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(54) **INTERNAL COMBUSTION ENGINE**

(57) The present invention relates to an internal combustion engine comprising a system for exhaust gas recirculation and a method for running an internal combustion engine.

The Internal combustion engine (10) is a large vessel engine or a stationary engine, preferably is a two-stroke engine or a two-stroke cross head engine. The internal combustion engine (10) comprises at least one cylinder (11) having an inner diameter (12) of at least 200mm. The internal combustion engine (10) comprises a system (40) for exhaust gas recirculation with at least two EGR paths (41a, 41b) fluidly arranged at least partly in parallel between an exhaust outlet (13) and an air inlet (14) of the cylinder (10). Each EGR path (41a, 41b) comprising at least one EGR valve (42a, 42b) and/or at least one EGR blower (49, 49a, 49b). Each of the EGR paths (41a, 41b) is fluidly connected to a respective sensing path (51a, 51b) or connectable with the respective sensing path (51a, 51b), which sensing path (51a, 51b) is fluidly connected or connectable to a measuring path (53) with at least one gas sensor device (54) providing values representative for the amount of EGR gas in the respective EGR path (41a, 41b).

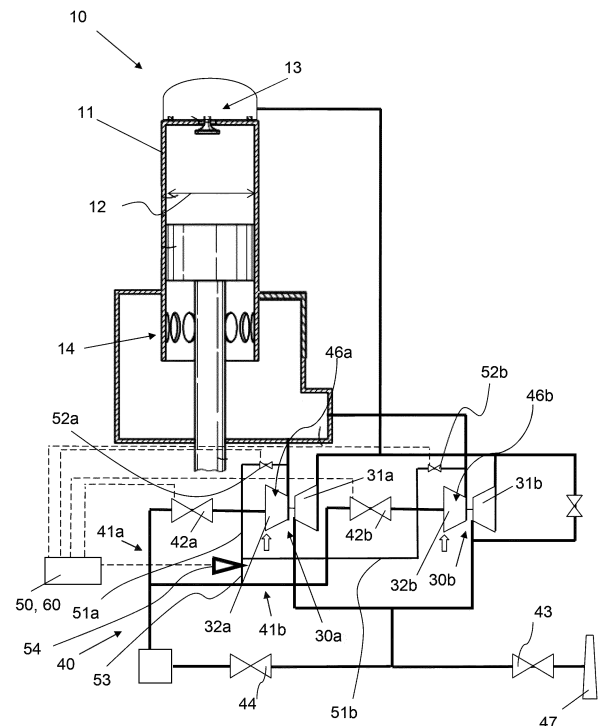


Fig. 1

Description

[0001] The present invention relates to an internal combustion engine comprising a system for exhaust gas recirculation and a method for running an internal combustion engine.

[0002] The present invention preferably relates to an internal combustion engine like a large marine or ship engine or a stationary engine whose cylinders have an inner diameter of at least 200 mm. The engine preferably is a two-stroke engine or a two-stroke cross head engine. The engine can be a diesel or a gas engine, a dual fuel or a multi fuel engine. Burning of liquid and or gaseous fuels in such engines is possible as well as self-igniting or forced igniting.

[0003] The engine has at least one cylinder having a piston therein. The piston is connected to a crankshaft. The piston reciprocates between a top dead centre (TDC) and a bottom dead centre (BDC) during operation of the engine. The cylinder typically has at least one air passage opening for intake, the air inlet in particular arranged in the liner of the cylinder, and at least one air passage opening for exhaust, the exhaust outlet in particular arranged in the cover of the cylinder.

[0004] The internal combustion engine can be a longitudinally flushed two-stroke engine.

[0005] The term internal combustion engine also refers to large engines which can be operated not only in diesel mode, which is characterised by the self-ignition of the fuel, but also in Otto mode, which is characterised by the positive ignition of the fuel, or in mixtures of the two. Furthermore, the term internal combustion engine includes in particular dual-fuel engines and large engines in which the self-ignition of the fuel is used for the positive ignition of another fuel.

[0006] Engine speed is preferably below 800 RPM (4-stroke) and more preferably below 200 RPM (2-stroke) which indicates the designation of low speed engines.

[0007] Fuel can be diesel or marine diesel oils or heavy fuel oils or emulsions or slurries or methanol or ethanol as well as gases like liquefied natural gas (LNG), liquefied petroleum gas (LPG) and so on.

[0008] Further possible fuels which might be added on request are: LBG (Liquefied Biogas), biological Fuels (e. g. Algae fuel or Seaweed Oil), hydrogen, synthetic fuels from CO₂ (e. g. made by Power-To-Gas or Power-To-Liquid).

[0009] To reduce the reactivity of gas/air mixture and methane slip, it is known to provide exhaust gas recirculation (EGR), in particular low pressure exhaust gas recirculation (EGR) as shown for example in EP 3 722 572 A1. A part of the exhaust gas is recirculated into the cylinder, while another part of the exhaust gas is guided to a funnel and is released into the environment.

[0010] According for example to DE4222414 C2 and to EP0896139 A2 an oxygen sensor is provided at least in the air intake pipe and is connected to a control unit which determines from the signals generated by the ox-

ygen sensor the actual exhaust gas recirculation rate. Dependent thereon the exhaust gas recirculation valve is controlled.

[0011] US7783408B2 discloses an engine with a plurality of cylinders. Exhaust gas introduced from a common EGR valve is fed to each of the cylinders. A control unit detects imbalance of air-fuel ratio among cylinders, based on cylinder-by-cylinder air-fuel ratio detected by air-fuel ratio sensors provided on exhaust pipes of the cylinders. If there is an imbalance in air-fuel ratio among cylinders, the EGR valve is closed. An individual cylinder EGR rate is not provided.

[0012] US6382198B1 discloses an internal combustion engine fuel control wherein a single oxygen sensor responsive to the combined exhaust gas flow of several engine cylinders is used. The oxygen sensor output is sampled in synchronism with the engine firing events to form a measure of the air/fuel ratio imbalance with respect to time. As sampling has to be synchronised with the engine firing events a considerable computational burden on the engine controller is imposed.

[0013] It is an object of the present invention to avoid the drawbacks of the prior art and in particular to provide an internal combustion engine and a method of operating an internal combustion engine reducing or preventing an imbalance of recirculated exhaust gas.

[0014] According to the invention, the internal combustion engine is a large engine, for example a marine engine, or a stationary engine. The internal combustion engine preferably is a two-stroke engine or a two-stroke cross head engine. The internal combustion engine comprises at least one cylinder having an inner diameter of at least 200mm.

[0015] Typically the cylinder comprises at least one air inlet and at least one exhaust outlet. Preferably, the internal combustion engine is a longitudinally flushed reciprocating piston combustion engine with scavenging ports in the lower part of the cylinder wall and with exhaust outlets in the cover of the cylinder.

[0016] The internal combustion engine may comprise a plurality of cylinders which are fed from a common scavenge air receiver and which deliver exhaust gas to a common exhaust manifold.

[0017] Preferably, the internal combustion engine comprises at least one turbocharger with a turbine and a compressor.

[0018] The internal combustion engine comprises a system for exhaust gas recirculation with at least two EGR paths, fluidly arranged at least partly in parallel, between an exhaust outlet and an air inlet of the cylinder.

[0019] A common EGR pipe may split off in parallel lines, wherein exhaust gas of each line is mixed with fresh air.

[0020] Multiple EGR paths may be necessary when for example there are multiple scavenge airlines feeding fresh air or a mixture of fresh air and exhaust gas to an scavenge air receiver or to the air inlets of the cylinder and/or when there is an enlarged scavenge air receiver.

Multiple scavenge airlines and/or an enlarged scavenge air receiver might be necessary for internal combustion engines with multiple cylinders, which typically also comprise more than one turbocharger.

[0021] A scavenge airline for guiding a mixture of fresh air and exhaust gas may be understood as a part of the EGR path downstream a mixing zone, where fresh air and exhaust gas merge.

