(19) DANMARK

(10) **DK 182020 B9**

Patent- og
Varemærkestyrelsen

(12) PATENTSKRIFT

Omtryk publiceret 2025-06-24

(51) Int.Cl.: ***F02B 47/10 (2006.01)***

(21) Ansøgningsnummer: **PA 2023 70389**

(22) Indleveringsdato: **2023-07-28**

(24) Løbedag: **2023-07-28**

(41) Alm. tilgængelig: **2025-01-29**

(45) Patentets meddelelse bkg. og publiceret den: **2025-05-28**

(48) Korrektionen bkg. og publiceret den: **2025-06-24**

(73) Patenthaver:
Everllence, filial af Everllence SE, TYSKLAND, Teglholmsgade 41, 2450 København SV, Danmark

(72) Opfinder:
Henrik Christensen, --, 2300 København S, Danmark
Westlye Fredrik, --, 1260 København K, Danmark

(74) Fuldmægtig:
NORDIC PATENT SERVICE A/S, Bredgade 30, 1260 København K, Danmark

(54) Titel: **A LARGE TWO-STROKE UNIFLOW SCAVENGED SUPERCHARGED CLOSED CYCLE OXI-FUEL INTERNAL COMBUSTION ENGINE**

(56) Fremdragne publikationer:
WO 90/08693 A1
US 2015/0121849 A1
WO 2022/123215 A2
US 11022078 B1
GB 1513958 A
DK 202170181 A1

(57) Sammendrag:
A large two-stroke uniflow scavenged internal combustion engine, the engine comprising a plurality of cylinders (1) containing a combustion chamber, an intake system comprising a scavenge gas receiver (2) connected to the cylinders for supplying scavenge gas to the combustion chambers in the cylinders, a fuel system (30) configured for supplying a carbon-based fuel to the combustion chambers, an exhaust system comprising an exhaust gas receiver (3) coupled to the combustion chambers via the exhaust valves (4) for receiving a stream of exhaust gas generated by combustion of the carbon-based fuel in the combustion chambers, wherein the engine is a closed-cycle oxi-fuel engine and comprises a recirculation conduit (5) connecting the exhaust gas receiver (3) to the scavenge gas receiver (2), a blower (7) in the recirculation conduit (5), an oxygen supply system (12) configured, and a separation and carbon dioxide liquefaction system (60), wherein a portion of the stream of exhaust gas generated in the combustion chambers is diverted to the separation and carbon dioxide liquefaction system (60) that is configured to separate oxygen from the diverted stream of exhaust gas, assisted by liquefaction of carbon dioxide from the diverted stream of exhaust gas.

Fortsættes...

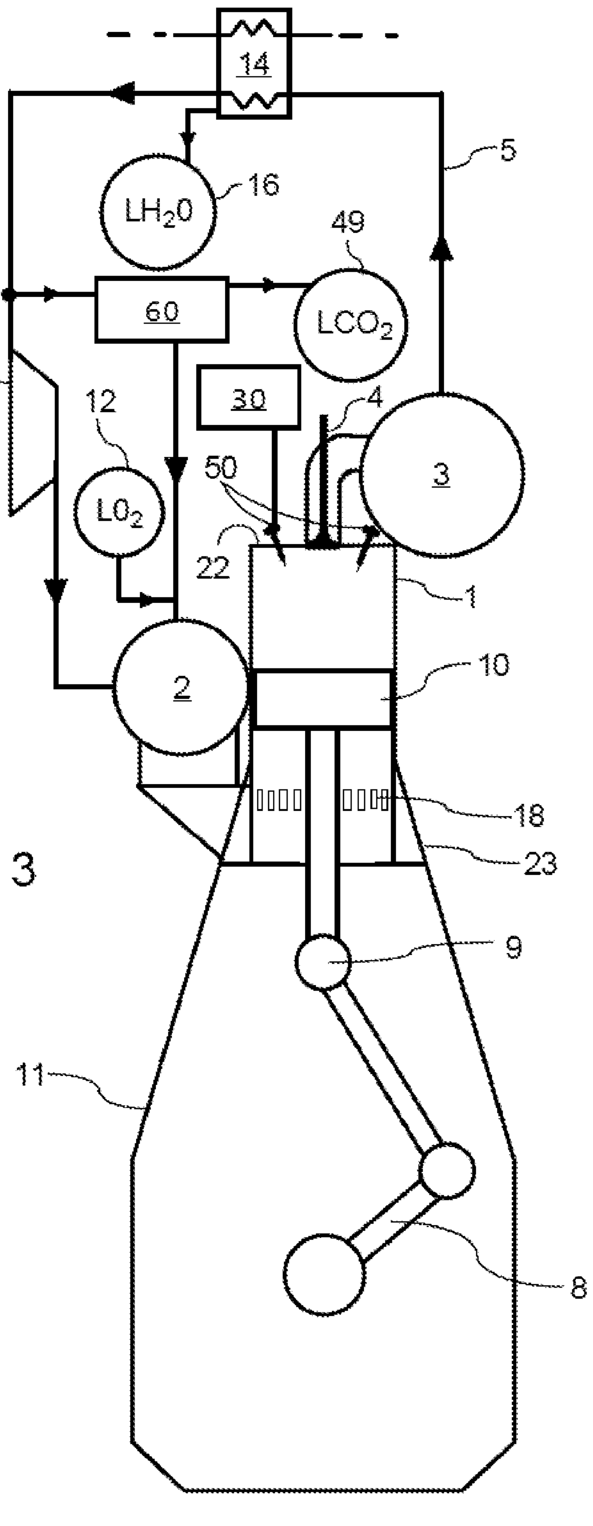

Fig. 3

A LARGE TWO-STROKE UNIFLOW SCAVENGED SUPERCHARGED CLOSED CYCLE OXI-FUEL INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

This disclosure relates to large two-stroke internal combustion engines, in particular, large two-stroke uniflow scavenged supercharged closed cycle oxi-fuel internal combustion engines, that are provided with a CO2 capture system.

