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Effect of Pre-Chamber Charge Temperature on Engine Performances and Emissions of a Dual Chamber Spark Ignition Engine

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ABSTRACT

The performances, fuel economy and emissions from a dual chamber, stratified charge, spark ignition engine with heated pre-chamber charge temperature were investigated. The total hydrocarbon emissions from the engine, when tested at Leeds, proved considerably lower than in the early British Leyland study. The vaporizer system used at Leeds would probably have led to increased pre-chamber mixture temperature. It was therefore decided to investigate the effects of this mixture chamber temperature, by raising its value from 30°C used in the reference test to 45°C in a comparative test series. The good specific fuel economy and NO_x *emissions noted in the Leyland study were confirmed in the current work; however the (reduced)* UHC *emissions found in the current tests were still excess of those expected from a conventional single chamber engine.*

ABSTRAK

Kecekapan, ekonomi bahan api dan pelepasan dari dua kebuk, cas berstrata dan suhu cas enjin cucuhan bunga api dengan cas prakebuk yang dipanaskan telah dikaji. Jumlah pelepasan hidrokarbon dari enjin yang telah diuji di Leeds adalah lebih rendah dari kajian awal yang dibuat di British Leyland. Sistem pengewapan yang digunakan di Leeds mungkin menyebabkan peningkatan suhu campuran prakebuk. Oleh yang demikian, keputusan dibuat untuk mengkaji kesan suhu campuran kebuk, dengan menaikkan suhu tersebut dari 30°C yang digunakan dalam ujian rujukan kepada 45°C dalam ujian-ujian perbandingan seterusnya. Ekonomi bahan api tentu yang baik dan pelepasan NO_x *yang diperolehi dari kajian di Leyland telah disahkan dalam kajian ini. Walaubagai mana pun, pengurangan pelepasan hidrokarbon yang tak terbakar (*UHC*) yang diperolehi dari kajian ini masih melebihi dari yang dijangkakan dari enjin satu kebuk biasa.*

INTRODUCTION

In the earlier investigations using the same engine, British Leyland Technology Ltd. specified a "base-line" test condition which they used as a standard/ reference for comparing performance at other test conditions. The base-line conditions were at engine speed of 2000 rpm., pre-chamber air flow 6 % of total air inlet and pre-chamber air fuel ratio (AFR) of 6 : 1. This condition was reported to give the best emissions compromise for the engine as compared to the previous Leyland experiments,.

The tests at the reference running condition revealed some differences in engine performance as compared to those conducted previously at British Leyland. In particular, unburned hydrocarbon emissions were significantly lower in the Leeds tests. Unburned hydrocarbons (UHC) emissions were considered to be the major problem with the engine. Hence further consideration was given to the differences between the two sets of results. A number of possible explanations for the lower UHC emissions was explained. These included possible differences in carburation methods. The Leeds carburetion method was likely to result in increased pre-chamber mixture temperature, with consequent improvements in fuel evaporation and pre-chamber mixture homogeneity. It would also effect the transfer of charge between the two chambers during induction and compression, with possible implications for pre-chamber equivalence ratio at ignition. This change might account for the small differences in burning rates, exemplified by the differences in maximum best torque (MBT) ignition timing, between the two set of results. Reported in this paper are experiments designed to explore this difference; in particular, examining the effects of: pre-chamber air temperature.

The reduced UHC emissions recorded at Leeds, vis a' vis those noted in British Leyland, could be related to differences in pre-chamber carburation methods. The vaporizer system used at Leeds would probably have led to increased pre-chamber mixture temperature. It was therefore decided to investigate the effects of this mixture chamber temperature, by raising its value from the 30°C used in the reference tests to 45°C in a comparative test series.

To achieve the 45°C mixture temperature, it was necessary to heat the fresh inlet air to about 65°C by means of an electric tape heater, which was wrapped around the pre-chamber air inlet tube. The temperature of the air and the fuel vapour/air mixture were monitored using thermocouples.

