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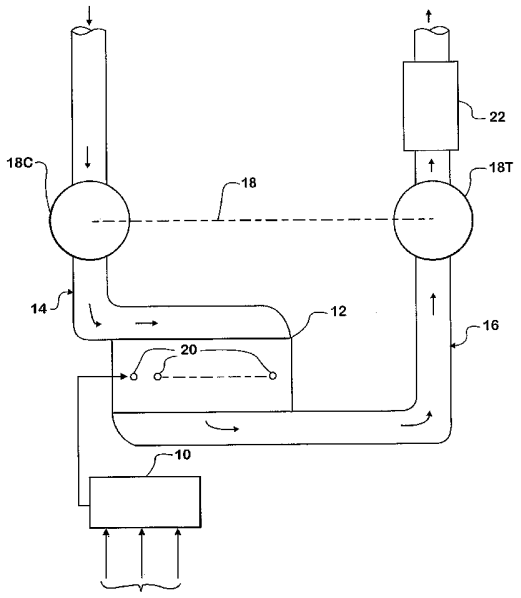
(54) **Title:** STRATEGY FOR QUENCHING INCIPIENT COMBUSTION OF RESIDUAL HOMOGENEOUS CHARGES DURING COMPRESSION STROKES IN A DIESEL ENGINE



(57) **Abstract:** During regeneration of a DPF (22), cylinders of a diesel engine (12) are fueled by main injections and post-injections. This creates exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the DPF to burn off. However, residual unburnt fuel will create an air-fuel mixture that is sufficiently homogeneous to begin combusting during a subsequent compression stroke. The invention quenches incipient combustion of the mixture during the compression stroke by injecting fuel into the respective cylinder before the next main injection of fuel.

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STRATEGY FOR QUENCHING INCIPIENT COMBUSTION OF RESIDUAL HOMOGENEOUS CHARGES DURING COMPRESSION STROKES IN A DIESEL ENGINE

Field of the Invention

This invention relates generally to diesel engines, such as those that propel motor vehicles. More specifically, the invention relates to a strategy for quenching incipient combustion of homogeneous air-fuel charges during compression strokes of such engines in advance of main fuel injections when some unburnt fuel, such as fuel that was not combusted during regeneration of a diesel particulate filter (DPF) in the engine exhaust system, remains in the engine cylinders after exhaust strokes.

Background of the Invention

An exhaust system of a diesel engine that comprises a DPF is capable of physically trapping diesel particulate matter (DPM) in exhaust gas passing through the exhaust system from the engine. This prevents significant amounts of DPM from entering the atmosphere. Soot is one constituent of DPM. Other constituents include the soluble organic fraction (SOF) and ash (i.e. lube oil additives etc.). The trapping of soot by a DPF prevents what is sometimes seen as black smoke billowing from a vehicle's exhaust pipe.

As the amount of trapped DPM increases, so does the exhaust back-pressure (EBP). A process commonly called regeneration counteracts increasing EBP by burning off accumulated particulates in a DPF. Commonly owned U.S. Patent Application No. 10/217,729, filed 13 August 2002, (Published Application No. US20040031262A1) describes

both a natural regeneration process and a forced regeneration process. The latter process occurs whenever the level of accumulated DPM becomes undesirably high and involves the use of the engine control system to raise exhaust gas temperature to a range that is high enough to burn off the accumulated DPM. Natural regeneration may occur at any time during normal engine operation when temperatures that are sufficiently high to burn off DPM occur in a DPF.

Known processes for forcing regeneration comprise adjusting both engine fueling and the timing of engine fueling to provide suitable constituency and temperature elevation for the exhaust gas to burn off trapped DPM. Post-injection of fuel occurring after main injection is one example of such a process. Post-injection is intended to provide O_2 depletion in conjunction with CO formation to assure that regeneration occurs.

Summary of the Invention

The present invention arises through the recognition that after combustion of post-injected fuel ceases, some quantity of fuel may remain unburnt in a cylinder. A sufficient quantity of such residual fuel, when mixed with charge air that enters the cylinder during the ensuing intake stroke, will create a potentially combustible homogeneous charge that will begin to burn when sufficiently compressed during the ensuing compression stroke. If such burning commences too early during the compression stroke, uncontrolled combustion results, typically an undesirable event.

The present invention is directed toward a solution for avoiding such an event.

Principles of the invention can be embodied in an engine control as part of an overall engine control strategy. The creation of an engine and an operating strategy that can avoid uncontrolled combustion of air-fuel charges during compression strokes in advance of main fuel injections, where the fuel component of the charges is residual unburnt fuel from a prior injection is seen as a beneficial advancement in diesel engine technology.