BACKGROUND

Large two-stroke uniflow scavenged turbocharged internal combustion crosshead engines are typically used in propulsion systems of large ships or as a prime mover in power plants. The sheer size, weight, and power output render them completely different from common combustion engines and place large two-stroke turbocharged compression-ignited internal combustion engines in a class for themselves.

These Large two-stroke uniflow scavenged turbocharged internal combustion crosshead engines have in the past mainly been operated with hydrocarbon fuels, such as fuel oil, e.g. diesel oil, or fuel gas, e.g. natural gas or petroleum gas. The combustion of hydrocarbon fuels releases carbon dioxide (CO2), as well as other greenhouse gases that contribute to atmospheric pollution and climate change. Unlike fossil fuel impurities that result in byproduct emissions, CO2 is an unavoidable result of hydrocarbon combustion. The energy density and CO2 footprint of a specific fuel depend on the hydrocarbon chain length and the complexity of its hydrocarbon molecules. Hence, gaseous hydrocarbon fuels have a lower footprint than liquid hydrocarbon fuels, with the drawback that gaseous hydrocarbon fuels are more challenging and costly to handle and store. To reduce the CO2 footprint, large two-stroke uniflow scavenged turbocharged compression-ignited internal combustion crosshead engines that operate with a hydrocarbon fuel have been proposed with a system for capture and storage of CO2.

DK202170181 discloses a large two-stroke uniflow scavenged internal combustion engine according to the preamble of claim 1.
One known CO2 capture and storage technology comprises fitting these Large two-stroke uniflow scavenged turbocharged internal combustion crosshead engines with an amine-based scrubber. This is believed to be the presently most mature carbon capture solution, and it is at present planned to be installed on ships as pilot and demonstration plants during the coming years. The disadvantages of this technology are: The amine is degraded over time as it is sensitive towards SOx, NOx, O2, particulate matter, and temperatures above approximately 150 °C. The amine forms harmful emissions, which must be controlled. The energy consumption in the reboiler is huge – up to equivalent to 60% of the engine shaft-power.

Another known CO2 capture and storage technology comprises fitting the Large two-stroke uniflow scavenged turbocharged internal combustion crosshead engine with EGR and upstream air separation (N2 and O2), followed by downstream CO2 liquefaction. The upstream air separation is done by a membrane. The disadvantages of this technology are: The air separation membrane is spacious, expensive, has a significant pressure loss, and may be fragile. Initially, the technology was tested on land-based power plants (to avoid NOx formation), but it was never a success. Furthermore, a considerable amount of the O2 can potentially be wasted when O2 and CO2 are separated in the exhaust gas.

Another known technology is upstream thermal cracking/reforming of fuels to a mixture of H2 and CO2. H2 and CO2 are separated by a membrane, H2 is combusted in a hydrogen engine and CO2 is liquefied. The disadvantages of this technology are: The thermal cracking/reforming requires a catalyst, which lowers the operating temperature and improves the selectivity of the reaction. The catalyst is expensive, maybe sensitive towards impurities in the fuel, has a limited lifetime and the product stream from the cracking/reforming process may contain other species than the desired CO2+H2 (could be CO, CH4). The energy consumption for the thermal cracking/reforming is in the order of 40% of the engine shaft power. Furthermore, the technology requires a membrane to separate H2 and CO2 efficiently. Little information on CO2/H2-membrane separation has been found, however, the costs, size and lifetime must be considered. Lastly, this technology requires a hydrogen large two-stroke uniflow scavenged turbocharged internal combustion crosshead engine to be developed.

Yet another technology is a large two-stroke uniflow scavenged turbocharged internal combustion crosshead engine running on ammonia fuel synthesized from hydrogen and nitrogen. This technology is under development. The disadvantages of this technology are: Ammonia is extremely toxic and corrosive towards certain materials. An ammonia engine will also require an SCR catalyst and perhaps an N2O catalyst. Despite being carbon-free, an ammonia ICE can be expected to reduce the GWP by around 90% relative to diesel oil on account of N2O emissions. The combustion properties of ammonia are poorly suited for a compression ignition (diesel) engine.

<u>SUMMARY</u>

It is an object to provide a large two-stroke uniflow scavenged turbocharged internal combustion crosshead engine that overcomes or at least reduces the problems mentioned above. It is another object to provide a method for eliminating or at least reducing gaseous CO2 emissions from a large two-stroke uniflow scavenged turbocharged internal combustion crosshead engine.

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 the first aspect, there is provided a large two-stroke uniflow scavenged internal combustion engine, said engine comprising:
- a plurality of cylinders with a cylinder liner and a reciprocating piston therein and a cylinder cover covering the cylinder,
- a combustion chamber formed inside the cylinder liner 1 between the reciprocating piston and the 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,
- an intake system comprising a scavenge gas receiver connected to the cylinders for supplying scavenge gas to the combustion chambers in the cylinders,
- a fuel system configured for supplying a carbon-based fuel to the combustion chambers,
- an exhaust system comprising an exhaust gas receiver coupled to the combustion chambers via the exhaust valves for receiving a stream of exhaust gas generated by combustion of the carbon-based fuel in the combustion chambers,

wherein that the engine is a closed-cycle oxi-fuel engine and comprises:

- a recirculation conduit connecting the exhaust gas receiver to the scavenge gas receiver,
- a blower in the recirculation conduit for compressing exhaust gas from the exhaust gas receiver and forcing compressed exhaust gas to the scavenge gas receiver,
- an oxygen supply system configured for supplying oxygen to the intake system, and
- a separation and carbon dioxide liquefaction system, wherein a portion of the stream of exhaust gas generated in the combustion chambers is diverted to the separation and carbon dioxide liquefaction system that is configured to separate oxygen and carbon dioxide from the diverted stream of exhaust gas, assisted by liquefaction of carbon dioxide from the diverted stream of exhaust gas
- a diversion conduit for diverting the diverted portion of the stream of exhaust gas, the diversion conduit being coupled to the recirculation circuit, the diversion conduit comprises a diversion compressor and one or more coolers.

