The Catalytic Engine

PLATINUM IMPROVES ECONOMY AND REDUCES POLLUTANTS FROM A RANGE OF FUELS

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The concept of an internal combustion engine where the oxidation of the fuel is brought about with the aid of a catalyst offers the advantages of a stratified charge engine without the disadvantages. It should give good economy and low emissions of exhaust pollutants. Several such catalytic engines have been built and run, and test results are promising; in particular, one engine shows better fuel economy than the conventional petrol engine coupled with lower hydrocarbon emissions than either petrol or diesel engines.

Since the late 1960s, increasingly severe legislation aimed at controlling emissions from motor vehicles has had a growing impact on the design of engines and associated emissions control systems. In the U.S.A. and Japan platinum catalysts have been used for emission control since 1975 and continue to be first choice system for the majority of cars sold there.

In addition to emission control, other important considerations when designing engines for motor vehicles are fuel economy, fuel type and the future availability of gasoline and diesel fuel in the 1990s. Using existing technology, the two goals of low emissions of exhaust pollutants coupled with improved fuel economy are not readily achievable, either with conventional piston engines or alternative power sources such as gas turbine or Stirling engines. As a result world wide research and development aimed at improved power systems continues on a high level.

To date, platinum catalyst systems have been used on motor vehicles solely for reducing exhaust emissions, by promoting the oxidation/reduction processes in the exhaust gases after they have left the engine. However, platinum metals catalysts have been used for many years as a means of initiating combustion, for example in flameless heaters. More recently their utilisation in the combustion system of gas turbine engines has resulted in the emission of greatly reduced levels of nitrogen oxides (1).

A Platinum Metals Catalyst in the Combustion Chamber

The use of a platinum metals catalyst in the combustion chamber of an internal combustion engine offers an opportunity to develop an engine which emits particularly low levels of nitrogen oxides while giving the fuel economy generally associated with an unthrottled engine, such as a diesel. This second advantage arises since, by using a platinum metal catalyst to initiate combustion, the engine is not dependent on fuel/air flammability limits as is the spark ignition engine, or on compression temperature as in the diesel engine. Thus the requirement for fuels of closely controlled characteristics that are presently needed by petrol and diesel engines would be relaxed, the addition of lead to petrols would no longer be necessary, and alternative fuels could be considered.

A catalytic engine is an internal combustion engine where the heat release is brought about by the use of a catalyst. This definition includes engines where the combustion is commenced, sustained, or aided by the action of a catalyst on the air/fuel mixture.

The concept of a catalytic engine is not new; there are patents on the idea dating back to 1920 but the revival of interest has been brought about by the introduction of exhaust emission legislation for automotive vehicles, coupled with the need to improve fuel economy.

It is known that in order to obtain good fuel economy from an internal combustion engine it is desirable to operate unthrottled. This is one of the reasons why the diesel engine gives better economy than the petrol engine, although the diesel engine suffers from other problems such as high noise, high smoke at full load and the need for a high cetane fuel. The petrol engine suffers from relatively high fuel consumption, requires a high octane fuel and the untreated exhaust contains high concentrations of pollutants, mainly carbon monoxide, unburnt hydrocarbons and nitrogen oxides.

The compression ratio of an internal combustion engine directly affects the fuel economy. The compression ratio of the petrol engine cannot be raised too high because of the tendency of the engine to "knock". This is a result of premature spontaneous combustion in the unburnt portion of the charge ahead of the flame front, and is brought about by the use of a fuel with too low an octane number; the octane number being a measure of the fuel's resistance to knock in a spark ignition engine. Ignition of the charge before the spark timing is also a problem under these circumstances. The compression ratio of the diesel engine cannot be brought too low or the compression temperature will be too low and the engine will not start. It has been shown that as the compression ratio of the petrol engine is increased so its economy increases, but as the compression ratio of the diesel is increased so its economy decreases.

There is, from the economy point of view, an optimum compression ratio in between, at about 12:1, where neither engine is satisfactory in a conventional form.

