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(57) Sammendrag:
**A large two-stroke turbocharged uniflow scavenged internal combustion engine and a method of operating the engine by supplying a carbon-based fuel to the combustion chambers, combusting the carbon-based fuel in the combustion chambers, thereby producing combustion gas containing carbon dioxide, recirculating a portion of the combustion gas, and exhausting another portion of the combustion gas as exhaust gas, supplying pressurized scavenge gas to the combustion chambers, the pressurized scavenge gas containing at least 40% by mass recirculated combustion gas, preferably 40 to 55%, separating carbon dioxide from the exhaust gas in a carbon dioxide separation process, and storing the separated carbon dioxide in a storage unit (80).**

**Fortsættes...**

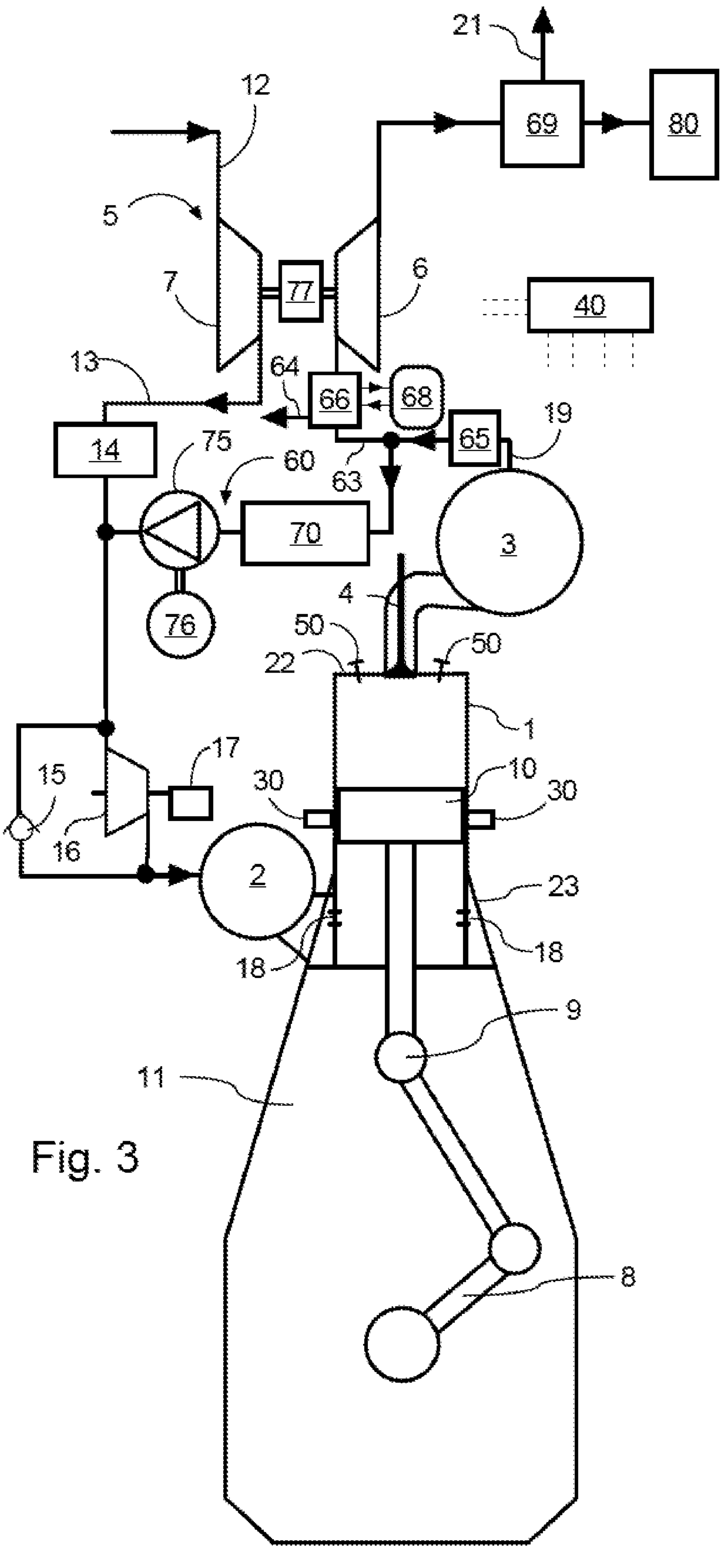
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Fig. 3

# METHOD AND LARGE TWO-STROKE UNIFLOW SCAVENGED INTERNAL COMBUSTION ENGINE FOR CARBON DIOXIDE CAPTURE

## TECHNICAL FIELD

The disclosure relates to large two-stroke internal combustion engines, in particular, large two-stroke uniflow scavenged internal combustion engines with crossheads running on a carbon-based fuel (gaseous or liquid fuel), and a method of operating such a type of engine, to reduce carbon dioxide emissions.

## BACKGROUND

Large two-stroke turbocharged uniflow scavenged internal combustion engines with crossheads are for example used for propulsion of large oceangoing vessels or as the primary mover in a power plant. Not only due to their sheer size, these two-stroke diesel engines are constructed differently from any other internal combustion engine. Their exhaust valves may weigh up to 400 kg, pistons have a diameter up to 100 cm and the maximum operating pressure in the combustion chamber is typically several hundred bar. The forces involved at these high pressure levels and piston sizes are enormous.

Large two-stroke turbocharged internal combustion engines that are operated with liquid fuel (e.g. fuel oil, marine diesel, heavy fuel oil, ethanol, Dimethyl ether (DME) or with gaseous fuel (e.g. natural gas (LNG), petroleum gas (LPG), Methanol or Ethane).

Engines that operate with a gaseous fuel may operate according to the Otto cycle in which gaseous fuel is admitted by fuel valves arranged medially along the length of the cylinder liner or in the cylinder cover, i.e. these engines admit the gaseous fuel during the upward stroke (from BDC to TDC) of the piston starting well before the exhaust valve closes, and compress a mixture of gaseous fuel and scavenging air in the combustion chamber and ignites the compressed mixture at or near TDC by timed ignition means, such as e.g. liquid fuel injection.

Engines that are operated with liquid fuel, and also engines that are operated with gaseous fuel with high-pressure injection, inject the gaseous- or liquid fuel when the piston is close to or at TDC, i.e. when the compression pressure in the combustion chamber is at or close to its maximum, and are thus operated according to the Diesel cycle, i.e. with compression ignition.

The liquid- and gaseous fuels used in known large two-stroke turbocharged unit flow scavenged internal combustion engines generally contain carbon, i.e. these are carbon-based fuels, and their combustion results in the generation of carbon dioxide that is exhausted into the atmosphere. Carbon dioxide emissions are generally considered detrimental to the environment and to be minimized or avoided.

KR20180072552 discloses a large two-stroke turbocharged uniflow scavenged internal combustion engine with crossheads according to the preamble of claim 1.

## SUMMARY

It is an object to provide an engine and a method that overcomes or at least reduces the problems indicated above.

The foregoing and other objects are achieved by the features of the independent claims. Further implementation forms are apparent from the dependent claims, the description, and the figures.