This large two-stroke uniflow scavenged internal combustion engine has no gaseous emissions. Energy consumption for the oxygen separation and carbon dioxide liquefaction in this engine is relatively low compared to known technologies. Efficient oxygen and carbon dioxide separation, which minimizes O2 consumption. The engine is compatible with a range of fuels and potential retrofit solutions. No rare or expensive earth metals are required these are used in catalysts and gas separation membranes known carbon dioxide capture technologies. Another advantage of the engine is that the oxygen concentration in the scavenging air can be set freely. Moreover, SFOC Specific Fuel Oil Consumption is reduced since no consideration has to be given to NOx formation, i.e. the engine can operate with higher combustion temperatures and pressures and thereby improve fuel efficiency.

In a possible implementation form of the first aspect, the diversion conduit is coupled to the recirculation circuit at a position downstream of the first cooler and preferably upstream of the blower.

In a possible implementation form of the first aspect, the one or more coolers are arranged downstream of the diversion compressor, the diversion conduit preferably leading to a separation and liquefaction vessel.

In a possible implementation form of the first aspect, the separation and carbon dioxide liquefaction system comprises a compressor for compressing the diverted stream to a target pressure and one or more heat exchangers for cooling the diverted stream to a target temperature, the combination of the desired pressure and desired temperature causing the carbon dioxide in the steam to liquefy and thereby separate from oxygen in the diverted stream, in a separation vessel, the target pressure preferably being at least 7 bara and the target temperature preferably being below -50°C.

In a possible implementation form of the first aspect, the source of oxygen comprises a liquid oxygen tank.

In a possible implementation form of the first aspect, the carbon-based fuel is a hydrocarbon fuel, and water is generated by the combustion of the hydrocarbon fuel in the combustion chambers, the engine comprising a water separation system configured to separate water from the stream of exhaust gas.

In a possible implementation form of the first aspect, the engine comprises a first cooler in the recirculating conduit for cooling the exhaust gas, the first cooler being arranged upstream of the blower.

In a possible implementation form of the first aspect, the first cooler is configured to separate water from the exhaust gas.

In a possible implementation form of the first aspect, the combustion chambers are configured for combusting the carbon-based fuel with the oxygen thereby generating a stream of carbon dioxide containing exhaust gas

In a possible implementation form of the first aspect, the molecular fraction of carbon dioxide in the scavenge gas supplied to the combustion chambers is above 0.70 mol/mol.

In a possible implementation form of the first aspect, the molecular fraction of nitrogen in the scavenge gas supplied to the combustion chambers is below 0.05 mol/mol.

In a possible implementation form of the first aspect, the molecular fraction of oxygen in the scavenge supplied to the combustion chambers is above 0.17 mol/mol.

In a possible implementation form of the first aspect, at least one of the coolers in the diversion conduit is a heat exchanger that exchanges heat between the diverted exhaust gas and liquid oxygen that is supplied by the source of liquid oxygen to the scavenge gas receiver.

These and other aspects will be apparent from the drawings and the embodiment(s) 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 an elevated front view of a large two-stroke internal combustion engine according to an embodiment,

Fig. 2 is an elevated side view of the large two-stroke engine of Fig. 1,
Fig. 3 is a diagrammatic representation of an embodiment of the large two-stroke engine of Fig. 1 with a separation and carbon dioxide liquefaction system, and
Fig. 4, is a diagrammatic representation of the embodiment of the large two-stroke engine of Fig. 1 with a separation and carbon dioxide liquefaction system.

DETAILED DESCRIPTION

In the following detailed description, an internal combustion engine will be described with reference to a large two-stroke low-speed uniflow scavenged turbocharged internal combustion engine with crossheads in the example embodiments. The large two-stroke low-speed uniflow scavenged turbocharged internal combustion engine with crossheds can be of the (high-pressure) type in which fuel is injected at or near top dead center (TDC) of the pistons that is compression-ignited or of the (low-pressure) type in which fuel is mixed with the scavenging air before or during compression (pre-mix engine) and the mixture of air and fuel is spark ignited or the like. In the pre-mix engine, there will typically be a “pilot” ignition with an ignition fluid, e.g. fuel oil, at or near TDC for ensuring reliable ignition.

Figs. 1, 2, and 3 show a large low-speed turbocharged two-stroke engine with a crankshaft 8 and crossheads 9 that is configured to operate according to the Diesel principle, i.e. it is a compression-ignition engine. Fig. 3 shows a diagrammatic representation of a large low-speed turbocharged two-stroke diesel engine with its intake and exhaust systems.

In this example embodiment, the engine has six cylinders in line. Large low-speed turbocharged two-stroke internal combustion engines have typically between four and fourteen cylinders in line, carried by a cylinder frame 23 that is 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 can be configured as a dual-fuel engine. The engine can be a compression-ignited engine or a premix engine. The engine according to the present embodiment is of the two-stroke uniflow type with scavenging ports 18 in the lower region of the cylinder liners 1 and a central exhaust valve 4 at the top of each cylinder liner 1. The engine has at least one mode in which the engine is operated on a carbon-based fuel, e.g. natural gas, methanol, Dimethyl Ether (DME), or fuel oil (e.g. marine diesel).

