

A Fuel Gas Injection System, Method of Installing and Operating the Same

Technical Field

[0001] The present invention generally relates to a fuel gas injection system, method of installing and operating the same.

Background Art

[0002] Compression-ignition engines, known commonly as diesel engines, are widely used in industrial applications for their high thermal efficiency and reliability. The high thermal efficiency of compression-ignition engines is due in part to the high compression ratio of the combustion chamber and lean air-fuel ratio, where the fuel is burned in more air than is needed for the reaction. The lack of an electrical ignition system greatly improves the reliability of diesel engines. Diesel fuel is used in the diesel engines and petroleum diesel, produced from fractional distillation of crude oil, is the most common type of diesel fuel used.

[0003] However, petroleum diesel contains high levels of sulphur which can be oxidised during combustion to form sulphur dioxide and sulphur trioxide. Nitrogen oxides are also formed through high temperature oxidation of nitrogen within the combustion chamber and conversion of fuel bound nitrogen during combustion. These compounds, together with particulate matter, are generally emitted through the exhaust of the diesel engines. These compounds can damage the environment and can also be potentially harmful to human health. Particularly, sulphur dioxide, sulphur trioxide and nitrogen oxides can dissolve readily in water present in the atmosphere to form sulphurous acid, sulphuric acid and nitric acid respectively. These compounds contribute to acid rain and destruction of the environment.

[0004] Many emission standards have been enacted to address the release of air pollutants into the atmosphere. For example, the International Maritime Organisation (IMO), an agency of the United Nations, has recently adopted a provision that seeks to reduce sulphur emissions from the current 3.50% m/m (mass by mass) to 0.50% m/m by 1 January 2020. Many solutions have been adopted to meet such emission requirements. One solution is to convert the diesel engines into dual fuel combustion engines, such that the amount of sulphur-rich diesel fuel used to drive the engines can be reduced. In such dual fuel engines, the diesel fuel is typically replaced with an equivalent amount of gaseous fuel, such as natural gas (NG). Gaseous fuels are generally considered clean-burning relative to diesel fuels, with reduced emission levels of sulphur oxides and nitrogen oxides. Another solution is to convert diesel engines into fuel gas engines. The conversion can include modifying an

entire engine into a spark-ignition engine, and usually involves the replacement of the diesel fuel injectors with spark plugs connected to a suitable ignition system and installation of a throttle body on intake manifold of the engine. However, the current conversions into a dual fuel combustion engine or a spark-ignition engine can incur significant downtime due to the extensive modifications required. Moreover, the converted engines are typically required to meet stringent safety regulations concerning explosive atmosphere since gaseous fuels may leak in normal operation of a fuel gas engine. Converted dual fuel engines in marine applications may also have to meet strict requirements of various marine classification societies.

[0005] Accordingly, what is needed is a gas injection system, method of installing and operating the same that seek to address some of the above problems. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

Summary of Invention

[0006] A first aspect of the present invention provides a fuel gas injection system for an engine, the system comprising:

- a valve block;

- a plurality of fuel gas injectors mounted on the valve block;

- a fuel gas supply line connected to each of the plurality of fuel gas injectors, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, wherein the first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated; and

- a controller communicatively coupled to the plurality of fuel gas injectors;

- wherein each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.

[0007] The fuel gas injection system may further comprise a fuel gas injection line connected downstream of the plurality of fuel gas injectors. The injection line may comprise a second inner tube and a second outer tube disposed around the second inner tube such that a second annular space is provided therebetween. The second inner tube may be

configured to deliver the quantity of the fuel gas into the engine and the second annular space is configured to be continuously ventilated.

[0008] Each of the plurality of fuel gas injectors may comprise a solenoid-actuated valve electromagnetically operable by a respective solenoid to control a flow of the fuel gas to be injected into the engine.

[0009] Each of the plurality of fuel gas injectors may comprise an airtight compartment surrounding the respective solenoid.

[0010] The controller may be configured to operate the plurality of fuel gas injectors intermittently.

[0011] The controller may be configured to operate the plurality of fuel gas injectors continuously.

[0012] A second aspect of the present invention provides an engine comprising a fuel gas injection system as defined in the first aspect, wherein the fuel gas is configured to be injected proximate to an air inlet port of the engine.

[0013] The engine may comprise a gas combustion engine.

