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[54] **TEMPERATURE CONTROL SYSTEM FOR EMISSION DEVICE COUPLED TO DIRECT INJECTION ENGINES**

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[51] **Int. Cl.**[6] **F01N 3/00**

[52] **U.S. Cl.** **60/274**; 60/286; 60/276; 60/303

[58] **Field of Search** 60/286, 274, 303, 60/311, 276

[56] **References Cited**

U.S. PATENT DOCUMENTS

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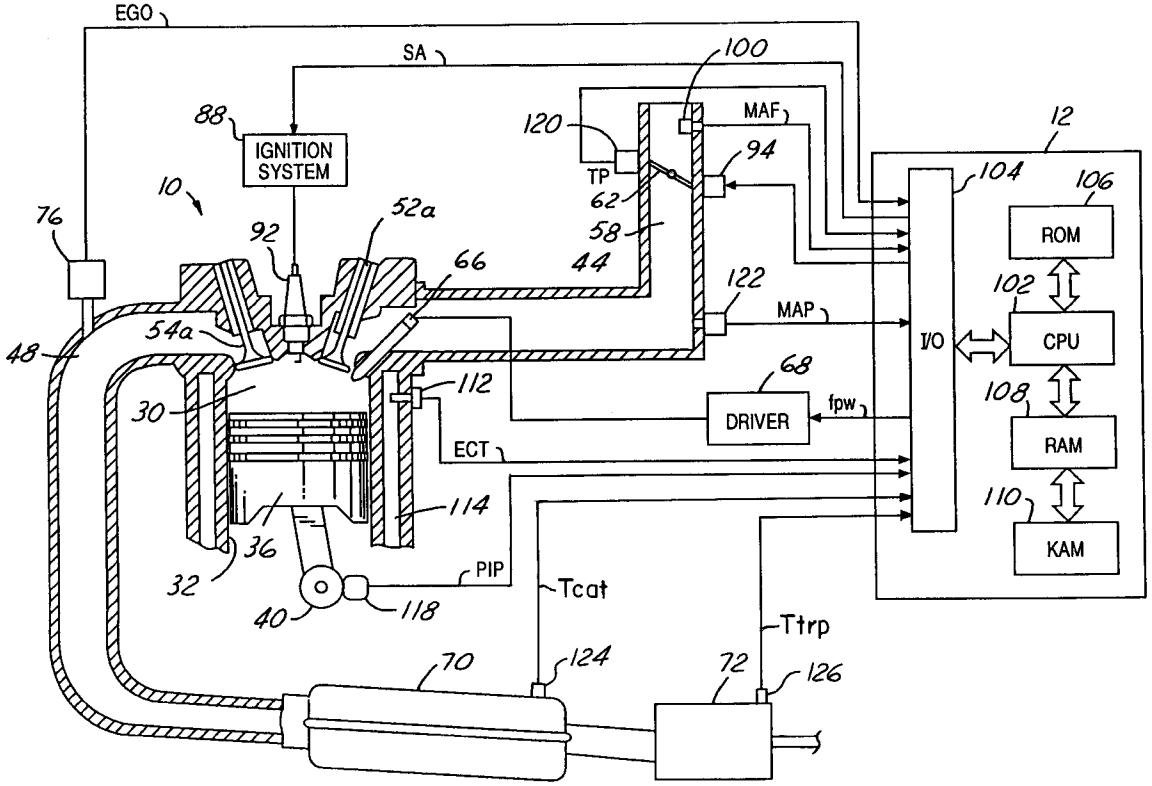
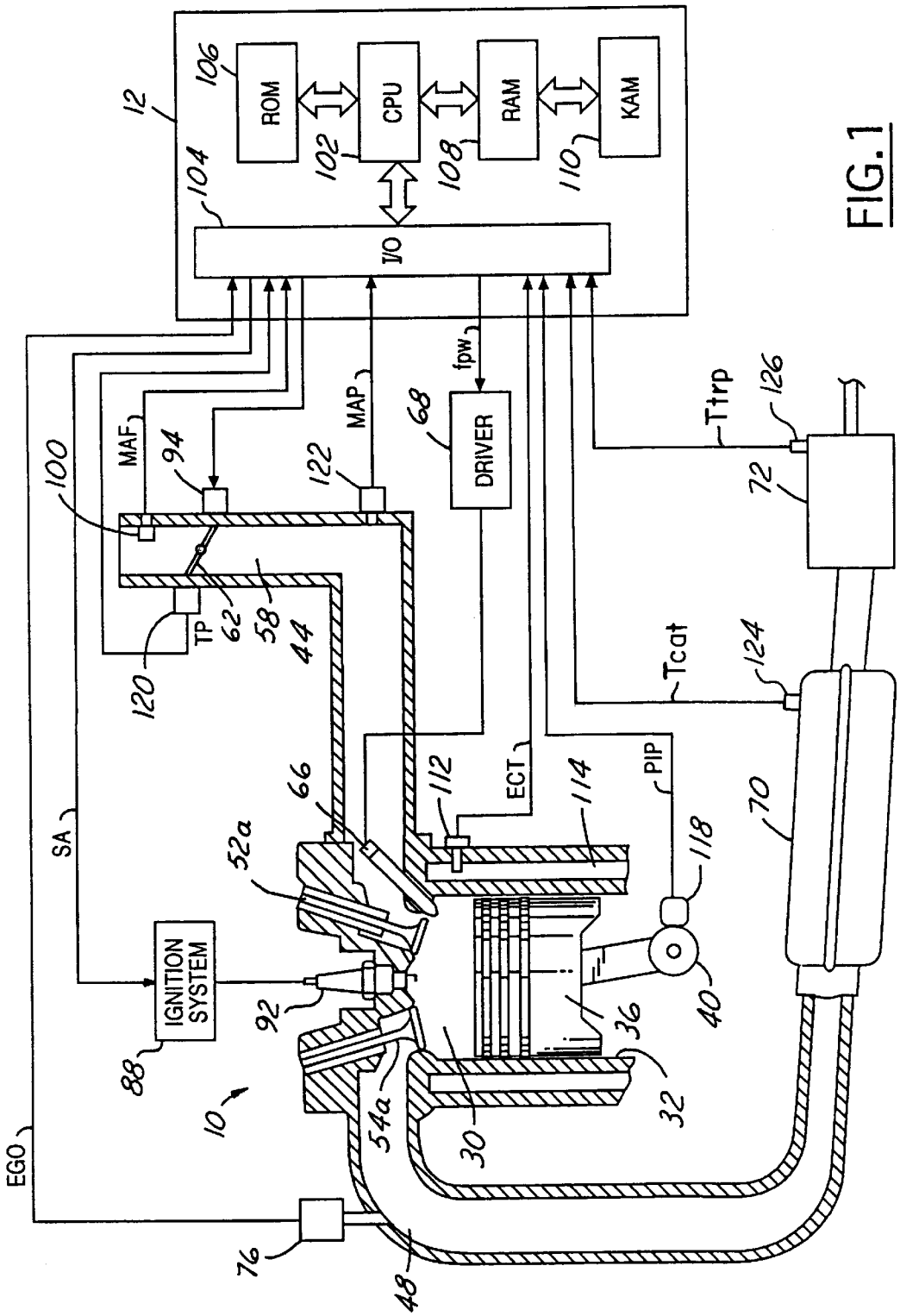
[57] **ABSTRACT**