The scavenge gas is passed from the scavenge gas receiver 2 to the scavenge ports 18 of the individual cylinders 1. A piston 10 that reciprocates in the cylinder liner 1 between the bottom dead center (BDC) and top dead center (TDC) compresses the scavenge gas. Fuel is injected through fuel valves 50 that are arranged in the cylinder cover 22 into the combustion chamber at high pressure when the piston is at or near TDC (Diesel principle - compression ignition). When the engine is configured as a pre-mix engine, the fuel is admitted at a relatively low pressure when the piston is on its way towards TDC (Otto principle - premix engine) from fuel admission valves (there will typically be 2 or more fuel admission valves for each cylinder). The fuel admission valves can be arranged in the cylinder liner at a position above the scavenge ports 18, or in the cylinder cover 22. Combustion follows, and exhaust gas is generated. If the engine is configured for compression-ignition, each cylinder cover 22 is provided with two or more fuel valves 50. The fuel valves 50 are configured to inject only fuel into the combustion chamber. The fuel valves 50 are arranged in the cylinder cover 22 around the central exhaust valve 4. Further, additional, typically smaller fuel valves (not shown) are optionally provided in the cylinder cover 22 for injecting ignition fluid, for ensuring reliable ignition of the fuel (e.g. gaseous fuel). The ignition fluid is e.g. dimethyl ether (DME) or fuel oil, but can also be another form of ignition enhancer, such as hydrogen. In an embodiment (not shown), the fuel valves are arranged along the cylinder liner (shown by the interrupted lines) and admit the fuel into the cylinder before the piston 10 passes the fuel valves on its way from BDC to TDC. Thus, when the engine is configured for pre-mix operation, the piston 10 compresses a mixture of scavenging air and fuel. Timed ignition at or near TDC is triggered by spark, laser, ignition fluid injection, or the like. In the embodiment with the fuel valves, the pressure at which the fuel is admitted is substantially lower than the pressure at which the fuel is injected in the embodiment with the fuel valves 50 in the cylinder cover 22, which injects when the piston is at or near top dead center (TDC) and the pressure at which the fuel is injected needs to be significantly higher than the compression pressure.

When an exhaust valve 4 is opened, the exhaust gas flows through an exhaust duct associated with the cylinders into the exhaust gas receiver 3 and onwards through recirculation conduit 5 via a first cooler 14 to a blower 7, from which the exhaust gas flows back into the scavenge gas receiver 2. If the fuel is a hydrocarbon fuel and therefore water is produced during combustion, the cooler 14 will be configured to remove most of the water from the stream of exhaust gas and divert the water in a water tank 16. A portion of the exhaust gas is diverted from the recirculation conduit 5, preferably at a position downstream of the first cooler 14 and upstream of the blower 7, to a separation and carbon dioxide liquefaction system 60. The separation of carbon dioxide liquefaction system 60 liquefies the carbon dioxide and stores the liquefied carbon dioxide in a liquefied carbon dioxide storage tank 49 and transports oxygen that was separated from carbon dioxide in the diverted stream of exhaust gas to the scavenge gas receiver 2. A source of oxygen, in this embodiment a tank of liquid oxygen 12, feeds a stream of oxygen into the scavenge air receiver 2.

The compressed exhaust gas leaving the blower 7 is mixed in the scavenge gas receiver with the oxygen from the source of oxygen 12 to form scavenge gas that is ready to be supplied to the combustion chamber in the cylinder liners 1 through the scavenge ports 18.

Referring now to Fig. 4, the engine of Figs. 1-3 is disclosed in greater detail, in particular with respect to the separation and carbon dioxide liquefaction system. In this version of this embodiment, the engine is operated with a hydrocarbon fuel, and accordingly, the combustion gas comprises both water and carbon dioxide. Accordingly, the first cooler 14 is configured to condense and separate a major portion of the water in the exhaust gas. The condensed and separated water from the exhaust gas is transported by a conduit 15 to a water tank 16. A portion of the exhaust gas leaving the first cooler 14 is diverted from the mainstream of cooled exhaust gas to a diversion conduit 40. The amount of exhaust gas that is diverted from the recirculation conduit 5 is in an embodiment regulated by a control valve 38 that is arranged in the diversion conduit 40. The amount of exhaust gas that is diverted is regulated to correspond to the amount of carbon dioxide produced in the combustion process so that the total amount of carbon dioxide that re-circulates in the engine is substantially constant. Preferably, the engine comprises a controller (not shown) such as a microcontroller, that is informed of the amount of carbon in the fuel that is injected, and is configured to calculate the amount of carbon dioxide produced by combustion, and configured to regulate the amount of exhaust gas that is diverted accordingly. The remaining portion of the exhaust gas coming from the first cooler 14 goes to the blower 7 and from there, it goes as compressed exhaust gas to the scavenge gas receiver 2. However, it should be understood that the engine operation can be controlled differently, without needing to determine the amount of carbon dioxide needs to be removed, and could for example use the absolute pressure in e.g. the exhaust gas receiver as a parameter for determining how much exhaust carbon dioxide has to be removed. In this example, a reference pressure in the exhaust gas receiver or a reference pressure pressure that is a function of engine operating conditions,

such as engine load is used the controller to increase or decrease or maintain the amount of carbon dioxide is removed, e.g. when the determined or measured pressure in the exhaust gas receiver is above the reference pressure, more carbon dioxide is removed, when the determined or measured pressure in the exhaust gas receiver is below the reference pressure, less carbon dioxide is removed, and when the determined or measured pressure in the exhaust gas receiver within a tolerated bandwidth around the reference pressure, no changes made to the amount of carbon dioxide is removed.
The diversion conduit 40 comprises a compressor 42. The compressor is configured to substantially increase the pressure of the diverted exhaust gas, for example by at least 40 bar. Downstream of the compressor 42, a second cooler 44 is provided. The second cooler 44 will cause any residual water to condense and this water will be separated and conveyed to the water tank 16. A third cooler 45 is arranged downstream of the second cooler. The third cooler 45 is a heat exchanger that exchanges heat with liquid oxygen from a liquid oxygen tank 61 that is conveyed through the production conduit 63 to the scavenge gas receiver 2.