[0022] Each EGR path comprises at least one EGR valve and/or at least one EGR blower. Preferably, each EGR path also comprises an EGR cooler, an EGR demister, an EGR scrubber and/or an EGR economizer.

[0023] Preferably, each of the EGR paths is fluidly connected to a respective sensing path or connectable with the respective sensing path.

[0024] Alternatively, only a selection of at least two EGR paths of a plurality of EGR paths is fluidly connected to a respective sensing path or connectable with the respective sensing path.

[0025] Fluidly connected means that a fluid, typically the EGR gas or a mixture of EGR gas and fresh air, may be guided from the EGR paths to the sensing path. A fluid connection may for example be prevented by a closed valve between the EGR path and the sensing path or a closed valve within the sensing path.

[0026] Said sensing path is fluidly connected or connectable to a measuring path. The measuring path comprises at least one gas sensor device providing values representative for an amount of EGR gas in the respective EGR path.

[0027] The sensing path may be established by a sensing path pipe which is connected to a respective EGR path, for example to a pipe of the respective EGR path or to an air inlet cooler arranged in the respective EGR path.

[0028] As only a small amount of gas is necessary for measurement, the sensing paths may have a pipe diameter which is smaller than the diameter of the pipes of the EGR paths, for example the sensing paths may have a pipe diameter of 8-25mm, whereas pipes of the EGR paths may have a diameter of 360-800 mm.

[0029] The sensing path only conducts a very small portion of the total mass flow of the EGR path.

[0030] The sensing path may comprise at least one sensing valve for establishing a fluid connection to the EGR path and/or to the measuring path.

[0031] The gas sensor device may provide values representative for the concentration of EGR gas in the respective EGR path, be a preferably in a part of the EGR path containing fresh air and exhaust gas, when exhaust gas recirculation is operating. A value representative for the concentration of EGR gas is considered to be a value representative for the amount of EGR gas.

[0032] The gas sensor device may comprise at least one gas sensor for evaluating a species representative for the EGR amount or EGR concentration, such as an O₂ sensor, a NO_x sensor and/or a CO₂ sensor.

[0033] Each sensing path may branch off the respec-

tive EGR path downstream of a mixing zone, where fresh air and exhaust gas merge. In a low-pressure EGR path, as described further below, the sensing path may branch off downstream the compressor of a turbocharger.

[0034] The measuring path may on the one hand be connectable to the EGR paths, on the other hand the measuring path may be connected to any suitable path for guiding exhaust gas or directly to the funnel. Preferably, in a suitable path for guiding exhaust gas the pressure is lower than in the part of the EGR path from which the sensing path branches off.

[0035] The internal combustion engine may comprise a first control unit configured for receiving the values provided by the at least one gas sensor device and configured for operating the EGR valves and/or the EGR blowers in order to provide all EGR paths with essentially the same EGR concentration after mixing with the fresh air.

[0036] Equal EGR concentrations in the EGR paths downstream the mixing zone may provide for a balanced EGR concentration in all air inlets and/or a homogenous EGR concentration in a scavenge air receiver and therefore also for equal EGR concentrations in all cylinders.

[0037] The first control unit provides for balancing the EGR concentrations for all air inlets or scavenge airlines. EGR concentrations for different EGR paths downstream of a mixing zone, where exhaust gas is mixed with fresh air, shall not deviate from each other and/or from an average over all EGR paths by more than $\pm 1\%$.

[0038] The overall EGR rate generally is not affected by the operation of the first control unit.

[0039] However, the first control unit may be part of an engine control unit which also controls the overall EGR rate, for example depending on ambient conditions, load, cylinder temperature and/or cylinder pressure, preferably determined by a closed-loop controller in a gas or diesel mode.

[0040] Preferably, the first control unit operates at least one flow regulating valve in at least one respective EGR path. The setting of the flow regulating valve may be changed in steps of 0.5%-1% or 0.45°-0.9°, in case of a butterfly valve. An opening of 100% may correspond to a valve setting of 90°.

[0041] Typically, flow regulating valves of more than one EGR path of the plurality of EGR paths have to be operated for balancing the concentration without changing the overall EGR rate.

[0042] An EGR valve of an EGR path may be further opened or closed in case the value determined by the sensor of the respective EGR path is smaller or larger than a mean value of all EGR paths by a predetermined value or percentage.

[0043] Additionally or alternatively, an EGR blower of an EGR path may be accelerated or slowed down in case the value determined by the sensor is smaller or larger than a mean value of all EGR paths by a predetermined value or percentage.

[0044] The predetermined value or percentage may be stored in the control unit. The predetermined value or

percentage may be determined based on shop tests.

[0045] The first control unit may operate the EGR valves and/or the EGR blowers as soon as the internal combustion machine has reached a stable operating point. A stable operating point is reached when for example the load, ambient conditions and/or cylinder pressure conditions do not change any more and an overall EGR rate has been chosen.

[0046] If for example the load is constant and the respective closed-loop controllers for gas or diesel mode no longer change the settings of the back pressure valve and the flow regulating valves. The settings remain constant during the measurement. Then one can also assume that the EGR rate is approximately constant during the measurement.

[0047] The measurement duration preferably is not more than a few minutes.

[0048] As soon as the internal combustion machine has reached a stable operating point measurements of values representative for the amount of EGR gas in the EGR paths may be taken continuously or regularly in specific time intervals, for example every few minutes.

[0049] Preferably, two or more EGR paths are connectable to a common measuring path.

[0050] More preferably, the internal combustion engine comprises only one measuring path and all EGR paths are connectable to said measuring path. Each sensing path branching off a respective EGR path may be fluidly connected with the measuring path or may be connectable to the measuring path.

[0051] As the values representative for the EGR amount in the EGR paths are provided by the same gas sensor device and only differences of the respective measurements are of interest, a calibration of the gas sensor system to absolute values is not necessary.

[0052] Each sensing path may comprise a sensing valve for establishing and preventing a fluid connection between a respective EGR path and the measuring path.

[0053] The sensing valves are switchable fast and reliable to prevent cross contamination of different EGR paths. Preferably, magnetic valves are used as sensing valves.

[0054] The internal combustion engine may comprise a second control unit configured for operating the sensing valves in order to successively connect the measuring path with a respective EGR path.

[0055] The second control unit may be part of the first control unit and/or may be part of an engine control unit.

[0056] The second control unit may be configured to run a measurement cycle. The measurement cycle may comprise at least the following steps.

[0057] Initially, all sensing valves are may be opened to heat the gas sensor device, in particular a gas sensor.

[0058] All sensing valves may be closed and a first sensing valve may be opened.

[0059] Alternatively, all sensing valves except a first sensing valve may be closed, such that a first EGR path is connected with the measuring path while all other sens-

ing valves are closed.

[0060] Alternatively, a first sensing valve may be opened without having opened all sensing valves before.

[0061] The open first sensing valve allows a value representative for the amount of EGR gas in the first EGR path to be determined.

[0062] Preferably, the first sensing valve is open for a first time interval to flush the measuring path with exhaust gas of the first EGR path, for example for 30 seconds, and the first sensing valve remains open for an immediately following second time interval, for example of 60 seconds, wherein the gas sensor device collects data and provides values representative for the amount of EGR gas and/or for the EGR concentration in the first EGR path.

[0063] During the second time interval a mean value for the amount of EGR gas and/or for the EGR concentration in the first EGR path may be determined. Then the first sensing valve is closed.

[0064] A second sensing valve is opened after or before the first sensing valve has been closed to connect a second EGR path with the measuring path while all other sensing valves remain closed.

[0065] The second sensing valve may be open for time intervals as described for the first sensing valve. The second time interval may start after the first sensing valve is closed.

[0066] The open second sensing valve allows a value representative for the amount of EGR gas in the second EGR path to be determined.

