been assumed that every engine runs under the specified conditions. It is thought that the truth must lie between these limits.

The figures for solid fuel in the second column of Table 1 were obtained from those for the whole of Great Britain [2] by scaling down in the proportion of the population of Great Britain to that of Greater London (approximately a radius of 15 miles from Charing Cross). The validity of this procedure has been tested by calculating, from these figures, the amount of grit deposited per square mile and comparing it with observed values.[3] The calculated and observed values were found to agree roughly.

The amount of pollution by petrol and gas oil was estimated from statistics obtained from several sources: the total consumption of these fuels in Greater London was obtained from the leading oil companies, the composition of petrol engine exhaust from a standard work of reference,[4] and the smoke and partial combustion products of diesel engine exhaust from experimental work at C.A.V. and other research organizations.[5]

To get some idea of the 'avoidable smoke' from solid fuels a calculation has been made of the pollution expected even if all coal were burnt with no more smoke than in power station practice and there were a considerable improvement in coke-burning appliances. Finally, the pollution which would be produced if the gas oil consumption equalled the present combined total of gas oil and petrol has been worked out. These estimates are compared in Table 2.

Table 1 shows that the present contribution of road vehicles to the overall atmospheric pollution in London is negligible under all headings except that of carbon monoxide from petrol engines. This is likely to cause harm [2] when actually produced under fog conditions because it is discharged at ground level, but not otherwise.

As regards the future, Table 2 shows that an enormous increase in the number of diesel-engined vehicles on the road would hardly alter the balance. The position would change only if, at the same time, the amount of smoke produced by coal burning were radically reduced.

AIR POLLUTION AND LUNG CANCER

Knowledge of the possible relationship between air pollution and lung cancer is even more incomplete than the quantitative aspect that has just been discussed. Nevertheless, an attempt will be made here to summarize the results of some of the biological experiments that have been done and also to assess the significance of the sources of the substances that may contribute to the development of lung cancer.

It is known that certain types of aromatic hydrocarbons, of which benzpyrene is the best-known example,

	COAL IDEAL	GAS OIL	
Total consumption ...	34700	1180	
		All Engines Normal	All Engines Neglected
Smoke	20	5	24
Grit	100	—	—
Sulphur dioxide ...	770	20	20
Carbon monoxide ...	1500	45	80
Hydrochloric acid, etc.	50	48	67

Table 2. Estimated pollution in Greater London by solid fuels, if burnt economically, and by vehicle exhaust, if all gas oil (All figures in 1000 ton/year)

are carcinogenic, that is, tumour inducing. It is also known that they are found in trace quantities in city air (usually adsorbed on carbon or soot particles) as a consequence of incomplete combustion.

Biological Experiments

The biological experiments that have been carried out may be divided into three groups: those in which carcinogenicity of combustion products is demonstrated by painting extracts on the skin of mice; those in which carcinogenicity is demonstrated by direct inhalation of the pollutant; and those investigating the conditions under which carcinogens are active.

Of the more recent investigations in the first group, one may mention the work of Kotin and others,[6] who experimented with extracts from city air, petrol engine exhaust and diesel exhaust, and Clemo and others,[7] who used extracts from chimney soot and diesel exhaust. In both cases the experiments were made by painting extracts on the skin of mice. All tests, except Clemo's on diesel exhaust which were inconclusive, showed a significant increase in tumour incidence among the painted mice. The carcinogenicity of these extracts, which all contain benzpyrene, must therefore be accepted, but two points are outstanding: firstly, the lethal dose has not been determined and, secondly, the experimental conditions may not be representative of the actual mode of exposure of human beings.

In the second group of experiments attempts were made to obtain a closer approximation to human environment by confining test animals in atmospheres loaded with the substances the carcinogenicity of which was to be tested. Few investigators follow this line, but mention may be made of the work of Campbell,[8] who exposed mice in chambers of various atmospheres simulating (*a*) five times the traffic block concentration of petrol exhaust, (*b*) cigarette smoke corresponding to a 'more-than-moderate smoker' and (*c*) tar dust from roads. He concluded that under his test conditions the effect of petrol exhaust is insignificant, the effect of cigarette smoke is more prominent, and the effect of tar dust is the most prominent.