A fourth cooler 46 is arranged downstream of the third cooler 45. The fourth cooler 46 exchanges heat with a mixture of oxygen and carbon dioxide coming from a carbon dioxide liquefaction and oxygen separation vessel 47 and coming from a liquefied carbon dioxide storage tank 49. The diversion conduit leads to the carbon dioxide liquefaction and oxygen separation vessel 47. When the diverted exhaust gas leaves the fourth cooler 46, the temperature is sufficiently low and the pressure sufficiently high for the carbon dioxide in the diverted exhaust gas to be liquefied in the carbon dioxide liquefaction and oxygen separation vessel 47, and thereby separated from the oxygen that does not liquefy at these temperatures and pressures. Thus, the lower part of the carbon dioxide liquefaction and oxygen separation vessel 47 will contain liquefied carbon dioxide, the upper part of the carbon dioxide liquefaction and oxygen separation vessel 47 will contain a mixture of oxygen and carbon dioxide in the gas phase. The lower part of the carbon dioxide liquefaction and oxygen separation vessel 47 is connected by a liquefied carbon dioxide conduit 48 to the liquefied carbon dioxide tank 49. The lower part of the liquefied carbon dioxide tank 49 holds liquefied carbon dioxide, the upper part of the liquefied carbon dioxide tank 49 holds a mixture of oxygen and carbon dioxide in the gas phase. The mixtures in the gas phase in the carbon dioxide liquefaction and oxygen separation vessel 47 and preferably also in the liquefied carbon dioxide tank 49 are conveyed in an oxygen return conduit 43 via expansion valves 65 and 66, respectively, to the scavenge gas receiver 2. The option return conduit 43 passes in an embodiment through the fourth cooler 46 for exchanging heat with the diverted exhaust gas.

The amount of oxygen in the scavenge gas is regulated by adjusting the flow of liquid oxygen from the liquid oxygen tank 61 to the scavenge gas receiver 3 through the liquid oxygen supply conduit 63. This flow is regulated by control valve 64 is arranged in the oxygen supply conduit 63, and is preferably under the control of the controller.

A bypass conduit 25 extends from the exhaust gas receiver 3 to the scavenge gas receiver 2 for bypassing the blower 7. A bypass control valve 26 regulates the flow of gas from the scavenge gas receiver 2 to the exhaust gas receiver 3.The bypass valve functions as a process control handle. The amount of overscavenge can be reduced by allowing carbon dioxide rich gas (before oxygen enrichment) to bypass the cylinder back to the exhaust receiver. In this way the amount of short circuited oxygen can be minimized. In addition, scavenge efficiency can be reduced, so that hot residual gases remain in the cylinder to the next cycle. In this way higher compression temperatures can be achieved if needed, e.g. to avoid knocking tendencies.

EXAMPLE

Operating conditions example using fuel with Sfoc = 362 gCH3OH/kWh and assuming 50% thermal efficiency):

In the exhaust gas receiver, the temperature of the exhaust gases typically between 400 to 500°C has a pressure of approximately 4 bar. yCO2 is approximately 0.85 mol/mol and yO2 is approximately 0.15 mol/mol.

Downstream of the first cooler 14, the temperature of the exhaust gases typically approximately 5°C has a pressure of approximately 4 bar. yCO2 is approximately 0.85 mol/mol and yO2 is approximately 0.15 mol/mol.

Blower 7 increases the pressure by 0.3 bar.

In the scavenge gas receiver, the temperature of the scavenge gas is approximately 10°C and has a pressure of approximately 4.3 bar. yCO_2 is approximately 0.79 mol/mol and yO_2 is approximately 0.21 mol/mol.

The compressor increases the pressure of the diverted exhaust gas by approximately 41 bar, and downstream of the second cooler 44 the diverted exhaust gas has a temperature of 10 °C and a pressure of approximately 45 bar. yCO_2 = 0.79 mol/mol and yO_2 = 0.21 mol/mol.

By the time the diverted exhaust gas reaches the carbon dioxide liquefaction and oxygen separation vessel 47 the temperature is minus 20°C and the pressure is approximately 45 bar.

The liquid oxygen in the liquid oxygen tank 61 is a temperature of approximately -140 °C and a pressure of approximately 20 bar.

The various aspects and implementations have been described in conjunction with various embodiments herein. However, 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. The reference signs used in the claims shall not be construed as limiting the scope. Unless otherwise indicated, the drawings are intended to be read (e.g., crosshatching, arrangement of parts, proportion, degree, etc.) together with the specification, and are to be considered a portion of the entire written description of this disclosure.

PATENTKRAV

1. Stor, totaktsforbrændingsmotor med længdeskylning, hvilken motor omfatter:
- en flerhed af cylindre med en cylinderforing (1) og et frem- og tilbagegående stempel (10) deri og et cylinderdæksel (22), der dækker cylinderen,
- et forbrændingskammer dannet inde i cylinderforingen (1) mellem det frem- og tilbagegående stempel (10) og cylinderdækslet (22),
- skylleåbninger (18), der er anbragt i cylinderforingen, (1) til at lade skyllegas trænge ind i forbrændingskammeret,
- et udstødningsgasudløb, der er anbragt i cylinderdækslet (22) og styres af en udstødningsventil (4),
- et indsugningssystem, der omfatter en skyllegasmodtager (2) forbundet med cylindrene, til tilførsel af skyllegas til forbrændingskamrene i cylindrene,
- et brændstofsystem (30), der er konfigureret til tilførsel af et carbonbaseret brændstof til forbrændingskamrene,
- et udstødningssystem, der omfatter en udstødningsgasmodtager (3) koblet til forbrændingskamrene via udstødningsventilerne (4) til modtagelse af en strøm af udstødningsgas genereret ved forbrænding af det carbonbaserede brændstof i forbrændingskamrene,
kendetegnet ved, at motoren er en oxy-fuel-motor med lukket kredsløb og omfatter:
- en recirkulationsledning (5), der forbinder udstødningsgasmodtageren (3) med skyllegasmodtageren(2),
- en blæser (7) i recirkulationsledningen (5) til at komprimere udstødningsgas fra udstødningsgasmodtageren (3) og

til at tvinge komprimeret udstødningsgas til skyllegasmodtageren (2),

- et oxygentilførselssystem (12), der er konfigureret til at tilføre oxygen til indsugningssystemet, og
- et separations- og carbondioxidflydendegørelsessystem (60), hvor en del af strømmen af udstødningsgas genereret i forbrændingskamrene omledes til separations- og carbondioxidflydendegørelsessystemet (60), der er konfigureret til at separere oxygen og carbondioxid fra den omledte strøm af udstødningsgas, assisteret af flydendegørelse af carbondioxid fra den omledte strøm af udstødningsgas,
- en omledningsledning (40) til omledning af den omledte del af strømmen af udstødningsgas, hvilken omledningsledning (40) er koblet til omledningskredsløbet (5), omledningsledningen (40) omfatter en omledningskompressor (42) og én eller flere kølere (44, 45, 46).