[0014] The engine may comprise a dual fuel combustion engine configured to operate with diesel fuel and/or fuel gas.

[0015] A third aspect of the present invention provides a method of installing a fuel gas injection system for an engine, the method comprising:

providing a valve block;

mounting a plurality of fuel gas injectors on the valve block;

connecting a fuel gas supply line to each of the plurality of fuel gas injectors, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, and such that the first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated; and

communicatively coupling a controller to the plurality of fuel gas injectors such that each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.

[0016] The method may further comprise connecting a fuel gas injection line downstream of the plurality of fuel gas injectors. The injection line comprises a second inner tube and a second outer tube disposed around the second inner tube such that a second annular space is provided therebetween, and such that the second inner tube is configured to deliver the quantity of the fuel gas into the engine and the second annular space is configured to be continuously ventilated.

[0017] Mounting the plurality of fuel gas injectors on the valve block may comprise providing the plurality of fuel gas injectors, each having a solenoid-actuated valve electromagnetically operable by a respective solenoid to control a flow of the fuel gas to be injected into the engine.

[0018] The method may further comprise providing an airtight compartment in each of the plurality of fuel gas injectors surrounding the respective solenoid.

[0019] The method may further comprise configuring the controller to operate the plurality of fuel gas injectors intermittently.

[0020] The method may further comprise configuring the controller to operate the plurality of fuel gas injectors continuously.

[0021] A fourth aspect of the present invention provides a method of operating fuel gas injection system for an engine, the method comprising:

determining, using a controller communicatively coupled to a plurality of fuel gas injectors, a quantity of a fuel gas to be injected into the engine;

drawing, using the plurality of fuel gas injectors, the quantity of the fuel gas from a fuel gas supply line, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, wherein the first inner tube is configured to carry the fuel gas;

injecting, using the plurality of fuel gas injectors, the quantity of the fuel gas into the engine; and

directing an air flow through the annular space of the fuel gas supply line to continuously ventilate the annular space.

[0022] Injecting the quantity of the fuel gas into the engine may comprise:

directing the quantity of the fuel gas into a fuel gas injection line connected downstream of the plurality of fuel gas injectors, wherein the injection line comprises a second inner tube

and a second outer tube disposed around the inner tube such that a second annular space is provided therebetween, wherein the second inner tube is configured to deliver the quantity of the fuel gas into the engine; and

continuously ventilating the second annular space.

[0023] Each of the plurality of fuel gas injectors may comprise a solenoid-actuated valve, and wherein drawing the quantity of the fuel gas from the fuel gas line comprises actuating the solenoid-actuated valve to control a flow of the fuel gas to be injected into the engine.

Brief Description of Drawings

[0024] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Fig.1

[0025] Fig. 1 shows a schematic diagram of a fuel gas injection system for an engine, in accordance with embodiments of the invention.

Fig.2

[0026] Fig. 2A shows a close-up schematic representation of a portion of the fuel gas injection system of Fig. 1. Fig. 2B shows a schematic representation of a fuel gas injector suitable for use in the fuel gas injection system of Fig. 1.

Fig.3

[0027] Figs. 3A, 3B and 3C show top, side and front views of the fuel gas injection system of Fig. 1 installed on an engine, in accordance with embodiments of the invention.

Fig.4

[0028] Fig. 4 shows a flowchart illustrating a method of installing a fuel gas injection system for an engine, in accordance with embodiments of the invention.

Fig.5

[0029] Fig. 5 shows a flowchart illustrating a method of operating fuel gas injection system for an engine, in accordance with embodiments of the invention.

Fig.6

[0030] Fig. 6 shows a flow diagram illustrating a procedure for dual fuel operation of an engine, implemented by a fuel gas injection system, in accordance with embodiments of the invention.

[0031] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale. For example, the dimensions of some of the elements in the illustrations, block diagrams or flowcharts may be exaggerated in respect to other elements to help to improve understanding of the present embodiments.

Description of Embodiments

[0032] The following detailed description is merely exemplary in nature and is not intended to limit the invention or the application and uses of the invention. Furthermore, there is no intention to be bound by any theory presented in the preceding background of the invention or the following detailed description. Herein, a fuel gas injection system, method of installing and operating the same are presented in accordance with present embodiments having the advantages of improved responsiveness, minimal installation downtime and improved operational safety.