The third group of experiments, which has been published recently, is the work of Steiner,[9] who aimed at determining the conditions under which the carcinogens in carbon black would be active or otherwise. His experiments are more informative than the others in that he has been able to conclude from his tests that carcinogens as such (for instance when adsorbed on carbon black particles) are not active unless in the presence of an eluent, or solvent. The theory advanced is that the eluent makes it possible for the chemicals, such as benzpyrene, to be available for carcinogenic action on the adjacent cells. This requirement for carcinogenic activity has helped to clarify some of the seemingly contradictory evidence of carcinogenicity previously found, but a full understanding of the problem is still very remote.

Contribution of Carcinogens by Engine Exhaust

Kotin found that with petrol engines the benzpyrene content of the exhaust varies with speed and load and was highest at low speed and light load, but that, with diesel engines, the benzpyrene production depended critically, and almost entirely, on the mechanical condition of the engine. In a well-maintained diesel engine with clean exhaust the benzpyrene production was negligible under all speeds and loads, but if the injection system was deliberately tampered with* so as to produce smoky exhaust the benzpyrene production was very high indeed. It is estimated that in the worst cases examined by Kotin the benzpyrene production was 1·4 parts per million by weight of the original fuel for the petrol engine and 47 parts per million for the diesel engine.

The average benzpyrene production from coal has been calculated from Waller's results,[10] and from data in Table 1, as 2·6 parts per million of the original weight of the fuel. Taking into account the annual consumption of each type of fuel, as shown in Table 1, and assuming that all the petrol is used under the worst conditions and that 10% of the diesel engines are deliberately abused, the relative amounts of benzpyrene produced from petrol, diesel, and solid fuel are as 1·5 : 1 : 100. It is clear, therefore, that the benzpyrene production from all internal combustion engines is only of the order of a few per cent of that due to the burning of solid fuel. This is in entire agreement with Waller's finding that the benzpyrene concentration in town air increases sharply during the winter months when the use of domestic fires also increases.

The above proportions refer, however, to town air in general. Over congested streets and at ground level the

*It is assumed that Kotin's tampering produced overfuelling.

exhaust from vehicles may make a major contribution to air pollution.

The mean benzpyrene concentration at 75 ft above street level at County Hall, London, has been measured by Waller [10] as 2·3 mg per million cu. ft, but the contribution of vehicles has not been measured. However, a peak value can be derived from the dilution of a particular component of the exhaust from exhaust pipe to street.

Such information is available for carbon monoxide from petrol engines. Assuming that the ratio of the time spent cruising to the time spent starting and idling is 2 : 1, then the mean carbon monoxide content of the exhaust would be about 3% and the mean benzpyrene content would be 460 mg per million cu. ft. The peak carbon monoxide content that has been measured at street level in London is of the order of 50 parts per million [11] (almost all due to petrol exhaust), which gives a dilution factor of about 600 between the exhaust pipe and the street. The corresponding peak benzpyrene content due to petrol engines, therefore, is 0·76 mg per million cu. ft. In Los Angeles (where the diesel and solid fuel consumed is negligible) the mean benzpyrene concentration at street level, as measured by Kotin, is 0·84 mg per million cu. ft, which indicates that the peak figure for petrol exhaust in London calculated above is of the right order.

Assuming that in London at street level the contributions of benzpyrene from petrol and diesel engines are in the same ratio, 1·5 : 1, as their total contributions to the atmosphere, the peak total vehicle contribution to the benzpyrene content is 1·25 mg per million cu. ft, which is only just over half the mean observed concentration (2·3 mg per million cu. ft).