Consequently a fundamental aspect of the present invention relates to a novel strategy for avoiding such uncontrolled combustion of air-fuel charges formed from unburnt fuel remaining in the cylinders after exhaust strokes.

One general aspect of the claimed invention relates to a method of operating a compression ignition engine having an exhaust system comprising a particulate filter that traps combustible particulates in exhaust resulting from combustion of fuel in cylinders of the engine and that at times is regenerated by in-cylinder combustion that creates exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the filter to burn off.

The method comprises, during regeneration of the filter: fueling the cylinders with main injections of fuel at or near top dead center (TDC) that demarcates a compression stroke and a power stroke for a respective cylinder to cause a main combustion event in a respective cylinder; after completion of a main injection of fuel for a respective cylinder, injecting additional fuel into the respective cylinder during the power stroke to create exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the filter to burn off

when exhaust from the respective cylinder passes through the filter after the respective cylinder has been opened to the exhaust system while leaving in the respective cylinder after it has been once again been closed to the exhaust system, a residuum of unburnt fuel that, after introduction of charge air during an ensuing intake stroke, will create an air-fuel mixture that is sufficiently homogeneous to begin combusting during a subsequent compression stroke.

The method further comprises quenching any incipient combustion of the mixture during the compression stroke by injecting fuel into the respective cylinder before the next main injection of fuel..

Another general aspect relates to an engine that at times performs the method just described.

Still another general aspect relates to a method of operating a compression ignition engine to avoid, in cylinders of the engine during compression strokes, uncontrolled combustion of homogeneous air-fuel charges created by residual unburnt fuel from fueling that occurred prior to the compression strokes.

The method comprises injecting fuel into the cylinders prior to compression strokes for operating the engine while at times leaving residual unburnt fuel capable of mixing with new fresh air charges to form homogeneous air-fuel mixtures that would begin combusting during the compression strokes, and injecting some quantity of fuel into the respective cylinders during the compression strokes in advance of top dead center (TDC) to quench any incipient combustion of such homogeneous mixtures.

Yet another general aspect relates to an engine that at times performs the method just described.

The foregoing, along with further aspects, features, and advantages of the invention, will be seen in this disclosure of a presently preferred embodiment of the invention depicting the best mode contemplated at this time for carrying out the invention. This specification includes drawings, briefly described below, and contains a detailed description that will make reference to those drawings.

Brief Description of the Drawings

Figure 1 is a general schematic diagram of an engine embodying principles of the invention.

Description of the Preferred Embodiment

Figure 1 illustrates an engine control system 10 associated with a multi-cylinder diesel engine 12 that propels a motor vehicle. An example of such a vehicle is a truck in which the engine is a fuel-injected turbocharged diesel engine operatively coupled through a drivetrain to driven wheels for propelling the vehicle.

Engine 12 comprises an intake system 14 through which charge air is delivered to the engine cylinders, and an exhaust system 16 for conveyance of exhaust gases created by combustion within the engine cylinders from the engine. The turbine 18T of a turbocharger 18 is disposed in exhaust system 16, and the turbocharger compressor 18C is disposed in intake system 14.

A fueling system controlled by control system 10 comprises fuel injectors 20 that inject fuel at proper times during the engine cycles into the engine cylinders. Main fuel injections provide most of the power for operating engine 10 and whatever load is being driven by the engine. Various fuel injection strategies may at times also use pilot- and post-injections.

Exhaust gases are treated before they can enter ambient surroundings. One treatment device is a DPF 22 disposed in exhaust system 16 downstream of turbine 18T. DPF 22 is capable of physically trapping diesel particulate matter (DPM) in exhaust gas passing through exhaust system 16 from the engine cylinders, thereby preventing significant amounts of DPM from entering the atmosphere.

When too much DPM has accumulated in a DPF, the DPF is regenerated by a process commonly called forced regeneration. A known regeneration strategy comprises fueling the engine in a manner that raises the exhaust gas temperature and provides suitable exhaust gas constituents for burning off trapped DPM. Post-injection of fuel occurring after main injection is one example of such a strategy. Post-injection is intended to provide O_2 depletion in conjunction with CO formation to assure that regeneration occurs.