Overview

[0033] Embodiments of the present invention seek to provide a fuel gas injection system for an engine. The fuel gas injection system according to various embodiments includes a valve block, a plurality of fuel gas injectors mounted on the valve block, a fuel gas supply line connected to each of the plurality of fuel gas injectors and a controller communicatively coupled to the plurality of fuel gas injectors. The valve block can be configured to hold the plurality of gas injectors in series. The fuel gas supply line includes a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween. The first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated. In various embodiments of the invention, the valve block and the plurality of fuel gas injectors can be disposed in an enclosure. The enclosure can be connected to the first annular space to form a volume that is continuously ventilated. Each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.

[0034] As the first annular space is continuously ventilated, risk of build-up of fuel gas in event of a leak of fuel gas during operation, and hence occurrence of an explosive atmosphere can be advantageously reduced. Moreover, as will be discussed in detail below, the plurality of fuel gas injectors can also be disposed within an enclosure which is connected to the first annular space to form a volume that is continuously ventilated, and hence can be compliant with industrial regulations such as Requirements of the International Maritime Organisation, ATEX (Appareils destinés à être utilisés en Atmosphères Explosibles) 95 equipment directive 94/9/EC and IGF (International Code of Safety for Ships using Gases or other Low-flashpoint fuels).

[0035] More advantageously, as each of the plurality of injectors can be configured to inject a precise amount of fuel gas quickly, the quantity of fuel gas injected into the engine can be accurately controlled. The flow of fuel gas from each of the plurality of fuel gas injectors can be merged downstream and delivered into the engine. As will be explained in detail below, since each of the plurality of injectors is selectively operated by the controller, the quantity of the fuel gas injected into the engine can be precisely varied, responsive to the operating conditions of the engine.

[0036] Further, the fuel gas injection system according to various embodiments of the invention can be configured for intermittent injection of fuel gas, or continuous injection of fuel gas into the engine, depending on speed of the engine, and consequent intake/exhaust valve overlap duration (i.e. the duration in which the intake and exhaust valves are opened at the same time). For example, long valve overlap durations are common in slow-speed engines operating in the range of up to 1000rpm (revolutions per minute). Flushing and/or cooling of the engine cylinders with intake air occurs during the valve overlap durations in slow-speed engines. In such embodiments, it would be necessary to interrupt gas flow into the engine to avoid presence of fuel gas in the hot exhaust manifold. Fuel gas, if present in the hot exhaust manifold, can be ignited and cause potential damage to the engine and injury to the persons working in the vicinity of the engine. Injection of fuel gas during flushing and/or cooling of the engine cylinders can also lead to substantial fuel losses. Hence, in exemplary implementations of the present invention with slow-speed engines, the controller can be configured to operate the plurality of fuel gas injectors intermittently, and each cylinder in the engine may be equipped with a gas injector with a variable gas injection timing controlled by the controller.

[0037] Conversely, high-speed engines, which can operate in the range of up to 1500rpm or 1800rpm, feature a small valve overlap. Hence, in exemplary implementations of the present invention in high-speed engines, a single-injection-point fuel gas injection system

can be installed. The single injection point can be positioned proximate to an air inlet port of the engine, for example, downstream of the turbocharger and intercooler of the engine, and near the cylinders. In exemplary implementations of the present invention with high-speed engines, the controller can be configured to operate the plurality of fuel gas injectors continuously, and the quantity of the fuel gas injected is varied according to required engine output and engine speed.

[0038] Advantageously, the fuel gas injection system can be installed on an existing compression-ignition engine, otherwise known as a diesel engine, to convert the diesel engine into a dual fuel engine without the need to modify the entire engine into a spark-ignition one, thereby circumventing the need to replace the diesel fuel injectors with spark plugs connected to a suitable ignition system and to install a throttle body on intake manifold of the engine. In various embodiments of the invention, the dual fuel engine can run primarily on gaseous fuel, with a minimum amount of diesel fuel injected as a pilot fuel to initiate the ignition of the gaseous fuel. The amount of fuel gas and diesel fuel injected into the converted dual fuel engine can be managed using the controller. In an exemplary implementation, the dual fuel engine can operate with diesel fuel and fuel gas simultaneously. For example, the fuel gas, as the main/primary fuel can comprise up to 70% of the fuel mixture, and the diesel fuel can comprise at least 30%, the diesel fuel used for ignition of the fuel/air mixture. The dual fuel engine can retain the capability to run on diesel fuel only.