EQUIPMENT

ENGINE

The engine was based on a 4 cylinder Triumph Slant-4 water cooled cylinder block. The engine detail shown in Table 1. The cylinder bore was 90.3 mm and it had a stroke of 78.0 mm. A piston was fitted to number one cylinder only. A three valve, pre-chamber, cylinder head was fitted to number one cylinder. The valves (intake, exhaust and pre-chamber) were actuated by cams on a single

Number of cylinder	: 1	Valve timing,	
Type	: S.I. dual chamber	*main chamber:*	
Cycle	: 4	inlet-open	: 16° BTDC
Bore	: 90.3 mm	inlet-close	: 56° ATDC
Stroke	: 78.0 mm	exhaust-open	: 56° BBDC
Volume displacement	: 499.5 cc	exhaust-close	: 16° ATDC
Connecting rod length	: 129.5 mm		
Pre-chamber volume	: 5 cc (nominally 10%)	*pre-chamber:*	
		inlet-open	: 20° ATDC
Throat size	: 7.94 mm	inlet-close	: 20° ABDC
Compression ratio	: 9.33 : 1		

TABLE 1. Engine details

overhead camshaft, driven by the crankshaft by means of a chain. Shown in Figure 1 is a cross section of the cylinder head fitted to the working cylinder. The engine crankshaft was fitted with an extension to drive, via a flexible coupling, a shaft encoder; the latter drove the data acquisition system as outlined in a subsequent section of this section.

The main chamber carburettor was an SU type AUB9203, and the fuel to the pre-chamber was supplied from the tank via a fine needle control valve, to a rotameter.

The pre and main chamber air flows used separate intake systems; the air supply to the main chamber was drawn in via a large surge tank fitted with a 16 mm diameter metering nozzle, made in accordance with the guidelines of British Standard Institution (BSI: 1042 (1981)).

The pre-chamber air flow-rate was measured by an air rotameter and this was fixed at 6 % of the air flow-rate into the engine in all experiments, as this amount proved to be the optimum in the earlier British Leyland study.

The cooling water outlet temperature was controlled using a commercial thermostat, fitted to the cooling water outlet on the engine block. This controlled the cooling water flow-rate, to give a constant 90°C water outlet temperature as monitored by a thermocouple. This temperature was maintained the same in all tests.

The engine was connected, by a flexible coupling, to a D.C motor type dynamometer. This was of 0 - 40 KW capacity, supplied by David Mc Clure Ltd. The dynamometer was governed using a Saftronic control system. If run at a set speed in the motoring mode, the dynamometer would automatically

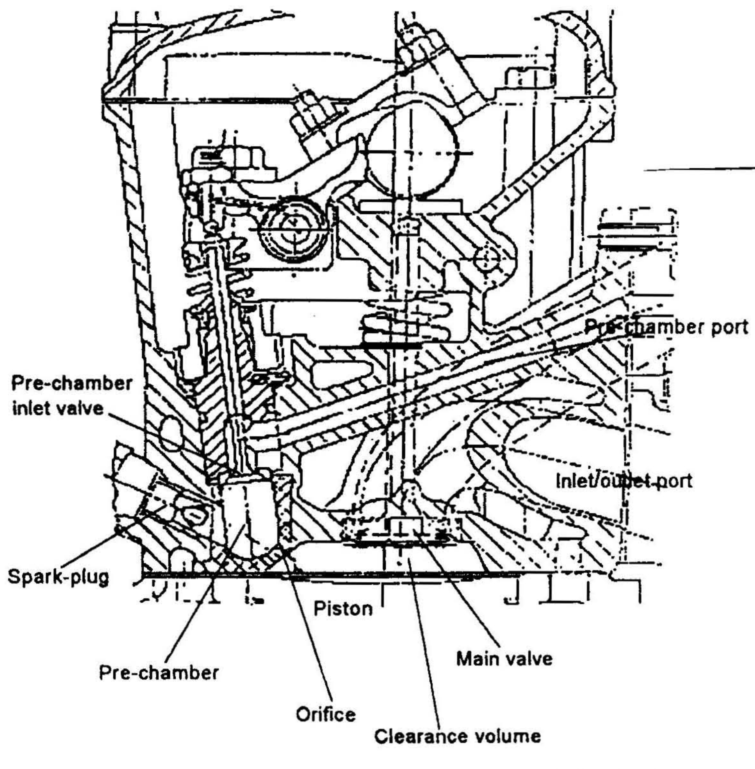

FIGURE 1. Schematic drawing of engine cylinder head

switch to the absorption mode when the engine's ignition switch was triggered and the engine generated sufficient power to maintain the set speed.

The torque developed by the firing engine was measured using a load cell supplied by Transducer (CEL) Limited. This had a range of 0 - 100 Newtons, this load was converted to an electric signal and displayed as torque on a meter supplied by Hottinger Baldwin Messtechnik. Dependent upon the direction of the rotation, the force on the load cell would be positive or negative. A switch at the control panel allowed the polarity of the signal to be changed. This allowed measurement of either firing or motoring torque for the engine.