The stratified charge engine can be operated at this compression ratio, and has the advantages of unthrottled operation, but it suffers from a fundamental problem. A stratified charge engine operates by obtaining a mixture strength at the spark plug which is rich enough to enable a pre-mixed flame front to commence propagation, and an overall average mixture strength which is lean enough to allow unthrottled operation. This means that at light load, because the overall average mixture strength is very lean, the mixture strength across the combustion chamber must vary from rich at the spark plug to almost pure air at the remote end of the chamber. Consequently, as the flame propagates across the chamber it will encounter, at some point, a mixture strength which is too lean to support combustion, and the flame will be extinguished. As a result the remaining portion of the charge will be emitted as unburnt hydrocarbons.

The New Concept

There is therefore a need for a method of combustion which would enable very lean mixtures to be efficiently oxidised, and operate in an internal combustion engine at a compression ratio of about 12:1. The concept of the new catalytic engine arose from this need. The principle of the new catalytic engine is that during the engine operating cycle the fuel is injected into the combustion chamber just before the start of combustion is required. This fuel is then mixed with the air already in the cylinder and then passed through the catalyst, where heat release occurs. The use of this principle overcomes the fundamental problem of the stratified charge engine, which was outlined above, because since all the charge is passed through a catalyst, oxidation can occur even at low temperatures and very lean mixtures. Thus all the fuel should be oxidised, and the engine can run unthrottled which should give good economy.

The formation of nitrogen oxides and carbon monoxide in the combustion chamber is also strongly dependent on the air/fuel ratio, and lean operation gives reduced emissions of these pollutants in the exhaust of the engine. The catalyst enables oxidation of hydrocarbons at

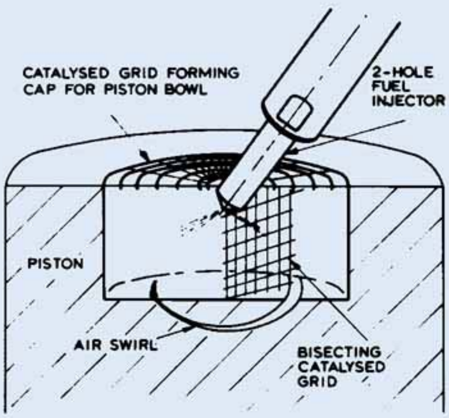

Fig. 1 Two platinised catalyst grids are used to initiate combustion in the combustion chamber of a Direct Injection diesel engine. Air and fuel are mixed together as they swirl through half a revolution of the piston bowl before being oxidised as they pass through a vertical catalyst grid; any unoxidised fuel being consumed as it passes through a second grid

much lower temperatures than normally possible, so these emissions are also reduced. Another important advantage of the catalytic engine concept is that it is capable of operating on many different liquid fuels. The engine does not require high octane fuel because: (a) since oxidation occurs on or immediately downstream of a catalyst, rather than in a flame front, there is less tendency for the unburnt gases to be heated above their spontaneous combustion temperature, and (b) since the fuel is injected late into the combustion chamber there is no possibility of pre-ignition; therefore the engine can be operated on fuels like diesel oils and paraffins. It has no requirement for fuels of high cetane number, this being a measure of the fuel's resistance to knock in a compression ignition engine, because the start of combustion is controlled by the catalyst instead of by the heat of compression; therefore it can be operated on fuels like petrols or alcohols.

Although there are patents in existence covering the concept of the catalytic engine, as far as is known no catalytic engine has been successfully operated. A programme of research was started in 1976 to find out if such an engine could be made to operate, and if it could to see if its performance could be developed to a point where it would have practical applications.

