A low emission vehicle operates an internal combustion engine with lean air fuel ratios over at least a portion of its operating load range. The vehicle satisfies EURO IV emission requirements with just a three way catalyst and without any NOX storage capability in the exhaust after treatment system. An electronic control unit is programmed to operate the engine such that 80% or less of any tail pipe NOX mass emitted by the vehicle is generated during lean operation of the engine whereby the vehicle satisfies the EURO IV emission requirements.
Low Thermal Inertia,

Tubular Exhaust Manifold

Close Coupled Catalyst

Located at 0.35m from exhaust manifold,

Volume: 85% of ESV

Cell density: 400CP/6

Hydrothermally aged at 1050 deg C,

2% O₂, 10% H₂O for 4 hours

Fig. 1b.
LOW EMISSION VEHICLE

FIELD OF INVENTION

This invention relates to internal combustion engines and emissions standards for internal combustion engines, and more particularly, to the calibration, control and operation of direct injection engines and lean burn stratified charge engines so as to comply with certain emissions standards.

BACKGROUND

The recent and future introduction of increasingly stringent internal combustion engine emissions legislation around the world, such as the proposed US ULEV II & SULEV emissions regulations and European Euro IV regulations, has resulted in increasing pressure on engine and vehicle manufacturers to reduce engine emissions.

In meeting these stringent emissions standards, most MPI (manifold port injected) vehicles suffer a fuel consumption penalty even though overall tail pipe emission levels decrease. This increase in fuel consumption arises for various reasons including increased engine hardware requirements that serve to increase the level of parasitic loading on the engine, increased fuel consumption due to the catalyst light-off strategies used and an increase in fuel consumption that arises when the engine is calibrated to produce reduced levels of hydrocarbon emissions and NOx emissions.

Direct injection (DI) engines can promise fuel economy advantages through their ability to operate as lean burn and stratified charge engines. However, they also present certain challenges in that conventional three-way catalytic converters (TWC’s) have been found to be unsatisfactory for efficiently treating NOx emissions produced during lean burn operation. One present way of addressing this is by incorporating a further Lean NOx Trap (LNT) catalyst which acts to adsorb NOx gases emitted from the engine until the engine is operated with a rich air/fuel ratio that is sufficient to reduce the NOx adsorbed by the LNT catalyst. Accordingly, in current systems incorporating an LNT, it has been found necessary for the engine to temporarily run with a rich air/fuel ratio to promote reduction of NOx stored/trapped on the LNT. This requirement for rich operation reduces the fuel consumption benefit that is available from direct injection engines.

There have also been found to exist certain other issues with the use of LNTs. Due to the precious metal loadings necessary on such LNTs, significant cost increases are likely to be incurred for any DI engine incorporating such an LNT. Furthermore and equally prohibitive is the sensitivity of an LNT to sulphur. Currently available fuels typically contain a significant proportion of sulphur which has been found to effectively “poison” an LNT such that after a certain period of time it is no longer effective in trapping and treating NOx. In many countries including the United States of America, low sulphur content fuel is still not readily available. It is therefore not possible at present to effectively use an LNT on vehicles to be driven in the U.S. and other such countries where the emission regulations require strict control of NOx emissions.

Under these circumstances, it would be preferable to be able to operate the DI engine such that it is only necessary to use a conventional catalytic converter such as a TWC without the need for an LNT catalyst. In this way, many of the advantages of adopting DI could be realised without the need to address the cost and durability problems associated with an LNT.

Some of the above issues are highlighted in a paper presented to the Society of Automotive Engineers in 2000, “A New Approach to Meeting Future European Emissions Standards with the Orbital Direct Injection Gasoline Engine", SAE Technical Paper Series SAE 2000-01-2913, Brogan et al, wherein the Applicants detail their efforts to produce a vehicle satisfying European Emissions requirements for 2005, known as the Euro IV requirements. At the time, the vehicle discussed in this paper was unable to satisfy Euro IV requirements without a NOx storage and reduction catalyst.

It is an object of the present invention to provide a low emission vehicle operating with lean air fuel ratios over at least a portion of its operating load range and that satisfies Euro IV emissions requirements.

SUMMARY OF INVENTION

With the above in mind, there is provided according to the present invention, a passenger vehicle having an engine equipped with a direct injection fuel system and an exhaust system comprising a catalyst with low NOx conversion efficiency under lean air fuel ratio operating conditions, the catalyst receiving engine out exhaust emissions and outputting treated exhaust emissions, the engine further comprising an electronic control unit for controlling operation of said engine and said electronic control unit adapted to operate said engine with lean air fuel ratios over more than 50% of the MVEG-B drive cycle and satisfying Euro IV emission requirements over said drive.

Preferably the catalyst has near zero percent NOx conversion efficiency under lean air fuel ratio operating conditions. Preferably the catalyst is a three way catalyst (TWC).

Preferably the vehicle has a fuel consumption in the order of 8 litres per 100 kilometres or less over the drive cycle and more preferably the fuel consumption is in the order of 7.8 Litres per 100 kilometres or less.

Preferably the direct injection fuel system is a central injection fuel system. Preferably the direct injection fuel system is a spray guided direct injection fuel system. Preferably the direct injection fuel system is an air assisted fuel system. Preferably the air assisted fuel system is a spray guided fuel system. Preferably the air assisted fuel system is a central injection spray guided fuel system.