ENGINE INSTRUMENTATION

The engine is coupled to the dynamometer by a flexible coupling; the control panel, consisting of cycle and timing selector, pressure transducer charge amplifiers, speed dial and torque meter dial.

A commercial shaft encoder was used; this was of Type 320D/360, supplied by Hohner Automation Ltd.

The pulses created were sent to an external clock, incorporated in a VAX-8600 computer, to instruct the analogue to digital converter (ADC) to take samples each time a pulse was generated by the encoder.

The ignition system used comprised a Mobelec Magnum contactless electronic ignition unit, a standard ignition coil, a 12 V battery and a commercial spark plug.

The control system counted pulses from the shaft encoder and triggered the spark at the required angle. The spark timing could be set to any crank-angle between 99° BTDC and 99° ATDC. A switch allowed either 2 or 4 stroke engine operation to be selected; ignition could be restricted to alternate or every 3rd, 4th or 5th cycle if required. The system provided spark and TDC signals to feed to the on-line computer; it also "gated" the shaft encoder pulse which triggered the computer's data acquisition system.

Engine cylinder pressure is clearly an important parameter; it provides information to permit calculation of the indicated power output and can be used as a basis for estimation of fuel mass burning rate. In the study reported here, the pressure in each chamber was measured using a piezo electric transducer; these were of type 6121, supplied by Kistler Instrumente A.G. They were capable of measuring rapidly varying pressure in the range of 0 div 250 bar, while maintaining good linearity and having a very good frequency response.

The signal from each transducer was transmitted, via two balanced leads, to a type 5007 Kistler universal electrostatic charge amplifier; this converted the electrostatic signals into a voltage. The charge amplifier was allowed to warm up and stabilize for a period of at least half an hour, before use either in calibration or experimental work.

ON-LINE DATA ACQUISITION

A Micro-Consultants very high speed ADC unit was used to convert the pressure signals (from both chambers), as well as spark and TDC signals, to a digital form. This unit allowed a maximum data acquisition of 14 bits at 200 kHZ. The ADC unit was interfaced to the VAX-8600 minicomputer via a direct memory access interface (DR-11B). The ADC system also allowed an external "gate" input, this only allowed sampling to occur when an external supply of +5 volts was supplied to the gate channel.

Once a signal was sampled, the information could be stored in the computer and immediately processed to yield output such as: pressure-crank angle diagram, pressure-volume diagram and indicated mean effective pressure (imep), the data to be used in the figures presented in this paper. The computer program used for this work was based largely on that developed by Hynes (1986).

GAS ANALYZERS

The system was designed to sample and measure the concentration of total unburned hydrocarbons, carbon monoxide, carbon dioxide, oxygen and NO_x in the engine exhaust. The system is set out diagrammatically in Figure 2. It includes sample probe, stop valves, heated filter, water traps, drying agents, three way valves and heated line with temperature control. The sample was fed to the hydrocarbon analyser via a continuously heated sampling line which kept the sample temperature at 150°C throughout, in order to prevent any condensation of the higher hydrocarbons. The gas samples fed to the other analysers were led via a water trap and tubes containing drying agents, as it was important to avoid water condensation in the instruments. The oxygen analyser sample was fed from the high range CO analyser, as the former analyser did not have a pump of its own.

TOTAL HYDROCARBON ANALYSER

The total unburned hydrocarbon concentrations were measured using an Analysis Automation Ltd. Series 520 Hydrocarbon Analyser; this incorporates a flame ionization detector (FID) for total unburned hydrocarbon measurement.

In the current work calibration was effected using a 400 ppm concentration of normal-hexane in nitrogen, the calibration (span) gas