[0039] More advantageously, the installation of the fuel gas injection system on an existing compression-ignition engine can be carried out onsite without the need to bring the engine to a workshop for conversion, as critical components of the existing diesel engine (e.g. intake and exhaust manifolds, cylinders, camshaft and flywheel) are not modified in the conversion process. In exemplary implementations, overhaul of the engine prior to conversion is also not mandatory. Furthermore, the fuel gas injection system in various embodiments of the invention can also be used in combination with a fuel gas engine (i.e. one that runs on 100% fuel gas).

Exemplary Embodiments

[0040] Embodiments of the present invention will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

[0041] Fig. 1 shows a schematic diagram of a fuel gas injection system 100 for an engine, in accordance with embodiments of the invention. Fig. 2A shows a close-up schematic

representation of the fuel gas injection system 100 of Fig. 1. Referring to Fig. 1, the fuel gas injection system 100 can include one or more valve blocks 202 (see Fig. 2A) fluidly connected to a plurality of fuel gas injectors 204 (Fig. 2A). The valve block is fluidly connected to a fuel gas injection line 206. The plurality of fuel gas injectors 204 can be configured to be mounted on the valve block 202, and each fuel gas injectors 204 is fluidly connected to a fuel gas supply line 208. The fuel gas supply line 208 includes a first inner tube 102 and a first outer tube 104. The first outer tube 104 is disposed around the first inner tube 102 such that a first annular space 106 is provided therebetween. The first inner tube 102 is configured to carry the fuel gas and the first annular space 104 is configured to be continuously ventilated by a ventilation system (not shown). In other words, the fuel gas supply line can be double-walled and the space between the walls can be continuously ventilated to remove any fuel gas that may have leaked from the inner tube 102 of the supply line 208. A controller (not shown) is communicatively coupled to the plurality of gas injectors 204 and each of the plurality of gas injectors 204 is selectively operable by the controller to control a quantity of the fuel gas injected into the engine. As shown in Fig. 1, the valve block 202 and the plurality of gas injectors 204 can be disposed within an enclosure. The enclosure is connected to the first annular space 106 that formed between the first inner tube 102 and the first outer tube 104. Thus, the enclosure and the annular space 106 can form a volume that is continuously ventilated.

[0042] The fuel gas injection system 100 also includes fuel gas injection line 206 as shown in Fig. 2A. The fuel gas injection line 206 is connected downstream of the plurality of fuel gas injectors 204. Similar to the fuel gas supply line 208, the fuel gas injection line 206 includes a second inner tube 108 and a second outer tube 110 disposed around the second inner tube 108 such that a second annular space (not shown) is provided therebetween. The second inner tube 108 is fluidly connected to the valve block 202 and is configured to deliver the quantity of fuel gas into the engine. In various embodiments, the second annular space can be configured to be continuously ventilated.

[0043] Each of the plurality of fuel gas injectors 204 includes a solenoid-actuated valve 210 electromagnetically operable by a respective solenoid 212 to control a flow of the fuel gas to be injected into the engine. In an embodiment of the present invention, the flow of the fuel gas is first injected into the valve block 202 fluidly connected to the fuel gas injection line 206. The flow of the fuel gas injected by each of the plurality of fuel gas injectors 204 can be precisely varied, as each of the plurality of fuel gas injectors 204 is independently controlled by the controller. In some embodiments of the present invention, multiple fuel gas injectors 204 can be actuated simultaneously to inject a desired quantity of fuel gas into the engine. The use of multiple fuel gas injectors 204 to inject a quantity of fuel gas into the engine can

be particularly advantageous compared to use of a single fuel gas injector, especially in terms of precision and responsiveness, since each fuel gas injector 204 only needs to supply a portion of the quantity required. Alternatively, the plurality of fuel gas injectors can be sequentially actuated to ensure a continuous flow of fuel gas (e.g. when operating a high-speed engine). Moreover, the number of fuel gas injectors 204 actuated can depend on the quantity of gas required. Hence, the fuel gas injection system 100 can respond rapidly to varying conditions in the engine to deliver the quantity of fuel gas required. It can be appreciated that the number of fuel gas injectors 204 is dependent on the requirements of the size of the engine, and the maximum amount of fuel gas required per cycle.