Preferably the catalyst has a volume of 110% of engine swept volume or less. Preferably the catalyst has a volume in the order of 85% of engine swept volume.

Preferably the vehicle is adapted to operate with a lean air fuel ratio under steady state cruise conditions in the order of 50 km/h or less.

Except for overrun cut conditions, it is possible that the vehicle operates with lean air fuel ratios of less than 25:0:1 and preferably said vehicle operates with a lean air fuel ratio in the range of 18:0:1 to 20:0:1 for vehicles speeds in the order of 50 km/h.
Preferably, the electronic control unit is adapted to operate said engine with lean air fuel ratios over approximately 70% of the MVEG-B drive cycle. Preferably, the engine is adapted to operate with stoichiometric or rich air fuel ratios when the vehicle speed is greater than 50 km/hr or during transient operating conditions. Preferably, engine out NOx mass for lean air fuel ratios over the Euro IV drive cycle is 80% or less of the Euro IV standard. Preferably, the electronic control unit is programmed to operate the engine with a lean air fuel ratio for loads having a NOx mass flow rate less than the Euro IV requirement.

There is further provided according to the present invention a vehicle having an internal combustion engine with a direct injection fuel system and an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine with at least lean and stoichiometric air fuel ratios and wherein engine out NOx mass for lean air fuel ratios over the Euro IV drive cycle is 80% or less of the Euro IV standard whereby said vehicle has tail pipe emissions over the Euro IV drive cycle that satisfy the Euro IV requirement.

Preferably, said catalyst has a volume of 85% or less engine swept volume (ESV). Preferably, said vehicle is operated with a stoichiometric air fuel ratio for engine loads equivalent to 50 km/h cruise on the vehicle’s road load curve.

There is further provided according to the present invention a vehicle having a lean burn internal combustion engine, an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine over a Euro IV drive cycle such that 80% or less of any tail pipe NOx mass emitted by the vehicle is generated during lean operation of the engine whereby said engine satisfies the Euro IV emission requirements.

Preferably, 20% or less of any tail pipe NOx mass emitted by the vehicle is generated during stoichiometric operation of the vehicle.

There is yet further provided according to the present invention a vehicle having an internal combustion engine with a direct injection fuel system and an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine with a lean air fuel ratio for loads having a NOx mass flow rate less than the Euro IV requirement.

Preferably, said NOx mass flow rate is 80% or less than the Euro IV requirement. Preferably, said vehicle has tail pipe emissions equal to or less than the Euro IV requirement.

DESCRIPTION OF DRAWINGS

Preferably, embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1a is a schematic representation of an internal combustion engine capable of operating as a lean burn engine or a stratified charge engine;

FIG. 1b is a pictorial representation of an exhaust system and a three way catalyst,

FIG. 2a is an air fuel ratio scan for an operating point with fixed speed and fuelling level;

FIG. 2b details an alternate air fuel ratio scan for an operating point with fixed speed and fuelling level;

FIG. 3 is a graph depicting the road load curve for the vehicle with which Euro IV emissions were satisfied using the engine of FIG. 1a and the exhaust system of FIG. 1b;

FIG. 4a is a graph depicting the air fuel ratio of the engine of FIG. 1 when operated in a vehicle over a Euro IV drive cycle; and

FIG. 4b depicts a portion of the graph of FIG. 4a in greater detail.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

The present embodiments provide direct injection lean burn and direct injection stratified charge internal combustion engines that operate with lean air fuel ratios across at least part of the MVEG-B drive cycle and that comply with Euro IV emissions requirements without the need for an exhaust system with NOx storage capability. One preferred embodiment utilises a spray guided direct injection fuel system.

Emissions legislation is being introduced around the world that requires engine and vehicle manufacturers to reduce the emissions produced by various types of vehicles. An example of such legislation that is applicable to Europe is commonly referred to as the Euro III and Euro IV emissions targets and should be well known to those skilled in the relevant art.

The Euro III and Euro IV emissions targets for passenger vehicles powered only by gasoline in respect of HC, CO and NOx emissions are:

<table>
<thead>
<tr>
<th>TEST</th>
<th>EMISSIONS</th>
<th>UNIT</th>
<th>EC 2000 (EURO III)</th>
<th>EC 2005 (EURO IV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rev.</td>
<td>HC</td>
<td>g/km</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>ECE +</td>
<td>NOx</td>
<td></td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>EUDC</td>
<td>CO</td>
<td></td>
<td>2.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Passenger Vehicles (≤2.5 t gross vehicle weight)

To make these measurements of vehicle emissions, a vehicle is typically operated on a dynamometer. The dynamometer is caused to operate with a specific drive cycle that simulates certain real world driving conditions. Euro III and Euro IV have specific drive cycles over which the emissions referred to above are measured, these drive cycles being referred to as the ECE and the EUDC drive cycles. The ECE drive cycle is repeated four times and the EUDC drive cycle is operated only once. In total, this series of drive cycles is referred to as the MVEG-B drive cycle. The emissions requirements referred to above are measured over the MVEG-B drive cycle, which is approximately 11 kilometres in length.