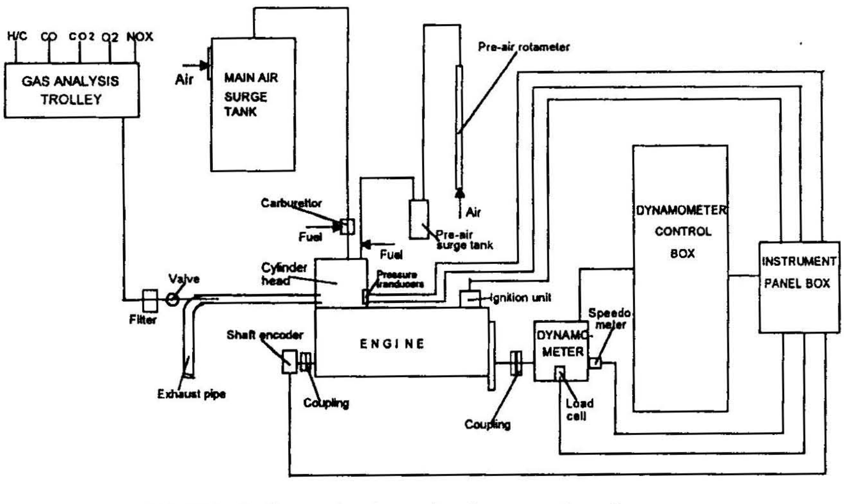

FIGURE 2. General schematic diagram of equipments

was supplied by the Special Gases Division of the British Oxygen Company (BOC). The analyser ion current output is a function of the carbon number, i.e. twice the concentration of propane (C3H8) would be required to give the same response as that of n-hexane (C6H14). The instrument therefore yielded the total unburned hydrocarbon concentration in terms of the equivalent concentration of hexane. The manufacturer's claimed accuracy for the unit was ± 1.5 % of full scale deflection (FSD); it had ranges 0-10, 0-100, 0-1000 and 0-10,000 ppm by volume.

INFRA RED ANALYSERS

Carbon monoxide concentrations were measured using two Grub-Parsons Series 20 infra red gas analysers, one with ranges of 0 - 0.1 % and 0 - 0.5 % the other having ranges of 0 - 3.0 % and 0 - 15.0 % by volume. Carbon dioxide concentrations were measured using a similar type of analyser, with ranges of 0 - 15.0 % by volume. The quoted accuracy of both instruments was ± 1 % full scale dial (FSD).

NO_x ANALYSER

A Thermo Electron Corporation chemiluminescence NO_x analyser was used to measure NO concentrations.

The principle of the chemiluminescence analyser is based upon the chemiluminescent gas phase reaction between ozone and nitric oxide. The reaction of ozone with nitric oxide, when heated under vacuum at 650°C, produces electronically exited molecules of nitrous oxide. When the electronically exited molecules decay, they emit light which can be measured using a photo multiplier. In the instrument this photo multiplier output was amplified and displayed. The light intensity was proportional to the nitric oxide concentration in the sample. Calibration was again performed by standardising with a known gas mixture. The instruments quoted accuracy was ± 1 % FSD and the unit had ranges of 0 - 25, 0 - 100, 0 - 250, 0 - 1000, 0 - 2500 and 0 - 10,000 ppm by volume.

TEST PROCEDURES

In the experimental work, considerable effort was made to ensure that variables assumed constant, such as mixture strength and inlet mixture temperature remained unchanged; if they did change the variation was not sufficiently great as to materially affect the results. Equipments had also to be used according to the manufacturer's recommendations.

EXPERIMENTAL RESULTS

ENGINE PERFORMANCE

It can be seen in Figure 3 that the effect of the increased pre-charge air temperature on engine performance was relatively marginal. Maximum power outputs were similar at corresponding throttle settings. Specific fuel