[0044] In embodiments of the present invention, each of the plurality of fuel gas injectors 204 comprises an airtight compartment (not shown) surrounding the respective solenoid 212. In other words, the solenoid 212 can be completely housed within the fuel gas injector, and can be sufficiently sealed airtight such that fuel gas is not present within the airtight compartment during normal operation of the dual fuel engine. The solenoid compartment is gastight, and can provide sufficient mechanical separation between the fuel gas and the solenoid 212 itself during normal operation. Thus, the solenoid 212 operates within a non-explosive atmosphere. Each solenoid 212 is mechanically coupled to respective solenoid-actuated valve 210.

[0045] Fig. 2B shows a schematic representation of an exemplary fuel gas injector 220 which can be used as the fuel gas injector 204 in Fig. 2A. The fuel gas injector 220 comprises a solenoid 222 disposed in an airtight compartment 224, a plunger 226 including an elastomer seal 228, the plunger 226 configured to abut a fuel gas valve seat 230 to seal a fuel gas valve inlet 232 from a fuel gas valve outlet 234 in a closed position, and a spring 236 configured to urge the plunger 226 toward the fuel gas valve seat 230 such that the fuel gas valve remains in the closed position. The solenoid 222 can be electrically energised such that the plunger 226 is electromagnetically actuated against the spring 236 to open the fuel gas valve and allow fuel gas to flow through the injector 220, from the fuel gas valve inlet 232 to the fuel gas valve outlet 234, and towards the gas injection line 206. In various embodiments of the invention, the plunger 226 can be seated within a tube 238 disposed within the coil of the solenoid 222. The plunger 226 is movable within the tube 238, and the tube is sealed at one end with an O-ring seal 240 to seal the tube 238 against fuel gas flow when the plunger 226 is actuated. An O-ring seal 242 is disposed between a wall of the inlet 232 and a base 248 of the airtight compartment 224. An O-ring seal 244 is disposed between the base 248 and the tube 238. Advantageously, the O-ring seals 240, 242, 244 can ensure that the solenoid 222 is separated from the fuel gas flow, and there is sufficient mechanical separation between the electrical components and the gas mixture. The outlet

234 is fluidly connected to the fuel gas injection line 206. O-ring seals 246 are disposed between the gas injection line 206, the fuel gas valve seat 230 and the walls of the inlet 232 to ensure that there is sufficient separation between components to prevent backflow of the fuel gas from the fuel gas injection line 206 and the fuel gas injector 220.

[0046] Fig. 1 also shows an exemplary dual fuel combustion engine. The dual fuel combustion engine includes an engine unit, a boost air system having suction manifold 112 and intercooler 114, a diesel fuel system (not shown) and an exhaust system (exhaust manifolds 120). The engine unit comprises an engine block including at least one cylinder (L1-L8, R1-R8), the cylinders each providing a combustion chamber for combusting fuel. Each cylinder can be communicatively coupled to a knocking sensor (KS) configured to sense vibrations caused by engine knock or detonation. Each knocking sensor (KS) can generate a signal responsive to engine knock and transmit the signal to the controller. The controller can, based on the signal, alter the injection timing of the fuel gas. Temperature sensors, e.g. thermocouples (T/mV) can also be connected to the exhaust system, the boost air system and the boost air channels. The temperature sensors are coupled to the controller and can be configured to monitor engine operating parameters on a real time basis.

[0047] The boost air system includes suction manifold 112 and intercooler 114. The suction manifold 112 includes an air intake 116 and an air filter disposed downstream of the air intake 116. The suction manifold 112 is coupled to compressor of turbochargers 118. The compressor of turbochargers 118 is configured to compress boost air from air intake 116 during operation, and to channel the boost air at a higher pressure to an air inlet port of the engine. In the exemplary embodiment as shown in Fig. 1, the fuel gas injection line 206 is fluidly coupled to the boost air channel 120 disposed between the compressor of turbochargers 118 and the intercooler 114. In alternate embodiments of the invention, the fuel gas injection line 206 is fluidly coupled to the boost air channel 120 disposed after the intercooler 114. Advantageously, coupling the fuel gas injection line 206 after the boost air system, and proximate to an air inlet port of the cylinder can minimise leakage, as the injected fuel gas travels a minimal distance within the boost air tube 120 after injection. Injecting fuel gas proximate to the air inlet port of the cylinder also ensures that the injected gas readily enters the combustion chambers of the engine, thereby reducing performance lag.