A direct injection spark ignition engine is disclosed in which fuel is injected during a compression stroke of each combustion chamber for stratified mode operation. Additional fuel is injected into each combustion chamber during its exhaust stroke while operating in the stratified mode to provide an exotherm for heating the NOx trap in response to a low temperature indication. When total fuel injected into the combustion chamber exceeds a predetermined value, engine operation is switched from the stratified to the homogeneous mode.

8 Claims, 2 Drawing Sheets




ROM
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52a
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124
126

FIG. 1

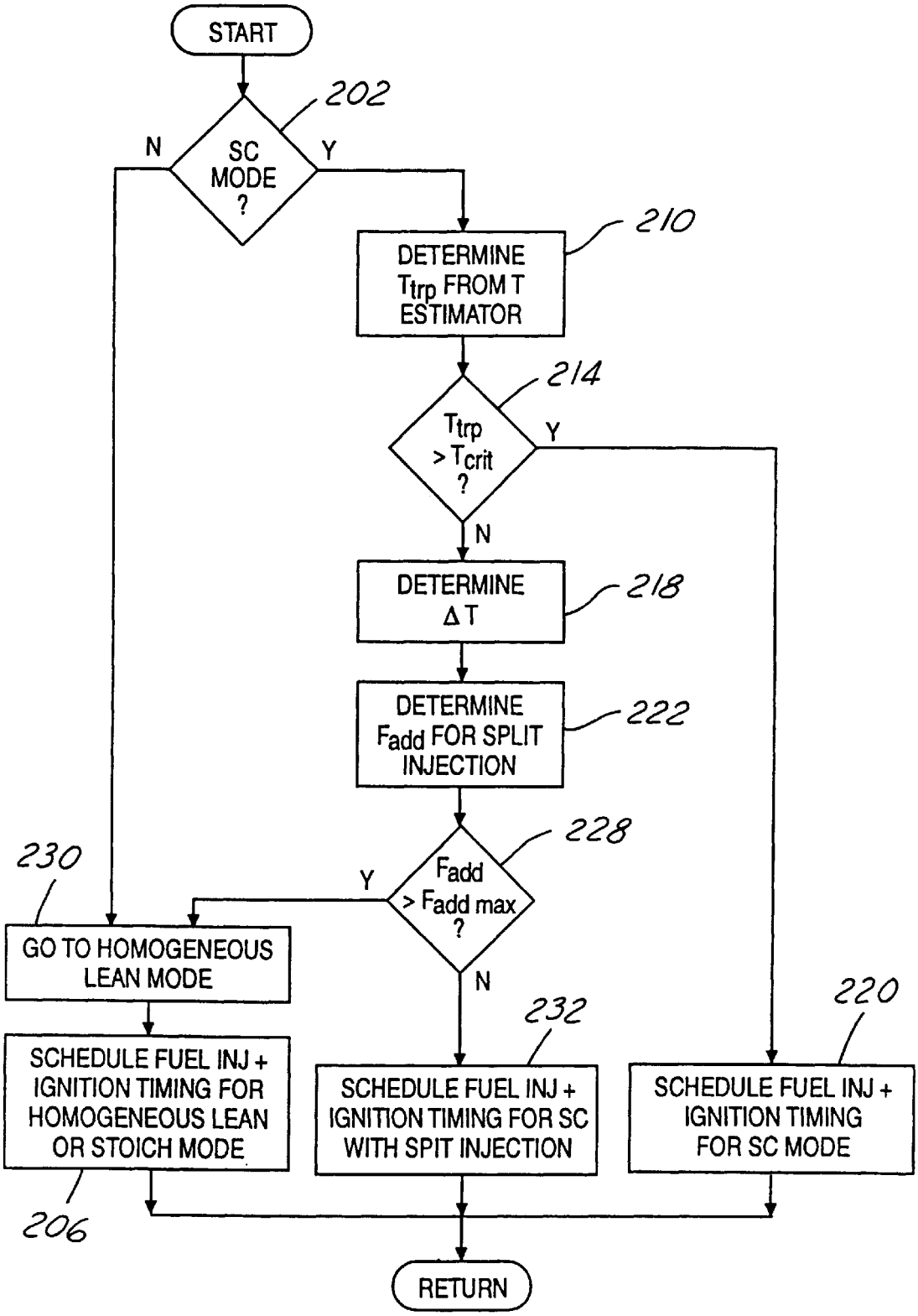
START
202
SC MODE ?
N
Y
210
DETERMINE Ttrp FROM T ESTIMATOR
214
Ttrp > Tcrit ?
Y
N
DETERMINE ΔT
218
DETERMINE Fadd FOR SPLIT INJECTION
222
228
Fadd > Fadd max ?
Y
N
230
GO TO HOMOGENEOUS LEAN MODE
SCHEDULE FUEL INJ + IGNITION TIMING FOR HOMOGENEOUS LEAN OR STOICH MODE
206
232
SCHEDULE FUEL INJ + IGNITION TIMING FOR SC WITH SPIT INJECTION
220
SCHEDULE FUEL INJ + IGNITION TIMING FOR SC MODE
RETURN