According to a first aspect, there is provided a large two-stroke turbocharged uniflow scavenged internal combustion engine with crossheads, the engine comprising: a plurality of combustion chambers, each delimited by a cylinder liner, a piston configured to reciprocate in the cylinder liner, and a cylinder cover, scavenge ports arranged in the cylinder liner for admitting scavenge gas into the combustion chamber, an exhaust gas outlet arranged in the cylinder cover and controlled by an exhaust valve, a fuel system configured for supplying a carbon-based fuel to the combustion chambers, the combustion chambers being configured for combusting the carbon-based fuel thereby generating carbon dioxide containing combustion gas, the combustion chambers being connected to a scavenge air receiver via the scavenge ports and to a combustion gas receiver via the exhaust gas outlet, an exhaust gas recirculation system configured for recirculating a portion of the combustion gas originating from the combustion chambers to the scavenge gas receiver, the exhaust gas recirculation system comprising a blower for assisting the flow of combustion gas to the scavenge air receiver, an exhaust gas system configured for exhausting another portion of the combusting gas originated from the combustion chambers as exhaust gas, the exhaust gas system comprising turbine of a turbocharger system driven by the exhaust gas, an air inlet system comprises a compressor of the turbocharger system, the compressor being configured for supplying pressurized scavenge air to the scavenge gas receiver, the exhaust gas system comprising a carbon dioxide separation system and a cardon dioxide storage unit connected to an outlet of the carbon dioxide separation system, and the carbon dioxide separation system being configured to receive exhaust gas, to separate at least a portion of the carbon dioxide in the exhaust gas from the exhaust gas, preferably by solidifying and/or liquifyingthe carbon dioxide, and to convey the separated carbon dioxide to the carbon dioxide storage unit.

By operating the engine with combustion gas recirculation, the concentration of carbon dioxide in the exhaust gas is increased, thereby rendering the separation of carbon dioxide from the exhaust gas more effective, and by separating the carbon dioxide from the exhaust gas, and storing the carbon dioxide, carbon dioxide emissions by the engine are reduced.

In a possible implementation form of the first aspect, The engine comprises a controller configured to regulate the percentage by mass of recirculated combustion gas in the scavenge gas to at least 40%, preferably between 40% and 55%.

In a possible implementation form of the first aspect, the controller is configured to control the speed of the blower to regulate the percentage of recirculated combustion gas in the scavenge gas.

In a possible implementation form of the first aspect, the engine comprises a combustion gas to water cooler, preferably a combustion gas to seawater cooler, the combustion gas to water cooler preferably being arranged upstream of a position where the stream of combustion gas from the engine is split into the portion that is recirculated and the other portion that is exhausted.

In a possible implementation form of the first aspect, the engine comprises a combustion gas to cooling medium heat exchanger, and a cooling plant, the cooling plant is configured to circulate the cooling medium through the combustion gas to cooling medium heat exchanger, the combustion gas to medium heat exchanger preferably being arranged downstream of a position where the stream of combustion gas from the engine is split into the portion that is recirculated and the other portion that is exhausted.

In a possible implementation form of the first aspect, the combustion gas to cooling medium heat exchanger is connected to a cooling plant.

In a possible implementation form of the first aspect, the engine comprises a cooler downstream of the turbine for cooling the exhaust gas for solidifying carbon dioxide in the exhaust gas.

In a possible implementation form of the first aspect, the cooler is connected to a cooling plant.

In a possible implementation form of the first aspect, the controller is configured to control the operation of the engine to result in the temperature of the exhaust gas when it reaches atmospheric pressure downstream of the turbine being -82 degrees Celcius or below, thereby solidifying carbon dioxide in the exhaust gas.

In a possible implementation form of the first aspect, the turbine is mechanically coupled to drive the compressor preferably assisted by an electric drive motor. For the turbine to provide sufficient expansion and thereby sufficient cooling to the exhaust gas, there will be operating conditions where the turbine does not deliver sufficient energy for operating the compressor, and in these operating conditions, additional energy needs to be added to the turbocharging system by the electric drive motor.

In a possible implementation form of the first aspect, the compressor is driven by an electric drive motor, and wherein the turbine drives an electric generator or alternator (79). In this setup of the turbocharging system, additional energy that may be required by the turbocharging system can be delivered by the electric drive motor that drives the compressor, from external sources of electric power, which may be in the form of an electric generator or an alternator driven by the engine, or by a generator set associated with the engine.

In a possible implementation form of the first aspect, the engine is operated according to the Otto cycle and gaseous fuel is admitted to the combustion chambers from fuel valves during the stoke of the piston from Bottom Dead Center (BDC) to Top Dead Center (TDC).

In a possible implementation form of the first aspect, the engine is operated according to the Diesel cycle, and gaseous or liquid fuel is injected into the combustion chambers from fuel valves when the piston is close to Top Dead Center (TDC).

According to a second aspect, there is provided a method of operating a large two-stroke turbocharged uniflow scavenged internal combustion engine with a plurality of combustion chambers, the method comprising: supplying a carbon-based fuel to the combustion chambers, combusting the carbon-based fuel in the combustion chambers, thereby generating combustion gas containing carbon dioxide, recirculating a portion of the combustion gas, and exhausting another portion of the combustion gas as exhaust gas, supplying pressurized scavenge gas to the combustion chambers, the pressurized scavenge gas containing at least 40% by mass recirculated combustion gas, preferably 40 to 55%, separating carbon dioxide from the exhaust gas in a carbon dioxide separation process, and storing the separated carbon dioxide in a storage unit.

By operating the engine with a high combustion gas recirculation ratio, the concentration of carbon dioxide in the exhaust gas is increased, thereby facilitating the separation of carbon dioxide from the exhaust gas, and by separating the carbon dioxide from the exhaust gas, and storing the carbon dioxide, emissions of carbon dioxide by the engine are avoided or at least reduced.

In a possible implementation form of the second aspect, the method comprises solidifying (freezing) at least a portion of the carbon dioxide in the exhaust gas. By freezing the carbon dioxide, it becomes relatively simple to separate the carbon dioxide from the other components of the exhaust gas. Further, storage of the carbon dioxide in solid form requires little space and can be performed in a container that does not need to be pressurized.

In a possible implementation form of the second aspect, the method comprises subjecting the exhaust gas to one or more cooling and expanding processes thereby or solidifying and/or liquefying the carbon dioxide downstream of the turbine.

In a possible implementation form of the second aspect, the method comprises storing the carbon dioxide in liquid or solid form in the storage unit.

In a possible implementation form of the second aspect, the method comprises controlling the speed of a blower in an exhaust gas recirculation system regulating the percentage of recirculated combustion gas in the pressurized scavenge gas.

In a possible implementation form of the second aspect, at least a part of the expanding process takes part in the turbine.

In a possible implementation form of the second aspect, the engine comprises a combustion gas to water cooler, preferably an exhaust gas to seawater cooler, preferably arranged upstream of a position where the stream of combustion gas from the engine is split into a portion that is recirculated and the portion that is exhausted, and the method comprises cooling the combustion gas with the combustion gas to water cooler, preferably to a temperature below 40 degrees Celsius, more preferably 31 degrees Celsius or below.

In a possible implementation form of the second aspect, the engine comprises an exhaust gas to cooling medium heat exchanger, and a cooling plant, the cooling plant is configured to circulate the cooling medium through the combustion gas to cooling medium heat exchanger preferably to a temperature below -10 degrees Celsius, more preferably -15 degrees Celsius or below.

In a possible implementation form of the second aspect, the solidified water content (ice) in the exhaust gas is separated from the exhaust gas, e.g. through a gravitational or centrifugal separation process, and stored or disposed of.

In a possible implementation form of the second aspect, the engine comprises a cooler downstream of the turbine for further cooling the exhaust gas for solidifying the carbon dioxide in the exhaust gas, preferably to a temperature below -80 degrees Celsius or below, preferably at atmospheric pressure.

In a possible implementation form of the second aspect, the method comprises compressing air with a compressor and mixing the combustion gas with the compressed air to obtain scavenge gas.

In a possible implementation form of the second aspect, the method comprises pressurizing the recirculated combustion gas with a blower compressor before mixing the combustion gas with the compressed air.