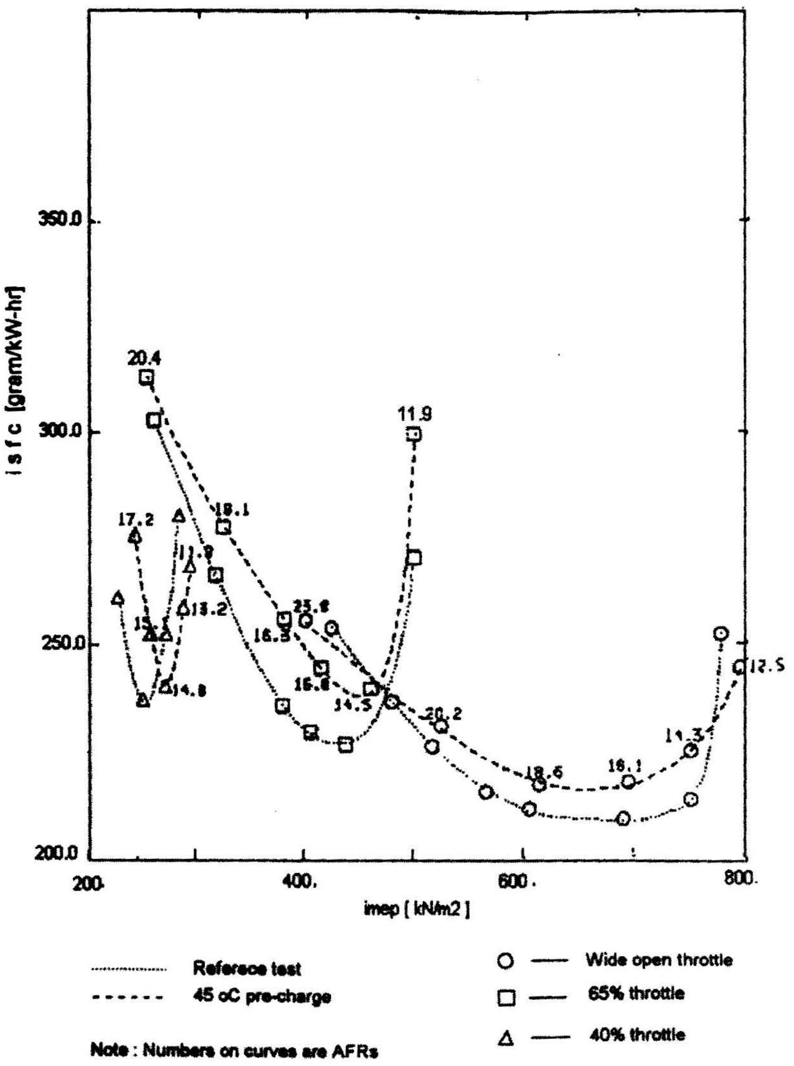

FIGURE 3. Effect of prechamber inlet charge temperature on engine performance

consumption was slightly worse (typically by about 4%) at each throttle setting. However, the engine was able to function at weaker ultimate AFR, without misfire, at both wide-open and 65% throttle settings, when the pre-chamber mixture temperature was higher.

UNBURNED HYDROCARBONS

From Figure 4 it can be seen that the increased pre-chamber mixture temperature led to marginally reduced UHC emissions as compared to the reference test, at corresponding power outputs and throttle settings. This reduction in UHC might be associated changes in pre-chamber mixture strength and/or temperature at ignition, consequent upon charge density changes affecting the flow between chambers during compression.

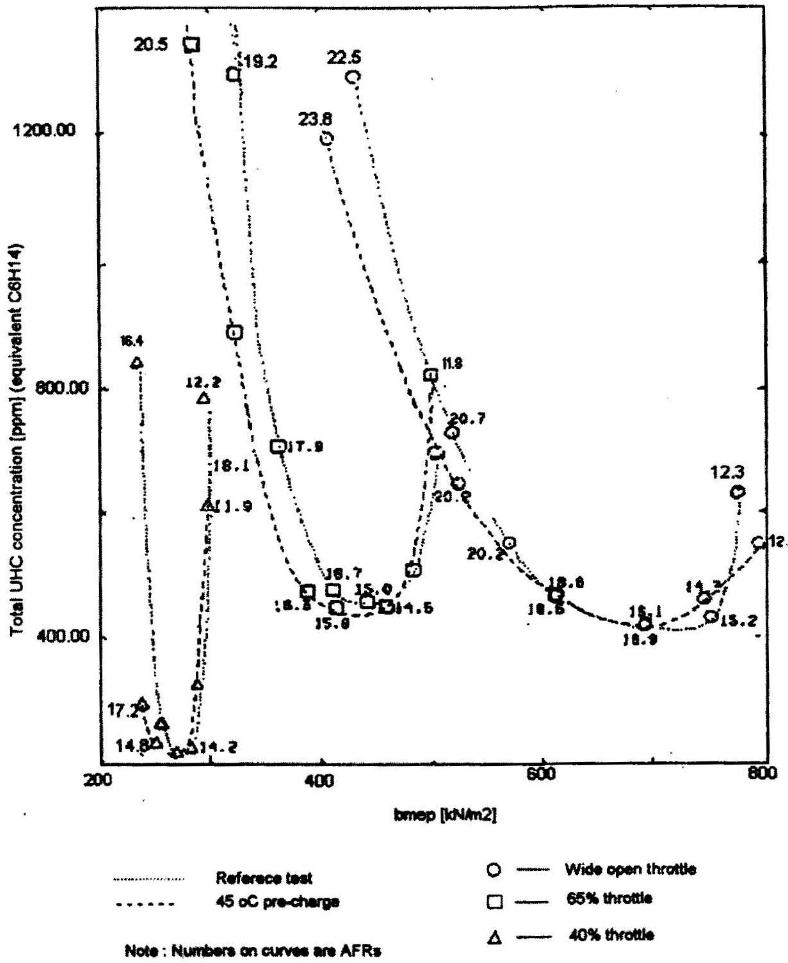

FIGURE 4. Effect of prechamber inlet charge temperature on total UHC emissions

Nevertheless the UHC emission changes resultant from the 15°C change in pre-chamber mixture temperature were small, compared to the differences between the Leeds and British Leyland UHC figures. Therefore, even though the pre-chamber mixture temperature at Leeds was likely to exceed that generated by the pre-chamber carburettor used by British Leyland, it is considered unlikely that this could alone account for the much reduced UHC output of the engine at Leeds.