[0067] A mean value for a value representative for the amount of EGR gas and/or for the EGR concentration in the second EGR path may be determined. Then the second sensing valve is closed.

[0068] Preferably, if available and/or selected, further sensing valves are successively opened and closed as described above for the second sensing valve. Values representative for the amount of EGR gas in further EGR paths are allowed to be determined.

[0069] There may be an overlap of opening times of successively opened sensing valves, such that the gas sensor is kept hot.

[0070] Finally, an overall average value of values determined for each EGR path may be determined.

[0071] The first control unit may be configured to determine the mean values and the overall average values after receiving the values provided by the gas sensor device.

[0072] If the value of a respective EGR path differs from the overall average by more than a predetermined limit value or a predetermined limit percentage, the first control unit may operate the respective EGR valve and/or EGR blower of the respective EGR path.

[0073] The second control unit may be configured to run the measurement cycle at least two times immediately in succession, such that an average of values representative for an amount of EGR gas of each EGR path is determinable over more than one measurement cycle.

[0074] The second control unit may be configured to run the measurement cycle continuously again and again or regularly after a predetermined time interval, such that values representative for an amount of EGR gas of each EGR path or respective averages are determinable on-going.

[0075] The internal combustion engine may comprise a low-pressure system for exhaust gas recirculation.

[0076] The internal combustion engine with a low-pressure system comprises low-pressure EGR paths. The internal combustion engine may comprise at least one turbocharger with a turbine and a compressor.

[0077] In a low-pressure EGR system exhaust gas is guidable via the turbine of the turbocharger and at least a part of the exhaust gas may be branched off downstream the turbine and is guidable to the air inlet of the cylinder through the compressor of a turbocharger.

[0078] The internal combustion engine may comprise at least one turbocharger for each EGR path. In each low-pressure EGR path exhaust gas may be guidable through a respective compressor of a respective turbocharger.

[0079] The internal combustion engine with a low pressure EGR system may comprise an inlet air cooler downstream the compressor. The sensing path may branch off upstream or downstream the inlet air cooler.

[0080] In case the sensing path branches off upstream the inlet air cooler warm gas may be guided to the gas sensor device. Otherwise, the colder gas may have a higher moisture content and the gas sensor device may need to be warmed up to prevent condensation.

[0081] Alternatively, the internal combustion engine may comprise a high pressure EGR system.

[0082] The internal combustion engine may comprise at least one turbocharger with a turbine and a compressor. In a system for exhaust gas recirculation being a high-pressure system exhaust gas is branchable off upstream of the turbine of the turbocharger and at least a part of the exhaust gas is guidable to the air inlet of the cylinder. The recirculated exhaust gas is mixable with scavenging air downstream of the compressor of the turbocharger.

[0083] The internal combustion engine may comprise more than one turbocharger. Upstream each turbine exhaust gas may be branchable off for recirculation. Downstream each compressor, exhaust gas may be mixable with fresh air in a respective mixing zone.

[0084] According to the invention a method of running an internal combustion engine as described above comprises the following steps.

[0085] The EGR paths are successively fluidly connected to the measuring path comprising a gas sensor device. For each EGR path a value representative for an amount of EGR gas in the respective EGR path and/or for a concentration of exhaust gas downstream a respective mixing zone is provided by the gas sensor device.

[0086] EGR valves and/or the EGR blowers are operated such that the values representative for amounts of

EGR gas in the EGR paths and/or for the concentrations of exhaust gas downstream the respective mixing zones are balanced.

[0087] For balancing amounts of EGR gas in the EGR paths and/or for the concentrations of exhaust gas downstream the respective mixing zones the amounts and/or the concentrations do not have to be determined explicitly. It is sufficient to compare the measured values for example with each other and/or with an overall average.

[0088] In particular, the method comprises the following steps.

[0089] Initially, all sensing valves may be opened to heat the gas sensor device. After that, all sensing valves may be closed and a first sensing valve may be opened.

[0090] Alternatively, all sensing valves may be closed except of a first sensing valve.

[0091] Alternatively, a first sensing valve may be opened without having opened all sensing valves before.

[0092] Hence, a first EGR path is connected with the measuring path while all other sensing valves are closed.

[0093] A value representative for the amount of EGR gas in the first EGR path and/or for a concentration of exhaust gas downstream a respective mixing zone is provided. The first sensing valve may stay open for a first time interval and second time interval. Preferably, only in the second time interval values are provided and/or a mean value over the second time interval is determined.

[0094] The first sensing valve is closed. Before or after the first sensing valve is closed a second sensing valve is opened to connect a second EGR path with the measuring path while all other sensing valves are closed.

[0095] A value representative for the amount of EGR gas in the second EGR path and/or for a concentration of exhaust gas downstream a respective mixing zone is provided. The second sensing valve may stay open for a first time interval and a second time interval, wherein in the second time interval all other sensing valves including the first sensing valve are closed and values are provided and/or a mean value of values over the second time interval is determined. The first time interval may take 30 seconds, the second time interval 60 seconds.

[0096] The second sensing valve is closed.

[0097] Preferably, if available and/or selected further sensing valves successively are opened and closed and values representative for the amount of EGR gas and/or for a concentration of exhaust gas downstream a respective mixing zone in further EGR paths are provided.

[0098] All EGR paths or only selected EGR paths may be successively connected to the measuring path.

[0099] Optionally, in order to improve measurement quality, for each connected EGR path several measurements are taken successively and a mean value for each EGR path or for each of the selected EGR paths is determined.

[0100] The connection between a respective EGR path and the measuring path may remain established for at least several seconds. The respective sensing path may be open for this time.

[0101] An overall mean value may be determined from the values of all EGR paths. Differences between the overall mean value and the values of the individual EGR paths may be determined and the EGR valves and/or the EGR blowers may be operated, such that the differences become small and do not deviate more than $\pm 1\%$ from the overall mean value.

[0102] In the following, the invention is further explained in embodiments by means of figures. Same reference numbers refer to functionally corresponding features.

- Figure 1: shows a schematic view of a first example of an internal combustion engine;
- Figure 2: shows a schematic view of a second example of an internal combustion engine;
- Figure 3: shows a schematic view of a third example of an internal combustion engine;
- Figure 4: shows a schematic view of a fourth example of an internal combustion engine;
- Figure 5: shows a schematic view of a fifth example of an internal combustion engine;
- Figure 6: shows a schematic view of a sixth example of an internal combustion engine;
- Figure 7: shows a schematic view of a seventh example of an internal combustion engine;
- Figure 8: shows a schematic view of an eighth example of an internal combustion engine;
- Figure 9: shows a schematic view of a ninth example of an internal combustion engine.

[0103] Figure 1 shows a schematic view of a first example of an internal combustion engine 10. The internal combustion engine 10 comprises a cylinder 11 having an inner diameter 12 of at least 200mm.

[0104] The internal combustion engine 10 comprises two turbochargers 30a, 30b with a turbine 31a, 31b and a compressor 32a, 32b.

[0105] The internal combustion engine 10 comprising a system 40 for exhaust gas recirculation with two low-pressure EGR paths 41a, 41b fluidly arranged in parallel between an exhaust outlet 13 of the cylinder 10 and an air inlet 14 of the cylinder 10.

[0106] Exhaust gas is guidable via the turbine 31a, 31b of the turbocharger 30a, 30b. In each EGR path 41a, 41b recirculated exhaust gas is guidable to the air inlet 14 of the cylinder 11 through the compressor 32a, 32b of the turbocharger 30a, 30b, which forms a mixing zone 46a, 46b, where exhaust gas is mixed with fresh air.

[0107] Each EGR path 41a, 41b comprises an EGR valve 42a, 42b. All EGR paths 41a, 41b comprise a common shut off valve 44. The pressure in the EGR paths 41a, 41b can be regulated by a back pressure valve 43 arranged between the EGR paths 41a, 41b and a funnel 47.