These and other aspects will be apparent from the embodiments described below.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the following detailed portion of the present disclosure, the aspects, embodiments, and implementations will be explained in more detail with reference to the example embodiments shown in the drawings, in which:

Fig. 1 is a front view of a large two-stroke diesel engine according to an example embodiment,

Fig. 2 is a side view of the large two-stroke engine of Fig. 1,

Fig. 3 is a diagrammatic representation of the large two-stroke engine according to Fig. 1 in an embodiment,

Fig. 4 is a diagrammatic representation of the large two-stroke engine according to Fig. 1, in another embodiment, and

Fig. 5 is a diagrammatic representation of the large two-stroke engine according to Fig. 1, in yet another embodiment.

## DETAILED DESCRIPTION

In the following detailed description, an internal combustion engine will be described with reference to a large two-stroke low-speed turbocharged internal combustion crosshead engine in the example embodiments. Figs. 1, 2, and 3 show an embodiment of a large low-speed turbocharged two-stroke diesel engine with a crankshaft 8 and crossheads 9. Figs. 1 and 2 are front and side views, respectively. Fig. 3 is a diagrammatic representation of an embodiment of the large low-speed turbocharged two-stroke diesel engine of Figs. 1 and 2 with its intake and exhaust systems. In this embodiment, the engine has four cylinders in line. However, the large low-speed turbocharged two-stroke internal combustion engine may have between four and fourteen cylinders in line, with the cylinder liners carried by an engine frame 11. The engine may e.g. be used as the main engine in a marine vessel or as a stationary engine for operating a generator in a power station. The total output of the engine may, for example, range from 1,000 to 110,000 kW.

The engine is in this example embodiment an engine of the two-stroke uniflow scavenged type with scavenging ports 18 in the lower region of the cylinder liners 1 and a central exhaust valve 4 in a cylinder cover 22 at the top of the cylinder liners 1. The scavenge gas is passed from the scavenge gas receiver 2 through the scavenge ports 18 of the individual cylinder liners 1 when the piston 10 is below the scavenge ports 18. Gaseous fuel (e.g. Methanol, petroleum gas or LPG, natural gas LNG, or Ethane) is admitted from gaseous fuel valves 30 under control of an electronic controller 60 when the piston is in its upward movement (from BDC to TDC) and before the piston passes the fuel valves 30 (gas admission valves) and/or liquid fuel (e.g. fuel oil) is injected at high pressure (preferably 300 bar or more) through liquid fuel valves 50 when the piston 10 is at or near TDC. The fuel gas is admitted at a relatively low pressure that is below 30 bar, preferably below 25 bar, more preferably below 20 bar. The fuel valves 30 are, preferably evenly, distributed around the circumference of the cylinder liner and placed in the central region of the length of the cylinder liner 1.The admission of the gaseous fuel takes place when the compression pressure is relatively low, i.e. much lower than the compression pressure when the piston reaches TDC, hence allowing admission at relatively low pressure.

A piston 10 in the cylinder liner 1 compresses the charge of gaseous fuel and scavenge gas, (or compresses the scavenge gas in case the operation is with liquid fuel injection at TDC only) and at or near TDC ignition is triggered by injection of liquid fuel at high pressure from liquid fuel valves 50 that are preferably arranged in the cylinder cover 22 or through the compression in case of liquid fuel injection at or near TDC only. Combustion follows and combustion gas containing carbon dioxide is generated.

When the exhaust valve 4 is opened, the combustion gas flows through a combustion gas duct associated with the cylinder 1 into the combustion gas receiver 3 and onwards through a combustion gas conduit 19 that includes a combustion gas to water cooler 65. The combustion gas to water cooler 65 is operated with seawater if the engine is installed in a marine vessel. The activity of the combustion gas to water cooler 65 is controlled by a controller 40 and operated to cool the combustion gas from a temperature of 425 to 475 degrees Celsius at the inlet of the combustion gas to water cooler 65 to a temperature below 40, preferably below 35 most preferable below 31 degrees Celcius, at the outlet of the combustion gas to water cooler 65. At a position, preferably downstream of the combustion gas to water cooler 65, the flow of combustion gas is divided into a portion that flows to a combustion gas recirculation system 60 and another portion that flows into an exhaust system. The combustion gas recirculating system 60 connects to the scavenging system as described further below. The combustion gas recirculation system 60 includes a conduit connecting to the scavenging system and may include (preferably water operated) scrubber 70 for cleaning the combustion gas. The combustion gas recirculation system 60 also comprises a blower 75 (preferably driven by an electric drive motor 76) for forcing combustion gas through the combustion gas system 60 to the scavenging system. The operation of the blower 75 is controlled by the controller 40. In an embodiment, the controller 40 regulates the combustion gas ratio (by mass) in the scavenging gas by adjusting the operation of the blower 75. The controller 40 is in an embodiment configured to regulate the combustion gas ratio (by mass) in the scavenging gas to be above 40%, preferably above 45%, most preferably between 40 and 55%. The combustion gas ratio is defined as the percentage of the mass of combustion gas of the total gas mass induced into the engine.

The exhaust system comprises an exhaust conduit 63 that includes exhaust gas to cooling medium heat exchanger 66 and leads to a turbine 6 of a turbocharger 5. The exhaust gas to cooling medium heat exchanger 66, is operably connected to a cooling plant 68. The cooling plant 60 is configured to circulate the cooling medium through the combustion gas to cooling medium heat exchanger 68 to cool the exhaust gas at the outlet of the cooling medium heat exchanger 66 to a temperature below -10 degrees Celsius, more preferably -15 degrees Celsius or below. The water in the exhaust gas is thereby solidified (to form ice or snow) and separated in a gravitational or centrifugal process and removed through drain 64. The cooling medium (refrigerant) may have a temperature in the range of -20 to -30 degrees Celcius at a cooling medium inlet of the cooling medium heat exchanger 66. Suitable cooling media (refrigerants) are e.g. ammonia, propane, isobutane, carbon dioxide and other known cooling media for industrial cooling plants. The operation of the cooling medium heat exchanger 66 is controlled by the controller 40 to obtain a temperature of the exhaust gas at the outlet of the cooling medium heat exchanger 66 at the desired temperature.

From the outlet of the exhaust gas to cooling the exchanger 66, the exhaust gas flows to the inlet of the turbine 6. At the outlet of the turbine 6, the exhaust gas has through expansion in the turbine 6 reached a temperature of below minus 80 degrees Celsius, preferably below minus 82 degrees Celcius and at ambient (atmospheric pressure. In these conditions, the carbon dioxide in the exhaust gas solidifies (freezes) and is separated, e.g. through a gravitational or centrifugal separation process. The separated solid carbon dioxide is stored in a storage unit 80. The remaining exhaust gas contains no carbon dioxide or only a little amount of carbon dioxide and is allowed to flow away through an outlet 21 and into the atmosphere.

In this embodiment, the engine comprises a cooler 69 downstream of the turbine 6 for further cooling the exhaust gas for solidifying the carbon dioxide in the exhaust gas, preferably to a temperature below -80 degrees Celsius or below, at atmospheric pressure. In this embodiment the solid carbon dioxide is separated, e.g. through a gravitational or centrifugal process, in the cooler 69, at the outlet of the cooler 69, or just downstream of the cooler 69. The separated solid carbon dioxide is stored in the carbon dioxide unit 80. The carbon dioxide stored in the carbon dioxide storage unit 80 may subsequently be stored in a more permanent solution for storing captured carbon dioxide.

Through a shaft, the turbine 6 drives a compressor 7 supplied with fresh air via an air inlet 12. The turbocharger 5 is assisted by an electric drive motor 77 that assists the turbocharger 5 when the turbine 6 does not provide sufficient power to drive the compressor 7.

The compressor 7 delivers pressurized scavenge air to a scavenge air conduit 13 leading to the scavenge air receiver 2. The scavenge air in conduit 13 passes an intercooler 14 for cooling the scavenge air.