The Direct Injection Catalytic Engine

The first idea to be tried was to use a Direct Injection diesel engine type of combustion chamber; Figure 1 shows the arrangement of the two platinised grids that were used to initiate combustion of the fuel. The theory was that the fuel would be injected by a two hole injection nozzle into the combustion chamber which was in the form of a bowl in the crown of the piston. The air would be made to swirl in the bowl by the use of a swirling intake port, and the fuel would be injected immediately downstream of the vertical grid, thus allowing half a revolution of the bowl for the fuel and air to mix before passing through the catalysed mesh and being oxidised. Any fuel remaining

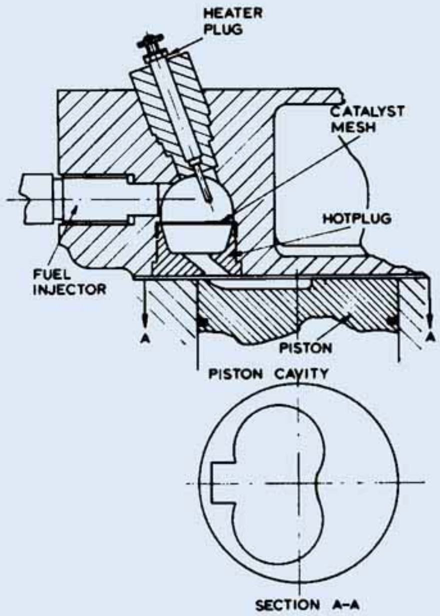

Fig. 2 In the Catalytic Comet engine the platinum catalyst mesh is arranged in a pre-combustion chamber located on the cylinder head, and connected to the main combustion chamber by a narrow passage

unoxidised would be consumed on passing through the second catalysed grid, which forms a cap to the piston bowl, as the piston moved downwards on the expansion stroke.

This concept was realised by converting a Ricardo E16 engine, which in standard form is a single cylinder direct injection diesel research engine. The engine was made to run, and it operated much more quietly than the standard engine even though it was fuelled with petrol. Various catalysts were used, which were all platinum based. However, in spite of considerable effort to improve its performance, the engine was not very successful due to limited torque output, and also torque range, that is the build that was best for maximum torque would not operate at low torques, and vice versa. It was considered that this was due to insufficient movement of the charge within the combustion chamber, a theory which was later confirmed by combustion photography, and this led to the idea of the Catalytic Comet.

The Catalytic Comet

The Ricardo Comet is a diesel engine combustion system where the fuel, instead of being injected directly into the main combustion chamber over the piston, is injected into a pre-combustion chamber located in the cylinder head and connected to the main combustion chamber by a narrow passage. Normally the combustion system operates at a compression ratio of around 22:1. The Catalytic Comet consisted of a similar geometry but with a catalytic mesh mounted in the pre-combustion chamber and the compression ratio reduced to 12:1; Figure 2 shows the arrangement. This combustion system gave a swirl ratio of about 30, instead of about 6 in the direct injection system. (Swirl ratio is the ratio of the maximum rotational speed of the swirling charge divided by the rotational speed of the crankshaft.) The results from the Catalytic Comet proved to be much better than those from the direct injection engine—this engine would operate from idling up to nearly as much torque as the standard engine, and across the normal speed range of the engine.

To date the experimental programme on the Comet engine has included the evaluation of a number of platinum metal catalyst systems in order to assess the effect of catalyst composition and physical form on engine performance. Pure platinum, rhodium-platinum and palladium-platinum alloys have been evaluated as unsupported metal grids and also as supported catalysts on base metal grids. Further development of the engine is planned to include optimisation of the catalyst system.

The Catalytic Engine Compared to Conventional Engines

The best results obtained from the Catalytic Comet are compared to those from other engines in Figures 3 and 4. The results were all obtained from single cylinder research engines

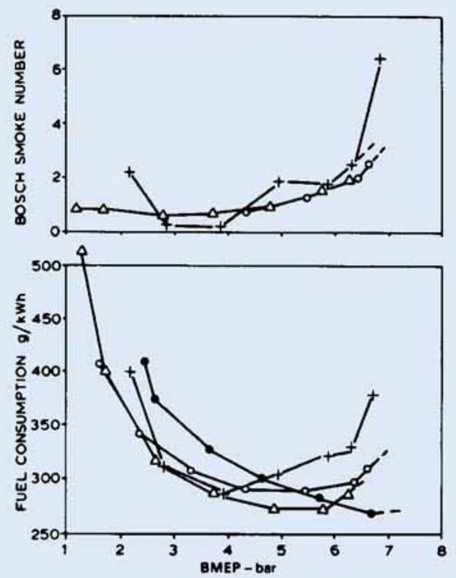

Fig. 3 The performance results obtained from a Catalytic Comet engine are compared with those obtained from other engines of similar cylinder size. The figures are extrapolated to brake performance of four cylinder engines. All engines at all loads were set for best economy. Engine speed 1500 rpm