[0108] Each of the EGR paths 41a, 41b is fluidly connectable with a measuring path 53 via a respective sensing path 51a, 51b. Each sensing path 51a, 51b comprises

a sensing valve 52a, 52b for fluidly connecting the measuring path 53 with the respective EGR paths 41a, 41b. Each sensing path 51a, 51b branches off the respective EGR path 41a, 41b downstream of the mixing zone 46a, 46b, that is downstream the compressor 32a, 32b.

[0109] Each sensing paths 51a, 51b is fluidly connected to the measuring path 53 with at least one gas sensor device 54. The gas sensor device 54 provides values representative for the amount of EGR gas in the respective EGR path 41a, 41b and/or for an EGR concentration of the respective EGR path 41a, 41b downstream the mixing zone 46a, 46b.

[0110] All EGR paths 41a, 41b are connectable to said same measuring path 53.

[0111] The internal combustion engine 10 comprises a first control unit 50 configured for receiving the values provided by the gas sensor device 54. The first control unit 50 is configured for operating the EGR valves 42a, 42b in order to provide all EGR paths 41a, 41b with essentially the same EGR concentration downstream the mixing zones 46a, 46b.

[0112] The internal combustion engine 10 further comprises a second control unit 60 configured for operating the sensing valves 52a, 52b in order to successively connect the measuring path 53 with a respective EGR path 41a, 41b.

[0113] The first control unit 50 and the second control unit 60 form an integrated control unit.

[0114] The measurement path 53 is fluidly connected to the second EGR path 41b upstream of the compressor 32b. Hence, when connected to the respective EGR path 41a, 41b the measurement path 53 upstream of the gas sensor device 54 has a pressure level of the EGR path downstream the compressor 32a, 32b, that is a high pressure level, and the measurement path 53 downstream of the gas sensor device 54 has a pressure level of the EGR path upstream the compressor 32b, that is lower pressure level.

[0115] Figure 2 shows a schematic view of a second example of internal combustion engine 10 similar to the first example. EGR paths 41a, 41b are arranged between an exhaust manifold 15 and a scavenge air receiver 25.

[0116] Before the recirculated exhaust gas is distributed into the first EGR path 41a and the second EGR path 41b, the exhaust gas is guided through an EGR cooler 45 and an EGR demister 48.

[0117] In this example the measurement path is fluidly connected to the first EGR path 41a upstream of the compressor 32a.

[0118] Downstream each compressor 32a, 32b the internal combustion engine 10 comprises an inlet air cooler 33a, 33b.

[0119] Principally, the sensing paths 51a, 51b may branch off the respective EGR path 41a, 41b upstream the inlet air cooler 33a, 33b, such that hot air may be guided to the gas sensor device 54.

[0120] Alternatively, the sensing paths 51a, 51b may branch off the respective EGR path 41a, 41b downstream

the inlet air cooler 33a, 33b, shown in dashed lines (see also figures 3-5).

[0121] Figure 3 shows a schematic view of a third example of an internal combustion engine 10 similar to the second example.

[0122] Figure 4 shows a schematic view of a fourth example of an internal combustion engine similar to the third example.

[0123] Instead of a back pressure valve 43 as shown in figures 1-3 an exhaust gas blower 49 is provided, to establish sufficient pressure in the EGR paths 41a, 41b.

[0124] Figure 5 shows a schematic view of a fifth example of an internal combustion engine 10 similar to the fourth example.

[0125] Instead of a common EGR blower 40 as shown in figure 4, each EGR path 41a, 41b comprises a respective EGR blower 49a, 49b.

[0126] In this case the first control unit 50 is configured for operating the EGR valves 42a, 42b and/or the EGR blowers 49a, 49b in order to provide all EGR paths 41a, 41b with essentially the same EGR concentration downstream the mixing zones 46a, 46b.

[0127] Figure 6 shows a schematic view of a sixth example of an internal combustion engine 10.

[0128] The internal combustion engine 10 comprises two turbochargers 30a, 30b. The system 40 for exhaust gas recirculation is a high-pressure system, wherein exhaust gas is branchable off upstream of the turbines 31a, 31b of the turbochargers 30a, 30b.

[0129] A part of the exhaust gas is guidable to the scavenge air receiver 25 via exhaust paths 41a, 41b and mixable with scavenging air in a respective mixing zone 46a, 46b downstream of the compressors 32a, 32b of the turbochargers 30a, 30b.

[0130] Downstream the mixing zone 46a, 46b respective sensing paths 51a, 51b branch off the EGR paths 41a, 41b. Each sensing path 51a, 51b comprises a sensing valve 52a, 52b for connecting the EGR paths 41a, 41b to the measuring path 53.

[0131] The measuring path 53 is fluidly connected to the funnel 47.

[0132] An integrated first and second control unit 50, 60 is configured

- to operate the sensing valve 52a, 52b in order to successively connecting the EGR paths 41a, 41b to the measuring path 53,
- to receive data representative for the EGR concentration in the EGR path 41a, 41b downstream the mixing zone 46a, 46b and
- to operate the EGR valves 42a, 42b in order to balance the EGR concentration in the EGR path 41a, 41b downstream the mixing zone 46a, 46b and to provide an homogenous EGR concentration in the scavenge air receiver 25.

[0133] The first turbine 31a can be bypassed via a bypass 35 when a waste gate 34 is open. A back pressure

valve 43 is arranged upstream of the bypass.

[0134] Figure 7 shows a schematic view of a seventh example of an internal combustion engine 10 similar to the sixth example.

[0135] In this example the bypass 35 branches off upstream of the back pressure valve 43.

[0136] Figure 8 shows a schematic view of an eighth example of internal combustion engine 10 similar to the sixth example and to the seventh example. Instead of a back pressure valve 43 (see figures 6 and 7) an EGR blower 49 provides for guiding exhaust gas into the first EGR path 41a and the second EGR path 41b. The first EGR path 41a and the second EGR path 41b comprise a common EGR cooler 45.

[0137] Figure 9 shows a schematic view of a ninth example of internal combustion engine 10 similar to the eighth example. Instead of a common EGR blower 49 and a common EGR cooler 45 (see figure 8), in this example each EGR path 41a, 41b comprises a respective EGR blower 49a, 49b and a respective EGR cooler 45a, 45b.

[0138] All figures show examples of internal combustion engines 10 with two turbochargers and with two parallel EGR paths 41a, 41b. However, the internal combustion engine 10 may comprise further turbochargers arranged in parallel and/or more EGR paths arranged in parallel, not shown in the figure.

[0139] Similarly, the internal combustion engine 10 may comprise more than one cylinder.

Claims

1. Internal combustion engine (10), namely a large vessel engine or a stationary engine, preferably is a two-stroke engine or a two-stroke cross head engine,

the internal combustion engine (10) comprising at least one cylinder (11) having an inner diameter (12) of at least 200mm,

the internal combustion engine (10) comprising a system (40) for exhaust gas recirculation with at least two EGR paths (41a, 41b) fluidly arranged at least partly in parallel between an exhaust outlet (13) and an air inlet (14) of the cylinder (10);

each EGR path (41a, 41b) comprising at least one EGR valve (42a, 42b) and/or at least one EGR blower (49, 49a, 49b);

characterized in that

each of the EGR paths (41a, 41b) is fluidly connected to a respective sensing path (51a, 51b) or connectable with the respective sensing path (51a, 51b), which sensing path (51a, 51b) is fluidly connected or connectable to a measuring path (53) with at least one gas sensor device (54) providing values representative for the amount of EGR gas in the respective EGR path

