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THE OXIDATION, IGNITION, AND DETONATION OF FUEL VAPORS AND GASES

VI. THE PREVENTION OF PRE-IGNITION AND DETONATION IN GAS ENGINES[1]

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VI. THE PREVENTION OF PRE-IGNITION AND DETONATION IN GAS ENGINES[1]

BY R. O. KING[2], W. A. WALLACE[3] AND B. MAHAPATRA[4]

Abstract

The experiments described show that town gas containing hydrogen in large concentration can be used as fuel for a carburetor type Otto cycle engine at compression ratios rising to 10 : 1 and in mixtures with air in any proportion, if the accumulation of fluffy carbon in the combustion space be prevented. The carbon is produced mainly by pyrolysis of the lubricating oil. Confirmation of the nuclear theory of ignition, advanced in Part IV to explain the cause of detonation in engines, is thus obtained. Performance data are given for the variation of power and economy with mixture strength and ignition timing at compression ratios of 6, 8, and 10 : 1.

Introduction

It has long been known that the power and efficiency of gas engines have been limited by the necessity of using relatively weak gas–air mixtures and low compression ratios in order to avoid pre-ignition and detonation. Both effects are commonly believed to be due to ignition of the combustible mixture by sudden compression and/or by hot surfaces in the combustion space. Both increase in severity with increase in the proportion of hydrogen in the gas.

The severity of the effects mentioned has been mitigated by reducing the inflammability of the combustible mixture or by cooling the more highly heated surfaces of the combustion space. Thus, Dugald Clerk (1) added cooled exhaust gases to the entering mixture; Bertram Hopkinson (4) provided a water sprinkler system in the combustion space and a modification of the system was used in the Crossley Gas Engine (2, p. 39). The Koerting Gas Engine (German) was fitted with a separate water cooled body in the combustion space (2, p. 95). Recent developments aimed to avoid pre-ignition and detonation are the high compression gas engine and the Dual Fuel engine using gas and injected oil. Both operate at Diesel engine compression ratios. High pressure gas is injected late in the compression stroke in the first mentioned type (Walter (9) and Erren (3)) and ignition is by electric spark. Ignition is by injected oil in the Dual Fuel type as in the compression ignition engine, and mixing of the gas with air does not occur until the inlet valve opens (Jones (5, p. 37)).

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Contribution by the Defence Research Board (Canada) and the Department of Mechanical Engineering, University of Toronto.
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The above mentioned methods of increasing the power and economy of gas engines are based on the theory that pre-ignition and detonation are inherent in the nature of the gas, especially of the hydrogen constituent. It is shown, however, by the experiments described in Part V (8) that the pre-ignition and detonation observed when hydrogen–air mixtures are used in an engine are due to the igniting effect of finely divided carbon derived from pyrolysis of the lubricating oil.

Commercial fuel gases, even if composed mainly of hydrogen and carbon monoxide, usually contain some proportion of hydrocarbon which by pyrolysis at end gas temperatures might yield finely divided carbon in sufficient concentration to cause ignition and consequent detonation (Part IV (7)). The lubricating oil would otherwise be the sole source of carbon, as when using hydrogen.

It became of interest, therefore, to determine if pre-ignition and detonation in engines using fuel gas could be avoided, as in the hydrogen engine, by preventing the accumulation of finely divided carbon in the combustion space. Experiments made accordingly are described in this Part and show that the gas, pre-mixed with air in any proportion, can be used at compression ratios rising to 10 : 1, the limit of the variable compression C.F.R. engine, without pre-ignition or detonation and with a consequent increase in power and economy.

Experimental

The C.F.R. knock testing engine in the Department of Mechanical Engineering, University of Toronto, was used for the experiments with Toronto town gas as the fuel. The special features of the engine are described in Part V (8).

The Fuel Gas

The composition and calorific value of Toronto town gas are checked continuously by the Consumers Gas Company. The composition at the time of the experiments was as below, in percentage volumes.

Hydrogen	49.1	Ethane	2.3
Carbon monoxide	19.1	Nitrogen	7.8
Methane	12.9	Carbon dioxide	3.7
Heavy hydrocarbons	4.3	Oxygen	0.8

The calorific value was 475 B.t.u. per cu. ft. at 60° F. and 30 in. of mercury barometric pressure, when saturated with water vapor. Temperature at time of use was 78.5° F. and pressure 29.9 in. of mercury, the calorific value being then,—

$$475 \times \frac{520}{538.5} \times \frac{29.9}{30} = 459 \text{ B.t.u.}$$

The gas was supplied to the engine by using the device illustrated in Fig. 1, the standard diffuser being removed from the throat of the carburetor venturi.

The C.F.R. carburetor was otherwise intact and a change to liquid fuel could be made when required.

The rate of gas supply to the engine was measured by a new and freshly calibrated No. 1A Sprague meter.

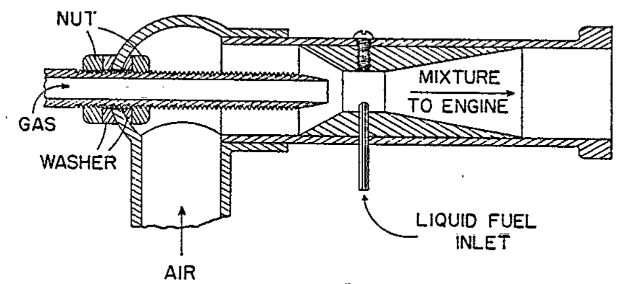

FIG. 1. *Carburetor arrangement used for running the C.F.R. engine on town gas.*

Experimental Procedure and Conditions

The engine had been run on hydrogen prior to the experiments with town gas and the routine cleaning method then adopted, Part V (8), to prevent the accumulation of fluffy carbon in the combustion space was continued. The engine was always run at 900 r.p.m. The jacket water temperature was maintained at 212° F. by the C.F.R. standard method of evaporative cooling, using distilled water.