2. Motor ifølge krav 1, hvor omledningsledningen (40) er koblet til recirkulationskredsløbet (5) på en position nedstrøms for den første køler (14) og fortrinsvis opstrøms for blæseren (7).

3. Motor ifølge krav 1 eller 2, hvor den ene eller flere kølere (44, 45, 46) anbringes opstrøms for omledningskompressoren (42), hvor omledningsledningen (40) fortrinsvis fører til en separations- og carbondioxidflydendegørelsesbeholder (47).

4. Motor ifølge et hvilket som helst af krav 1 til 3, hvor separations- og carbondioxidflydendegørelsessystemet (60)

omfatter en kompressor (42) til komprimering af den omledte strøm til et måltryk og én eller flere varmevekslerne (44, 45, 46) til afkøling af den omledte strøm til en måltemperatur, hvor kombinationen af det ønskede tryk og den ønskede temperatur bevirker, at carbondioxiden i strømmen gøres flydende og derved separeres fra oxygen i den omledte strøm, i en separationsbeholder (49), hvor måltrykket fortrinsvis er mindst 7 bara og måltemperaturen fortrinsvis er under -50 °C.

5. Motor ifølge et hvilket som helst af krav 1 til 4, hvor kilden til oxygen omfatter en tank (61) til flydende oxygen.

6. Motor ifølge et hvilket som helst af krav 1 til 5, hvor det carbonbaserede brændstof er et carbonhydridbrændstof, og vand genereres ved forbrændingen af carbonhydridbrændstoffet i forbrændingskamrene, idet motoren omfatter et vandseparationssystem (14, 15, 16), der er konfigureret til at separere vand fra strømmen af udstødningsgas.

7. Motor ifølge et hvilket som helst af krav 1 til 6, og som omfatter en første køler (14) i recirkulationsledningen (5) til afkøling af udstødningsgassen, hvor den første køler (14) fortrinsvis placeres opstrøms for blæseren(7).

8. Motor ifølge krav 7, når det afhænger af krav 6, hvor den første køler (14) er konfigureret til at adskille vand fra udstødningsgassen.

9. Motor ifølge et hvilket som helst af krav 1 til 8, hvor forbrændingskamrene er konfigureret til forbrænding af det

carbonbaserede brændstof med oxygenet, hvorved der genereres en strøm af carbondioxidholdig udstødningsgas.

10. Motor ifølge et hvilket som helst af krav 1 til 9, hvor motoren er konfigureret således at den molekylære fraktion af carbondioxid i skyllegassen tilført forbrændingskamrene er over 0,70 mol/mol.

11. Motor ifølge et hvilket som helst af krav 1 til 10, hvor motoren er konfigureret således at den molekylære fraktion af nitrogen i skyllegassen tilført forbrændingskamrene er under 0,05 mol/mol.

12. Motor ifølge et hvilket som helst af krav 1 til 11, hvor motoren er konfigureret således at den molekylære fraktion af oxygen i skyllegassen tilført forbrændingskamrene er over 0,17 mol/mol.

13. Motor ifølge et hvilket som helst af krav 5 til 12, hvor mindst én af kølerne (45) i omledningsledningen (40) er en varmeveksler, der udveksler varme mellem den omledte udstødningsgas og det flydende oxygen, som tilføres skyllegasmodtageren (2) fra kilden til flydende oxygen (61).