- (41a, 41b).
2. Internal combustion engine (10) according to claim 1, wherein each sensing path (51a, 51b) branches off the respective EGR path (41a, 41b) downstream of a mixing zone (46a, 46b), where fresh air and exhaust gas merge.
 3. Internal combustion engine (10) according to claim 1 or 2, and wherein the internal combustion engine (10) comprises a first control unit (50) configured for receiving the values provided by the at least one gas sensor device (54) and configured for operating the EGR valves (42a, 42b) and/or the EGR blowers (49a, 49b) in order to provide all EGR paths (41a, 41b) with essentially the same EGR concentration after mixing with the fresh air.
 4. Internal combustion engine (10) according to claim 1, 2 or 3, wherein the internal combustion engine comprises only one measuring path (53) and all EGR paths (41a, 41b) are connectable to said measuring path (53).
 5. Internal combustion engine (10) according to claim 4, wherein each sensing path comprises (51a, 51b) a sensing valve (52a, 52b), and wherein the internal combustion engine (10) comprises a second control unit (60) configured for operating the sensing valves (52a, 52b) in order to successively connect the measuring path (53) with a respective EGR path (41a, 41b).
 6. Internal combustion engine (10) according to claim 5, wherein the second control unit (60) is configured to run the following measurement cycle comprising the steps of
 - open all sensing valves (52a, 52b) to heat the gas sensor device (54),
 - close all sensing valves (52a, 52b) except of one, such that a first EGR path (41a) is connected with the measuring path (53) while all other sensing valves are closed (52b), allow determination of a value representative for the amount of EGR gas in the first EGR path (41a), close the first sensing valve (51a),
 - Open a second sensing valve (51b) to connect a second EGR path (41b) with the measuring path (53) while all other sensing valves are closed (52a), allow determination of a value representative for the amount of EGR gas in the second EGR path (41b), close the second sensing valve (51b),
 - Preferably, successively open and close further sensing valves and allow determination of values for amounts of EGR gas in further EGR paths, if available.
 7. Internal combustion engine (10) according to claim 6, wherein the second control unit (60) is configured to run the measurement cycle at least two times, such that a value for an average amount of EGR gas of each EGR path (41a, 41b) is determinable.
 8. Internal combustion engine (10) according to at least one of the preceding claims,
 - the internal combustion engine comprises low-pressure EGR paths (41a, 41b), wherein the internal combustion engine (10) comprises at least one turbocharger (30a, 30b), preferably at least one turbocharger (30a, 30b) for each EGR path, the turbocharger (30a, 30b) comprising a turbine (31a, 31b) and a compressor (32a, 32b), and wherein exhaust gas is guidable via the turbine (31a, 31b) of the turbocharger (30a, 30b) and at least a part of the exhaust gas is guidable to the air inlet (14) of the cylinder (11) through the compressor (32a, 32b) of the turbocharger (30a, 30b), preferably in each low-pressure EGR path (41a, 41b).
 9. Internal combustion engine (10) according to claim 8 wherein the internal combustion engine comprises an inlet air cooler (33a, 33b) downstream the compressor (32a, 32b), and wherein the sensing path (51a, 51b) branches off upstream or downstream the inlet air cooler (33a, 33b).
 10. Internal combustion engine (10) according the at least one of the preceding claims 1-7, wherein
 - the internal combustion engine (10) comprises at least one turbocharger (30a, 30b) comprising a turbine (31a, 31b) and a compressor (32a, 32b);
 - wherein the system (40) for exhaust gas recirculation is a high-pressure system, wherein exhaust gas is branchable off upstream of the turbine (31a, 31b) of the turbocharger (30a, 30b) and at least a part of the exhaust gas is guidable to the air inlet (14) of the cylinder (11) and mixable with scavenging air downstream of the compressor (32a, 32b) of the turbocharger (30a, 30b).
 11. Method of running an internal combustion engine according to one of the preceding claims, comprising the steps of
 - Successively connecting the EGR paths to the measuring path;
 - Provide a value representative for an amount of EGR gas of the respective EGR path;
 - Operating the EGR valves and/or the EGR blowers, such that the values representative for

amounts of EGR gas in the in the EGR paths are balanced.

12. Method according to claim 11, comprising the following steps

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- Open all sensing valves (52a, 52b) to heat the gas sensor device (54),

- close all sensing valves (52a, 52b) except of a first sensing valve (52a), such that a first EGR path (41a) is connected with the measuring path (53) while all other sensing valves are closed (52b),

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- provide a value representative for the amount of EGR gas in the first EGR path (41a), close the first sensing valve (51a),

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- Open a second sensing valve (51b) to connect a second EGR path (41b) with the measuring path (53) while all other sensing valves are closed (52a), determine a value representative for the amount of EGR gas in the second EGR path (41b), close the second sensing valve (51b),

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- Preferably, successively open and close further sensing valves and determine values representative for the amounts of EGR gas in further EGR paths, if available.

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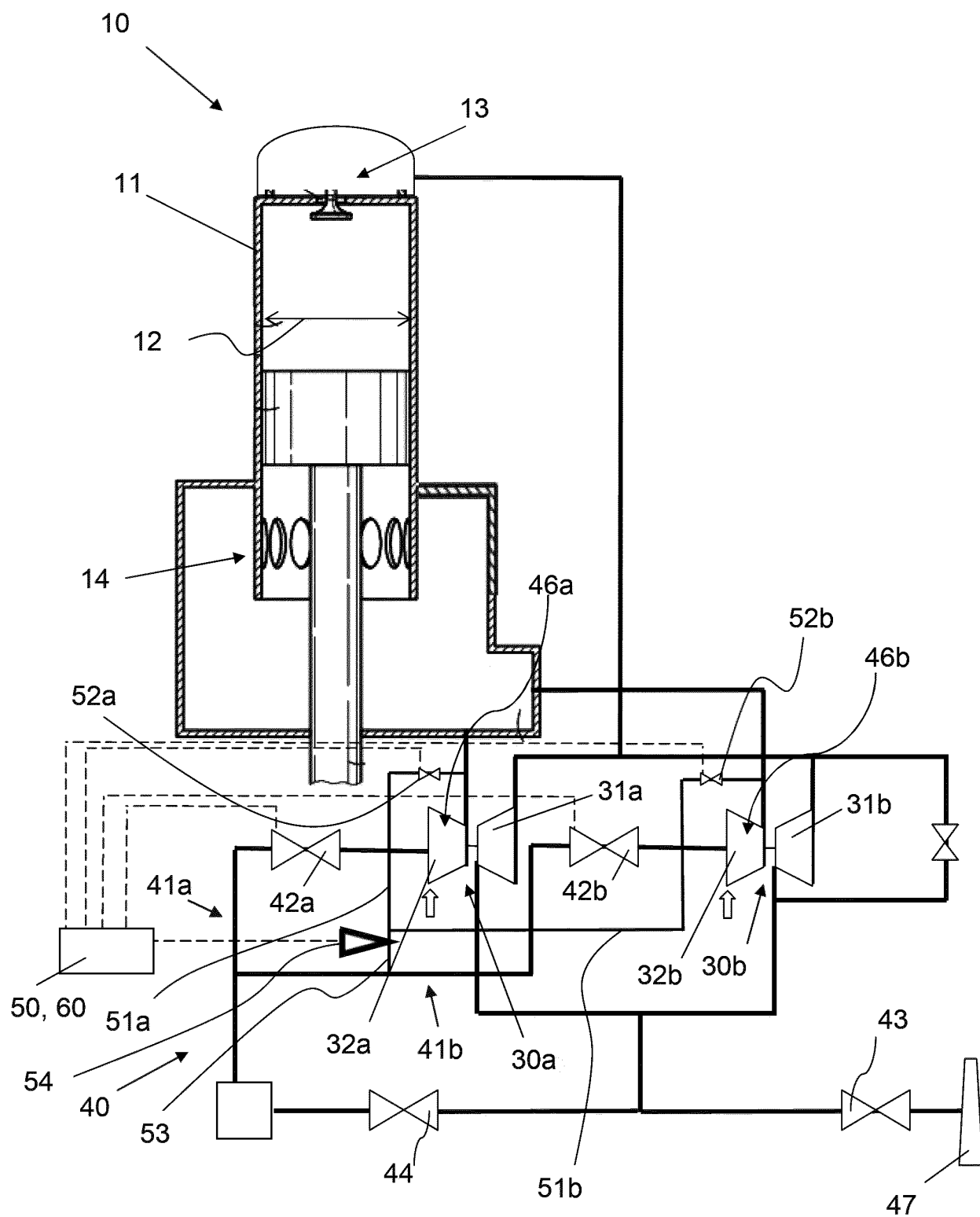


