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ADVANCED SCHOOL OF AUTOMOBILE ENGINEERING
CRANFIELD



RESEARCH ON THE EFFECT OF MIXTURE QUALITY
ON THE EXHAUST GAS EMISSIONS OF A PETROL
ENGINE

Submission
to:-

Science Research Council

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SUMMARY

To meet the existing and proposed legislation for the control of air pollution by the exhaust emissions of petrol engines, a major research effort is required within the next five years. Not only are the regulations expected to become more stringent as the number of motor vehicles increases, but improvements will show a diminishing return in terms of the percentage reduction of emissions when primary factors have been treated. A fundamental problem that is not well understood is the effect of the quality of the fuel-air mixture on combustion in the spark ignition engine. Knowledge of this factor could be important when the emissions are at a low level as a consequence of the employment of devices that treat factors such as mixture strength or the distribution of the fuel. Although the devices are effective in the reduction of the concentrations of hydrocarbons it is thought that many have an undesirable effect on the concentrations of the oxides of nitrogen.

To improve the knowledge of these problems, it is the proposal that the research at the Advanced School of Automobile Engineering should be extended to a comprehensive study of the effects of mixture quality on the concentrations of carbon monoxide, hydrocarbons and oxides of nitrogen in the exhaust gas of a spark ignition engine. The facilities at the School are comprehensive and no financial assistance is requested for equipment. To allow the study to be completed within a time that is relevant to the urgency of the problem, a grant is requested for the employment of a Senior Technical Officer and a Laboratory Technician for a period of three years.

INTRODUCTION

Air pollution by the exhaust emissions of petrol engines is now recognised to be a problem that will have considerable influence on the design of engines for motor vehicles. It is economically essential for the British motor industry and the British economy that a major effort is put into combustion research in order that motor vehicles can meet existing and proposed legislation and, consequently, can be exported to all overseas markets. Although vast sums of money have been spent by the automobile industry of the United States of America and to a lesser extent by British industry, much of the work is directed towards the satisfaction of the arbitrary regulations of the Californian authorities and many of the more fundamental problems are not yet understood. This situation is particularly so in the case of engines of size and proportions that are typical of British motor vehicles.

It is now well known that a major reduction of the emissions of carbon monoxide and unburnt hydrocarbons can be effected by supplying the engine with a fuel-air mixture wherein the fuel is finely divided or completely evaporated. An opinion that is strongly supported by experimental evidence is that most of the improvement is due to a better distribution of the fuel, that is, each cylinder is provided with a mixture strength that is consistent from cycle to cycle and from cylinder to cylinder. Less obvious is the influence and importance of mixture quality - defined as the homogeneity of the dispersion of the fuel in the air and the physical state of the fuel - when the effects of distribution are insignificant.

Although the quality of the mixture at the valve port may have only a secondary influence on the exhaust emissions of existing engines, it could be an important factor in three to five years time when the possible reductions will be marginal as a consequence of improvements that are readily obtained by other means

It is the purpose of this memorandum to outline the progress of relevant research at the Advanced School of Automobile Engineering and to propose the means by which the work can be extended and accelerated to provide a significant contribution to an important and formidable problem.

Previous Work and the Work in Progress

Research on the influence of mixture quality on factors such as flame propagation and the cyclic variation of cylinder pressure has been in progress at the School since 1962. Most of the work was primarily concerned with the intermittent injection of petrol to the induction manifold or port but, for the purposes of comparison, similar tests with a carburetted mixture were frequently included.

For a first investigation (1), a stroboscopic method was developed for an assessment of the cyclic variation of the cylinder pressure at any particular crank angle within the engine cycle. Statistical measures of the pressure variations were compared for two methods of fuel supply - normal carburation and intermittent fuel injection to the manifold riser. The experimental results suggest that the cyclic variation, with the engine on full throttle, is similar whether the fuel is injected or carburetted. At part throttle conditions, the difference is small but the cyclic variation is less for intermittent injection. An observation of interest was that the fuel energy tends to be released more slowly when the injection is intermittent.