FIG.2

TEMPERATURE CONTROL SYSTEM FOR EMISSION DEVICE COUPLED TO DIRECT INJECTION ENGINES

BACKGROUND OF THE INVENTION

The field of the invention relates to temperature control of emission control devices coupled to direct injection spark ignition engines.

In direct injection spark ignition engines, the engine operates at or near wide open throttle during stratified air/fuel operation in which the combustion chambers contain stratified layers of different air/fuel mixtures. The strata closest to the spark plug contains a stoichiometric mixture or a mixture slightly rich of stoichiometry, and subsequent strata contain progressively leaner mixtures. The engine may also operate in a homogeneous mode of operation with a homogeneous mixture of air and fuel generated in the combustion chamber by early injection of fuel into the combustion chamber during its intake stroke. Homogeneous operation may be either lean of stoichiometry, at stoichiometry, or rich of stoichiometry.

Direct injection engines are also coupled to conventional three way catalytic converters to reduce CO, HC, and NOx. When operating at air/fuel mixtures lean of stoichiometry, a NOx trap or catalyst is typically coupled downstream of the three way catalytic converter to further reduce NOx.

The inventors herein have recognized that lean air/fuel operation may cause the catalytic converter and NOx trap to operate inefficiently. The inventors herein have also recognized numerous disadvantages in prior approached to heating catalytic converters. For example, retarding ignition timing is inefficient because engine surfaces such as cylinder walls will be heated in addition to heating exhaust gases. Further, the amount of heat which may be generated by retarding ignition timing is limited. And, retarding ignition timing is not feasible during stratified mode operation. The inventors also recognize that use of a variable length exhaust pipes to control NOx trap temperature is limited i8n the range of temperature change and not desirable because of cost and packaging.

SUMMARY OF THE INVENTION

An object of the invention herein is to control temperature of emission control devices coupled to direct injection spark ignition internal combustion engines without adding hardware and with minimal effect on fuel economy.

The above object is achieved, problems of prior approaches overcome, and the inherent advantages obtained, by providing a control method and system for a spark ignited four stroke engine having multiple combustion chambers coupled to an emission control device. In one particular aspect of the invention, the control method comprises injecting a first quantity of fuel directly into each of the combustion chambers to operate the combustion chambers at an average air/fuel mixture lean of stoichiometry; indicating when temperature of the emission control device is below a preselected temperature; and injecting an additional second quantity of fuel directly into each of the combustion chambers during an exhaust stroke of each of the combustion chambers to provide an exotherm for heating the emission control device in response to said low temperature indication.

An advantage of the above aspect of the invention is that temperature of the emission control device is maintained at a desired temperature for effective operation without creating wasted energy to heat the engine such as combustion chamber walls. A further advantage is that temperature of the emission control device is maintained at a desired temperature for effective operation without adding additional hardware.