Fig. 1

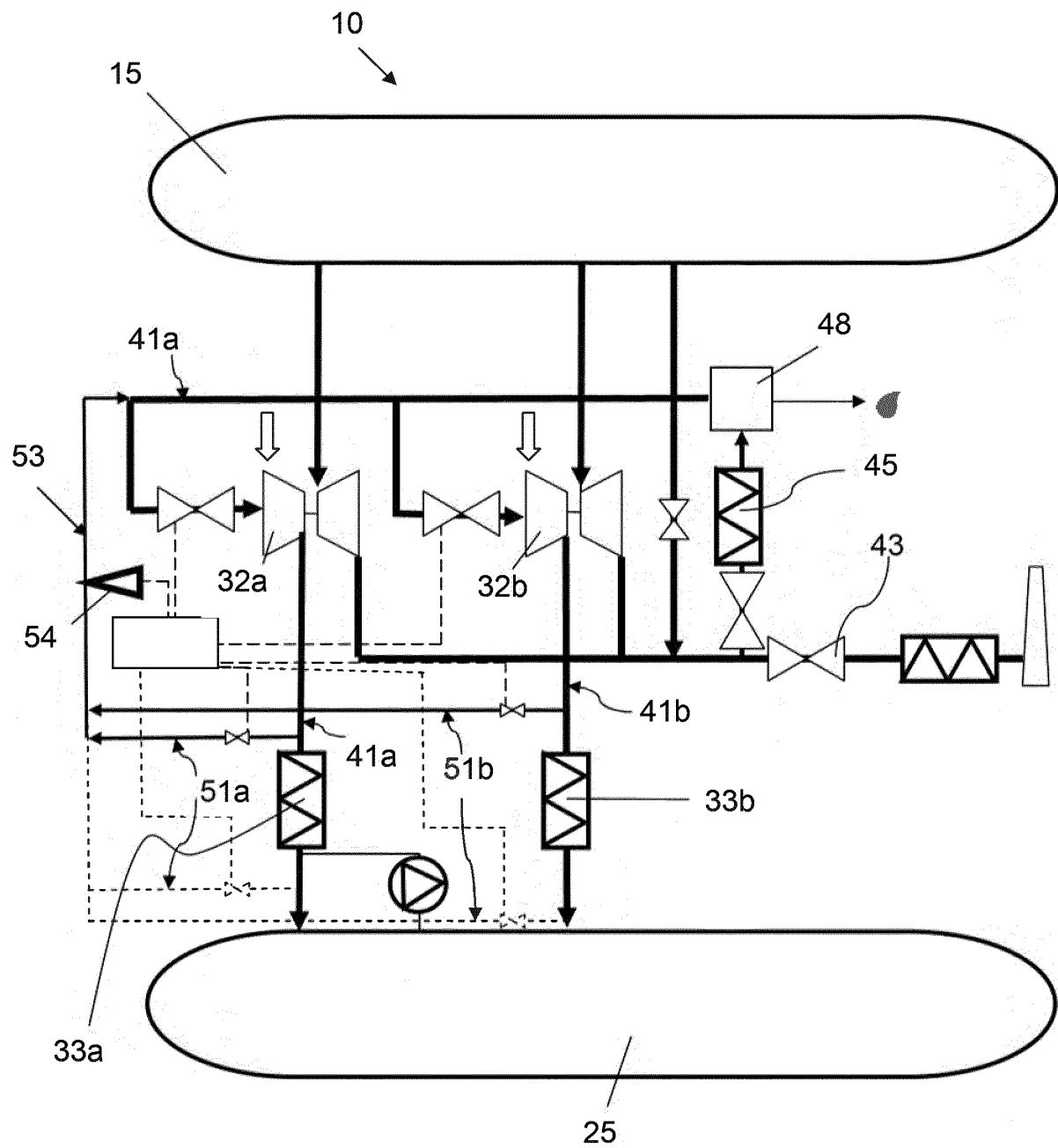


Fig. 2

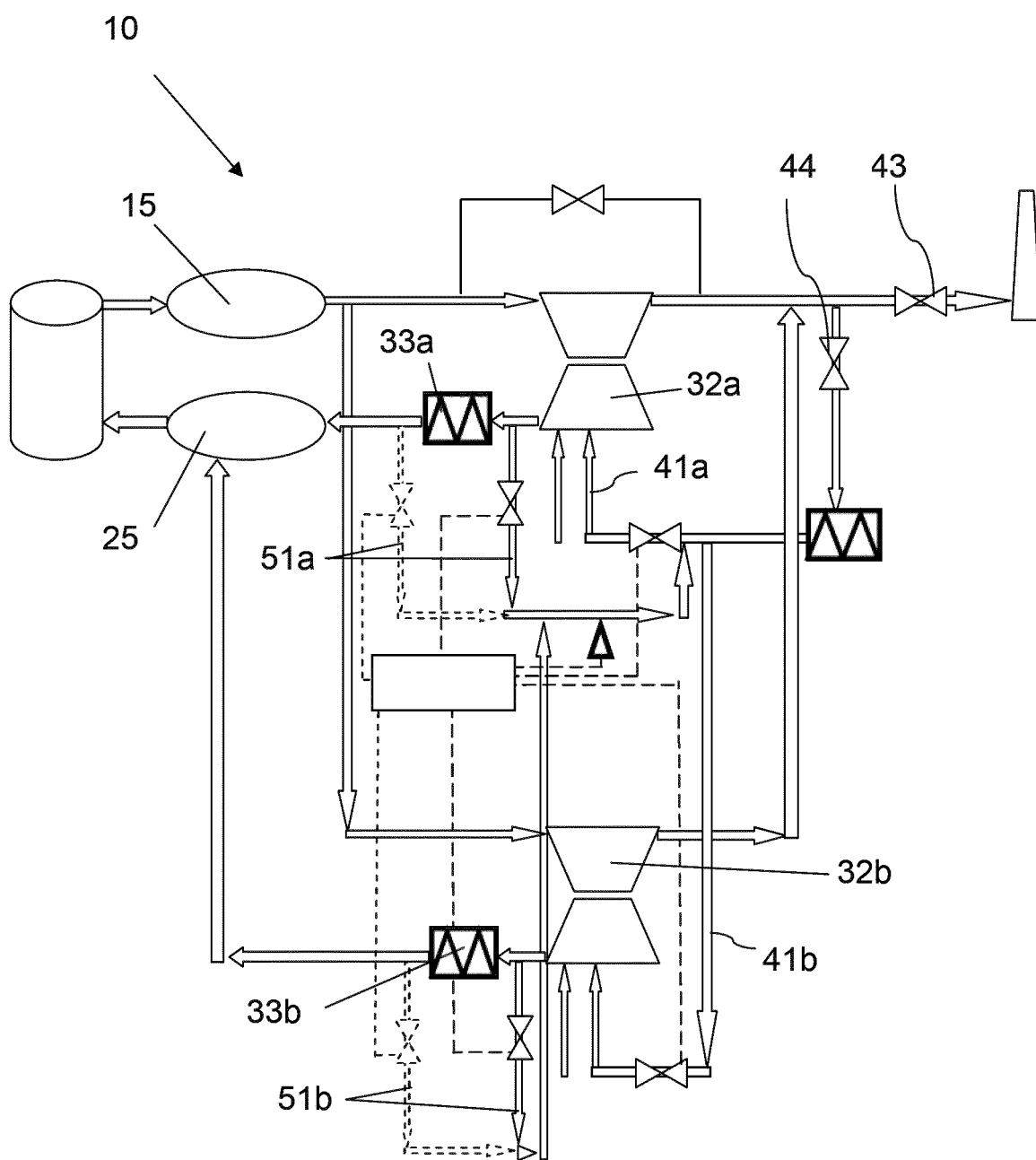


