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(54) Title: **CONDITIONING ENGINE EXHAUST GAS FOR RECIRCULATION**

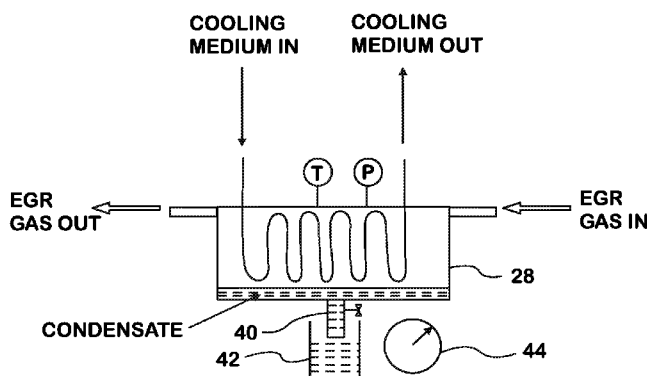


FIG. 2

(57) **Abstract:** Exhaust gas being recirculated from an exhaust system (20) of an internal combustion engine (10) entrains with air being conveyed through an intake system (14) of the engine to create a bulk air/exhaust gas mixture for cylinders (12) of the engine. At least one temperature inside an EGR cooler (28) through which the exhaust gas being recirculated passes is controlled to cause water vapor in exhaust gas that has entered the EGR cooler to condense into droplets that remain entrained with exhaust gas leaving the EGR cooler for entrainment with the air being conveyed through the intake system.



CONDITIONING ENGINE EXHAUST GAS FOR RECIRCULATION

Technical Field

[0001] This disclosure relates to internal combustion engines, especially diesel engines in motor vehicles, that use exhaust gas recirculation (EGR) as a component of tailpipe emission control strategy.

Background of the Disclosure

[0002] An example of a diesel engine EGR system comprises an EGR valve for metering some engine exhaust gas from the engine's exhaust system to mix with fresh air that has passed through the engine's intake system so that a bulk air/exhaust mixture is delivered to an intake manifold. The mixture enters engine cylinders from the intake manifold when intake valves for the cylinders open. The mixture is subsequently compressed by a piston that reciprocates within each cylinder. When fuel is injected into the compressed mixture, it combusts with the fresh air to power the engine and in the process create engine exhaust gas.

[0003] The exhaust gas being metered by the EGR system limits in-cylinder temperature rise in comparison to that which would occur in the absence of exhaust gas in the bulk mixture. As a consequence, the quantity of oxides of nitrogen (NO_x) created in the exhaust gas by combustion of fuel is also limited.

[0004] Some EGR systems, especially those designed for diesel engines, have one or more heat exchangers for cooling recirculated exhaust gas before it mixes with fresh air. Cooling of the exhaust gas can further limit the generation of NO_x.

[0005] It is recognized in the industry that cooling of recirculated exhaust gas creates the potential for condensation of gaseous non-water constituents. Over time such condensates may accumulate sufficiently to have a detrimental effect on performance and/or components. For example,

coolant passageways in coolers may become restricted, components may corrode, and moving parts may stick.

- [0006] Various strategies have been proposed for controlling condensation of gaseous non-water constituents in ways intended to mitigate such detrimental effects without adverse impact on the quantity of NO_x in tailpipe emissions.

Summary of the Disclosure

- [0007] This disclosure concerns a system and method for controlling cooling of water vapor in recirculated engine exhaust gas to convert some of the water vapor into a liquid droplet phase that remains entrained with exhaust gas being recirculated. The temperature of the recirculated exhaust gas is cooled to a temperature at least as low as a temperature at which water vapor will begin to condense in the EGR flow based on the partial pressure of the water vapor in the EGR flow.
- [0008] The condensing water appears as minute droplets that remain entrained in the EGR flow, giving the flow a two-phase water content consisting of both vapor and liquid. At some point after the exhaust gas flow has mixed with fresh air and created the bulk air/exhaust mixture, the temperature of the mixture will increase to the vaporization temperature of the entrained water droplets. The evaporative cooling mostly occurs in the premixing phase of the combustion process and during the initial phase of the combustion burn.
- [0009] As the droplets evaporate, the heat of vaporization of the water extracts some thermal energy from the bulk air/exhaust mixture. It is that effect that imparts some cooling of the bulk mixture that makes the recirculated exhaust gas more effective in limiting NO_x formation by a greater reduction of the adiabatic flame temperature than if the water droplets were absent from the recirculated exhaust gas.
- [0010] The lower flame temperature may also approach the soot formation limit. The combustion process passes briefly into the soot formation island

in a (T – phi) map, thus generating little soot emissions. Consequently, the added reduction in NO_x emission may be accompanied by a noticeable reduction of soot emission. The combustion regime at which these phenomena occur is typically referred to as “Cold Combustion”.

