Abstract: A method for removing excess air from a gas receiver (9) of a dual fuel reciprocating engine before changing fuel mode from a liquid fuel mode to a gas mode, which dual fuel reciprocating engine comprises a separate gas feed valve (17) for each engine cylinder (1), which gas feed valve (17) is arranged to feed gaseous fuel from the gas receiver (9) into an inlet port (10) of an engine cylinder (1) during the gas mode operation. In the method liquid fuel is fed into the cylinders (1) and gaseous fuel is fed from a gas source (8) into the gas receiver (9) via a gas inlet line (12). Before changing fuel mode from the liquid fuel mode to the gas mode at least one gas feed valve (17) is opened for removing air from the gas receiver (9).
METHOD FOR OPERATING A DUAL FUEL ENGINE

The invention relates to a method for removing excess air from a gas receiver of a dual fuel reciprocating engine before changing fuel mode from a liquid fuel mode to a gas mode. The invention also relates to a gas feed system for a dual fuel engine.

A dual fuel engine can typically operate in two modes. In a liquid fuel mode liquid fuel, such as diesel fuel, is injected directly into an engine cylinder or a precombustion chamber as the sole source of energy during combustion. In a gas mode a gaseous fuel, such as natural gas, is mixed with air in an intake port of a cylinder and a small amount of liquid pilot fuel is injected into the cylinder or the precombustion chamber in order to ignite the mixture of air and gaseous fuel. In gas mode the gaseous fuel is injected into intake ports through gas injection valves, which are positioned between a gas receiver and the intake port of each cylinder. In some dual fuel engines the gaseous fuel is injected directly into the cylinder before or after the liquid pilot fuel.

When the dual fuel engine is running in liquid fuel mode, engine charge air may leak into the gas receiver through the gas injection valves. In order to remove excess charge air from the gas receiver before switching to gas mode, the gas receiver is provided with a gas ventilation valve, via which the accumulated charge air can be vented to the atmosphere. During the venting of the charge air also some gaseous fuel escapes to the atmosphere. Since unburned methane is a strong greenhouse gas, it is desirable to minimize the amount of escaping methane.

An object of the present invention is to provide an improved method for removing excess air from a gas receiver of a dual fuel engine before changing fuel mode from a liquid fuel mode to a gas mode. The object of the invention is also to provide an improved gas feed system for a dual fuel engine.
The object of the present invention can be achieved by a method and a system according to respective independent claims.

The dual fuel reciprocating engine comprises a separate gas feed valve for each engine cylinder, which gas feed valve is arranged to feed gaseous fuel from the gas receiver into an inlet port of an engine cylinder during the gas mode operation. In the method according to the invention liquid fuel is fed into the engine cylinders and gaseous fuel is fed from a gas source into the gas receiver via a gas inlet line. Before changing fuel mode from the liquid fuel mode to the gas mode at least one gas feed valve is opened for removing air from the gas receiver.

The gas feed system according to the invention comprises a gas receiver for receiving gaseous fuel from a gas source, a gas inlet line for feeding gas from the gas source into the gas receiver, which gas inlet line is provided with a shut-off valve for opening and closing flow communication between the gas source and the gas receiver. The gas feed system further comprises a separate gas feed valve for each engine cylinder, which gas feed valve is arranged to feed gaseous fuel from the gas receiver into an inlet port of the cylinder during the gas mode operation, and a control unit that is, before changing fuel mode from a liquid fuel mode to a gas mode, configured to open the shut-off valve and open at least one gas feed valve for removing air from the gas receiver.

By means of the invention the amount methane released to the atmosphere can be reduced. Instead, methane is utilized in the combustion process of the engine. The system according to the invention can be easily installed or retrofitted to the dual fuel engines, as only minor modifications are required to the existing system.

In the following the invention will be described by way of examples with reference to the accompanying drawings, in which
Fig. 1 shows schematically a gas feed system for a dual fuel engine, in which cylinders are arranged in a single bank.

Fig. 2 shows schematically a gas feed system for a dual fuel engine, in which cylinders are arranged in two banks.

Fig. 3 shows schematically another gas feed system for a dual fuel engine, in which cylinders are arranged in two banks.

Fig. 4 shows schematically a third gas feed system for a dual fuel engine, in which cylinders are arranged in two banks.

The drawings show a gas feed system of a dual fuel reciprocating engine. The dual fuel engine can operate in two modes. In a liquid fuel mode a liquid fuel, such as diesel or heavy fuel oil, is injected directly into an engine cylinders as a sole source of energy during combustion. In a gas mode (or a dual fuel mode) a gaseous fuel, such as natural gas, is mixed with combustion air in intake ports of the cylinders and a small amount of liquid pilot fuel is injected into the cylinders in order to ignite the mixture of air and gaseous fuel. Typically, the pilot fuel consumption in the gas mode is less than 5% of the total fuel consumption. The dual fuel engine can be switched over from the gas mode to the liquid fuel mode and vice versa during the engine operation.