Although it is useful and effective, the stroboscopic method employed for pressure measurement was extremely time consuming. For this reason a long term programme of instrumentation development for the automatic acquisition and processing of test data was started. The progress of this work will be discussed later in the memorandum. For the short term, the engine was fitted with ionisation gaps to detect the position and speed of the flame point in the cycle because this is a more sensitive means of monitoring the changes of the combustion process.

To give a direct comparison with the results of other investigations, it is essential to take flame propagation measurements with the engine running on a pure hydrocarbon fuel. To avoid unduly high running costs, the manifold system of the six cylinder

test engine was altered so that four cylinders were operating normally with a carburetted mixture of petrol and air, while the two remaining cylinders were operating simultaneously with an intermittent injection of iso-octane to the back of the inlet valves. The engine has run for many hours in this condition and is quite satisfactory.

The time for the flame to propagate was found to be only slightly dependent upon the timing of the fuel injection. An investigation (2) into the effect of air-fuel ratio and engine speed gave results that could be usefully compared with similar work by 'Shell' Research on a Ricardo single cylinder E6 engine. Certain non-dimensional parameters, which were originally suggested by Professor Spalding (Imperial College), were found to correlate similarly for the multi-cylinder engine and the single cylinder engine. This was thought to be significant since the size and shape of the combustion chambers of the engines are very different. It was also shown, however, that a dimension which was thought to be a characteristic of the fuel was significantly different from one engine to another.

A further investigation (3), which ran simultaneously with the engine tests, was concerned with the flow of a fuel-air mixture through the inlet port and valve passage. With air velocities that are typical of high speed engines and with the fuel injected to the back of a 'cold' valve, the characteristics of the mixture were recorded by high speed photography. According to the photographs, a considerable proportion of the fuel 'wets' the surface of the valve and streams off the edge in droplets that are very large compared with those of the original spray. This is particularly so when the gas velocity through the valve is relatively low. Also exhibited was a marked tendency for the fuel to stream from one side of the valve. These observations are thought to be particularly relevant to the homogeneity of the mixture in the

cylinder at the beginning of the compression stroke.

The work in progress is directed towards an extension of the previous investigations to include the effect of mixture quality on the propagation of the flame and the concentrations of carbon monoxide, hydrocarbons and oxides of nitrogen in the exhaust gas. The instrumentation for the times for flame propagation is now developed so that it gives an automatic print-out of about 300 values per minute. A programme for a digital computer is used to process the data for the statistical parameters of each group of measurements. Monitoring the exhaust gas is a flame ionisation detector for hydrocarbons and a gas chromatograph for carbon monoxide. The gas analysis equipment is loaned by the Associated Octel Co. and will eventually be replaced by a complete system of infra-red equipment that is now overdue for delivery by the manufacturers.

Within the long-term plan for the development of engine instrumentation and engine testing is the provision of an on-line facility with an I.C.T. 1905 computer. This facility, which will provide a powerful aid to research, is expected to be available by the summer of 1968, that is, about twelve months after the installation of the computer. Orders have already been placed for part of the equipment that is required for this facility.

Available Facilities

The following facilities will be available for the investigation by July 1967.

- 1) 150 h.p. electric dynamometer.
- 2) Fully instrumented engine test bed.
- 3) Ford & Rover engines - fitted with accurate timing discs, pressure transducers and flame ionisation detectors.
- 4) Trigger and pulse circuits for flame ionisation measurements.
- 5) Electronic time counter " " " "
- 6) High speed printer " " " "
- 7) Complete system of infra-red gas analysis equipment
and two two-pen recorders for high and low range
hydrocarbons, carbon monoxide, and carbon dioxide.
- 8) Analytical equipment for the oxides of nitrogen.
- 9) Quartz crystal pressure transducers and amplifiers.
- 10) Camera and high voltage spark equipment.
- 11) High mass flow rig.

Excluding the dynamometer and test bed - an installation costing £12,000 - the replacement cost of the above equipment is estimated to be £7,500.

Support by Industry

Many manufacturers have expressed an interest in the investigation and have given support by the provision of engines, equipment and laboratory services. Material support has been given by:

Ford Motor Co. Ltd.