In another aspect of the invention a control method is provided for a spark ignited four stroke engine having multiple combustion chambers with fuel injected directly into each combustion chamber and at least one of the combustion chambers being coupled to an emission control device and the combustion chamber has a homogeneous mode of operation with a homogeneous mixture of air and fuel and a stratified mode of operation with a stratified mixture of air and fuel. The method comprises injecting fuel into the combustion chamber during a compression stroke to operate the combustion chamber in the stratified mode; indicating when temperature of the emission control device is below a preselected temperature; injecting additional fuel into the combustion chamber during an exhaust stroke while the combustion chamber is operating in the stratified mode to provide an exotherm for heating the emission device in response to said low temperature indication; and switching from the stratified mode to the homogeneous mode and discontinuing the additional injection of fuel when total fuel injected into the combustion chamber exceeds a predetermined value. Preferably, the predetermined value of fuel occurs when total fuel injected during stratified operation, including the additional amount, is approximately equal to the fuel which would be expended during the homogeneous mode to produce substantially the same power. Stated another way, when the stratified mode no longer provides a fuel savings because of the additional fuel injected to maintain temperature of the emission control device, the engine air/fuel operating mode is switched to the homogeneous mode and injection of additional fuel is discontinued thereby maximizing fuel economy.

An advantage of the above aspect of the invention is that temperature of the emission control device is maintained at a desired temperature for effective operation without wasting any fuel.

DESCRIPTION OF THE DRAWINGS

The object and advantages of the invention claimed herein will be more readily understood by reading an example of an embodiment in which the invention is used to advantage with reference to the following drawings wherein:

FIG. **1** is a block diagram of an embodiment in which the invention is used to advantage; and

FIG. **2** is a high level flowchart which a portion of operation of the embodiment shown in FIG. **1**

DESCRIPTION OF AN EXAMPLE OF OPERATION

Direct injection spark ignited internal combustion engine **10**, comprising a plurality of combustion chambers, is controlled by electronic engine controller **12**. Combustion chamber **30** of engine **10** is shown in FIG. **1** including combustion chamber walls **32** with piston **36** positioned therein and connected to crankshaft **40**. In this particular example piston **30** includes a recess or bowl (not shown) to help in forming stratified charges of air and fuel. Combustion chamber **30** is shown communicating with intake manifold **44** and exhaust manifold **48** via respective intake valves **52***a* and **52***b* (not shown), and exhaust valves **54***a* and **54***b* (not shown). Fuel injector **66** is shown directly coupled to combustion chamber **30** for delivering liquid fuel directly

therein in proportion to the pulse width of signal fpw received from controller **12** via conventional electronic driver **68**. Signal fpw represents the fuel pulse width in seconds that is sent from controller **12** to driver **68** determining the time duration in which injector **66** is energized. Fuel is delivered to fuel injector **66** by a conventional high pressure fuel system (not shown) including a fuel tank, fuel pumps, and a fuel rail.

Intake manifold **44** is shown communicating with throttle body **58** via throttle plate **62**. In this particular example, throttle plate **62** is coupled to electric motor **94** so that the position of throttle plate **62** is controlled by controller **12** via electric motor **94**. This configuration is commonly referred to as electronic throttle control (ETC) which is also utilized during idle speed control. In an alternative embodiment (not shown), which is well known to those skilled in the art, a bypass air passageway is arranged in parallel with throttle plate **62** to control inducted airflow during idle speed control via a throttle control valve positioned within the air passageway.

Exhaust gas oxygen sensor **76** is shown coupled to exhaust manifold **48** upstream of catalytic converter **70**. In this particular example, sensor **76** provides signal EGO to controller **12** which converts signal EGO into two-state signal EGOS. A high voltage state of signal EGOS indicates exhaust gases are rich of stoichiometry and a low voltage state of signal EGOS indicates exhaust gases are lean of stoichiometry. Signal EGOS is used to advantage during feedback air/fuel control in a conventional manner to maintain average air/fuel at stoichiometry during the stoichiometric homogeneous mode of operation.

Conventional distributorless ignition system **88** provides ignition spark to combustion chamber **30** via spark plug **92** in response to spark advance signal SA from controller **12**.