Either upstream (shown) or downstream (not shown) of the intercooler 14 the combustion gas recirculation system 60 connects to the scavenge air conduit 13. At this position, the recirculated combustion gas is mixed with the scavenge air to form scavenge gas. The controller 40 is configured to ensure that the scavenge gas contains 40 to 55 % by mass combustion gas.

The cooled scavenge air or gas passes via an auxiliary blower 16 driven by an electric motor 17 that pressurizes the scavenge air flow when the compressor 7 of the turbocharger 5 does not deliver sufficient pressure for the scavenge air receiver 2, i.e. in low- or partial load conditions of the engine. At higher engine loads the turbocharger compressor 7 delivers sufficient compressed scavenge air and then the auxiliary blower 16 is bypassed via a non-return valve 15.

A controller 40 (electronic control unit), which as such may be comprised of several interconnected electronic units that comprise a processor and other hardware for performing the function of a controller), is generally in control of the operation of the engine and exceeds control over e.g. gaseous fuel admission (quantity and timing), liquid fuel injection (quantity and timing), and opening and closing of the exhaust valve 4 (timing and extent of lift), recirculated combustion gas ratio and operation of various coolers. Hereto, the controller 40 is in receipt of various signals from sensors that inform the controller of the operating conditions of the engine (engine load, engine speed, blower speed, scavenging gas temperature, combustion gas temperature at various locations, exhaust gas temperature at various locations, pressures in the scavenging system, in the combustion chambers, in the exhaust gas system, and in the combustion gas recirculation system. Preferably, the engine comprises a variable timing exhaust valve actuation system allowing individual control of the exhaust valve timing for each combustion chamber. The controller 40 is connected via signal lines or wireless connections to the fuel valves 30, the liquid fuel valves 50, the exhaust valve actuator, an angular position sensor that detects the angle of the crankshaft and generates a signal representative of the position of the crankshaft, and a pressure sensor, preferably in the cylinder cover 22 or alternatively in the cylinder liner 1 generating a signal representative of the pressure in the combustion chamber.

Depending on the engine size, the cylinder liner 1 may be manufactured in different sizes with cylinder bores typically ranging from 250 mm to 1000 mm, and corresponding typical lengths ranging from 1000 mm to 4500 mm.

The cylinder liners 1 are mounted in a cylinder frame 23 with a cylinder cover 22 placed on the top of each cylinder liner 1 with a gas-tight interface therebetween. The piston 10 is arranged to reciprocate between Bottom Dead Center (BDC) and Top Dead Center (TDC). These two positions are separated by a 180 degrees revolution of the crankshaft 8. The cylinder liner 1 is provided with a plurality of circumferentially distributed cylinder lubrication holes that are connected to a cylinder lubrication line that provides a supply of cylinder lubrication oil when the piston 10 passes the cylinder lubrication holes 25, thereafter piston rings in the piston 10 (not shown) distribute the cylinder lubrication oil over the running surface (inner surface) of the cylinder liner 1.

The liquid fuel valves 50 (typically more than one per cylinder, preferably three or four), are mounted in the cylinder cover 22 and connected to a source of liquid fuel (not shown). The liquid fuel valves 50 are preferably arranged around the exhaust valve 4, in particular around the central outlet (opening) in the cylinder cover 22 that is controlled by the exhaust valve 4. The timing and quantity of the liquid fuel injection are controlled by the controller 40. The liquid fuel valves 50 are only used to inject a small amount of ignition liquid (pilot) if the engine is operating in the gaseous fuel mode. If the engine is operating in a liquid fuel mode, the amount of liquid fuel required for operating the engine with the actual engine load is injected through the liquid fuel valves 50. The cylinder 22 cover may be provided with pre-chambers (not shown) and a tip of the liquid fuel valves 50, typically a tip provided with a nozzle with one or more nozzle holes is arranged such that the pilot oil (ignition liquid) is injected and atomized into the pre-chambers to trigger ignition. The pre-chambers assist in ensuring reliable ignition. In an embodiment, the pre-chambers are double pre-chambers, i.e. two pre-chambers connected in series.

The fuel vales 30 are installed in the cylinder liner 1 (or in the cylinder cover 22), with their nozzle substantially flush with the inner surface of the cylinder liner 1 and with the rear end of the fuel valve 30 protruding from the outer wall of the cylinder liner 1. Typically, one or two, but possibly as much as three or four fuel valves 30 are provided in each cylinder liner 1, circumferentially distributed (preferably circumferentially evenly distributed) around the cylinder liner 1. The fuel valves 30 are in an embodiment arranged substantially medial along the length of the cylinder liner 1. The fuel valves 30 are connected to a pressurized source of gaseous fuel 40 (e.g. Methanol, LPG, LNG, Ethane or Ammonia), i.e. the fuel is in the gaseous phase when it is delivered to the fuel valves 30. Since the gaseous fuel is admitted during the stroke of the piston 10 from BDC to TDC, the pressure of the source of gaseous fuel merely needs to be higher than the pressure residing in the cylinder liner 1, and typically a pressure of less than 20 bar is sufficient for the gaseous fuel delivered to the fuel valve 30. The fuel valves 30 are connected to the controller 40, which determines the timing of the opening and closing of the fuel valve, and the duration of the opening of the fuel valves 30.

The liquid fuel for ignition is in an embodiment a fuel oil, marine diesel, heavy fuel oil, ethanol, or Dimethyl ether (DME).

The gaseous operation mode can be one of several operation modes of the engine. Other modes may include a liquid fuel operation mode, in which all of the fuel required for the operation of the engine is provided in liquid form through the liquid fuel valves 50. In the gaseous fuel operation mode, the engine is operated with gaseous fuel that is admitted during the stroke of the piston from BDC to TDC at relatively low pressure as the main fuel, i.e. providing for a major portion of the energy supplied to the engine, whereas the liquid fuel is, by comparison, constitutes a relatively small amount of fuel that makes only a relatively small contribution to the amount of energy supplied to the engine, the purpose of the liquid fuel being timed ignition, i.e. the liquid fuel serves as an ignition liquid .

Thus, the engine of the present embodiment can be a dual-fuel engine, i.e. the engine has a mode in which it operates exclusively on liquid fuel and a mode in which is nearly exclusively operates on gaseous fuel .

The engine is operated by supplying a carbon-based fuel to the combustion chambers (liquid and/or gaseous fuel), combusting the carbon-based fuel in the combustion chambers, thereby generating combustion gas containing carbon dioxide, recirculating a portion of the combustion gas, and exhausting another portion of the combustion gas as exhaust gas, supplying pressurized scavenge gas to the combustion chambers, the pressurized scavenge gas containing at least 40% by mass recirculated combustion gas, preferably 40 to 55%, separating carbon dioxide from the exhaust gas in a carbon dioxide separation process, and storing the separated carbon dioxide in a storage unit 80.

In this process, the exhaust gas is subjected to cooling and expanding processes that solidifies (freezes) the carbon dioxide in the exhaust gas at the outlet of the turbine 6 or downstream the turbine 6 in the cooler 69. The frozen carbon dioxide is, separated, e.g. in a gravitational or centrifugal separation process, and thereafter stored in solid form in the storage unit 80. The storage unit 80 is in an embodiment a thermally insulated non-pressurized container or tank.

The controller 40, controls the speed of the blower 75 in the exhaust gas recirculation system 60 for regulating the percentage of recirculated combustion gas in the pressurized scavenge gas, preferably to a percentage by mass of at least 40% to increase the concentration of carbon dioxide in the combustion gas. In an embodiment, the controller 40 is configured to adjust the recirculated combustion gas ratio to result in a carbon dioxide concentration in the combustion gas that is at least double that when compared to operating without combustion gas recirculation.