Benzpyrene is not the only carcinogen among the aromatic hydrocarbons released into the air, and it is relevant to compare the relative production of total hydrocarbons by the petrol engine and the diesel engine. Using Kotin's data, such a comparison has been made in Table 3, the first part of which shows the effect of differing loads on petrol engines and of the standard of maintenance on diesel engines. However, to arrive at the actual carcinogen output, account must be taken of the time spent under various operating conditions. This has been done in the second part of Table 3, which is based on a load-time analysis made by C.A.V. over a typical London bus route and chosen as a fair estimate of actual running conditions. When these figures are weighted according to the total fuel consumed the relative total aromatic production, given in the last part of Table 3, is obtained.

This comparison emphasizes again the importance of adequate maintenance of the diesel engine. With petrol engines, the aromatic hydrocarbon emission cannot be entirely suppressed without introducing additional

		PETROL ENGINE	DIESEL ENGINE 100% good	DIESEL ENGINE 90% good	DIESEL ENGINE 100% bad
1	Light load	3·94	0·15	0·67	5·36
	Full load	0·11	0·26	9·71	94·2
2	½ fuel at light load, ½ fuel at full load ...	1·37	0·22	6·72	64·8
3	Relative total production in London ... ... (Petrol = unity)	1·00	0·03	0·98	9·45

Table 3 Production of all aromatic hydrocarbons per unit capacity of petrol and diesel engine under varying load conditions
Unit (in 1 and 2) = μg per cu. in. capacity per min (at 1000 r.p.m.)

measures, but with diesel engines it can be avoided simply by good maintenance. If, on the other hand, the diesel engine is deliberately abused, then the offence is very great indeed.

Summary

This brief survey of the highly complex problem of engine exhaust and its possible relation to lung cancer does not claim to be comprehensive, neither does it claim a high degree of accuracy for the estimates made. Nevertheless, with these reservations in mind, it is believed that the problem has been viewed in its proper perspective and that first order estimates have been made based on the best information available.

To sum up, city air and engine exhaust contain substances that have been proved carcinogenic to mice, but the exact mechanism of the development of cancer is not yet fully understood. Even less is known of the conditions under which human beings contract lung cancer.

In analysing the pollution from all sources it has been found that the contribution by engine exhaust to overall pollution is extremely small compared with that from the burning of solid fuels. This applies to gaseous and solid pollutants and to the aromatic compounds which may have some bearing on the development of lung cancer.

At street level, in congested streets, relatively high concentrations of pollutants due to engine exhaust can develop but, even so, it is estimated that the peak contribution by engine exhaust is only about half the mean concentration.

In comparing pollution by diesel and petrol engines it has been shown that in the well-maintained diesel engine the quantity of carcinogens produced is negligible; in a petrol engine the production of carcinogens appears to be unavoidable and it would require special devices to remove them. Increasing use of diesel engines in the future need not, therefore, worsen the position—in fact, given good maintenance, an appreciable improvement could be achieved. But it must be borne in mind that a badly adjusted (particularly overfuelled), smoky, diesel engine can become many times worse than the petrol engine. The importance of proper maintenance of diesel engines, and of the fuel injection equipment in particular, cannot therefore be over-emphasized.

POSTSCRIPT

Since this article was written, the evidence collected here has been corroborated by two papers on 'Exhaust Gases from Motor Vehicles' presented to the Royal Society of Health by Dr. A. Fitton and Dr. E. Wilkins, of the Fuel Research Station, D.S.I.R., and by the contributors to the subsequent discussion, notably Dr. P. J. Lawther, of the Medical Research Council (Atmospheric Pollution Group). Drs. Fitton and Wilkins showed, both by direct measurement and by estimation, that the total contribution to air pollution by vehicle exhaust is small indeed compared with that by the burning of solid fuels, although under the most severe conditions the carbon monoxide from petrol engines may be objectionable. Dr. Lawther reported that the Medical Research Council has not been able to measure any significant amount of 3 : 4 benzpyrene in the exhausts of London diesel buses. Furthermore, he stated that they had been 'unable to demonstrate that the combined efforts of about 200 buses raise the benzpyrene content of the air at all; and they were in a fairly confined space, exhaust pollution reaching levels undreamt of in the streets.'

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