The engine is a large reciprocating engine, which can be used as a main and/or an auxiliary engine in ships and/or in power plants for generation of electricity and/or heat. The engine is a medium speed, four-stroke engine. The rotational speed of the engine is 300-1200 rpm. Cylinders of the engine can be arranged in a single bank (embodiment of fig. 1) or in two banks 11, 11' in a V-configuration (embodiments of figs. 2-4).
The engine 4 comprises a gas feed system 7 for feeding gaseous fuel from a gas source 8, such as a gas tank, into the cylinders 1. The gas feed system 7 comprises a gas receiver 9 for receiving gaseous fuel from the gas source 8. The gas receiver 9 is used for storing gaseous fuel before conducting into inlet ports 10 of the cylinders 1. The gas receiver 9 can be an elongated tank, which is parallel to the cylinder bank 11, 11'. The gas feed system 7 further comprises a gas inlet line 12 for connecting the gas source 8 to the gas receiver 9. The gas inlet line 12 is provided with a shut-off valve 13 for opening and closing flow communication between the gas source 8 and the gas receiver 9.

The gas feed system 7 further comprises a separate gas feed valve 17 for each cylinder 1. The gas feed valve 17 is arranged to feed gaseous fuel from the gas receiver 9 into the inlet port 10 of the cylinder during the gas mode operation of the engine. The gas feed system 7 comprises a ventilation line 19 for discharging gaseous fuel from the gas receiver 9 and/or for depressurizing the gas receiver 9. The ventilation line 19 is provided with a ventilation valve 18 for allowing and preventing the discharge of the gaseous fuel from the gas receiver 9. The gas feed system 7 comprises a control unit 20, which is configured to operate the shut-off valve 13 and gas feed valves 17 in a desired manner.

When the engine is operated in the liquid fuel mode, the gas receiver 9 is depressurized by opening the ventilation valve 18 and keeping the shut-off valve 13 closed. When the pressure in the gas receiver 9 has fallen to a desired level, the ventilation valve 18 is closed. During the liquid fuel mode operation, liquid fuel is fed directly into the cylinders 1. Before switching over from the liquid fuel mode to the gas mode, air that has been leaked into the gas receiver 9 through the gas feed valves 17 must be removed. The air removal is performed during the liquid fuel mode operation such that the shut-off valve 13 is opened and thereafter at least one gas feed valve 17 is opened for removing air from the gas receiver 9. When the gas feed valve 17 is open, air flows from the gas receiver 9 into the cylinder 1 through the inlet port 10. At the same time, the gas
receiver 9 is filled with gaseous fuel, which is conducted from the gas source 8 via the gas inlet line 12.

According to an embodiment of the invention, at least one gas feed valve 17 of the cylinders 1, which are located between the longitudinal midpoint of the cylinder bank 11, 11' and the cylinder bank 11, 11' end 5, 5' that is farthest away from a gas feed point 16 of the gas inlet line 12, is opened for removing excess air from the gas receiver 9.

Typically, the gas feed valve 17, which is farthest away from the gas feed point 16 of the gas inlet line 12, is opened. For enhancing the air removal from the gas receiver 9, the gas feed valve 17, which is second farthest away from the gas feed point 16 of the gas feed line 12, can additionally or alternatively be opened. If the cylinders 1 are arranged in two banks 11, 11', the cylinders 1, whose gas feed valves 17 can be opened during the air removal of the gas receiver 9, are located at the same ends 5, 5' of both cylinder banks 11, 11'.

In the embodiments according to the invention, the distance between the gas feed valve 17 and the gas feed point 16 is defined along the flow path of gas in the gas receiver 9. Thus, e.g. in the embodiment of fig. 4 the gas feed valve 17 of the cylinder 1 at the first end 6' of the second cylinder bank 11' is farthest away from the gas feed point 16 of the gas inlet line 12.

The control unit 20 is configured to monitor combustion event in the cylinder 1, whose gas feed valve 17 is opened during the air removal of the gas receiver 9. When the monitoring indicates that gaseous fuel having an air concentration below a predetermined level is discharged from the gas receiver 9, the engine is ready for a change of fuel mode from the liquid fuel mode to the gas mode. The monitoring of the combustion event can be based on knocking level and/or cylinder pressure and/or exhaust gas temperature measurement of said cylinder 1. The control unit 20 receives signals from the knocking sensor 2 and/or cylinder
pressure sensor 3 and/or exhaust gas temperature sensor of said cylinder 1 and determines the knocking level and/or cylinder pressure and/or exhaust gas temperature from the signals. The decrease in knocking level and increase in cylinder pressure and exhaust gas temperature indicate that the air content of gaseous fuel discharged from the gas receiver 9 decreases. When the knocking level and/or cylinder pressure and/or exhaust gas temperature reaches a predetermined value, the air content of the gaseous fuel is below a predetermined level. Now, the engine is ready for a fuel mode change from the liquid fuel mode to the gas mode. The correlation between the air content of the gaseous fuel and the knocking level, cylinder pressure and exhaust gas temperature can be defined experimentally.