At least a part of the expansion process of the exhaust gas takes part in the turbine 6, thereby creating a large drop in temperature and pressure of the exhaust gas, preferably to atmospheric pressure and a temperature of -82 degrees or lower thereby solidifying carbon dioxide in the exhaust gas.

Fig. 4 shows another embodiment of the engine. In this embodiment, structures and features that are the same or similar to corresponding structures and features previously described or shown herein are denoted by the same reference numeral as previously used for simplicity. In this embodiment, the engine and the operation thereof is largely identical to the previous embodiment, and hence only the differences with the previous embodiment will be described in detail.

In this embodiment, the compressor 6 is driven by an electric drive motor 78, and the turbine 7 drives an electric generator or alternator 79. In this setup of the turbocharging system, additional energy that may be required by the turbocharging system is delivered by the electric drive motor 78 that drives the compressor 7. Hereto, the electric drive motor 78 is powered by a source of electric power, which may be in the form of an electric generator or an alternator driven by the engine, or by a generator set associated with the engine.

In this embodiment, the engine is shown as a compression ignition engine (operating according to the Diesel principle), with the carbon-based fuel (gaseous or liquid) being injected at high pressure when the piston 10 is at or near TDC. The shown engine neither requires pre-chambers nor fuel admission valves 30 in the cylinder liner 10. However, the engine according to this embodiment could also be operated according to the Otto principle with gaseous fuel admission during the stroke of the piston 10 from BDC to TDC.

In this embodiment, the controller 40 is configured to operate the engine such that the conditions (i.e. pressure and temperature) at the outlet of the turbine 6 are such that the carbon dioxide in the exhaust gas is solidified and the solidified carbon dioxide is separated at the outlet of the turbine 6 through a gravitational or centrifugal separation process and stored in the carbon dioxide storage unit 80.

Fig. 5 shows another embodiment of the engine. In this embodiment, structures and features that are the same or similar to corresponding structures and features previously described or shown herein are denoted by the same reference numeral as previously used for simplicity. In this embodiment, the engine and the operation thereof is largely identical to the previous embodiment, and hence only the differences with the previous embodiment will be described in detail.

In this embodiment the engine shown is a gas admission engine operating according to the Otto principle, but it should be understood that this embodiment may work just as well with a high-pressure fuel injection engine operating according to the Diesel principle.

In this embodiment, no measures are taken to achieve a lower than normal (conventional) the temperature of the exhaust gas at the outlet of the turbine 6. Hence, there is neither need for combustion gas and water cooler nor for an exhaust gas to cooling medium cooler connected to a cooling plant. Accordingly, the temperature of the exhaust gas will be in a conventional range of temperatures of 180 to 250 degrees Celsius.

Downstream of the turbine 6, a carbon dioxide separation unit 88 separates carbon dioxide from the exhaust gas and stores the separated carbon dioxide in a carbon dioxide container 80.

In an embodiment, the carbon dioxide separation unit 88 dries the exhaust gas, compresses the exhaust gas, and thereafter submits the exhaust gas to one or more refrigeration loops followed by an expanding process to liquefy or solidify the carbon dioxide in the exhaust gas, to thereafter separate the liquid or solid exhaust carbon dioxide and stored in a liquid or solid carbon dioxide storage unit 80.

In another embodiment (not shown in the drawings), the carbon dioxide separation unit 88 uses a carbon dioxide absorber (e.g. using an absorber solvent) that is operably connected to a regenerator, e.g. an amine regenerator to separate carbon dioxide from the exhaust gas. The regenerator may use steam to strip the CO2 from the absorber solvent.

The various aspects and implementations have been described in conjunction with various embodiments herein. The embodiments can be combined in various ways. Further, other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed subject-matter, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor, controller, or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage. The reference signs used in the claims shall not be construed as limiting the scope.

PATENTKRAV

1. Stor, turboladet totaktsforbrændingsmotor med længdeskylning og med krydshoveder, hvilken motor omfatter:

en flerhed af forbrændingskamre, der hvert er afgrænset af en cylinderforing (1), et stempel (10), der er konfigureret til at bevæge sig frem og tilbage i cylinderforingen (1), og et cylinderdæksel (22),

skylleporte (18), der er anbragt i cylinderforingen (1), til at lade skyllegas komme ind i forbrændingskammeret,

et udstødningsgasudgang, der er anbragt i cylinderdækslet (22) og styres af en udstødningsventil (4),

et brændstofsystem, der er konfigureret til tilføre et carbonbaseret brændstof til forbrændingskamrene,

hvor forbrændingskamrene er konfigureret til at forbrænde det carbonbaserede brændstof, hvorved der genereres carbondioxid indeholdende forbrændingsgas,

hvor forbrændingskamrene er forbundet med en skylleluftmodtager (2) via skylleportene (18) og med en forbrændingsgasmodtager (3) via udstødningsgasudgangen,

et udstødningsgasrecirkulationssystem (60), der er konfigureret til at recirkulere en del af forbrændingsgassen, der kommer fra forbrændingskamrene, til skyllegasmodtageren (2), hvilket udstødningsgasrecirkulationssystem (60) omfatter en blæser (75) til at assistere strømmen af forbrændingsgas til skylleluftmodtageren (2),

et udstødningsgassystem, der er konfigureret til at udstøde en anden del af forbrændingsgassen, der kommer fra forbrændingskamrene, som udstødningsgas,

hvilket udstødningsgassystem omfatter en turbine (6) fra et turboladersystem (5), der drives af udstødningsgassen,

et luftindgangssystem omfatter en kompressor (7) fra turboladersystemet (5), hvilken kompressor (7) er konfigureret til at tilføre skylleluft under tryk til skyllegasmodtageren (2),

kendetegnet ved, at udstødningsgassystemet omfatter et carbondioxidseparationssystem og en carbondioxidoplagringsenhed (80), der er forbundet med en udgang fra carbondioxidseparationssystemet, og

hvor carbondioxidseparationssystemet er konfigureret til at modtage udstødningsgas, til at separere mindst en del af carbondioxidet i udstødningsgassen fra udstødningsgassen, fortrinsvis ved flydendegørelse og/eller størkning af carbondioxidet, og til at transportere det separerede carbondioxid til carbondioxidoplagringsenheden (80).

2. Motor ifølge krav 1, der omfatter en styreenhed (40), der er konfigureret til at regulere vægtprocenten af recirkuleret forbrændingsgas i skyllegassen til mindst 40 %, fortrinsvis mellem 40 % og 55 %.

3. Motor ifølge krav 2, hvor styreenheden (40) er konfigureret til at styre blæserens (75) hastighed for at regulere procentsatsen af recirkuleret forbrændingsgas i skylleluften.

4. Motor ifølge et hvilket som helst af de foregående krav, der omfatter en forbrændingsgas til vandkøler (65), fortrinsvis en forbrændingsgas til havvandkøler, hvilken forbrændingsgas til vandkøler (65) fortrinsvis er anbragt opstrøms for en position, hvor strømmen af forbrændingsgas fra motoren er opdelt i delen, der recirkuleres, og den anden del, der udstødes.

5. Motor ifølge et hvilket som helst af de foregående krav, der omfatter en forbrændingsgas til kølemiddelvarmeveksler (66), og et køleanlæg (68), hvilket køleanlæg (68) er konfigureret til at cirkulere kølemidlet gennem forbrændingsgas til kølemiddelvarmeveksleren (66), hvilken forbrændingsgas til kølemiddelvarmeveksler (66) fortrinsvis er anbragt nedstrøms for en position, hvor strømmen af forbrændingsgas fra motoren opdeles i delen, der recirkuleres, og den anden del, der udstødes.