[0048] Figs. 3A, 3B and 3C show top, side and front views of the fuel gas injection system of Fig. 1 installed on an exemplary engine, in accordance with embodiments of the invention. Figs. 3A, 3B and 3C also show placement of the valve block (shown as gas injector rail on Figs. 3A-3C), the knocking sensors and the temperature sensors on the exemplary engine.

Routing of the fuel gas supply line 208, the fuel injection line 206 and various electrical connections 302a, 302b, 302c connecting the knocking sensors and the temperature sensors to the controller on the exemplary engine is also shown. As would be appreciated, the provision of the sensors and routing of fuel gas lines 206, 208 and various electrical connections is dependent on geometry of the engine. The sensors, fuel lines and electrical connections can be provided on the exterior of the engine to minimise modifications made to the engine, and can therefore minimise conversion duration.

[0049] Fig. 4 shows a flowchart 400 illustrating a method of installing a fuel gas injection system for an engine, in accordance with embodiments of the invention. At step 402, a valve block is provided. At step 404, a plurality of fuel gas injectors are mounted on the valve block. At step 406, a fuel gas supply line is connected to each of the plurality of fuel gas injectors. The supply line can include a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, and such that the first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated. At step 408, a controller is communicatively coupled to the plurality of fuel gas injectors such that each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.

[0050] Fig. 5 shows a flowchart 500 illustrating a method of operating fuel gas injection system for an engine, in accordance with embodiments of the invention. At step 502, a quantity of a fuel gas to be injected into the engine is determined using a controller communicatively coupled to a plurality of fuel gas injectors. At step 504, the quantity of the fuel gas is drawn from a fuel gas supply line using the plurality of fuel gas injectors. The supply line comprises a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, wherein the first inner tube is configured to carry the fuel gas. At step 506, the quantity of the fuel gas is injected into the engine using the plurality of fuel gas injectors. At step 508, an air flow is directed through the annular space of the fuel gas supply line to continuously ventilate the annular space.

[0051] Operation of an exemplary fuel gas injection system installed on a dual fuel engine is now described. Fig. 6 shows a flow diagram illustrating a procedure 600 for dual fuel operation of an engine implemented by a gas injection system, in accordance with embodiments of the invention. The procedure broadly includes, but is not limited to, a calibration phase 602, an engine start-up phase 604, a dual fuel adjustment phase 606 and a monitoring phase 608 which can provide feedback to the dual fuel adjustment phase 606.

[0052] The calibration phase 602 for dual fuel operation of the engine can be generally performed prior to conversion of a diesel engine. Nevertheless, it is appreciated that the

calibration phase 602 can also be performed after the conversion to a dual fuel engine, with the converted engine running solely on diesel during such calibration. The calibration phase 602 can also be run periodically during the engine's service life. The calibration phase 602 broadly includes, but is not limited to, recording of various engine parameters at different engine load levels when run solely on diesel fuel. Engine parameters recorded can include diesel consumption rate, exhaust temperatures and amplitude of vibration registered by knocking sensors at various engine load levels. The recorded data can be used by the controller of the fuel gas control system to determine an equivalent amount of gaseous fuel (e.g. natural gas) to be injected in place of diesel, when the engine is running in dual fuel mode.

[0053] The dual fuel engine is configured to start on diesel fuel. Thereafter, the engine start-up phase 604 can be initiated. In start-up phase 604, the controller can be configured to monitor power output and temperature of the engine through various sensors connected to the engine, and switch operation of the engine to dual fuel mode, for example, upon a predetermined power output level, or a predetermined engine temperature, by engaging the fuel gas injection system.

[0054] In the dual fuel adjustment phase 606, the amount of fuel gas injected into the engine is increased gradually with time while monitoring for abnormalities in the engine performance (e.g. abnormal vibrations caused by engine knock or detonation). The amount of diesel injected into the engine is simultaneously reduced such that the sum of energy produced by combustion of fuel gas and the diesel fuel is equivalent to the energy required by the engine at a particular engine load. In other words, the controller can determine the amount of diesel fuel required for a particular engine load based on the data collected in the calibration phase, and can control the ratio of fuel gas and diesel fuel injected into the engine such that the fuel gas and diesel fuel have a combined energy content equivalent to that of diesel fuel required by the engine, when the engine is running solely on diesel fuel.