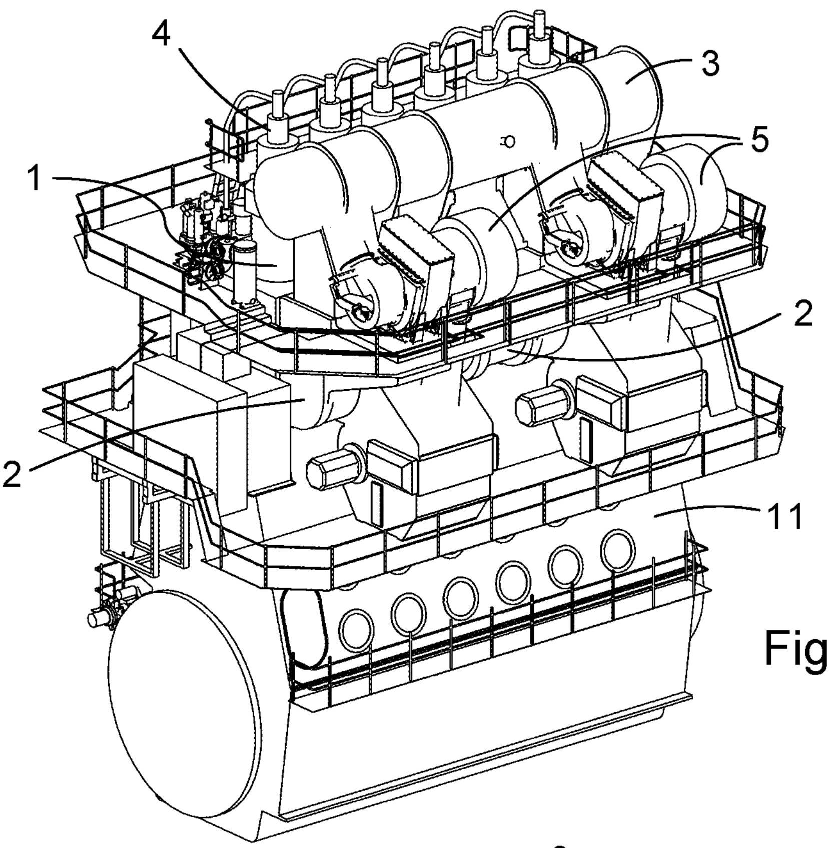

Fig. 1

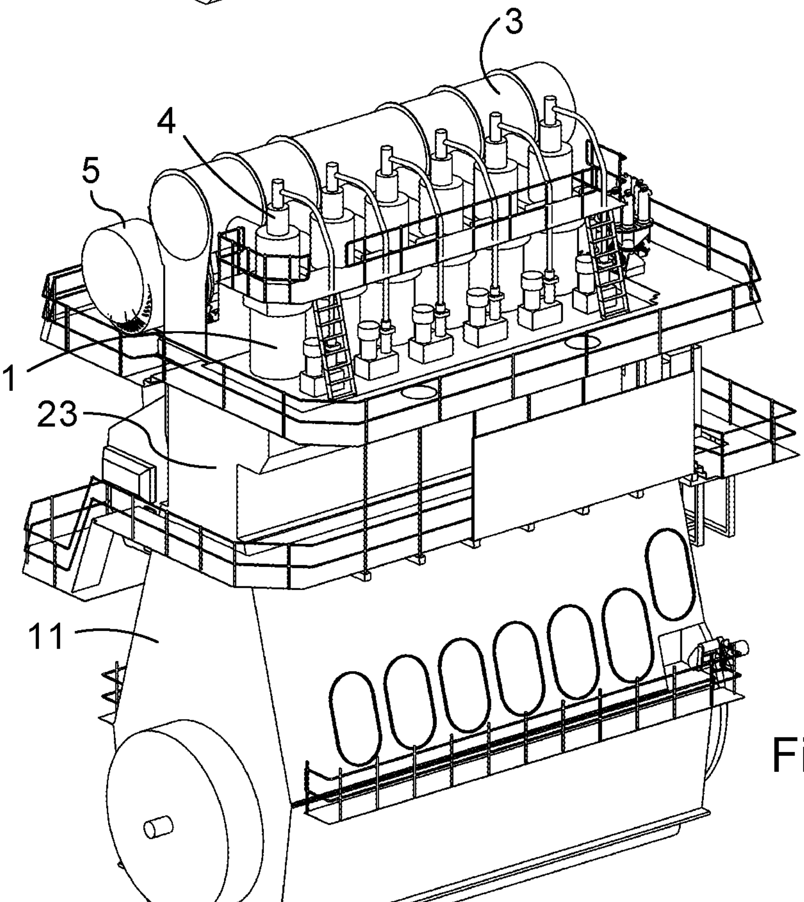

Fig. 2

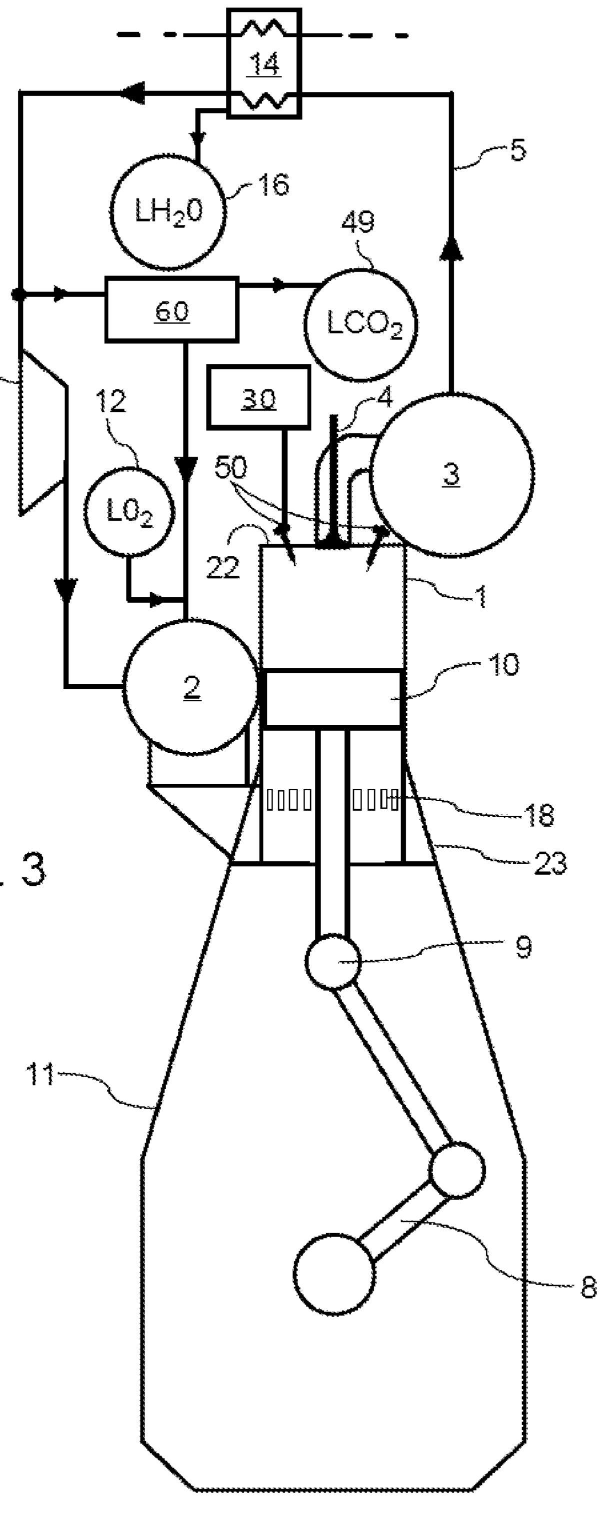

Fig. 3

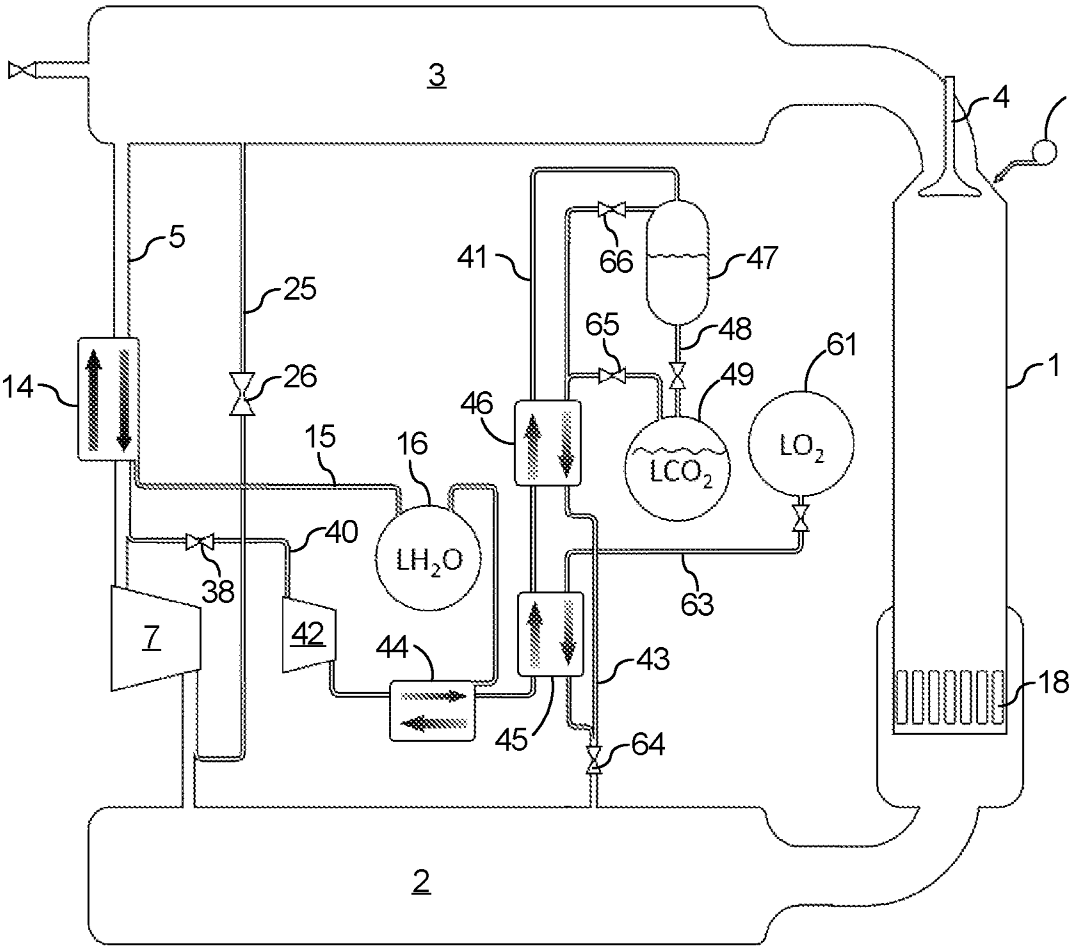
3
4
30
5
25
41
66
47
65
48
61
14
26
46
49
1
15
16
LCO2
LO2
LH2O
40
38
63
7
42
44
43
18
45
64
2

Fig. 4

DANISH PATENT AND TRADEMARK OFFICE

Search report - patent

Application No.
PA 2023 70389

1. ☐ Certain claims were found unsearchable (See Box No. I).
2. ☐ Lack of unity of invention was found prior to search (See Box No. II).

A. Classification

F02B 47/10 (2006.01)

According to International Patent Classification (IPC)

B. Fields searched

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

IPC, CPC: F02B

Documentation searched other than PCT-minimum documentation

DK, NO, SE, FI: IPC-classes as specified in Box A above

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

EPODOC

C. Documents considered to be relevant

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
Y A	DK 202170181 A1 (MAN ENERGY SOLUTIONS FILIAL AF MAN ENERGY SOLUTIONS SE TYSKLAND [DK]) 2022.09.23 See figs. 1 – 3, and p. 8, line 34 – p. 11, line 27.	1, 3 – 7, 9 2, 8, 10 - 13
Y A	WO 90/08693 A1 (COSWORTH DEEP SEA SYSTEMS) 1990.08.09 See figure and p. 5 - p. 16	1, 3 – 7, 9 2, 8, 10 - 13
A	US 2015/0121849 A1 (NEMITALLAH MEDHAT AHMED et al.) 2015.05.07 See fig. 1 and [0020])	1 – 13