Controller **12** causes combustion chamber **30** to operate in either a homogeneous air/fuel mode or a stratified air/fuel mode by controlling injection timing. In the stratified mode, controller **12** activates fuel injector **66** during the engine compression stroke so that fuel is sprayed directly into the bowl of piston **36**. Stratified air/fuel layers are thereby formed. The strata closest to the spark plug contains a stoichiometric mixture or a mixture slightly rich of stoichiometry, and subsequent strata contain progressively leaner mixtures. During the homogeneous mode, controller **12** activates fuel injector **66** during the intake stroke so that a substantially homogeneous air/fuel mixture is formed when ignition power is supplied to spark plug **92** by ignition system **88**. Controller **12** controls the amount of fuel delivered by fuel injector **66** so that the homogeneous air/fuel mixture in chamber **30** can be selected to be at stoichiometry, a value rich of stoichiometry, or a value lean of stoichiometry. The stratified air/fuel mixture will always be at a value lean of stoichiometry, the exact air/fuel being a function of the amount of fuel delivered to combustion chamber **30**. An additional split mode of operation wherein additional fuel is injected during the exhaust stroke while operating in the stratified mode is described later herein with particular reference to FIG. **2**. The split mode is used to create an exotherm for heating catalytic converter **70** and NOx trap **72**.

Nitrogen oxide (NOx) absorbent or trap **72** is shown positioned downstream of catalytic converter **70**. NOx trap **72** absorbs NOx when engine **10** is operating lean of stoichiometry. The absorbed NOx is subsequently reacted with HC and catalyzed during a NOx purge cycle when controller **12** causes engine **10** to operate in either a rich homogeneous mode or a stoichiometric homogeneous mode.

Controller **12** is shown in FIG. **1** as a conventional microcomputer including: microprocessor unit **102**, input/output ports **104**, an electronic storage medium for executable programs and calibration values shown as read only memory chip **106** in this particular example, random access memory **108**, keep alive memory **110**, and a conventional data bus. Controller **12** is shown receiving various signals from sensors coupled to engine **10**, in addition to those signals previously discussed, including: measurement of inducted mass air flow (MAF) from mass air flow sensor **100** coupled to throttle body **58**; engine coolant temperature (ECT) from temperature sensor **112** coupled to cooling sleeve **114**; a profile ignition pickup signal (PIP) from Hall effect sensor **118** coupled to crankshaft **40**; and throttle position TP from throttle position sensor **120**; and absolute Manifold Pressure Signal MAP from sensor **122**. Engine speed signal RPM is generated by controller **12** from signal PIP in a conventional manner and manifold pressure signal MAP provides an indication of engine load.

In this particular example, temperature Tcat of catalytic converter **70** and temperature Ttrap of NOx trap **72** are inferred from engine operation as disclosed in U.S. Pat. No. 5,414,994 the specification of which is incorporated herein by reference. In an alternate embodiment, temperature Tcat is provided by temperature sensor **124** and temperature Ttrap is provided by temperature sensor **126**.

Referring now to FIG. **2**, a process is described for maintaining the temperature of NOx trap **72**, and if desired, catalytic converter **70**, by use of the split mode injection timing previously referred to herein. When engine **10** is not operating in the stratified charge mode (SC) as indicated in step **202**, fuel injection and ignition timing are scheduled for the homogeneous lean mode or homogeneous stoichiometric mode (step **206**). Selection of homogeneous lean or stoichiometric mode is determined by other operating parameters such as desired power, fuel vapor purge, and NOx trap **72** purge.

When engine **10** is operating in the stratified mode (step **202**), temperature of NOx trap **72** (Ttrp) is determined from the Temperature estimator. As previously described herein, the Temperature estimator is described in U.S. Pat. No. 5,414,994, the specification of which is incorporated herein. Alternatively, the temperature of NOx trap **72** may be provided by temperature sensor **126**.

When NOx trap temperature Ttrp is greater than critical temperature (Tcrit), which is associated with lowest temperature for efficient trapping effectiveness of NOx trap **72** and HC oxidation of catalytic converter **70**, engine operation continues with fuel injection and ignition timing scheduled for stratified charge mode (steps **214** and **220**).