[0055] In the monitoring phase 608, various parameters of the engine are monitored so that the amount of fuel gas and diesel fuel injected into the engine during the dual fuel adjustment phase 606 can be precisely controlled. In other words, fuel gas and diesel fuel injection is adjusted depending on the feedback of various engine parameters.

[0056] For example, during the monitoring phase 608, the controller can receive signals generated by knocking sensors coupled to cylinders of the engine to monitor for abnormal vibrations that may be caused by engine knock, by comparing the signals against predetermined limits calculated from vibration readings obtained during normal engine operation, e.g. from the calibration phase 602. Should the vibration signals from the

knocking sensors show abnormal vibrations resulting from non-uniform combustion, the controller may, based on the signals received, gradually and temporarily reduce the amount of fuel gas injected into the engine to reduce such vibrations. If the vibrations continue beyond a predetermined period of time despite the reduction in the amount of fuel gas injected, the controller can be configured to transit the dual fuel engine to diesel-only mode i.e. to inject, using a diesel fuel injector fluidly connected to the combustion chamber, an appropriate quantity of diesel appropriate for the actual engine load. The fuel gas injectors can also be shut off automatically while the engine runs solely on diesel fuel. For example, the solenoids can be switch off such that the solenoid-actuated valves default to a closed position, thereby shutting off the flow of fuel gas. It can also be appreciated that diesel-only mode can also be invoked in case of a shortage of fuel gas or sudden cut off of fuel gas. Moreover, the controller can be configured to switch operation of the engine to dual fuel mode once fuel gas is available, or when the abnormal vibrations have reduced. Advantageously, in embodiments where the gas injection point is disposed proximate to the air inlet port of the engine, transitions between the diesel fuel mode and dual fuel mode can be rapid, and can be achieved while the engine is running without interruption of the load supply.

[0057] Moreover, during the monitoring phase 608, exhaust temperature can be monitored to estimate the temperature of the combustion chamber of the engine, hence engine performance. TDC (top dead centre) sensors can also be disposed within the engine to provide additional information such as real-time TDC position of the pistons, which can also be used in turn to determine engine performance. Further, the engine load can also be estimated during the monitoring phase 608 using boost air pressure readings at the air inlet port of the engine and temperature readings from various temperature sensors connected to the engine. Importantly, should any engine parameter (e.g. rpm / temperature) reach a maximum limit, the controller can be configured to reduce the amount of fuel gas injected into the engine, to limit engine power. If required, the controller can also be configured to shut the fuel gas injection system, to stop the supply of fuel gas into the engine, and to power the engine based only on diesel fuel. The amount of diesel fuel can be proportionally increased so that there is minimal or no disruption of power supplied by the engine.

[0058] Advantageously, the constant real-time monitoring of engine performance and parameters can allow the fuel gas injection system to handle any change in gas quality during engine operation. The fuel gas injection system can also be designed to handle a range of fuel gas quality (i.e. large range of methane numbers) by using the sensors to provide feedback control to the controller, so that the controller can adjust, based on the

signals, the quantity of fuel gas injected into the system, and the ratio of diesel fuel to fuel gas used based on the required engine output.

[0059] Thus it can be seen that fuel gas injection system, method of installing and operating the same in accordance with the present embodiments have the advantages of improved responsiveness, minimal installation downtime and improved operational safety. While exemplary embodiments have been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist.

[0060] It should further be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, operation, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention, it being understood that various changes may be made in the function and arrangement of elements and method of operation described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