After combustion of post-injected fuel ceases however, some quantity of fuel may remain unburnt in the engine cylinders. A sufficient quantity of such residual fuel, when mixed with charge air that enters a cylinder through intake system 14 during the ensuing intake stroke, will create a potentially combustible homogeneous charge that will begin to burn when sufficiently compressed during the ensuing compression stroke. If such burning commences too early during the compression stroke,

uncontrolled combustion results, and that can have adverse effects on engine performance and durability, not to mention drivability of a vehicle being powered by the engine.

The invention is embodied in engine control system 10 as an aspect of overall engine control strategy to avoid uncontrolled combustion of air-fuel charges during compression strokes in advance of main fuel injections, where the fuel component of such charges is residual unburnt fuel from a prior injection, such as from post-injection of fuel for regenerating DPF 22.

During regeneration of DPF 22, the engine cylinders are fueled with main injections of fuel at or near top dead center (TDC) that demarcates a compression stroke and a power stroke for a respective cylinder. A main injection of fuel causes a main combustion event in a respective cylinder, providing most of the power for operating the engine at a desired speed for a given load.

After completion of a main injection of fuel for a respective cylinder, additional fuel is injected into the respective cylinder as a post-injection during the power stroke to create exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in DPF 22 to burn off when exhaust from the respective cylinder passes through DPF 22 after the respective cylinder has been opened to exhaust system 16. Fuel may be injected in sufficient amount to deplete essentially all O_2 while leaving some excess of fuel unburnt. After a respective cylinder has been once again been closed to exhaust system 16 after an exhaust stroke, the residuum of unburnt fuel will mix with charge air introduced through intake system 14 during an ensuing intake stroke.

This can create an air-fuel mixture that is sufficiently homogeneous to begin combusting during a subsequent compression stroke. Depending on specific conditions, such combustion may occur earlier than desired, in which case it is what amounts to an uncontrolled combustion event.

The invention avoids the occurrence of such events by quenching any incipient combustion of the mixture during the compression stroke. Quenching is performed by injecting fuel into the respective cylinder before the next main injection of fuel. Such an injection might be seen as analogous to a pilot injection or an injection intended to create some form of alternative diesel combustion such as HCCI combustion, but it differs from such an injection in that it is timed and quantitized to quench incipient combustion of residual fuel known to be present in the cylinder after the preceding exhaust stroke. In other words, the injecting of fuel into the respective cylinder during the compression stroke is timed to commence substantially when the mixture of air and residual fuel being compressed would otherwise begin to combust, thereby avoiding uncontrolled combustion in advance of desired initiation of combustion. Such uncontrolled combustion obviously is disruptive of desired engine operation.

By way of example, the timing of such a quenching injection may commence at about 20° in advance of TDC for conventional diesel combustion with main injection occurring substantially at TDC. Post-injection for DPF regeneration typically commences no earlier than about 60° after TDC.

While the invention is believed especially useful during DPF regeneration, its principles may be useful whenever unburnt fuel remains

in a cylinder in sufficient amount that would cause uncontrolled combustion during a compression stroke.

While a presently preferred embodiment of the invention has been illustrated and described, it should be appreciated that principles of the invention are applicable to all embodiments and uses that fall within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A method of operating a compression ignition engine having an exhaust system comprising a diesel particulate filter (DPF) that traps combustible particulates in exhaust resulting from combustion of fuel in cylinders of the engine and that at times is regenerated by in-cylinder combustion that creates exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the DPF to burn off, the method comprising, during regeneration of the DPF:

fueling the cylinders with main injections of fuel at or near top dead center (TDC) that demarcates a compression stroke and a power stroke for a respective cylinder to cause a main combustion event in a respective cylinder;

after completion of a main injection of fuel for a respective cylinder, injecting additional fuel into the respective cylinder during the power stroke to create exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the DPF to burn off when exhaust from the respective cylinder passes through the DPF after the respective cylinder has been opened to the exhaust system while leaving in the respective cylinder after it has been once again been closed to the exhaust system, a residuum of unburnt fuel that, after introduction of charge air during an ensuing intake stroke, will create an air-fuel mixture that is sufficiently homogeneous to begin combusting during a subsequent compression stroke; and

quenching any incipient combustion of the mixture during the compression stroke by injecting fuel into the respective cylinder before the next main injection of fuel.

2. A method as set forth in Claim 1 wherein the fueling of cylinders with main injections of fuel at or near top dead center (TDC) is timed to commence in advance of TDC for a respective cylinder.

3. A method as set forth in Claim 1 wherein the injecting of additional fuel during the power stroke is timed to commence no earlier than about 60° after TDC for a respective cylinder.