The emissions that are measured are referred to as tail pipe emissions as they are emitted to atmosphere from the exhaust pipe (often referred to as the “tail pipe”) of the
vehicle. In a typical vehicle, emissions from the engine (often referred to as "engine out" emissions) are treated by an exhaust treatment system that typically utilises a catalytic converter which promotes further reduction and oxidation of engine out emissions so that the tail pipe emissions contain a greater proportion of \( \text{N}_2 \), \( \text{O}_2 \), \( \text{CO}_2 \), and \( \text{H}_2\text{O} \) than the engine out emissions. Hence the Euro III and Euro IV emissions specify maximum levels of tail pipe emissions of hydrocarbons, carbon-monoxide and oxides of Nitrogen for various classes of vehicles.

[0036] It is preferable that in meeting these emissions targets that the vehicle also have a fuel economy benefit over currently available MPI (Manifold Port Injected) engines and DI (Direct Injection) engines.

[0037] The Applicant has developed certain engines which utilise a two fluid direct fuel injection system. Simple application of such fuel injection systems to four stroke engines is not, in itself, sufficient to meet these emissions targets and further refinement is required before the above emissions targets can be met. In particular, it is necessary to calibrate an engine at various speed and load operating points in order for it to meet these emissions targets. Calibration however is a multi-variable, typically non-linear problem. In a direct injection engine, particularly, it involves consideration of variables such as fuel per cycle, air fuel ratio, and exhaust gas re-circulation levels.

[0038] To understand how these emissions targets may be met by use of a direct injection fuel system, the Applicant’s two fluid fuel injection system will first be described in some detail with reference to FIGS. 1a and 1b which are schematic representations of an engine 100 incorporating a dual fluid fuel injection system of the type described in the Applicant’s U.S. Pat. Nos. 4,693,224, RE 36768 and PCT Patent Application No. WO 99/28621, the contents of which are included herein by reference. Such an air-assist or dual fluid fuel system is particularly conducive to engine operation with a stratified fuel charge at certain engine operating points. Additional information on control strategies for use in controlling operation of such engines may also be found in the Applicant’s U.S. Pat. No. 4,800,862, U.S. Pat. No. 5,540,205 and are incorporated by reference.

[0039] The engine 100 utilises a fuel delivery injector 102 that delivers fuel directly to a combustion chamber of the engine 120. The fuel delivery injector utilises compressed air, supplied by a compressor 140, as a propellant for injecting fuel held in a holding chamber of the delivery injector 102 into the combustion chamber. Typically the delivery injector 102 is in fluid communication with a constant supply of compressed air and fuel is metered into a holding chamber within the delivery injector 102. A fuel injector of the type commonly used on MPI/PFI vehicles may be used as a metering device for metering quantities of fuel determined by an electronic control unit 114 to the holding chamber of the delivery injector 102.

[0040] The delivery injector is supplied with fuel and compressed air by either a combined fuel and air supply rail 120 or by a separate fuel supply rail and a separate air supply rail. The fuel and air supply rail 120 is in communication with a fuel supply circuit that includes a fuel tank 124, a fuel pump 128, a fuel pressure relief valve 126, a fuel filter 130 and a differential pressure regulator 132. The fuel and air supply rail 120 is also in communication with an air supply circuit that includes an air compressor 140 that has an air intake line 146 in communication with a silencer volume 147 and an inlet manifold 109 downstream from an air filter box 108. The compressed air supply circuit also includes an air pressure relief valve 148 and also communicates with the differential pressure regulator 132.

[0041] The differential pressure regulator 132 regulates the pressure of air and fuel supplied to the air and fuel rail 120 so that the pressure of the fuel is at a predetermined level above the pressure of the compressed air so that the fuel can be metered against the pressure of the compressed air.

[0042] The inlet manifold 109 contains an electronic throttle 106 that is actuated by the ECU 114 in response to a driver demand signal provided by an accelerator pedal sensor 112.

[0043] A charge of fuel delivered to the combustion chamber by compressed air from the delivery injector 102 is ignited at appropriate timings by a spark plug 118. The spark plug is activated upon receiving electrical energy generated by an ignition coil 116. The ignition coil is controlled by the ECU 114. The compressed air that delivers the fuel into the combustion chamber assists with atomising the fuel. Typical the fuel spray has a Sauter mean diameter (SMD) of less than 18 microns and may be as low as 7 microns depending on fuelling levels.

[0044] Raw engine exhaust gasses from combustion chambers of the engine 100 are delivered to a three way catalyst (TWC) 110. The TWC 110 promotes further oxidation of hydrocarbons and carbon monoxide in the exhaust gases so as to lower the level of emissions present in the engine output exhaust gasses before they pass to atmosphere. The TWC also reduces NOx (oxides of Nitrogen) to \( \text{N}_2 \) when the engine is operated with a stoichiometric or rich air fuel ratio.

[0045] A system allowing for the purging of fuel vapour from a carbon canister 134 associated with the fuel tank 124 is also provided. A carbon canister purge valve 136 communicates the carbon canister with the compressor 140 via conduit 138. The Applicant has developed such a system which is described in U.S. Pat. No. 5,245,974, the contents of which are included herein by way of reference. Further detail may also be found in Brogan et al referred to above and also incorporated by way of reference. When compared to existing MPI/PFI engines, the application of such a vapour purge system on a DI engine operated according to the preferred embodiment would enable vapour to be purged at all speeds and loads, the vapour canister capacity to be advantageously modified, and reduced purge fueling to be effected at light loads giving improved engine control.