6. Motor ifølge et hvilket som helst af de foregående krav, der omfatter en køler (69) nedstrøms for turbinen (6) til at køle udstødningsgassen for flydendegørelse og/eller størkning af carbondioxid i udstødningsgassen.

7. Motor ifølge et hvilket som helst af de foregående krav, hvor styreenheden (40) er konfigureret til at styre motorens

funktion til at resultere i udstødningsgassens temperatur, når den når atmosfærisk tryk nedstrøms for turbinen (6) på -82 grader Celsius eller lavere.

8. Motor ifølge et hvilket som helst af de foregående krav, hvor turbinen (6) er mekanisk koblet for at drive kompressoren (7), fortrinsvis assisteret af en elektrisk drivmotor (77).

9. Motor ifølge et hvilket som helst af kravene 1 til 7, hvor kompressoren (7) drives af en elektrisk drivmotor (78), og hvor turbinen (7) driver en elektrisk generator eller vekselstrømsgenerator (79).

10. Fremgangsmåde til drift af en stor, turboladet totaktsforbrændingsmotor med længdeskylning med en flerhed af forbrændingskamre, hvilken fremgangsmåde omfatter:

tilførsel af et carbonbaseret brændstof til forbrændings-kamrene,

forbrænding af det carbonbaserede brændstof i forbrændings-kamrene, hvorved der genereres forbrændingsgas indeholdende carbondioxid,

recirkulation af en del af forbrændingsgassen, og udstødning af en anden del af forbrændingsgassen som udstødningsgas,

tilførsel af skyllegas under tryk til forbrændingskamrene, hvilken skyllegas under tryk indeholder mindst 40 vægt-% recirkuleret forbrændingsgas, fortrinsvis 40 til 55 %, separation af carbondioxid fra udstødningsgassen i en carbondioxidseparationsproces, og

oplagring af det separerede carbondioxid i en oplagringsenhed (80).

11. Fremgangsmåde ifølge krav 10, der omfatter udsættelse af udstødningsgassen for én eller flere af afkølings- og ekspansionsprocesser for at flydendegøre og/eller størkne carbondioxidet nedstrøms for turbinen (6).

12. Fremgangsmåde ifølge krav 11, der omfatter oplagring af carbondioxidet i flydende eller fast form i oplagringsenheden (80).

13. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 12, der omfatter styring af en blæsers (75) hastighed i et udstødningsgasrecirkulationssystem, hvor procentsatsen af recirkuleret forbrændingsgas reguleres i skyllegassen under tryk.

14. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 13, hvor mindst en del af ekspansionsprocessen sker i turbinen (6).

15. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 14, hvor motoren omfatter en forbrændingsgas til vandkøler (65), fortrinsvis en udstødningsgas til havvandskøler, fortrinsvis anbragt opstrøms for en position, hvor strømmen af forbrændingsgas fra motoren fra motoren er opdelt i en del, der recirkuleres, og delen, der udstødes, hvor

fremgangsmåden omfatter køling af forbrændingsgassen med forbrændingsgassen til vandkøler (65), fortrinsvis til en temperatur under 40 grader Celsius, mere fortrinsvis 31 grader Celsius eller lavere.

16. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 15, hvor motoren omfatter en udstødningsgas til kølemiddelvarmeveksler (66), fortrinsvis anbragt nedstrøms for en position, hvor strømmen af forbrændingsgas fra motoren er opdelt i en del, der recirkuleres, og delen, der udstødes, og et køleanlæg (68), hvilket køleanlæg (68) er konfigureret til at cirkulere kølemidlet gennem forbrændingsgas til kølemiddelvarmeveksleren (68) fortrinsvis til en temperatur under -10 grader Celsius, mere fortrinsvis -15 grader Celsius eller lavere.

17. Fremgangsmåde ifølge et hvilket som helst af kravene 10 til 16, hvor motoren omfatter en køler (69) nedstrøms for turbinen (6) til yderligere afkøling af udstødningsgassen for flydendegørelse og/eller størkning af carbondioxid i udstødningsgassen, fortrinsvis til en temperatur under -80 grader Celsius eller lavere, fortrinsvis ved atmosfærisk tryk.