Fig. 3

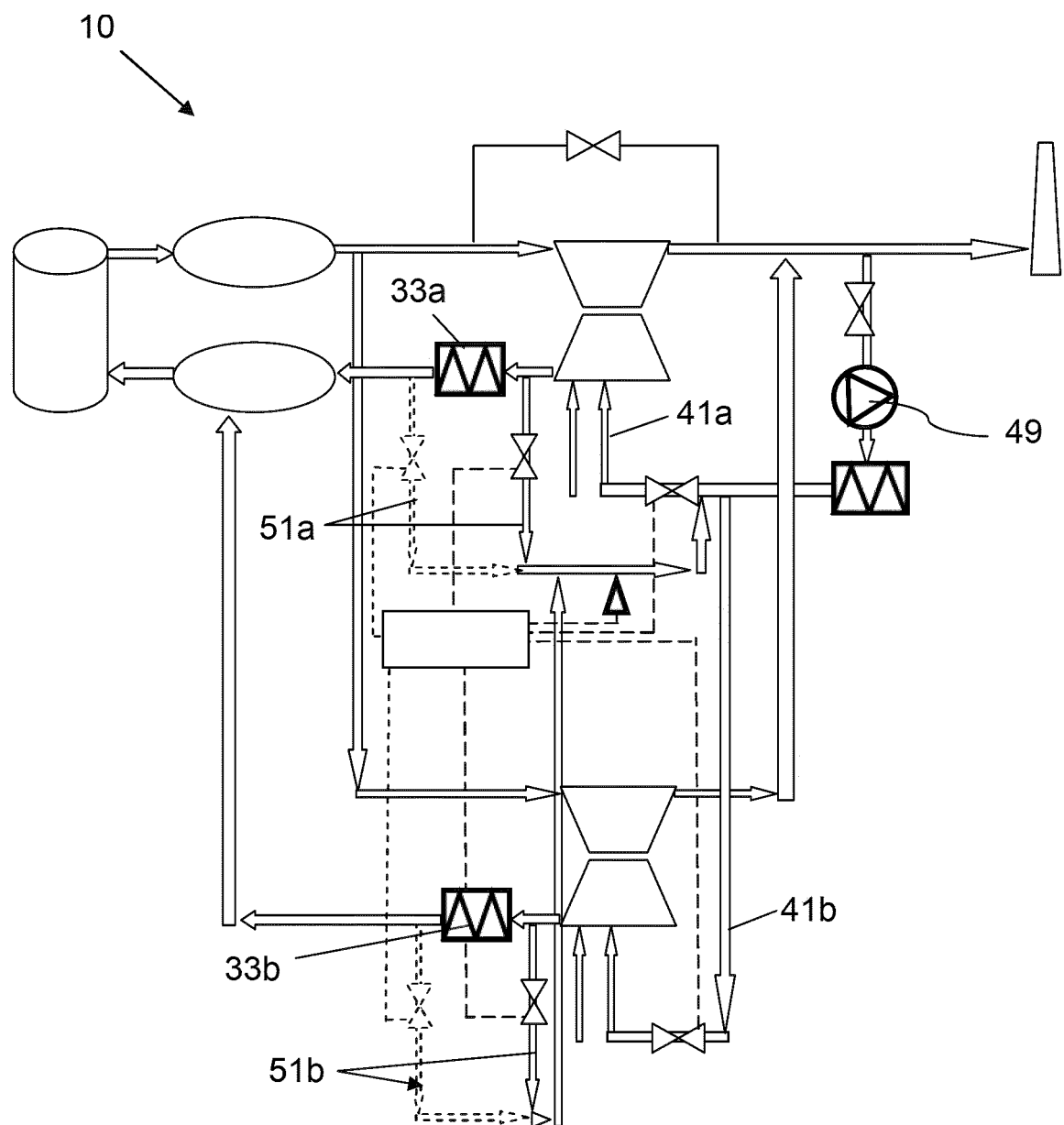


Fig. 4

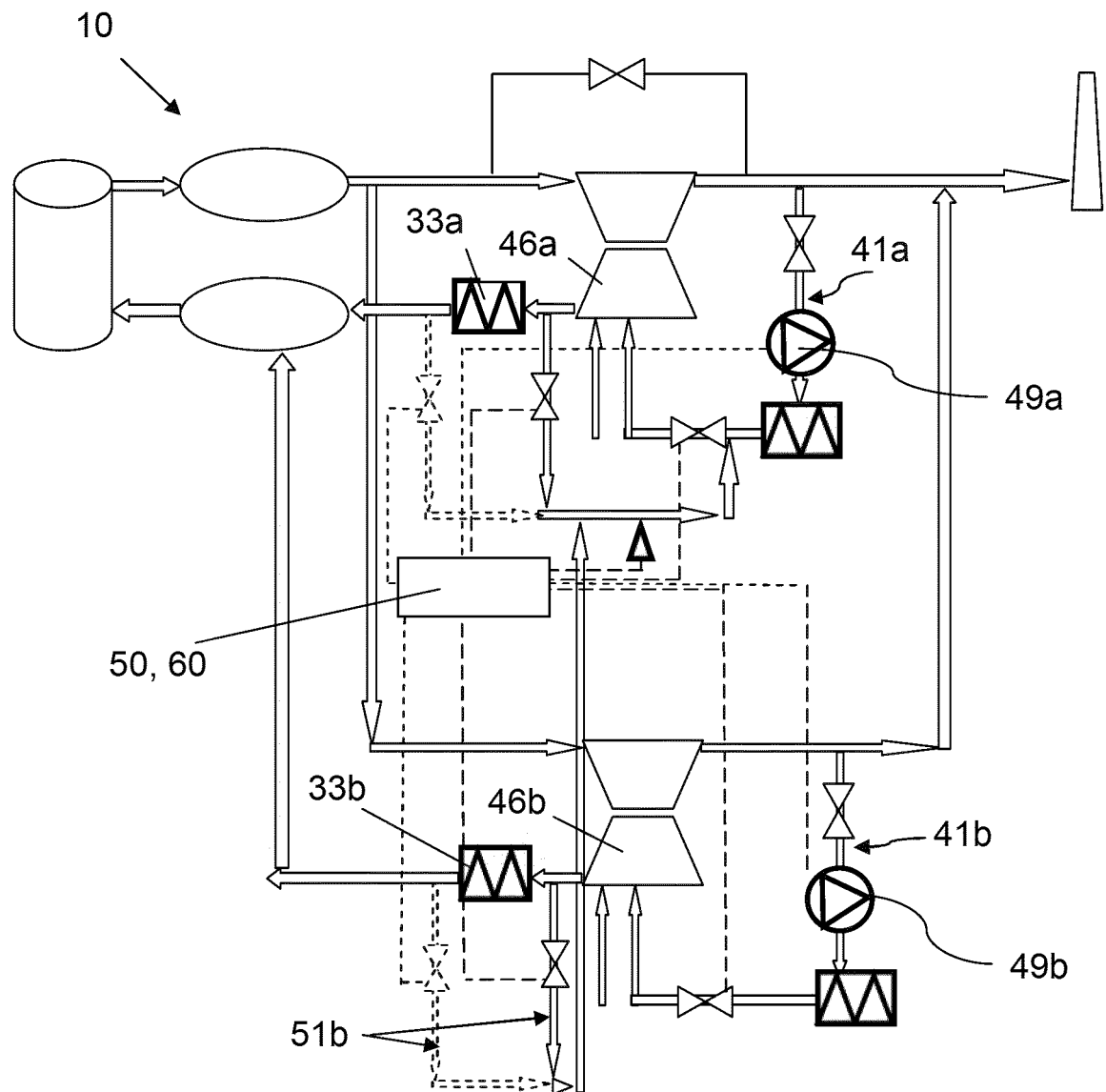


Fig. 5