[0046] In regard to the exhaust system and particularly the catalytic, it is known that TWCs have a preferred temperature window within which they promote conversion of emissions most efficiently. This window is typically elevated relative to ambient temperatures. Accordingly, to address the issue of a cold catalyst at start-up, an alternative mode of operation is suggested such that the catalyst may very quickly attain its light-off temperature and can hence commence high efficiency conversion of the engine emissions. In this regard, and either as an alternative to operating the engine in a lean mode at idle or together therewith, it is preferable that the engine undergo a "fast light-off" mode of operation to ensure
that the catalytic converter is heated to its light-off temperature as soon as possible. Such a mode of operation is described in the Applicant’s U.S. Pat. No. 5,655,365, the details of which are incorporated herein by reference. Further detail may also be found in Brogan et al referred to above and also incorporated by way of reference. This mode of operation requires, during initial start-up of the engine, retarding the ignition of the charge delivered to at least one cylinder of the engine to allow top dead centre in respect of the combustion cycle of said at least one cylinder of the engine and, while said ignition is so retarded, increasing the fuelling rate of said at least one cylinder to a level higher than that required when the engine is operating normally at idle. This assists in increasing the exhaust gas temperature of the engine to thereby heat the catalytic converter quickly to its light-off temperature. The timing of the introduction of the charge into the at least one cylinder may be maintained at before top dead centre. While this U.S. patent discloses one method of attaining fast catalyst light-off, it is to be appreciated that other suitable methods may possibly be used to facilitate a fast catalyst light-off.

[0047] The preferred embodiment may also provide an ability to perform post-oxidation or secondary air injection upstream of the TWC 110 in the exhaust system without the need for an auxiliary air pump or injector in the exhaust system. Such post-oxidation may be used to improve the catalyst efficiency and hence lead to a reduced level of tail-pipe emissions. Typically, the injection of secondary air may be effected by way of a dual injection strategy as discussed in the Applicant’s PCT Patent Application No. WO 99/28621. Additional information on post oxidation during light-off operation may also be found in Brogan et al, which again is incorporated by reference.

[0048] The engine 100 also utilizes Exhaust Gas Recirculation (EGR) by feeding exhaust gasses from an outlet manifold 154 to the inlet manifold 109 via an EGR conduit 150 and an EGR control valve 152. Use of EGR may provide certain emissions benefits at some load points, in particular it can assist with suppression of NOx emissions.

[0049] Engines such as the Ford ZETEC four cylinder four stroke two litre engine are suitable for modification so as to incorporate a direct injection fuel system of the type detailed above. Present embodiments utilised a 2.0 Litre Ford Zetec DOHC engine installed in a Ford Mondeo GLX vehicle with an inertia weight of 1360 kg. The engine had a compression ratio of 10.8. The exhaust valve cam provided retarded timings. Maximum exhaust gas recirculation (EGR) of 35% was provided. The transmission was a five speed manual gear box (FDR=3.84).

[0050] Other advantages such as the possibility of a reduced tumble/swirl requirement leading to improved full load performance through increased port flow and greater packaging flexibility for inlet port design may also be realised through the preferred embodiment. Still further, where a dual fluid fuel system is of the of the spray guided type where ignition can be effected directly off the issuing fuel spray, a flat top piston may be employed which can lead to advantages of reduced surface area in the combustion chamber, optimized squish and the use of a higher compression ratio. Further detail on spray guided combustion may be found in the Applicant’s Patent Application No. WO 01/29406, the contents of which are incorporated herein by way of reference. Information on poppet projections that are useful in effecting spray containment and assisting with implementation of a spray guided combustion chamber may also be found in the Applicant’s U.S. Pat. No. 5,551,638.

[0051] Importantly, the preferred embodiment allows engines having direct fuel injection to be sold in markets where low sulphur fuel is not readily available. Furthermore, and as alluded to hereinbefore, the cost of an LNT converter which is significantly higher than a conventional TWC, can be avoided where the DI engine is operated according to the present embodiments. Markets expected to have high sulphur fuels include the USA and Canada.

[0052] Present embodiments have complied With Euro IV emissions requirements using gasoline fuel with between 150 and 250 parts per million of sulphur. This is commonly regarded as a high sulphur fuel. In general terms, gasoline containing more than 50 parts per million of sulphur is a high sulphur fuel.

[0053] Referring now to FIG. 1b there is shown a pictorial representation of an exhaust system having a TWC without an LNT as utilised in achieving compliance with Euro IV. The TWC is located in a close coupled position at a length of 0.35 m from the exhaust manifold, although other distances could also be utilised depending on the precise characteristics of the catalyst selected. The exhaust manifold utilised a single tubular low thermal inertia construction. The TWC had a volume of 85% (engine swept volume) ESV with a cell density of 400 C/P. Its cross sectional area is 118.63 mm². Its minor axis is 80.8 mm, its major axis is 169.7 mm and its length is 83 mm.

[0054] It is believed that a TWC having a volume in the range of 85% to 110% of ESV would also be effective. Importantly the TWC may be generally classified as being of a type currently used on MPI/PFI vehicles to achieve Euro IV emissions standards. The TWC on which Euro IV was achieved had been hydrothermally aged at 1050° C., 2% O₂, 10% H₂O for four hours. This ageing is believed to be equivalent to a catalyst that has operated for 100,000 km. Improved emissions compliance is available with a fresh TWC that has not been aged. Three way catalysts are available from Johnson Matthey and TraFalgar Square, London, United Kingdom.