The rate of flame propagation in town gas – air mixtures is so much slower than in hydrogen–air mixtures and varies so much with mixture strength that maximum power for a particular compression ratio and mixture strength is obtained only if a particular ignition timing is used. It was decided, therefore, to run series of experiments at compression ratios of 6, 8, and 10 : 1 to determine the ignition timing required for maximum power when using a series of mixture strengths varying from very weak to very rich. Families of graphs were thus obtained relating maximum power to ignition timing and mixture strength at the three values of the compression ratio.

Experimental Results

The combined effect of mixture strength and ignition timing on power output when the compression ratio was 6 : 1 is shown by the graphs of Fig. 2. Similar families of graphs were obtained for compression ratios of 8 and 10 : 1, but are not reproduced.

The graphs of Fig. 3 then give the relation between power output and mixture strength when the optimum ignition timing is used for every experimental point; the timing in degrees advance being given by the figures in circles.

The engine ran smoothly without combustion noise even at the maximum available compression ratio of 10 : 1, and when using the mixture strength and spark advance giving maximum power.

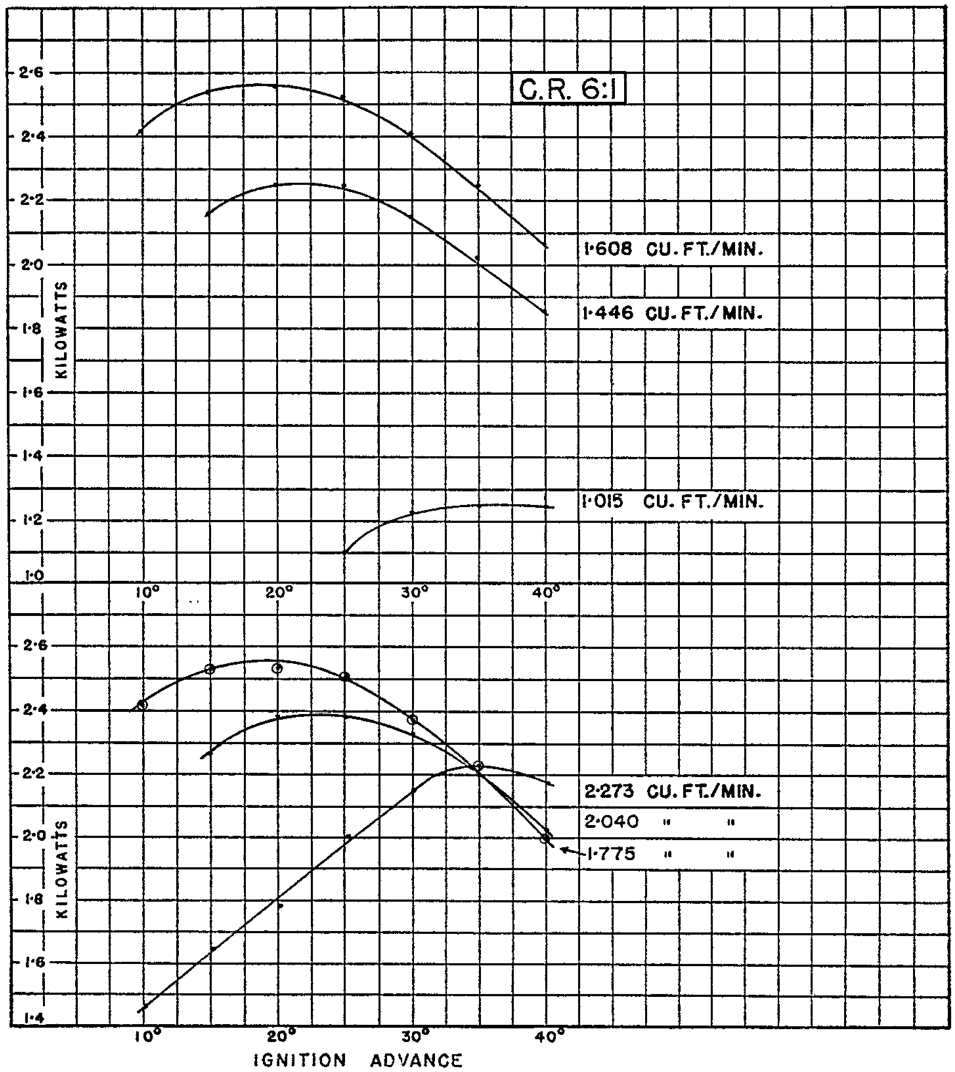

FIG. 2. *Effect of mixture strength and ignition advance on power output when using town gas as fuel for the C.F.R. engine, running at 900 r.p.m., compression ratio 6 : 1.*

Indicated thermal efficiencies and indicated mean effective pressures calculated from the graphs of Fig. 3 are given in Tables I, II, and III for compression ratios of 6, 8, and 10 : 1, respectively, and for varying mixture strengths. The percentages of mixture strength are in respect of the rate of gas supply required for maximum power, and it will be seen by reference to the graphs of Fig. 3 that this rate varies with compression ratio.

The values for indicated horse power given in the tables were obtained by the usual motor method. The power loss obtained accordingly is added to the net power output. The losses in the C.F.R. unit used for the experiments

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