Alternatively, the gas feed valve 17 can be kept open for a predetermined period of time during the air removal of the gas receiver 9. After this period, the engine is ready for a fuel mode change from the liquid fuel mode to the gas mode.

In the embodiment of fig. 1, the gas inlet line 12 is connected to the first end 14 of the gas receiver 9. Thus, the gas feed point 16 of the gas inlet line 12 is located at the first end 14 of the gas receiver 9. The vent line 19 is connected to the second end 15 of the gas receiver 9. The cylinder 1, whose gas feed valve 17 is opened during the air removal of the gas receiver 9, is located at the second end 5 of the cylinder bank 11. The second end 5 is located further from the gas feed point 16 than the first end 6 of the cylinder bank 11. Additionally, the gas feed valve 17 of the cylinder 1, which is second farthest away from the gas feed point 16, can be opened during the air removal from the gas receiver 9. In this manner, the air removal from the gas receiver 9 can be enhanced.

In the embodiment shown in fig 1, the gas feed point 16 of the gas inlet line 12 can be located between the ends 14, 15 of the gas receiver 9, for example between the gas feed valves 17 of two cylinders 1 that are in the middle of the cyl-
Cylinder bank 11. In this case, the fuel feed valves 17 of the cylinders 1 at both ends 5, 6 of the cylinder bank 11 are opened during the air removal.

Fig. 2 discloses an embodiment, in which the cylinders 1 are arranged in two banks 11, 11' in a V-configuration. The gas feed system 7 comprises with a gas receiver 9, from which gas can be conducted into the cylinders 1 of both the first cylinder bank 11 and the second cylinder bank 11'. The gas receiver 9 is placed between the cylinder banks 11, 11'. The gas inlet line 12 is connected to the first end 14 of the gas receiver 9. Thus, the gas feed point 16 of the gas inlet line 12 is located at the first end 14 of the gas receiver 9. The gas feed valve 17, which is farthest away from the gas feed point 16, is located at the second end 5 of the first cylinder bank 11 or at the second end 5' of the second cylinder bank 11'. The second ends 5, 5' are located further away from the gas feed point 16 than the first ends 6, 6' of the cylinder banks 11, 11'. Alternatively, the gas feed valves 17 of the cylinders 1 at the second ends 5, 5' of both cylinder banks 11, 11' can be opened during the air removal.

Also in the embodiment shown in fig 2, the gas feed point 16 of the gas inlet line 12 can be located between the ends 14, 15 of the gas receiver 9, for example between the gas feed valves 17 of the cylinders 1 that are in the middle of the cylinder bank 11, 11'. In this case, the fuel feed valves 17 of the cylinders 1 at both ends of one or both cylinder banks 11, 11' are opened during the air removal.

Fig. 3 discloses an embodiment, in which the cylinders 1 are arranged in two banks 11, 11' in a V-configuration. The gas feed system 7 comprises two gas receivers 9, 9', from which gaseous fuel can be conducted into the cylinders 1 of the first cylinder bank 11 and the second cylinder bank 11'. The gas receivers 9, 9' are placed between the cylinder banks 11, 11'. The gas inlet line 12 is connected to the first ends 14, 14' of the gas receivers 9, 9'. The venting line 19 is connected to the second ends 15, 15' of the gas receivers 9, 9'. Alternatively,
each gas receiver 9, 9' can be provided with its own venting line 19. In the embodiment of fig. 3, the gas feed valves 17, which are farthest away from the gas feed point 16, are located at the second end 5 of the first cylinder bank 11 and at the second end 5' of the second cylinder bank 11'. The second ends 5, 5' are located further away from the gas feed point 16 than the first ends 6, 6' of the cylinder banks 11, 11'.

Fig. 4 discloses an embodiment, in which the cylinders 1 are arranged in two banks 11, 11' in a V-configuration. The gas feed system 7 comprises an U-shaped gas receiver 9, which is placed between the first cylinder bank 11 and the second cylinder bank 11'. The gas inlet line 12 is connected to the first end 14 of the gas receiver 9. The venting line 19 is connected to the second end 15 of the gas receiver 9. In this embodiment, the gas feed valve 17, which is farthest away from the gas feed point 16 of the gas inlet line 12, is located at the first end 6' of the second cylinder bank 11'.