[0055] The TWC has low NOx conversion efficiency when treating exhaust emissions derived from operation of the engine under lean air fuel ratio conditions. Typically it is said to have 0% NOx conversion efficiency -under lean operating conditions.

[0056] Referring now to FIG. 2a there is shown a representative air fuel ratio scan for a vehicle having a four stroke engine with an air assisted direct injection spray guided fuel system. The air fuel ratio scan details engine out emissions of hydrocarbons, carbon monoxide, NOx and road force for different air fuel ratios when the engine is operated with the same engine speed and fuelling level per engine cycle.

[0057] From the graph it can be seen that at any particular operating point, the engine can be calibrated to produce engine out emissions over a wide range and also to transmit road force within a particular range.

[0058] To generate the scan, the vehicle is operated on a dynamometer. Throttle position is varied to change the air
fuel ratio. Ignition timing, fuel injection timing, exhaust gas recirculation levels are varied so as to achieve the same engine speed.

[0059] Referring now to FIG. 2b, there are shown the NOx and road force curves of FIG. 2a, though it should be noted that the axis for road force has been contracted to the range of 0-200 Newton and so the relative positions of the road force and NOx curves have changed. Four points are identified on the scan, Point A, Point B, Point C and Point D. Point A may be referred to as a best fuel consumption point and Point B may be referred to as a best NOx emissions point. At point A, road force is approximately 110N and NOx is approximately 12 ppm. At point B, road force is approximately 95N and NOx is approximately 8 ppm. Hence there is a difference in road force between point A and point B of greater than 10% and a difference in NOx of approximately 33%. Road force is indicative of fuel consumption. Hence a variation in road force of approximately 10% between point A and point B produces a 33% change in NOx emissions levels. In contrast, at point C, NOx is approximately 6 ppm and road force is approximately 50N. Hence in going from point B to point C, a change in road force of approximately 50% has produced a change in NOx of approximately 25%. Similarly, in going from point A to point D, road force remains at approximately 110N, however NOx has increased significantly to 26 ppm, a change of approximately 110%.

[0060] Hence to operate the engine with best fuel consumption for optimum NOx, an operating point near point A would be best selected and to operate with minimum NOx for optimum fuel consumption an operating point near point B would be best selected.

[0061] The vehicle of Brogan et al was calibrated for best fuel consumption and optimum NOx, whereas present embodiments are calibrated for best NOx with optimum fuel consumption. This selection of a best NOx calibration produced a greater fuel economy benefit than is believed available from the Brogan et al calibration. This increase in fuel economy benefit was available as the reduction in NOx emissions enabled the vehicle to operate with lean air fuel ratios over a greater proportion of the MVEG-B drive cycle. In particular, present embodiments operated with a stoichiometric air fuel ratio over 23% of the MVEG-B cycle. The embodiments also operated with an air fuel ratio between 14.6 and 20 over 33% of the MVEG-B cycle and operated with an air fuel ratio in excess of 20 over 43% of the MVEG-B cycle. Fuel consumption in the order of 8.0 Litres per 100 Kilometres or less over the MVEG-B drive cycle was achieved. In particular fuel consumption in the range of 8.0 to 7.5 Litres per 100 kilometres over the MVEG-B drive cycle is believed to be provided. Fuel consumption of 7.5 Litres per 100 Kilometres over the MVEG-B drive cycle represents a fuel economy benefit of approximately 13% over a base line MPI vehicle. Variations in the order of 4% between vehicles could be expected for a vehicle fleet operated in accordance with the present embodiments. Hence some vehicles may show a fuel consumption benefit in the order of 9% over a base line MPI vehicle. This corresponds with a fuel consumption of 7.8 Litres per 100 Kilometres over the MVEG-B drive cycle.

[0062] Referring now to FIG. 3 there is shown a road load curve for an embodiment being a Ford Mondeo vehicle in which was installed a direct injection engine and exhaust system of the type detailed in FIGS. 1 and 2 and on which the emissions levels detailed herein were achieved. The road load curve indicates the resistance experienced by the vehicle under steady state cruise conditions at various road speeds. The road load curve has superimposed thereon a second graph indicating engine out NOx flow in g/km at different road load speeds. To achieve these NOx flow rates the engine was provided with a best NOx calibration so as to minimise the engine out NOx flow rate at least over the lean operating load range.

[0063] The NOx flow rate is non-linear and it can be seen that at approximately the 70 km/h load point the engine out NOx flow rate has exceeded the Euro IV flow rate requirement in grams per kilometre. Accordingly the 70 km/h cruise was selected as the engine load at which stoichiometric operation should commence during the MVEG-B drive cycle. It can however be noted that the NOx flow rate at 60 km/h was less than the Euro IV requirement of 0.08 grams per kilometre, hence operation of an embodiment under lean steady state cruise conditions of 60 km/h appears to be possible.