The Rover Co. Ltd.

The Associated Octel Co. Ltd.

Associated Engineering Ltd.

Engineering Research and Application Ltd.

Simms Group Research and Development Ltd.

Joseph Lucas Ltd.

Proposals-

Facilities within the School for research on the combustion of fuel-air mixture are now considerable and are being improved further by the acquisition of new equipment and the introduction of modern methods for data reduction. A programme of work that utilises these facilities, and provides essential information to the motor industry, is described briefly as follows.

- 1) To develop the existing flow rig for the purpose of an investigation of the parameters that control the quality of the mixture downstream of the valve. For example, it is thought that, above a critical temperature, surface effects at the valve may be significant.
- 2) To develop high speed photography for an investigation of the quality of the mixture at the back of the valve when the gas flow is unsteady. It is well known that flow reversals can occur so that the mixture or gases within the cylinder may be blown back into the induction pipe or valve port at particular times in the cycle.
- 3) With the aid of the information provided by item 1 and 2, by the detection of the movement and extinction of the flame and by the analysis of the exhaust gas, to determine at various loads and speeds the factors that influence the mixture quality and the concentrations of the exhaust gas emissions.

The previous work and work in progress, as reported in the previous section, is the part-time research of a member of the academic staff and mainly the part-time research of students for partial satisfaction of the requirements of the postgraduate diploma D.Au.E. To utilise the facilities that are available at the School and to provide information within a period such that it

is useful to the motor industry, it is essential that a full-time professional staff is employed.

Support is requested for the employment of a Senior Technical Officer and a Laboratory Technician for a period of three years. The duties of the Senior Technical Officer will be to take day to day responsibility for the project, to plan the experiments with the principal investigator, to be responsible for the experimental work and to report the experimental results. A laboratory technician is required for the operation and control of the engine and brake, machining and fitting of new equipment, and the servicing of the engine and rigs.

The engine tests will most likely be confined to a six cylinder Ford 2550 cc engine and a four cylinder Rover 2000 cc engine. Negotiations are in progress, however, for the acquisition of a very high speed single cylinder engine with ratio of bore to stroke that is representative of a possible development of engines within the next ten to fifteen years. The facilities available for this work are comprehensive and no financial aid is requested for equipment. When engines are run on pure hydrocarbon fuels, however, the running costs are high and a request is made for a sum to cover the expected costs of consumable items.

Financial Requirements

	Salary	N.I. etc.	£
1 Senior Technical Officer	4800	468	5268
1 Laboratory Technician	2550	330	2880

Consumable items (based upon 500 hours of engine testing)

750 gallons of petrol	180
250 " " hydrocarbon fuel	300
Oil, filters, batteries etc.	20
	500

Total £ 8148 + 500 = £8648

References

- 1) Investigation into the effect of different methods of fuel supply on the combustion in a spark ignition engine.
M. GILBERT A.S.A.E. Thesis 1962-3
- 2) Flame propagation times and heat release calculations for a spark ignition engine.
J. GRANT A.S.A.E. Thesis 1964-5
- 3) A study of fuel atomisation in the induction tract of a fuel injection spark ignition engine.
N.R. BEALE A.S.A.E. Thesis 1964-5
- 4) The effects of mixture quality on flame propagation and the exhaust emissions of a spark ignition engine.
T.J.B. Jones and D. Hodgetts. (in preparation)