●—● *Petrol engine*
○—○ *Spark Ignited Comet*
△—△ *Comet diesel*
+—+ *Catalytic Comet*

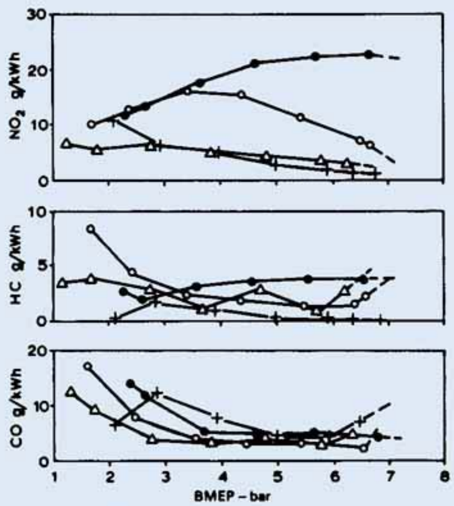

Fig. 4 The exhaust emissions from a Catalytic Comet engine are compared with those from various engines of similar cylinder size. The figures are extrapolated to brake values of four cylinder engines. All engines at all loads were set for best economy. Engine speed 1500 rpm

●—● *Petrol engine*
○—○ *Spark ignited Comet*
△—△ *Comet diesel*
+—+ *Catalytic Comet*

of about half litre swept volume, but they have been extrapolated to the performance to be expected from four cylinder engines of the same cylinder size by allowing for the difference in friction. The petrol engine and Comet diesel engine results are from conventional engines of their type. The spark ignited Comet results are those from a stratified charge engine based on the Comet diesel. The results from this work have been published (2). They are of interest for comparison because (a) they are from a combustion chamber of identical shape and compression ratio with a different method of combustion, and (b) they are from a stratified charge engine whose light load hydrocarbon problems should, according to theory, be overcome by catalytic combustion.

The brake specific fuel consumption (BSFC) and exhaust smoke versus torque expressed as brake mean effective pressure (BMEP) are shown in Figure 3. It can be seen that the fuel consumption of the Catalytic Comet was as good as the diesel in the region of 3 to 4 bar BMEP, and better than the petrol engine at loads up to 4.7 bar. However above this load fuel economy starts to deteriorate, and this is thought to be due to poor air utilisation. The smoke results also show good values in the 3 to 4 bar range, deteriorating outside this. An acceptable full load smoke limit might be between 2 and 3 Bosch smoke numbers, so that the smoke can be considered acceptable except above 6.4 bar BMEP, where the smoke (and BSFC) become suddenly much worse.

A comparison of exhaust emissions for the same engines is given in Figure 4. It can be seen that there is not much difference in carbon monoxide emissions between any of the engines in the ranges 3 to 6 bar. Below 4.5 bar the catalytic engine produced more carbon monoxide, but this started to decrease again below 3 bar. This was because it was found necessary to advance the injection timing slightly at light load to obtain stable combustion, thus giving decreased hydrocarbons and carbon monoxide but increased nitrogen oxides emissions. The hydrocarbon emissions from the Catalytic Comet are exceptionally low. It can be seen that they are lower than all the other engines across the load range; and of particular interest is the fact that they are much lower at light load than those of the stratified charge engine, where the light load hydrocarbon problem can be seen clearly. These features make this concept a very interesting one. The nitrogen oxides emitted are very similar to those of the diesel, only turning up at light load, and are much lower than those of the petrol engine or stratified charge engine.