[0064] The calibration that satisfied the Euro IV emissions standards with the catalyst detailed in FIG. 2 had target vehicle operation so that 80% or less of the tail pipe NOx emissions were generated under lean operating conditions and 20% or more of the tail pipe out NOx emissions were generated under stoichiometric operating conditions. This was achieved by operating the vehicle with lean air fuel ratio at cruise points on the road load curve where engine out NOx emissions were estimated to be less than the Euro IV requirement. This resulted in the engine being operated with a stoichiometric air fuel ratio at cruise points of 70 km/h or greater during the MVEG-B cycle. During the 50 km/h cruise, 35 km/h cruise, 32 km/h cruise and the 15 km/h cruise the engine was generally operated with a lean air fuel ratio. During the 50 km/h cruise the engine operated with a NOx flow rate of 0.00081 grams per second which corresponds with a NOx flow rate of 0.0583 g/km. At idle the engine operated with a NOx flow rate of 0.00026 g/s. Accordingly present embodiments operated with NOx flow rates in the range between 0.00081 g/s and 0.00026 g/s. The road force at the NOx flow rate of 0.00081 g/s was in the order of 250N and at idle the road force was zero Newtons (ON). An alternate embodiment may aim to operate the engine under lean operating conditions so that a NOx flow rate is 80% or less of the Euro IV requirement.

[0065] Referring now to FIG. 4a there is shown a graphical representation of the air fuel ratios utilised over the MVEG-B drive cycle 400. The air fuel ratios are indicated on the left hand index and correspond to the top one of the two graphs. The vehicle speed over the MVEG-B drive cycle is indicated by the right hand index, which corresponds with the lower of the two graphs. A horizontal broken line 440 indicates the stoichiometric air fuel ratio level. A succession of near vertical lines 442 indicate where the vehicle is operated in over-run cut. Over-run cut occurs where the operator has removed their foot from the accelerator pedal and the vehicle is decelerating. Typically, the throttle is closed during over-run cut and also fuelling to the engine is cut or substantially reduced, which provides for large air fuel ratio excursions 442 identified in the graph.
[0066] The MVEG-B drive cycle 400 is divided into the ECE 405 and the EUDC 410 drive cycles. The ECE drive cycle 405 is in turn divided into four identical cycles, each of which is referred to as an Elementary Urban Cycle 415.

[0067] The Elementary Urban Cycle 415 consists of a first 420, a second 422 and a third 424, and a fourth 426 steady state cruise points. The first steady state cruise point 420 is 15 km/h in first gear. The second steady state cruise point 422 is 32 km/h in second gear, the third steady state cruise point 424 is 50 km/h in third gear and the fourth steady state cruise 426 is 35 km/h in third gear. As detailed above this cycle is repeated four times in order to make up the ECE drive cycle 405.

[0068] The EUDC drive cycle consists of a fifth steady state cruise point 428 which is 70 km/h in fifth gear, a sixth steady state cruise point 430 which is 50 km/h in fourth gear, a sixth steady state cruise point 432 which is again 70 km/h in fifth gear, a seventh steady state cruise point 434 which is 100 km/h in fifth gear and an eighth steady state cruise point 438 which is 120 km/h in fifth gear.

[0069] Referring now to FIG. 46, the third Elementary Urban Cycle 415 is highlighted in greater detail. This Elementary Urban Cycle is linked to the air fuel ratio plot by a number of vertical lines. This is to indicate how the air fuel ratio plot (and hence engine operation) corresponds with the Elementary Urban Cycle 415. The vehicle is operated lean primarily over the ECE 405 drive cycle and hence the descriptive of the air fuel ratio over the Elementary Urban Drive cycle 415 is instructive of the engine calibration and operating points.

[0070] At point 444, the engine is at idle and the air fuel ratio is lean in the order of 25:0:1. At point 446 the vehicle is undergoing a first gear acceleration at approximately 1.04 m/s² and the engine is operating lean with air fuel ratio in the order of 19:0:1. At point 448 the vehicle is undergoing a 15 km/h steady state cruise in first gear with an air fuel ratio in the order of 25:0:1. The vehicle then decelerates back to idle. After resting at idle for, the vehicle, at point 450, accelerates in first gear at a rate of 0.83 m/s² up to a speed of 15 km/h. The air fuel ratio is lean during this period in the order of 19.0:1. At point 452 the vehicle then changes into second gear and accelerates at a rate of 0.94 m/s². The engine operates with a stoichiometric air fuel ratio during this acceleration. At point 454 the vehicle operates with a second gear steady state cruise at 32 km/h. The air fuel ratio returns to lean in the order of 20.0:1. At the end of the 32 km/h steady state cruise the vehicle decelerates back to being stationary and the engine enters over-run cut. At idle, the air fuel ratio returns to approximately 25:0:1. At the completion of this idle phase, the vehicle, at point 456, accelerates in first gear up to a speed of 15 km/h with an air fuel ratio in the order of 19.0:1. At point 458 the vehicle changes into second gear and accelerates with a stoichiometric air fuel ratio at a rate of 0.62 km/h up to a speed of 35 km/h, whereupon the vehicle experiences another gear change into third gear and a stoichiometric acceleration at a rate of 0.52 km/h. At point 460 the vehicle reaches a speed of 50 km/h and whilst remaining in third gear, enters a steady state cruise period, whereupon the vehicle switches back to lean operation with an air fuel ratio in the order of 19.0:1. At point 462 the vehicle completes this steady state cruise and decelerates down to 35 km/h under over-run cut conditions. At point 464 the vehicle operates under steady cruise conditions at 35 km/h with a lean air fuel ratio in the order of 20.0:1. The vehicle then decelerates back to a stationary position under over-run cut conditions and completes the third Elementary Urban Cycle 415.

[0071] The above calibration operates the engine with lean air fuel ratios over steady state cruise conditions up to 50 km/h. The engine is operated with stoichiometric air fuel ratios during acceleration periods, particularly in second, third and fourth gears. At steady state cruise speeds of 70 km/h the vehicle is operated with stoichiometric air fuel ratios.