CARBON MONOXIDE

With the higher pre-chamber inlet charge temperature one might expect marginally higher ultimate combustion and exhaust temperatures, as a result one might also anticipate increased partial oxidation to CO of hydrocarbons leaving crevices and quench layers late in the exhaust stroke. It can be seen in Figure 5 that the CO emissions were in fact slightly higher with increased pre-chamber mixture temperature (c.f. the reference tests) for all throttle settings. However, the differences were small.

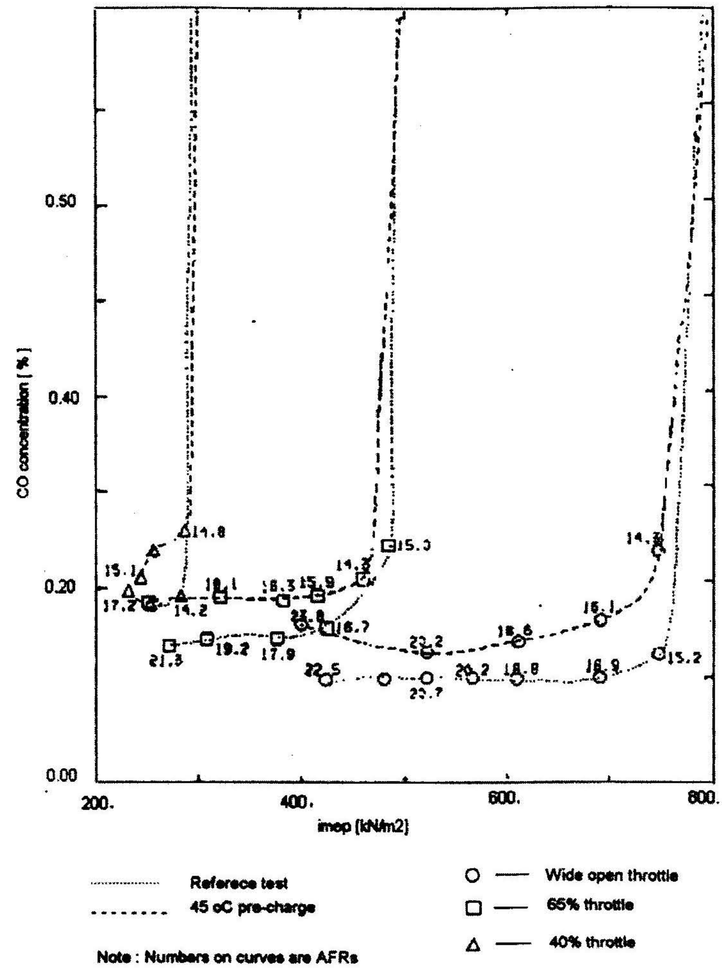

FIGURE 5. Effect of prechamber inlet charge temperature on CO emissions

NITROGEN OXIDES

The NO_x emissions at a given power output (and a given AFR) were higher with increased pre-chamber mixture temperature (vis a' vis the reference test condition). For the 40% throttle case, the trend is reversed. However this was not considered significant, given the very low NO_x levels recorded at the latter throttle setting. As discussed previously, NO_x levels are low because of the low combustion temperature resultant from the heavy throttling of the engine.

The generally higher NO_x levels were thought to be associated with the slightly higher combustion temperatures which are likely to follow from the higher pre-chamber charge temperature.

CONCLUSIONS

Reported in this paper are the effects of pre-chamber charge temperature on engine performance and emissions.

Increased pre-chamber inlet charge temperature yielded marginally higher fuel consumption at all throttle settings; UHC emissions were marginally lower for the lean mixtures but otherwise unaffected. It is considered unlikely that this could alone account for the much reduced UHC output of the engine at Leeds. Carbon monoxide emissions increased slightly with higher pre-chamber inlet temperature at all throttle settings, although NO_x emissions were higher at wide-open throttle and lower at part throttle, and this could be due to the slightly higher combustion temperature resulting from the higher pre-chamber charge temperature.

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