Combustion Photography

High speed photography of the combustion in engines is an analysis technique which has proved useful in the past for studying combustion systems. The catalytic engine was showing characteristics that were difficult to explain, and it was decided to carry out combustion photography to try to gain a better understanding of the processes that were occurring. Some

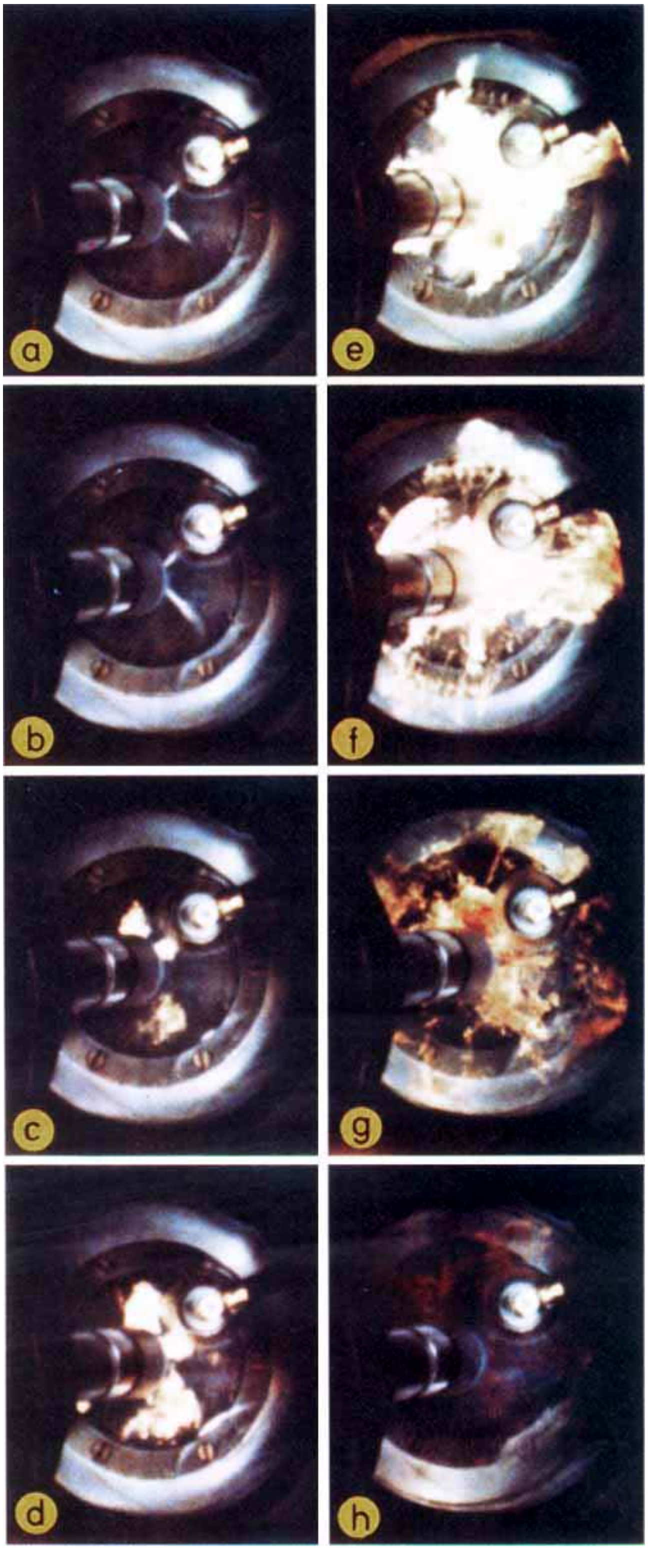

Fig. 5 This high-speed photographic record shows the sequence of events in the combustion chamber during one cycle of the Direct Injection catalytic engine. The spark plug, situated top right, was only used to provide a rapid start-up for photographic purposes. In (a), top left, injection has begun and this continues in (b). The start of combustion occurs in two distinct regions adjacent to the vertical catalyst mesh (c); combustion continues to be associated with the vertical mesh (d) although the flame front is now advancing rapidly into the surrounding air/fuel mixture. In (e), top right, the burning mixture begins to spill from the combustion bowl across the piston crown, but the combustion is fairly disorganised due to lack of air motion (f). As the piston descends and the charge begins to cool, combustion in droplet form proceeds slowly (g) with the last visible signs of combustion being shown in (h), bottom right