[0072] During the EUDC drive cycle 410, the vehicle operates with a lean air fuel ratio during first gear acceleration upon commencing the cycle 410 and during the 50 km/h cruise 430, which is performed in fourth gear. The remainder of the EUDC drive cycle is performed under stoichiometric air fuel ratio operating conditions, apart from over-run cut conditions and possibly transient air fuel ratio behaviour during gear changes.

[0073] During stoichiometric operation, NOx conversion efficiency exceeding 90% was achieved. It was however found preferable to operate with a slightly rich air fuel ratio in the order of 14.4:1 or 14.3:1. There was preferably a delay in the order of 5 seconds after entering closed loop stoichiometric air fuel ratio operating conditions before moving to this richer air fuel ratio. Monitoring and control of the NOx conversion efficiency was preferably achieved through use of a second oxygen sensor located down stream of the TWC 110 that monitored and provided air fuel ratio control based on the oxygen storage capability of the TWC. The five second delay referred to previously was to allow the rear oxygen sensor to stabilise.

[0074] The graph indicates that for approximately 70 to 75% of the MVEG-B drive cycle 400 the engine operated with lean air fuel ratios and for approximately 25 to 30% of the MVEG-B drive cycle, 400 the engine operated with stoichiometric air fuel ratios. The lean operation includes lean steady state operating conditions and transient air fuel ratio operating conditions from lean to stoichiometric. The graph also indicates that during over-run cut conditions the engine operated with air fuel ratios exceeding 25:1. The transient air fuel ratio conditions were approximately 20% of the lean operating conditions, the lean steady state operating conditions were approximately 40% of the operating conditions and the over-run cut conditions were approximately 15% of the lean operating conditions.

[0075] Fuel consumption in the range of 8.0 to 7.5 Litres per 100 kilometres over the MVEG-B drive cycle was provided. When operating with fuel consumption in the order of 7.5 Litres per 100 kilometres over the MVEG-B drive cycle, the fuel consumption over the ECE drive cycle is in the order of 10.4 Litres per 100 kilometres of the ECE drive cycle and over the EUDC drive cycle, fuel consumption in the order of 5.8 Litres per 100 kilometres of the EUDC drive cycle.

[0076] The calibration achieved cycle average tail pipe NOx emissions of less than the Euro IV requirement over the MVEG-B drive cycle. Over the MVEG-B cycle an average engine out NOx of 0.061 g/km was produced during lean operating conditions. This represents engine out NOx during
lean operation of approximately 76% of the Euro IV standard. The TWC is assumed to have minimal NOx conversion efficiency under lean operating conditions and so the engine out NOx emissions under lean conditions also correspond with the tail pipe NOx emissions under lean operating conditions. An average tail pipe NOx of 0.007 g/km at stoichiometric operation was produced. This represents a total engine out NOx of 190% of the Euro IV standard during λ=1 (stoichiometric) operation. A total average tail pipe NOx for both lean operating conditions and λ=1 (stoichiometric) conditions of 0.068 g/km over the MVEG-B drive cycle was produced. This represents approximately 85% of the Euro IV standard. Over the ECE drive cycle total tail pipe NOx emissions of 0.136 g/km were produced and over the EUDC drive cycle tail pipe NOx of 0.027 g/km were produced.

[0077] Over the ECE cycle engine out hydrocarbon emissions of 3.67 g/km were produced and over the EUDC cycle hydrocarbon emissions of 1.385 g/km were produced which provided average engine out hydrocarbon emissions of 2.21 g/km over the combined ECE and EUDC cycle.

[0078] Over the ECE drive cycle tailpipe hydrocarbon emissions of 0.172 g/km with an aged TWC were achieved. Over the EUDC cycle tailpipe hydrocarbon emissions of 0.033 g/km with an aged TWC were produced. Over the combined ECE and EUDC drive cycles tailpipe emissions of hydrocarbons of 0.084 g/km with an aged TWC were achieved. This represents approximately 85% of the Euro IV standard with the aged TWC.

[0079] Compared with a base line Ford Mondeo MPI vehicle a fuel consumption benefit of between 9% and 13% was achieved.

[0080] Levels of exhaust gas recirculation of up to 35% are believed to be suitable when minimising NOx emissions from a direct injection engine and particularly an air assisted or dual fluid direct injection engine.

[0081] Alternate embodiments may calibrate stoichiometric operation of the engine so as to minimise fuel consumption without exceeding the Euro IV requirement. This providing a stratified charge or lean burn engine calibrated for minimum NOx during lean operation and minimum fuel consumption during stoichiometric operation whereby a TWC can be utilised in satisfying Euro IV emissions standards.

[0082] The embodiments detailed above provide low emissions vehicles capable of operating with lean air fuel ratios and of satisfying Euro IV emissions requirements without the need for NOx storage capabilities in the exhaust after treatment system. In particular Euro IV emissions requirements are satisfied by the present embodiments when operated at a three way catalyst and without NOx storage capability. The embodiments provide fuel consumption in the order of 8 Litres per 100 kilometres or less.

[0083] Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

1. A vehicle having an internal combustion engine with a direct injection fuel system and an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine with at least lean and stoichiometric air fuel ratios and wherein engine out NOx mass for lean air fuel ratios over the Euro IV drive cycle is 80% or less of the Euro IV standard whereby said vehicle has tail pipe emissions over the Euro IV drive cycle that satisfy the Euro IV requirement.