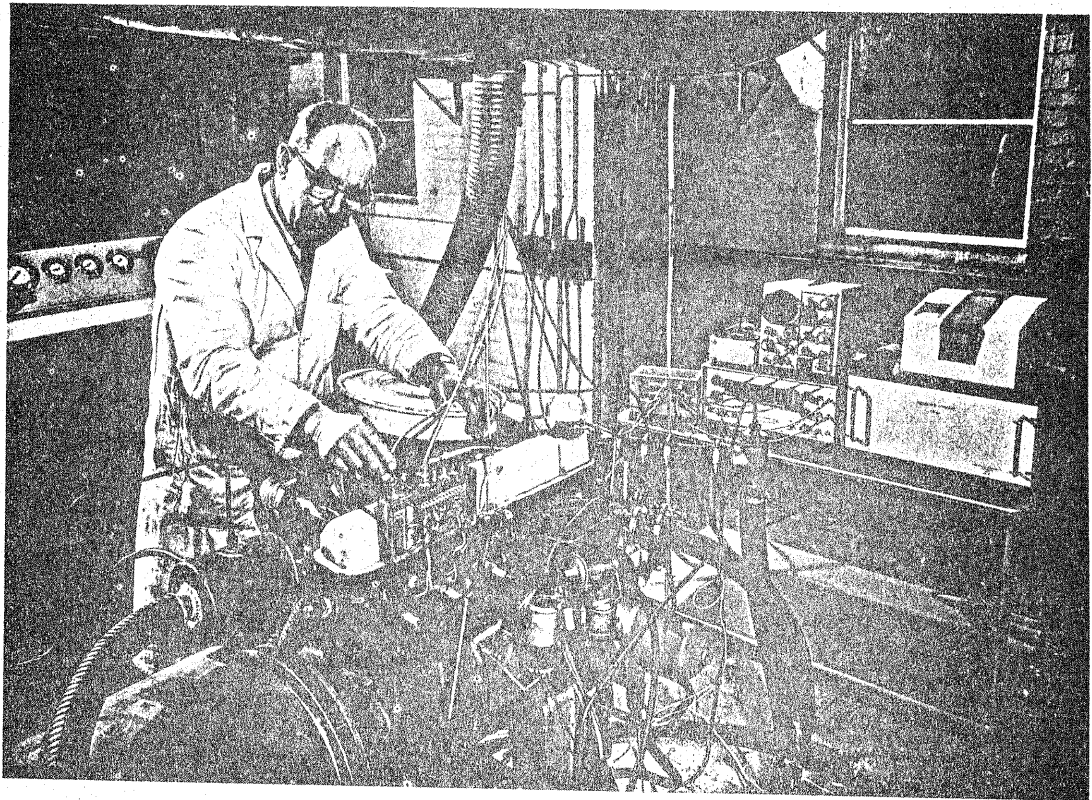


FIG. 1. FLAME TIME MEASURING EQUIPMENT AND TEST ENGINE

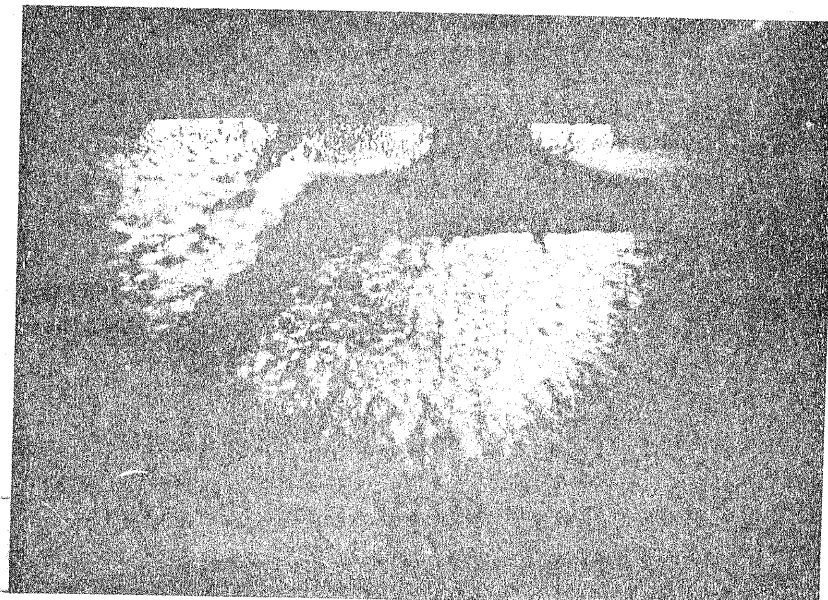


FIG. 2. SHADOW PHOTOGRAPH OF MIXTURE FLOW-DOWNSTREAM OF A POPPET VALVE