[0011] One general aspect of the disclosure relates to an internal combustion engine comprising: engine cylinders within which combustion of fuel occurs to operate the engine, an intake system for conveying air to the engine cylinders to support the combustion of fuel, an exhaust system for conveying combustion-created exhaust gas from the cylinders, an EGR system for recirculating some exhaust gas from the exhaust system for entrainment with air being conveyed through the intake system to create a bulk air/exhaust gas mixture for the cylinders and comprising an EGR cooler through which exhaust gas being recirculated passes, and a control system for controlling at least one temperature inside the EGR cooler to cause water vapor in exhaust gas that has entered the EGR cooler to condense into droplets that remain entrained with exhaust gas leaving the EGR cooler to entrain with the air being conveyed to the cylinders.

[0012] Another general aspect of the disclosure relates to a method of conditioning exhaust gas being recirculated from an exhaust system of an internal combustion engine for entrainment with air being conveyed through an intake system of the engine to create a bulk air/exhaust gas mixture for cylinders of the engine, the method comprising: controlling at least one temperature inside an EGR cooler through which the exhaust gas being recirculated passes to cause water vapor in exhaust gas that has entered the EGR cooler to condense into droplets that remain entrained with exhaust gas leaving the EGR cooler for entrainment with the air being conveyed through the intake system.

[0013] The foregoing summary, accompanied by further detail of the disclosure, will be presented in the Detailed Description below with reference to the following drawings that are part of this disclosure.

Brief Description of the Drawings

- [0014] Figure 1 is a schematic diagram of portions of a diesel engine relevant to the present disclosure.
- [0015] Figure 2 is a schematic diagram showing a process for measuring coolant-induced condensation of water vapor out of engine exhaust gas.
- [0016] Figure 3 is a graph plot showing correlation of certain parameters.

Detailed Description

- [0017] Figure 1 shows a turbocharged diesel engine 10 that comprises engine cylinders 12 within which combustion of fuel causes pistons (not shown) to reciprocate. Each piston is coupled to a respective throw of a crankshaft (not shown) by a corresponding connecting rod (not shown). Engine 10 further comprises: an intake system 14 through which fresh air passes to an engine intake manifold 16; an engine exhaust manifold 18 for collecting exhaust gases resulting from combustion of fuel in engine cylinders 12 for ensuing passage through an engine exhaust system 20 to a tailpipe 22 from which the gases exit to the surrounding atmosphere; and a fueling system 24 comprising fuel injectors for introducing fuel into engine cylinders 12 for combustion with fresh air.
- [0018] Engine intake system 14 may comprise other elements, such as a turbocharger compressor, an intake throttle, a charge air cooler, and an intake air filter, that are not specifically shown in Figure 1. Engine exhaust system 20 may comprise other elements, such as a turbocharger turbine for operating the intake system compressor and one or more after-treatment devices that also are not specifically shown in Figure 1.
- [0019] Engine 10 further comprises an EGR (exhaust gas recirculation) system 26 shown by way of example to comprise a liquid-to-gas heat exchanger forming a single EGR cooler 28 and a single EGR valve 30 downstream of the single EGR cooler 28. When EGR valve 30 is open, some of the exhaust gas coming from exhaust manifold 18 is diverted

from exhaust system 20 to mix with fresh air coming from intake system 14 and form an air/exhaust mixture that enters engine cylinders 12 through intake manifold 16. As the exhaust gas coming from exhaust manifold 18 flows through EGR cooler 28, it undergoes a cooling process.

[0020] A processor-based engine control system comprises an ECU (engine control unit) 32 that processes data from various sources to develop data for various parameters that serve to control various aspects of engine operation, such as EGR valve 30 and fueling system 24. ECU 32 may also control the flow of liquid engine coolant through EGR cooler 28 to control the temperature drop that EGR cooler 28 imposes on the recirculated exhaust gas flowing through it.

[0021] ECU 32 incorporates a strategy for controlling the temperature drop to achieve a target temperature for exhaust gas leaving EGR cooler 28 that ensures that the leaving flow has a two-phase water content consisting of liquid droplets and vapor.

[0022] The target temperature is one that is less than the saturation temperature corresponding to the partial pressure of water vapor in exhaust gas.