2. A vehicle as claimed in claim 1 wherein said catalyst has a volume of 85% or less engine swept volume (ESV).

3. A vehicle as claimed in claim 1 wherein said vehicle is operated with a stoichiometric air fuel ratio for engine loads equivalent to 50 km/h cruise on the vehicle's road load curve.

4. A vehicle as claimed in claim 1 wherein said engine is operated under lean steady state conditions with an air fuel ratio of 25:1 or less.

5. A vehicle as claimed in claim 1 wherein said engine is operated under lean transient conditions with an air fuel ratio of 20:1 or less.

6. A vehicle having a lean burn internal combustion engine, an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine over a Euro IV drive cycle such that 80% or less of any tail pipe NOx mass emitted by the vehicle is generated during lean operation of the engine whereby said engine satisfies the Euro IV emissions requirements.

7. A vehicle as claimed in claim 6 wherein 20% or less of any tail pipe NOx mass emitted by the vehicle is generated during stoichiometric operation of the vehicle.

8. A vehicle having an internal combustion engine with a direct injection fuel system and an electronic control unit and an exhaust system with a three way catalyst wherein the electronic control unit is programmed to operate the engine with a lean air fuel ratio for loads having a NOx mass flow rate less than the Euro IV requirement.

9. A vehicle as claimed in claim 8 wherein said NOx mass flow rate is 80% or less than the Euro IV requirement.

10. A vehicle as claimed in claim 8 wherein said vehicle has tail pipe emissions equal to or less than the Euro IV requirement.

11. A vehicle as claimed in claim 1 wherein the lean steady state air fuel ratio is less than 25:1.

12. A vehicle as claimed in claim 1 wherein lean steady state air fuel ratios are in the range between 25:1 and 20:1.

13. A vehicle as claimed in claim 1 the engine having an exhaust manifold with low thermal inertia.

14. A vehicle as claimed in claim 1 wherein said engine utilises an air assisted direct injection fuel delivery system.

15. A vehicle as claimed in claim 1 wherein said engine further comprises a spray guided direct injection fuel delivery system.

16. A vehicle as claimed in claim 1 wherein said engine is adapted to operate with high sulphur fuel.

17. A passenger vehicle having an engine equipped with a direct injection fuel system and an exhaust system comprising a catalyst with low NOx conversion efficiency under lean air fuel ratio operating conditions, the catalyst receiving engine out exhaust emissions and outputting treated exhaust emissions, the engine further comprising an electronic control unit for controlling operation of said engine and said electronic control unit adapted to operate said engine with
lean air fuel ratios over more than 50% of the MVEG-B drive cycle and satisfying Euro IV emission requirements over said drive cycle.

18. A passenger vehicle according to claim 18 wherein the catalyst has near zero percent NOx conversion efficiency under lean air fuel ratio operating conditions.

19. A passenger vehicle according to claim 17 wherein the catalyst is a three way catalyst (TWC).

20. A passenger vehicle according to claim 17 wherein the vehicle has a fuel consumption in the order of 8 litres per 100 kilometres or less over the drive cycle.

21. A passenger vehicle according to claim 20 wherein the fuel consumption is in the order of 7.8 Litres per 100 kilometres or less.

22. A passenger vehicle according to claim 17 wherein the direct injection fuel system is a central injection fuel system.

23. A passenger vehicle according to claim 17 wherein the direct injection fuel system is a spray guided direct injection fuel system.

24. A passenger vehicle according to claim 17 wherein the direct injection fuel system is an air assisted fuel system.

25. A passenger vehicle according to claim 24 wherein the air assisted fuel system is a spray guided fuel system.

26. A passenger vehicle according to claim 24 wherein the air assisted fuel system is a central injection spray guided fuel system.

27. A passenger vehicle according to claim 17 wherein the catalyst has a volume of 110% of engine swept volume or less.

28. A passenger vehicle according to claim 27 wherein the catalyst has a volume in the order of 85% of engine swept volume.

29. A passenger vehicle according to claim 17 wherein the vehicle is adapted to operate with a lean air fuel ratio under steady state cruise conditions in the order of 50 km/h or less.

30. A passenger vehicle as claimed in claim 29 wherein except for overrun cut conditions, the vehicle operates with lean air fuel ratios of 25.0:1 or less.

31. A passenger vehicle as claimed in claim 30 wherein said vehicle operates with a lean air fuel ratio in the range of 18.0:1 to 20.0:1 for vehicle speeds in the order of 50 km/h.

32. A passenger vehicle as claimed in claim 1 wherein said electronic control unit is adapted to operate said engine with lean air fuel ratios over approximately 70% of the MVEG-B drive cycle.

33. A passenger vehicle as claimed in claim 1 wherein the engine is adapted to operate with stoichiometric or rich air fuel ratios when the vehicle speed is greater than 50 km/hr or during transient operating conditions.

34. A passenger vehicle as claimed in claim 1 wherein engine out NOx mass for lean air fuel ratios over the Euro IV drive cycle is 80% or less of the Euro IV standard.

35. A passenger vehicle as claimed in claim 1 wherein the electronic control unit is programmed to operate the engine with a lean air fuel ratio for loads having a NOx mass flow rate less than the Euro IV requirement.

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