4. A method as set forth in Claim 1 wherein the injecting of fuel into the respective cylinder during the compression stroke is timed to commence substantially when the mixture being compressed would otherwise begin to combust.

5. A method as set forth in Claim 4 wherein the injecting of fuel into the respective cylinder during the compression stroke is timed to commence at about 20° in advance of TDC.

6. A compression ignition engine comprising:

cylinders within which combustion occurs;

an intake system for introducing air into the cylinders;

a fueling system for injecting fuel into the cylinders;

an exhaust system comprising a diesel particulate filter (DPF) that traps combustible particulates in exhaust resulting from combustion of fuel in the cylinders and that at times is regenerated by in-cylinder combustion that creates exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the DPF to burn off; and

a control system for controlling various aspects of engine operation including the injection of fuel into the cylinders by the fueling system

during regeneration of the DPF by a) causing the fueling system to inject main injections of fuel at or near top dead center (TDC) that demarcates a compression stroke and a power stroke for a respective cylinder to cause a main combustion event in a respective cylinder, b) causing the fueling system, during the power stroke for a respective cylinder, to inject additional fuel into the respective cylinder to create exhaust having sufficiently high temperature and suitable constituent content to cause particulates trapped in the DPF to burn off when exhaust from the respective cylinder passes through the DPF after the respective cylinder has been opened to the exhaust system while leaving in the respective cylinder after it has been once again been closed to the exhaust system, a residuum of unburnt fuel that, after introduction of air through the intake system during an ensuing intake stroke, creates an air-fuel mixture that is sufficiently homogeneous to begin combusting during a subsequent compression stroke, c) and quenching any incipient combustion of the mixture during the compression stroke by causing the fueling system to inject fuel into the respective cylinder before the next main injection of fuel.

7. An engine as set forth in Claim 6 wherein the control system causes the main injections of fuel at or near top dead center (TDC) to commence in advance of TDC for a respective cylinder.

8. An engine as set forth in Claim 6 wherein the control system causes injection of additional fuel during the power stroke to commence no earlier than about 60° after TDC for a respective cylinder.

9. An engine as set forth in Claim 6 wherein the control system causes the injecting of fuel into the respective cylinder during the

compression stroke to commence substantially when the mixture being compressed would otherwise begin to combust.

10. An engine as set forth in Claim 9 wherein the control system causes the injecting of fuel into the respective cylinder to commence at about 20° in advance of TDC.

11. A method of operating a compression ignition engine to avoid, in cylinders of the engine during compression strokes, uncontrolled combustion of homogeneous air-fuel charges created by residual unburnt fuel from fueling that occurred prior to the compression strokes, the method comprising:

injecting fuel into the cylinders prior to compression strokes for operating the engine while at times leaving residual unburnt fuel capable of mixing with new fresh air charges to form homogeneous air-fuel mixtures that would begin combusting during the compression strokes; and

injecting some quantity of fuel into the respective cylinders during the compression strokes in advance of top dead center (TDC) to quench any incipient combustion of such homogeneous mixtures.

12. A method as set forth in Claim 11 wherein the injecting of fuel into the cylinders prior to compression strokes comprises fueling the cylinders with main injections of fuel at or near top dead center (TDC) followed by post-injections of fuel during power strokes.

13. A method as set forth in Claim 12 wherein post-injections of fuel are timed to commence no earlier than about 60° after TDC.

14. A method as set forth in Claim 11 wherein the step of injecting some quantity of fuel into the respective cylinders is timed to commence substantially when the mixtures being compressed would otherwise begin to combust.

15. A method as set forth in Claim 14 wherein the step of injecting some quantity of fuel into the respective cylinders is timed to commence at about 20° in advance of TDC.

16. A compression ignition engine comprising:

cylinders within which combustion occurs;

an intake system through which air for combustion is delivered to the cylinders;

a fueling system for injecting fuel into the cylinders; and

a control system for controlling various aspects of engine operation including the injection of fuel into the cylinders by the fueling system by a) injecting fuel into the cylinders prior to compression strokes for operating the engine while at times leaving residual unburnt fuel capable of mixing with new fresh air charges delivered through the intake system to form homogeneous air-fuel mixtures that would begin combusting during the compression strokes, and b) injecting some quantity of fuel into the cylinders during the compression strokes in advance of top dead center (TDC) to quench any incipient combustion of such homogeneous mixtures.

17. An engine as set forth in Claim 16 wherein the control system causes the injecting of fuel into the cylinders prior to compression strokes by fueling the cylinders with main injections of fuel at or near top dead center (TDC) followed by post-injections of fuel during power strokes.