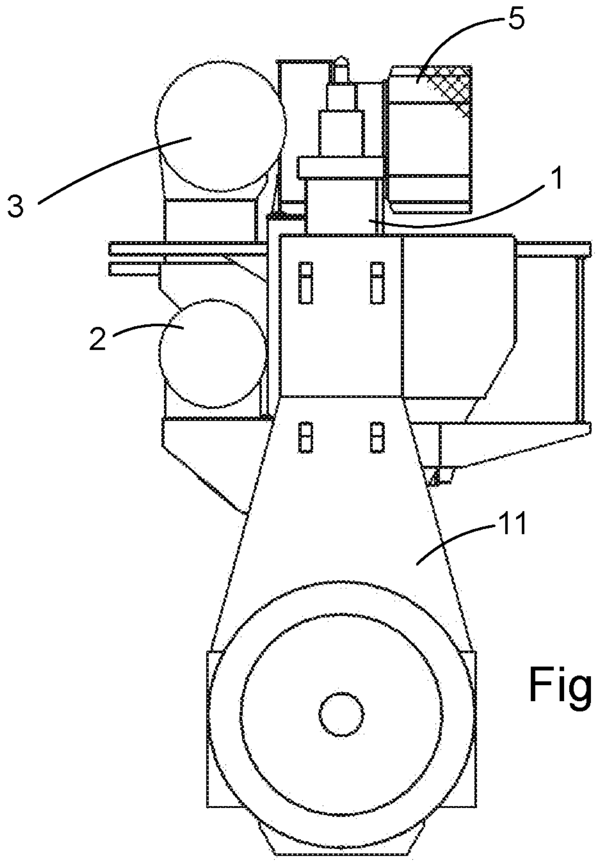


Fig. 1

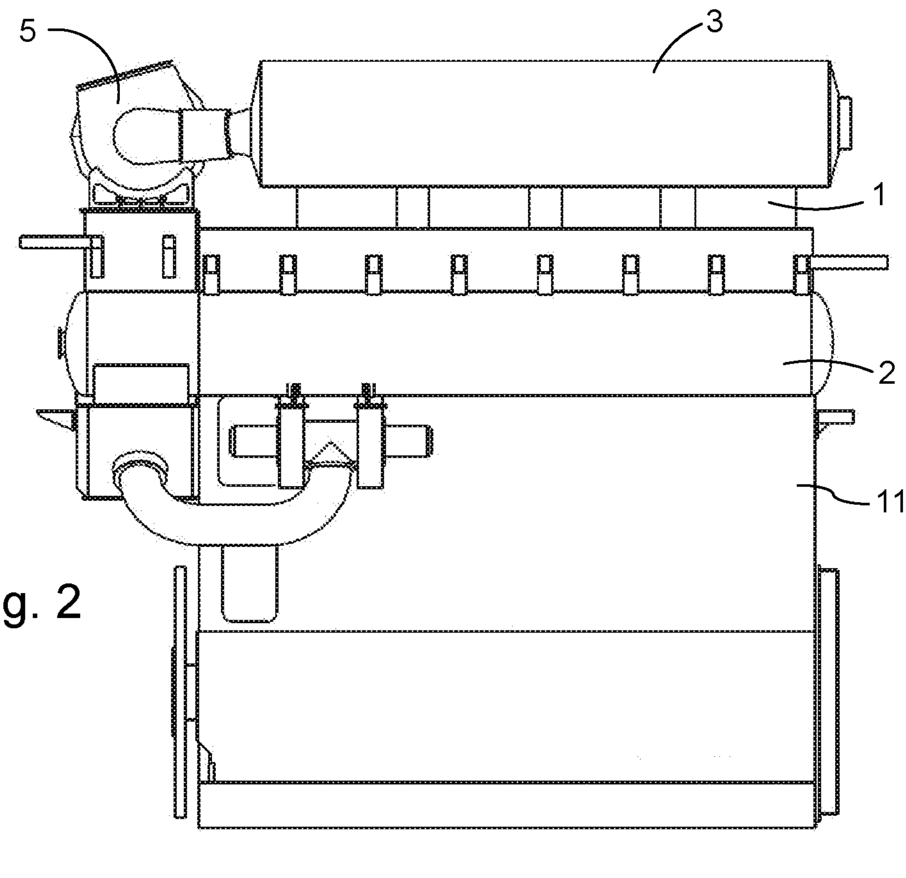


Fig. 2

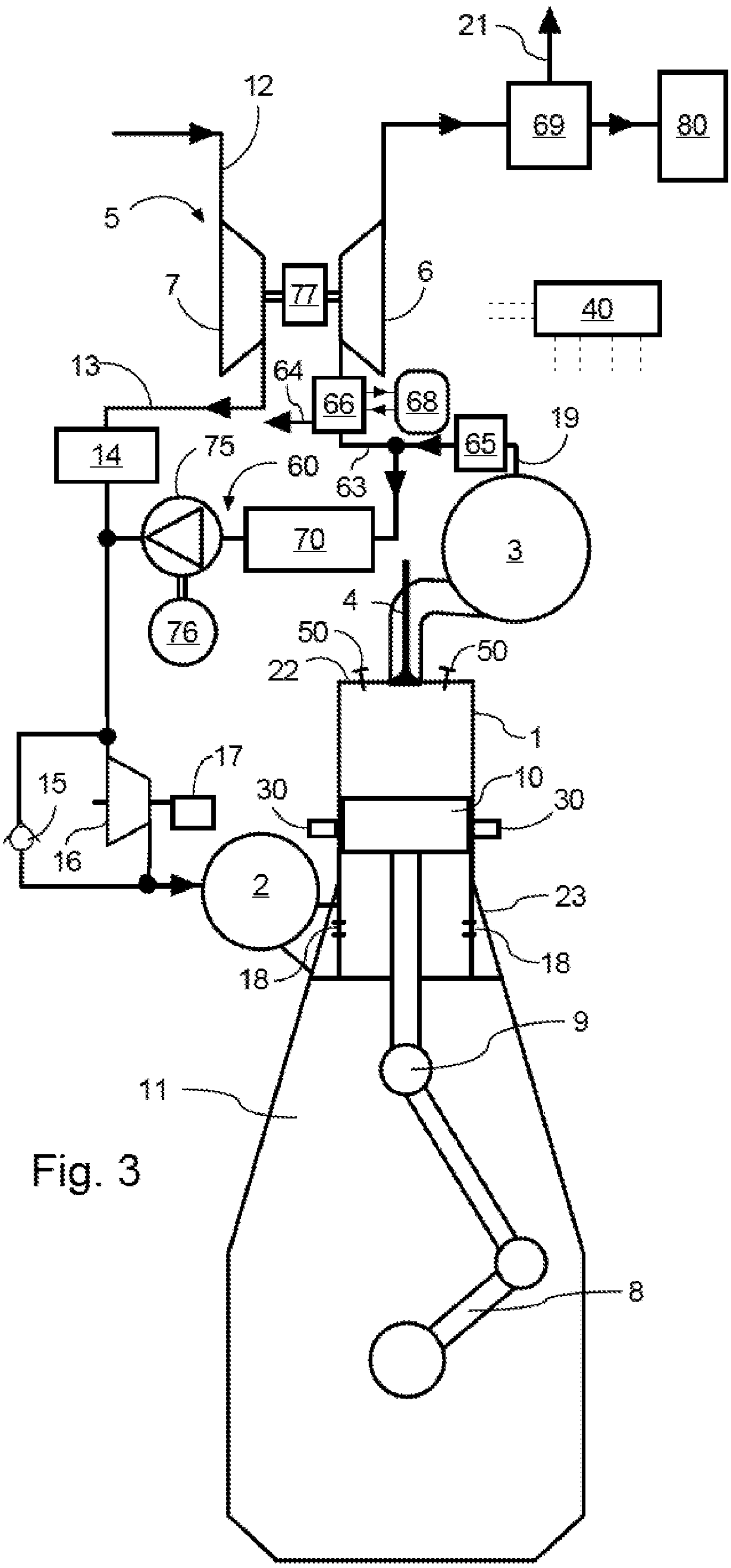
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Fig. 3

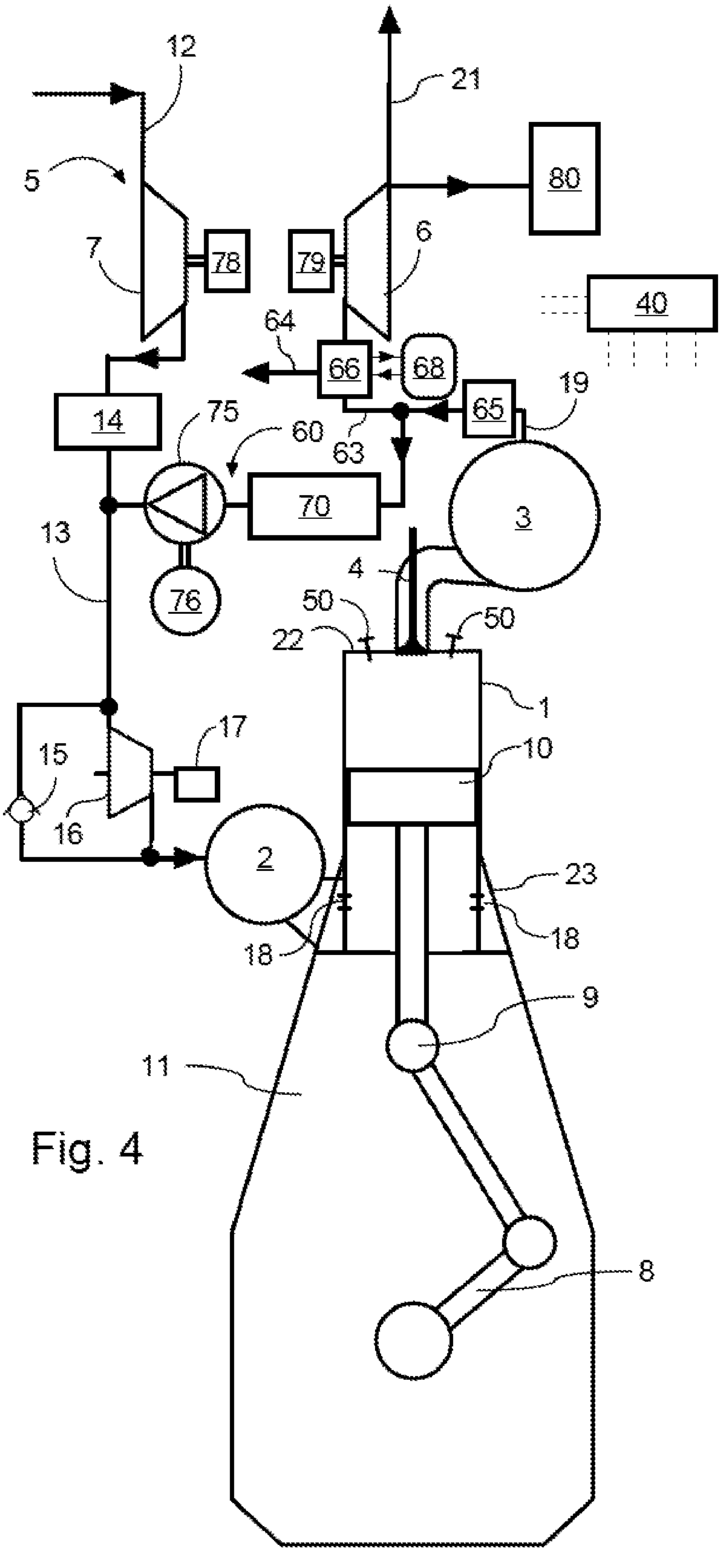
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Fig. 4