In the above embodiments, one or more gas feed valves 17 are opened and the other gas feed valves 17 are kept closed during the air removal of the gas receiver 9. Typically, the gas feed valve 17, which farthest away from the gas feed point 16 of the gas inlet line 12, is nearest to the inlet of the gas ventilation line 19.
CLAIMS

1. A method for removing excess air from a gas receiver (9) of a dual fuel reciprocating engine before changing fuel mode from a liquid fuel mode to a gas mode, which dual fuel reciprocating engine comprises a separate gas feed valve (17) for each engine cylinder (1), which gas feed valve (17) is arranged to feed gaseous fuel from the gas receiver (9) into an inlet port (10) of an engine cylinder (1) during the gas mode operation, in which method:
   - liquid fuel is fed into the cylinders (1),
   - gaseous fuel is fed from a gas source (8) into the gas receiver (9) via a gas inlet line (12), characterized in that before changing fuel mode from the liquid fuel mode to the gas mode at least one gas feed valve (17) is opened for removing air from the gas receiver (9).

2. The method according to claim 1, characterized in that at least one gas feed valve (17) of the cylinders (1), which are located between a longitudinal mid-point () of the cylinder bank (11, 11’) and a cylinder bank (11, 11’) end (5) that is farthest away from a gas feed point (16) of the gas inlet line (12), is opened.

3. The method according to claim 1 or 2, characterized in that the gas feed valve (17), which is farthest away from the gas feed point (16) of the gas inlet line (12), is opened.

4. The method according to claim 1, 2 or 3, characterized in that the gas feed valve (17), which is second farthest away from the gas feed point (16) of the gas inlet line (12), is opened.

5. The method according to claim 1, 2 or 3, characterized in that the cylinders (1) of the engine are arranged in at least one cylinder bank (11, 11’), and that...
the cylinder (1), whose gas feed valve (17) is opened, is located at a first end (6, 6') of the cylinder bank (11, 11').

6. The method according to claim 5, characterized in that the gas feed valve (17) of the cylinder (1) that is located at a second end (5, 5') of the cylinder bank (11, 11) is additionally opened.

7. The method according to any of the preceding claims, characterized in that the gas feed valve (17) is kept open for a predetermined period of time during the air removal of the gas receiver (9), after which the engine is ready for a fuel mode change from the liquid fuel mode to the gas mode.

8. The method according to any of claims 1-6, characterized in that combustion event in the cylinder (1), whose gas feed valve (17) is opened during the air removal of the gas receiver (9), is monitored, and when the monitoring indicates that gaseous fuel having an air concentration below a predetermined level is discharged from the gas receiver (9), the engine is ready for a change of fuel mode from the liquid fuel mode to the gas mode.

9. The method according to any of the preceding claims, characterized in that the cylinders (1) of the engine are arranged in two cylinder banks (11, 11'), and that the cylinders (1), whose gas feed valves (17) are opened, are located at the same ends (5, 5') of both cylinder banks (11, 11').

10. A gas feed system (7) for a duel fuel reciprocating engine capable of operating both in a gas mode and in a liquid fuel mode, the gas feed system (7) comprising:
- a gas receiver (9) for receiving gaseous fuel from a gas source (8),
- a gas inlet line (12) for feeding gas from the gas source (8) into the gas receiver (9), which gas inlet line (12) is provided with a shut-off valve (13) for
opening and closing flow communication between the gas source (8) and the gas receiver (9),
- a separate gas feed valve (17) for each engine cylinder (1), which gas feed valve (17) is arranged to feed gaseous fuel from the gas receiver (9) into an inlet port (10) of the cylinder (1) during the gas mode operation, characterized in that the gas feed system (7) further comprises a control unit (20) that is, before changing fuel mode from a liquid fuel mode to a gas mode, configured to:
- open the shut-off valve (13), and
- open at least one gas feed valve (17) for removing air from the gas receiver (9).

11. The gas feed system according to claim 10, characterized in that the control unit (20) is configured to monitor combustion event in the cylinder (1), whose gas feed valve (17) is opened during the air removal of the gas receiver (9), and to prepare for a change of fuel mode from the liquid fuel mode to gas mode when the monitoring indicates that gaseous fuel having an air concentration below a predetermined level is discharged from the gas receiver (9).

12. The system according to claim 10 or 11, characterized in that the gas feed point (16) of the gas inlet line (12) is located at an end (14) of the gas receiver (9).
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02D19/06 F02M21/02

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)

F02B F02D F02M

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>WO 99/45256 AI (CATERPILLAR INC [US]) 10 September 1999 (1999-09-10) abstract page 4, line 14 - page 5, line 16 figure 1</td>
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<td>DE 103 53 141 AI (BOSCH GMBH ROBERT [DE]) 9 June 2005 (2005-06-09) abstract figures 1, 2</td>
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Date of the actual completion of the international search

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