A	WO 2022/123215 A2 (LGE IP MAN COMPANY LIMITED) 2022.06.16 See fig. 1 and page 12, lines 29 – 32	1 – 13

☒ 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 essential difference when the document is taken alone.

"Y" Document of particular relevance; the claimed invention cannot be considered to involve an essential difference 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.

Danish Patent and Trademark Office

Helgeshøj Allé 81
DK-2630 Taastrup
Denmark

Tel.: +45 43 50 80 00

Date of completion of the search report

22/02/2024

Authorized officer

Jens Bjørn
Tel.: +45 43 50 81 68

 v. 03.23

Search report - patent

Application No.
PA 2023 70389

C. Documents considered to be relevant (continuation)

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
A	US 11022078 B1 (SCHECHTER MICHAEL MOSES et al.) 2021.06.01	1 – 13
A	GB 1513958 A (SHELL INT RESEARCH) 1978.06.14	1 – 13

DANISH PATENT AND TRADEMARK OFFICE

Search report - patent

Application No.
PA 2023 70389

Box No. I 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. Specifically:

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. Specifically:

Box No. II Lack of unity of invention was found prior to search

Prior to search, multiple independent inventions were found in the patent application. Specifically:

Search report - patent

Application No.
PA 2023 70389

Supplemental Box

Continuation of Box [.]