[0023] The onset of formation of tiny homogeneous liquid water droplets occurs once the bulk exhaust gas temperature becomes less than the saturation temperature. The droplets remain entrained in the flow that subsequently mixes with the fresh air to create a bulk air/exhaust mixture that then enters intake manifold 16.

[0024] As the bulk temperature of the bulk air/exhaust mixture increases, a point is reached at which the entrained water droplets start to vaporize. By extracting heat from the mixture, the vaporization provides an additional reduction in the adiabatic flame temperature of the combustion process beyond that which would occur if the mixture were free of the water droplets. Such extra cooling can further reduce the in-cylinder generation of NO_x in comparison to exhaust gas lacking the water droplets.

[0025] The process controls the “Degree of Under Cooling” (DOUC) for the water vapor in the exhaust gas leaving EGR cooler 28.

[0026] The DOUC is defined as the saturation temperature of water corresponding to its partial pressure in the exhaust gas leaving EGR cooler 28 minus the bulk temperature of the exhaust gas itself.

[0027] DOUC mainly controls the “Wetness Fraction” (WF) defined as the ratio of condensed mass of water in the liquid phase to the total mass of water in both liquid phase and vapor phase. A representative relationship of Wetness Fraction percentage to DOUC as measured in degrees Fahrenheit (F) is shown by the plot 52 in Figure 3. As presented, the greater the magnitude of DOUC, the larger the Wetness Fraction.

[0028] WF can be experimentally correlated to a quantity of water that condenses on an inside cold surface at or near the top of an EGR cooler and does not entrain with the exhaust gas flow, but rather falls downward and collects on the bottom of the cooler.

[0029] Figure 2 shows an example of this process. The flow and temperature of cooling medium are controlled to set temperature of the heat exchanger surfaces on which condensation occurs low enough to assure condensation of water vapor out of the exhaust gas flow. With the temperature set sufficiently low to cause water vapor to condense, condensed water will collect on the bottom of the EGR cooler 28.

[0030] When a sufficient volume of water has collected, water will begin to drip through an open tap 40 into a pressurized, transparent collection vessel 42. A starting time stamp from a stop watch 44 is recorded as the dripping proceeds, with the quantity of water in collection vessel 42 also being recorded. After some amount of time, a stopping time stamp is recorded on stop watch 44, with the quantity of water in collection vessel 42 also being recorded.

[0031] The rate of condensation is measured by the difference between the two recorded quantities of collected water divided by the difference between the two time stamps. Temperature of exhaust gas flowing across

the surfaces at which water condensation occurs is measured by a temperature sensor T. Pressure at that location is measured by a pressure sensor P.

[0032] In order to develop a plot like plot 52, certain parameters are varied. For example, the temperature of coolant passing through EGR cooler 28 can be varied to produce greater and lesser rates of condensation that result in different values for Wetness Fraction WF.

[0033] A second plot 50 in Figure 3 shows a correlation of exhaust emissions (in arbitrary units non-specific to any particular emission constituent, such as NO_x, smoke, etc.) with Wetness Fraction WF. The correlation shows that increases in the magnitude of Wetness Fraction corresponding to increases in the magnitude of DOUC can have favorable impact on exhaust emissions.

[0034] In a production engine, ECU 32 can process certain data to set the temperature of EGR cooler surfaces to an appropriate temperature within a range of temperatures for causing a corresponding amount of water vapor condensation to occur in the exhaust gas leaving EGR cooler 28. By varying the temperature, the quantity water droplets entrained in the exhaust can be varied.

WHAT IS CLAIMED IS:

1. An internal combustion engine comprising:
engine cylinders within which combustion of fuel occurs to operate the engine;
an intake system for conveying air to the engine cylinders to support the combustion of fuel;
an exhaust system for conveying combustion-created exhaust gas from the cylinders;
an EGR system for recirculating some exhaust gas from the exhaust system for entrainment with air being conveyed through the intake system to create a bulk air/exhaust gas mixture for the cylinders and comprising an EGR cooler through which exhaust gas being recirculated passes; and
a control system for controlling at least one temperature inside the EGR cooler to cause water vapor in exhaust gas that has entered the EGR cooler to condense into droplets that remain entrained with exhaust gas leaving the EGR cooler to entrain with the air being conveyed to the cylinders.
2. An engine as set forth in Claim 1 in which the control system controls temperature of heat exchanger surfaces that are exposed to the exhaust gas flow through the EGR cooler.
3. An engine as set forth in Claim 1 in which the control system controls temperature of heat exchanger surfaces that are exposed to the exhaust gas flow through the EGR cooler by controlling flow and temperature of liquid coolant flowing through the EGR cooler.
4. A method of conditioning exhaust gas being recirculated from an exhaust system of an internal combustion engine for entrainment with air being conveyed through an intake system of the engine to create a bulk air/exhaust gas mixture for cylinders of the engine, the method comprising:

controlling at least one temperature inside an EGR cooler through which the exhaust gas being recirculated passes to cause water vapor in exhaust gas that has entered the EGR cooler to condense into droplets that remain entrained with exhaust gas leaving the EGR cooler for entrainment with the air being conveyed through the intake system.