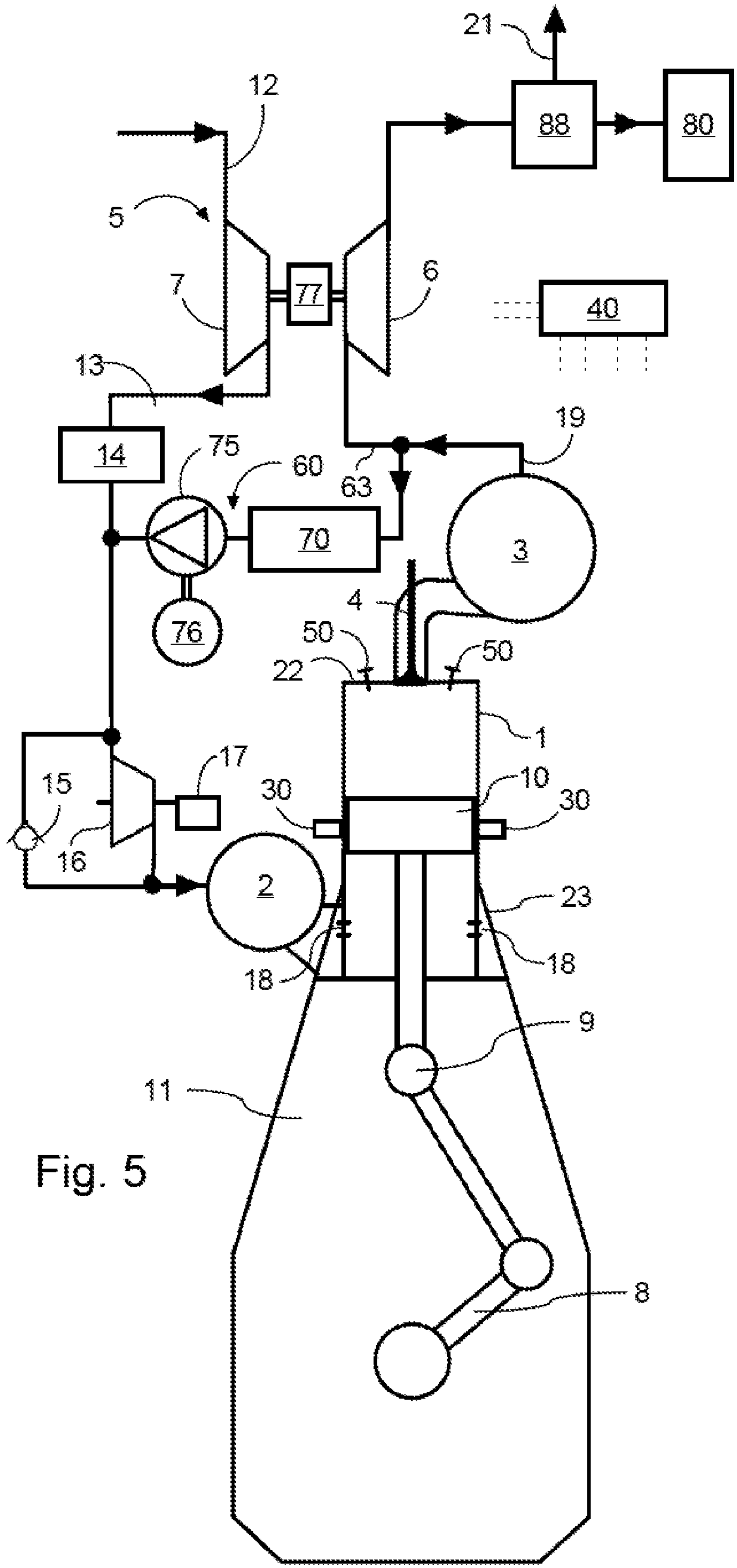
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Fig. 5

Danish Patent and Trademark Office

| **SEARCH REPORT - PATENT** | Application No.<br>PA 2022 70068 |
|---|---|

1. ☐ Certain claims were found unsearchable (See Box No. I).

2. ☐ Unity of invention is lacking prior to search (See Box No. II).

A. CLASSIFICATION OF SUBJECT MATTER

F25J 3/00 (2006.01); B01D 53/24 (2006.01); B63H 21/32 (2006.01); C10K 1/00 (2006.01); F01N 3/08 (2006.01); F23C 9/00 (2006.01)

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

PCT-minimum documentation searched (classification system followed by classification symbols)

IPC&CPC: B01D, B63H, C10K, F02B, F02G, F23C, F23J, F25J, F01N

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

DK, NO, SE, FI: IPC-classes: F25J 3/00, F01N 3/08, B01D 53/24, B01D 53/LOW, C10K 1/00, B63H 21/32, F23J 15/00, F23C 9/00

Electronic database consulted during the search (name of database and, where practicable, search terms used)

EPODOC, WPI, FULL TEXT: ENGLISH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant for claim No. |
|---|---|---|
| A | KR 20180072552 A (MAN DIESEL & TURBO FILIAL AF MAN DIESEL & TURBO SE TYSKLAND) 2018.06.29<br>Fig. 3, 8 and paragraphs [0018, 0019, 0037-0039]. | 1-17 |
| A | EP 3904648 A1 (KOREA SHIPBUILDING & OFFSHORE ENG CO LTD) 2021.11.03<br>See abstract and fig. 1-4. | 1-17 |
| A | KR 20180086566 A (DAEWOO SHIPBUILDING & MARINE) 2018.08.01<br>See abstract. | 1-17 |
| A | KR 20220019970 A (SAMSUNG HEAVY IND) 2022.02.18<br>See fig. 3. | 1-17 |

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

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance.

"D" Document cited in the application.

"E" Earlier application or patent but published on or after the filing date.

"L" Document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified).

"O" Document referring to an oral disclosure, use, exhibition or other means.

"P" Document published prior to the filing date but later than the priority date claimed.

"T" Document not in conflict with the application but cited to understand the principle or theory underlying the invention.

"X" Document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone.

"Y" Document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" Document member of the same patent family.

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Date of completion of the search report

02 September 2022

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Jesper Peis
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| SEARCH REPORT - PATENT | | Application No. PA 2022 70068 |
|---|---|---|
| C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT | | |
| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant for claim No. |
| A | JP 2014100696 A (FURUBAYASHI YOSHIHIRO) 2014.0605<br>See figs- and abstract. | 1-17 |
| A | KR 102231476B B1 (DAEWOO SHIPBUILDING & MARINE) 2021.03.25<br>See abstract. | 1-17 |

| SEARCH REPORT - PATENT | Application No.<br>PA 2022 70068 |
|---|---|

**Box No. I Observations where certain claims were found unsearchable**

This search report has not been established in respect of certain claims for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched, namely:

2. ☐ Claims Nos.:
because they relate to parts of the patent application that do not comply with the prescribed requirements to such an extent that no meaningful search can be carried out, specifically:

3. ☐ Claims Nos.:
because of other matters.

**Box No. II Observations where unity of invention is lacking prior to the search**

The Danish Patent and Trademark Office found multiple inventions in this patent application, as follows:


| SEARCH REPORT - PATENT | Application No.<br>PA 2022 70068 |
|---|---|

| SUPPLEMENTAL BOX |
| --- |
| Continuation of Box [.] |