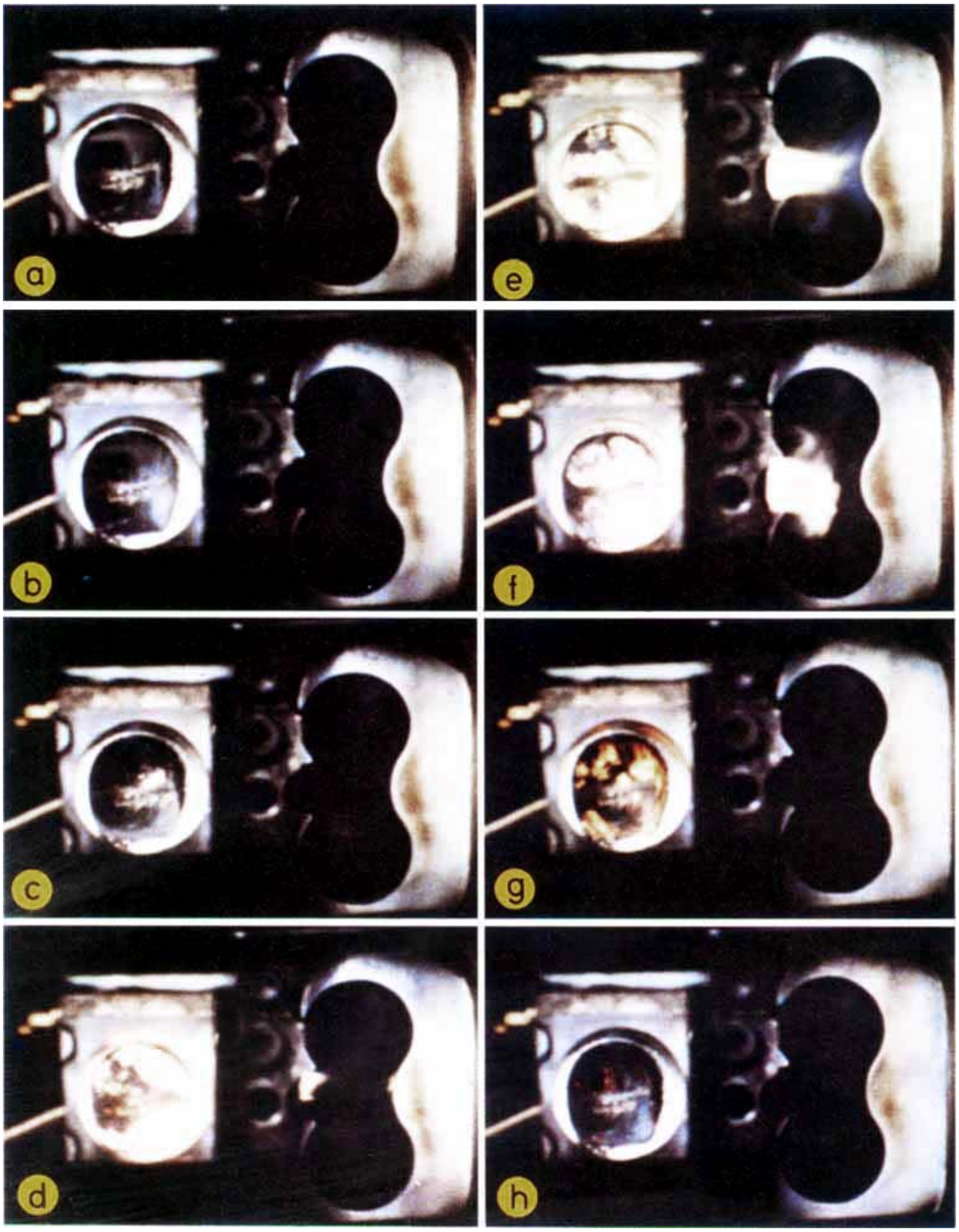

Fig. 6 This sequence shows the events in the Catalytic Comet; in each photograph the pre-combustion chamber viewed from the side appears on the left, while on the right the main chamber is seen from above. In (a) injection has begun, and as it continues onto the heater plug (b) droplets of fuel pass downwards through the catalyst. Combustion starts at the junction of the heater plug tip and the catalyst (c), and progresses to both sides of the catalyst with burning fuel/air appearing in the piston trench (d). In (e), pre-mixed combustion is occurring around the periphery of the flame in the abundant supply of air within the piston cavities, while in (f) the bulk of the combustion within the main chamber is complete but is still continuing in the pre-combustion chamber as the fuel/air mixture passes downwards through the catalyst mesh. This is reduced as the charge cools (g), and finally (h) combustion is complete with little sign of combustion products in the cylinder

of the results are shown in Figures 5 and 6. Figure 5 shows the sequence of events during one cycle in the Direct Injection engine. The view is looking down on the piston into the combustion chamber. The spark plug was used for rapid start up for photographic purposes only. It can be seen that while the combustion may have been commenced catalytically, the main part of the combustion is by droplet burning. It was also noticeable from the films that the catalyst mesh was almost totally destroying the charge swirl in the engine.

The sequence of events in the Catalytic Comet is shown in Figure 6. The part of the frame on the left is the pre-combustion chamber viewed from the side and on the right is the main chamber viewed from above. Once again although combustion may have been commenced catalytically the later part of the heat release is by droplet burning. The natural swirl of the combustion system was again greatly reduced, although there was more motion left than there was in the Direct Injection engine.

It was clear from the combustion photography that the simple theory of mixing the fuel with the air and passing it through the catalyst was not what was happening in practice. However it was also shown that the platinum catalyst was a necessary part of the system since if it were removed or replaced with a plain stainless steel mesh then the engine would not run. Therefore there is room for work to find other ways of carrying out the combustion to obtain further improvements in performance.