5. A method as set forth in Claim 4 in which controlling at least one temperature inside an EGR cooler through which the exhaust gas being recirculated passes comprises controlling temperature of heat exchanger surfaces that are exposed to the exhaust gas flow through the EGR cooler.

6. A method as set forth in Claim 4 in which controlling temperature of heat exchanger surfaces that are exposed to the exhaust gas flow through the EGR cooler comprises controlling flow and temperature of liquid coolant flowing through the EGR cooler.

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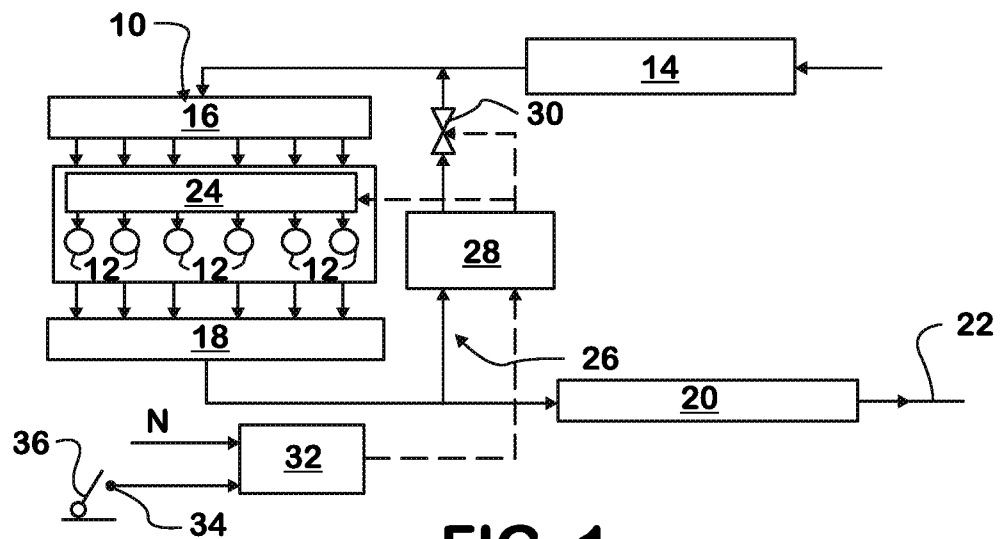