Claims

1. A fuel gas injection system for an engine, the system comprising:
 - a valve block;
 - a plurality of fuel gas injectors mounted on the valve block;
 - a fuel gas supply line connected to each of the plurality of fuel gas injectors, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, wherein the first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated; and
 - a controller communicatively coupled to the plurality of fuel gas injectors;
 - wherein each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.
2. The fuel gas injection system as claimed in claim 1, further comprising a fuel gas injection line connected downstream of the plurality of fuel gas injectors, wherein the injection line comprises a second inner tube and a second outer tube disposed around the second inner tube such that a second annular space is provided therebetween, wherein the second inner tube is configured to deliver the quantity of the fuel gas into the engine and the second annular space is configured to be continuously ventilated.
3. The fuel gas injection system as claimed in claim 1 or 2, wherein each of the plurality of fuel gas injectors comprises a solenoid-actuated valve electromagnetically operable by a respective solenoid to control a flow of the fuel gas to be injected into the engine.
4. The fuel gas injection system as claimed in claim 3, wherein each of the plurality of fuel gas injectors comprises an airtight compartment surrounding the respective solenoid.
5. The fuel gas injection system as claimed in any one of claims 1 to 4, wherein the controller is configured to operate the plurality of fuel gas injectors intermittently.
6. The fuel gas injection system as claimed in any one of claims 1 to 4, wherein the controller is configured to operate the plurality of fuel gas injectors continuously.
7. An engine comprising a fuel gas injection system as claimed in any one of claims 1 to 6, wherein the fuel gas is configured to be injected proximate to an air inlet port of the engine.

8. The engine as claimed in claim 7, wherein the engine comprises a gas combustion engine.
9. The engine as claimed in claim 7, wherein the engine comprises a dual fuel combustion engine configured to operate with diesel fuel and/or fuel gas.
10. A method of installing a fuel gas injection system for an engine, the method comprising:
 - providing a valve block;
 - mounting a plurality of fuel gas injectors on the valve block;
 - connecting a fuel gas supply line to each of the plurality of fuel gas injectors, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, and such that the first inner tube is configured to carry a fuel gas and the first annular space is configured to be continuously ventilated; and
 - communicatively coupling a controller to the plurality of fuel gas injectors such that each of the plurality of fuel gas injectors is selectively operable by the controller to control a quantity of the fuel gas injected into the engine.
11. The method as claimed in claim 10, further comprising connecting a fuel gas injection line downstream of the plurality of fuel gas injectors, wherein the injection line comprises a second inner tube and a second outer tube disposed around the second inner tube such that a second annular space is provided therebetween, and such that the second inner tube is configured to deliver the quantity of the fuel gas into the engine and the second annular space is configured to be continuously ventilated.
12. The method as claimed in claim 10 or 11, wherein mounting the plurality of fuel gas injectors on the valve block comprises providing the plurality of fuel gas injectors, each having:
 - a solenoid-actuated valve electromagnetically operable by a respective solenoid to control a flow of the fuel gas to be injected into the engine.
13. The method as claimed in claim 12, further comprising providing an airtight compartment in each of the plurality of fuel gas injectors surrounding the respective solenoid.

14. The method as claimed in any one of claims 10-13, further comprising configuring the controller to operate the plurality of fuel gas injectors intermittently.
15. The method as claimed in any one of claims 10-13, further comprising configuring the controller to operate the plurality of fuel gas injectors continuously.
16. A method of operating a fuel gas injection system for an engine, the method comprising:
 - determining, using a controller communicatively coupled to a plurality of fuel gas injectors, a quantity of a fuel gas to be injected into the engine;
 - drawing, using the plurality of fuel gas injectors, the quantity of the fuel gas from a fuel gas supply line, the supply line comprising a first inner tube and a first outer tube disposed around the first inner tube such that a first annular space is provided therebetween, wherein the first inner tube is configured to carry the fuel gas;
 - injecting, using the plurality of fuel gas injectors, the quantity of the fuel gas into the engine; and
 - directing an air flow through the annular space of the fuel gas supply line to continuously ventilate the annular space.
17. The method as claimed in claim 16, wherein injecting the quantity of the fuel gas into the engine comprises:
 - directing the quantity of the fuel gas into a fuel gas injection line connected downstream of the plurality of fuel gas injectors, wherein the injection line comprises a second inner tube and a second outer tube disposed around the inner tube such that a second annular space is provided therebetween, wherein the second inner tube is configured to deliver the quantity of the fuel gas into the engine; and
 - continuously ventilating the second annular space.
18. The method as claimed in claim 16 or 17, wherein each of the plurality of fuel gas injectors comprises a solenoid-actuated valve, and wherein drawing the quantity of the fuel gas from the fuel gas line comprises actuating the solenoid-actuated valve to control a flow of the fuel gas to be injected into the engine.