The Catalytic Engine with Methanol Fuel

The generation of power in coal mines has recently become a problem, particularly in the U.S.A., because the diesel engines currently used are becoming unacceptable as standards of air cleanliness are increased, because of their emissions of smoke and nitrogen oxides. The requirements are for an engine with no high tension electrics, low exhaust pollutant emission, and a low fire risk fuel. The petrol engine is ruled out on the first count, the diesel engine on the latter two, while electric motors are undesirable because of their associated fire risk. Alternatives being considered are the Rankine Cycle, Stirling Cycle, and a number of other possibilities including the use of high pressure hydrogen. The possibility of using a catalytic engine operating on methanol fuel was considered, because it offered the possibility of low exhaust smoke, no electrics and furthermore methanol is soluble in water so the fuel tank and fuel system could be entirely surrounded by water jackets, so that in the event of an accident the fuel would be automatically diluted below its flash concentration.

Both the Direct Injection Catalytic engine and the Catalytic Comet were tested using methanol, and were found to run very well. The results showed better brake thermal efficiency than that obtained on petrol, zero smoke and very low emissions of nitrogen oxides.

Conclusions

A catalytic combustion system incorporating platinum metals has been produced for internal combustion engines. These have the following advantages:

(1) Fuel economy as good as a diesel, over part of the load range.

(2) The amount of nitrogen oxides emitted is as low as from a diesel.

(3) Hydrocarbon emissions are less than those produced by a petrol or a diesel engine.

(4) Multi-fuel capability; it runs well on petrol and methanol.

(5) Quieter than a diesel.

(6) Lighter than a diesel.

Further work is needed to improve the maximum torque, the fuel economy at high loads, and the durability of the catalyst.

Acknowledgement

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