On the other hand, when NOx trap temperature Ttrap is less than critical temperature Tcrit (step **214**), difference in temperature ΔT is determined in step **218**. Additional quantity of fuel Fadd, which is proportional to ΔT is determined in step **222**. Additional quantity of fuel Fadd is injected during the exhaust stroke of each combustion chamber to introduce unburned HC into the exhaust stream. The HC will create an exotherm with the oxygen occurring during lean stratified operation to heat catalytic converter **70** and NOx trap **72**. In this manner, the temperature of NOx trap **72** is maintained above critical temperature Tcrit.

When additional fuel Fadd needed to raise NOx trap **72** temperature to the desired temperature is greater than the fuel savings associated with stratified engine operation, engine **10** is switched from the stratified mode to the homogeneous lean mode (steps **228** and **230**). Stated another

way, when additional fuel Fadd is greater than maximum fuel Faddmax (step **228**), engine **10** is switched to the homogeneous lean mode (step **230**). Fuel injection and ignition timing are then set for the homogeneous lean mode in step **206**.

On the other hand, when additional fuel Fadd is less than Faddmax (step **228**), stratified operation continues with additional fuel Fadd added as shown in step **232**.

Those skilled in the art may also practice the invention by using the above described process to more rapidly heat catalytic converter **70** during engine cold start. And, the invention may be used to heat NOx trap **72** to a temperature associated with purging sulfur oxides.

This concludes a description of an example in which the invention is used to advantage. Those skilled in the art will recognize that many modifications may be practiced without departing from the spirit and scope of the invention. Accordingly, it is intended that the invention be limited only by the following claims.

What is claimed:

1. A control method for a spark ignited four stroke engine having multiple combustion chambers with fuel injected directly into each combustion chamber and at least one of the combustion chambers being coupled to an emission control device and the combustion chamber has a homogeneous mode of operation with a homogeneous mixture of air and fuel and a stratified mode of operation with a stratified mixture of air and fuel, comprising:

injecting fuel into the combustion chamber during a compression stroke to operate the combustion chamber in the stratified mode;

providing an indication of temperature of the emission control device;

indicating when said emission control device temperature is below a preselected temperature;

injecting additional fuel into the combustion chamber during an exhaust stroke while the combustion chamber is operating in the stratified mode to provide an exotherm for heating the emission device in response to said low temperature indication; and

switching from the stratified mode to the homogeneous mode and discontinuing said injection of additional fuel when total fuel injected into the combustion chamber exceeds a predetermined value.

2. The method recited in claim **1** wherein said second quantity of fuel is proportional to a difference between said emission control device temperature and said preselected temperature.

3. The method recited in claim **1** wherein the emission control device comprises a catalytic converter.

4. The method recited in claim **1** wherein the emission control device comprises a NOx trap.

5. A control method for a spark ignited four stroke engine having multiple combustion chambers with fuel injected directly into each combustion chamber and at least one of the combustion chambers being coupled to an emission control device, comprising:

injecting fuel into the combustion chamber during a first time period corresponding to a compression stroke to operate the combustion chamber in a stratified mode with a stratified mixture of air and fuel;

indicating temperature of the emission control device;

providing a low temperature indication when said temperature indication is below a preselected temperature;

injecting additional fuel into the combustion chamber during a second time period corresponding to an exhaust stroke in response to said low temperature indication while the combustion chamber is operating in said stratified mode to provide an exotherm for heating the emission device; and

changing said fuel injection during said first time period to injecting fuel during a third time period corresponding to an intake stroke so that said stratified mixture of air and fuel is changed to a homogeneous mixture of air and fuel and also ceasing said additional fuel injection during said second time period when a total of fuel injected into the combustion chamber exceeds a predetermined value.

6. The method recited in claim **5** wherein the emission control device comprises a catalytic converter.

7. The method recited in claim **5** wherein the emission control device comprises a NOx trap.

8. The method recited in claim **5** wherein said second quantity of fuel is proportional to a difference between said emission control device temperature and said preselected temperature.

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