FIG. 1

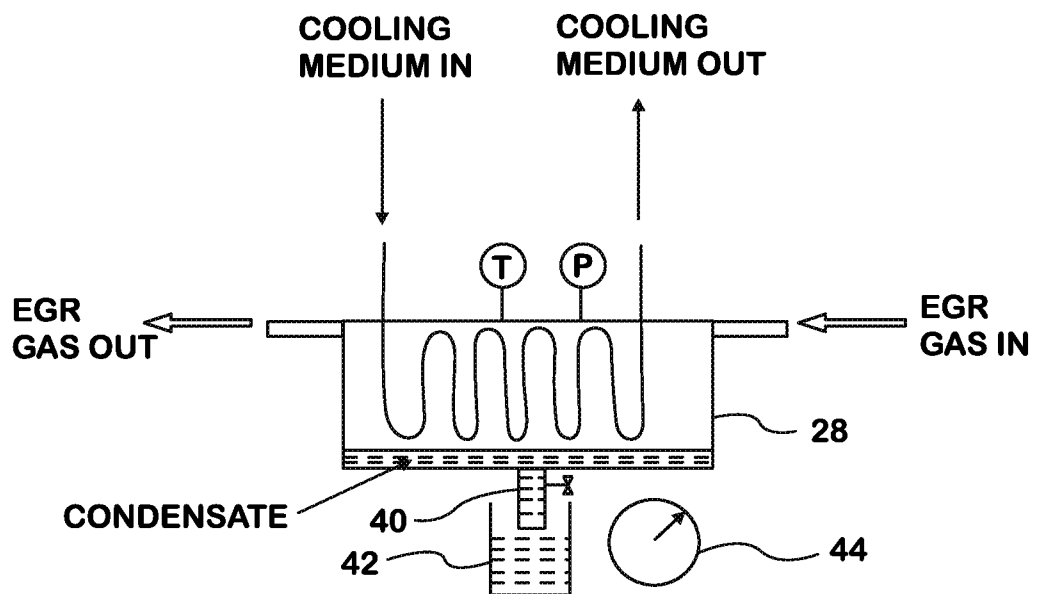


FIG. 2

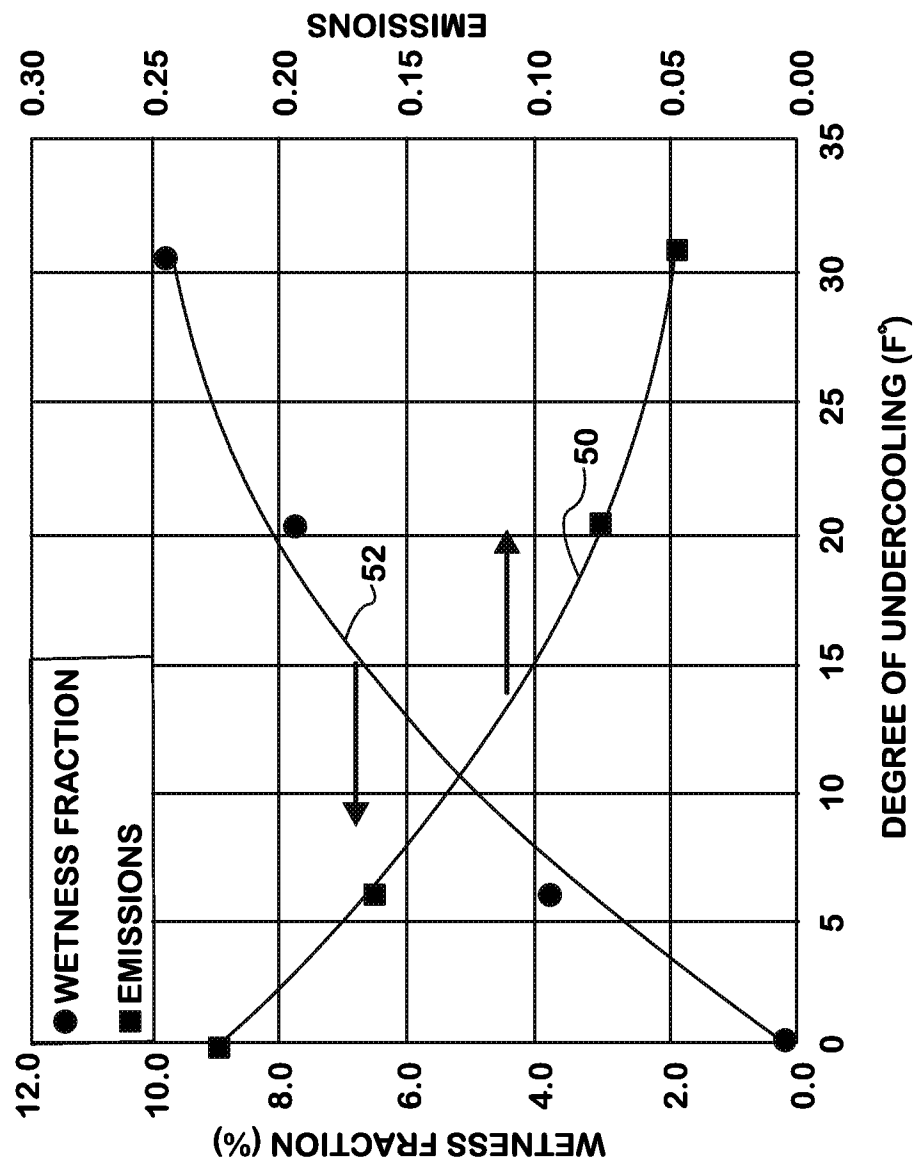


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/022223

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02B 47/08 (2011.01)

USPC - 60/599

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - F02B 47/08 (2011.01)

USPC - 60/597, 598, 599, 605.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit, MicroPatent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/0264081 A1 (CROWELL et al) 30 October 2008 (30.10.2008) entire document	1-6
A	US 2009/0249782 A1 (LI et al) 08 October 2009 (08.10.2009) entire document	1-6
A	WO 2010/005347 A1 (BERTILSSON et al) 14 January 2010 (14.01.2010) entire document	1-6

☐ Further documents are listed in the continuation of Box C.

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

02 March 2011

Date of mailing of the international search report

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