18. An engine as set forth in Claim 17 wherein the control system causes post-injections of fuel to commence no earlier than about 60° after TDC.

19. An engine as set forth in Claim 16 wherein the control system causes the injecting of some quantity of fuel into the respective cylinders to commence substantially when the mixtures being compressed would otherwise begin to combust.

20. An engine as set forth in Claim 19 wherein the control system causes the injecting some quantity of fuel into the respective cylinders to commence at about 20° in advance of TDC.

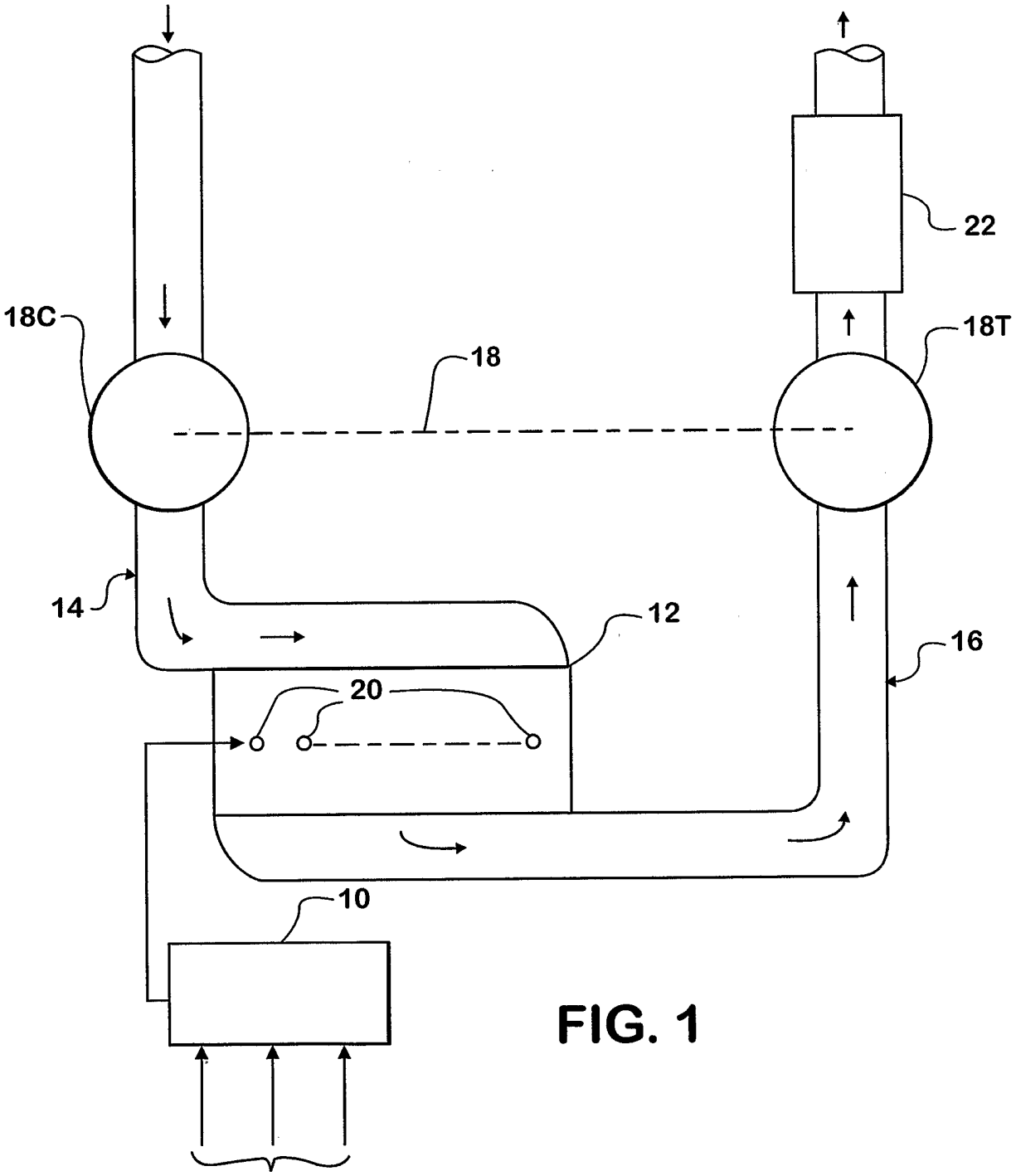

FIG. 1