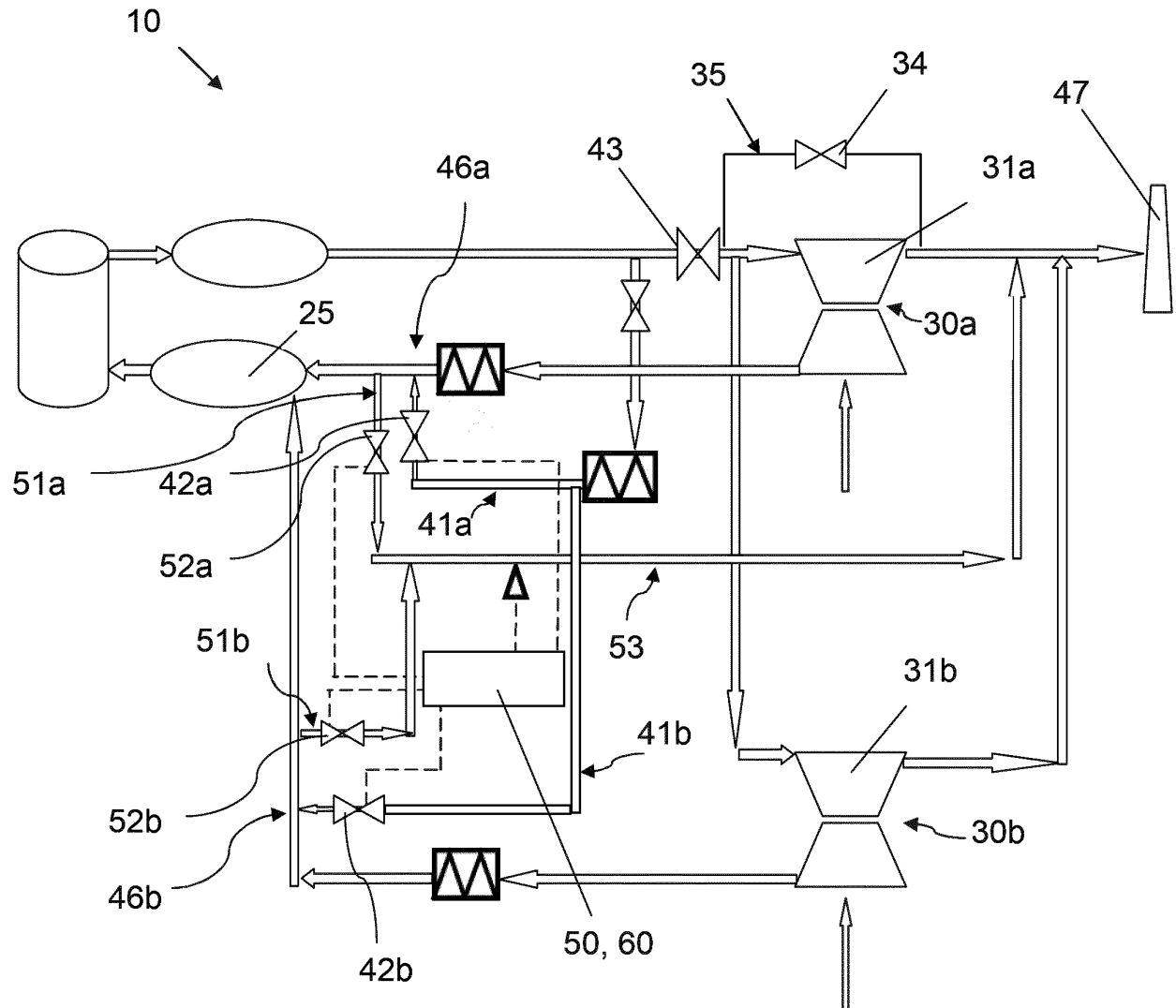


Fig. 6

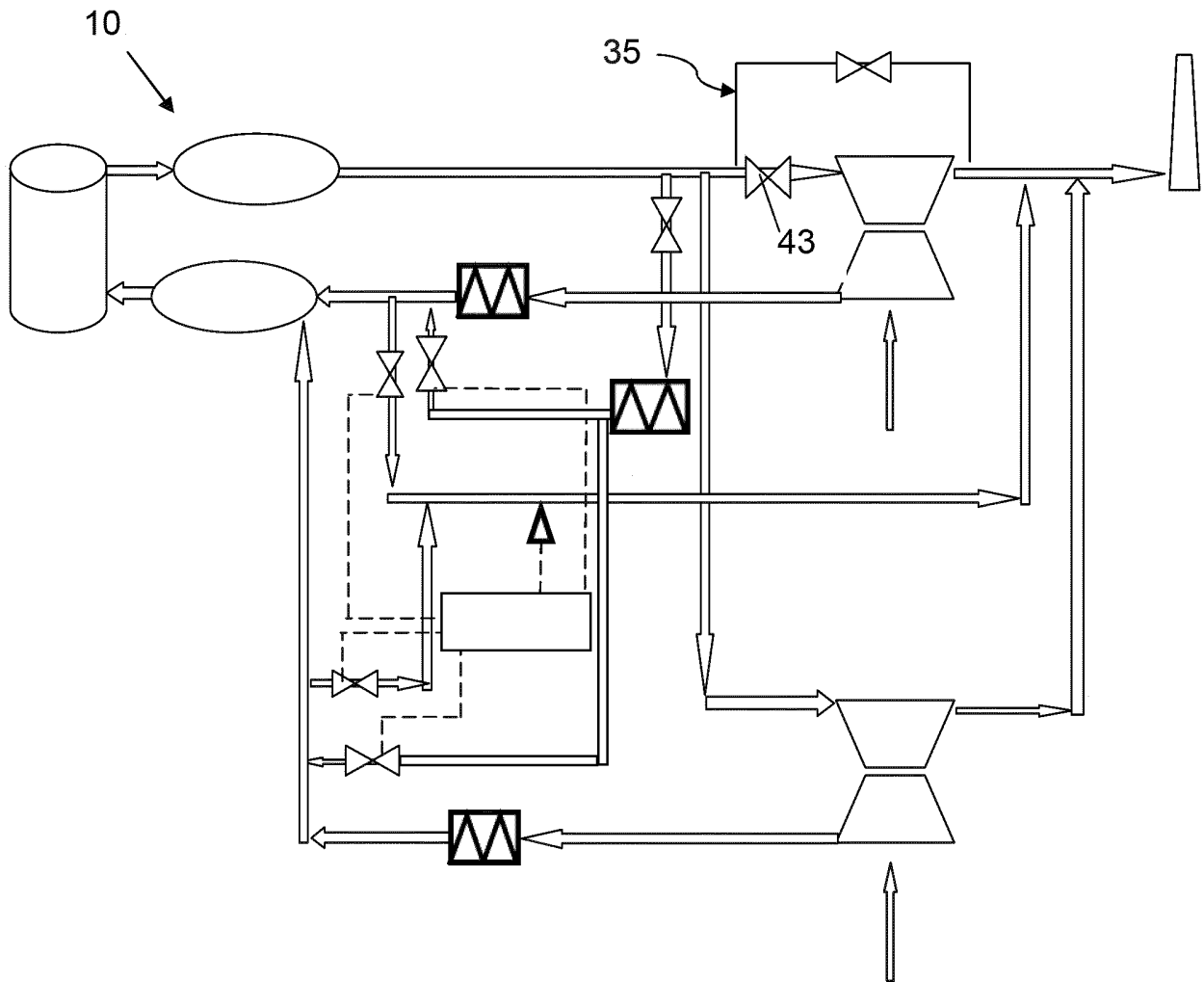


Fig. 7

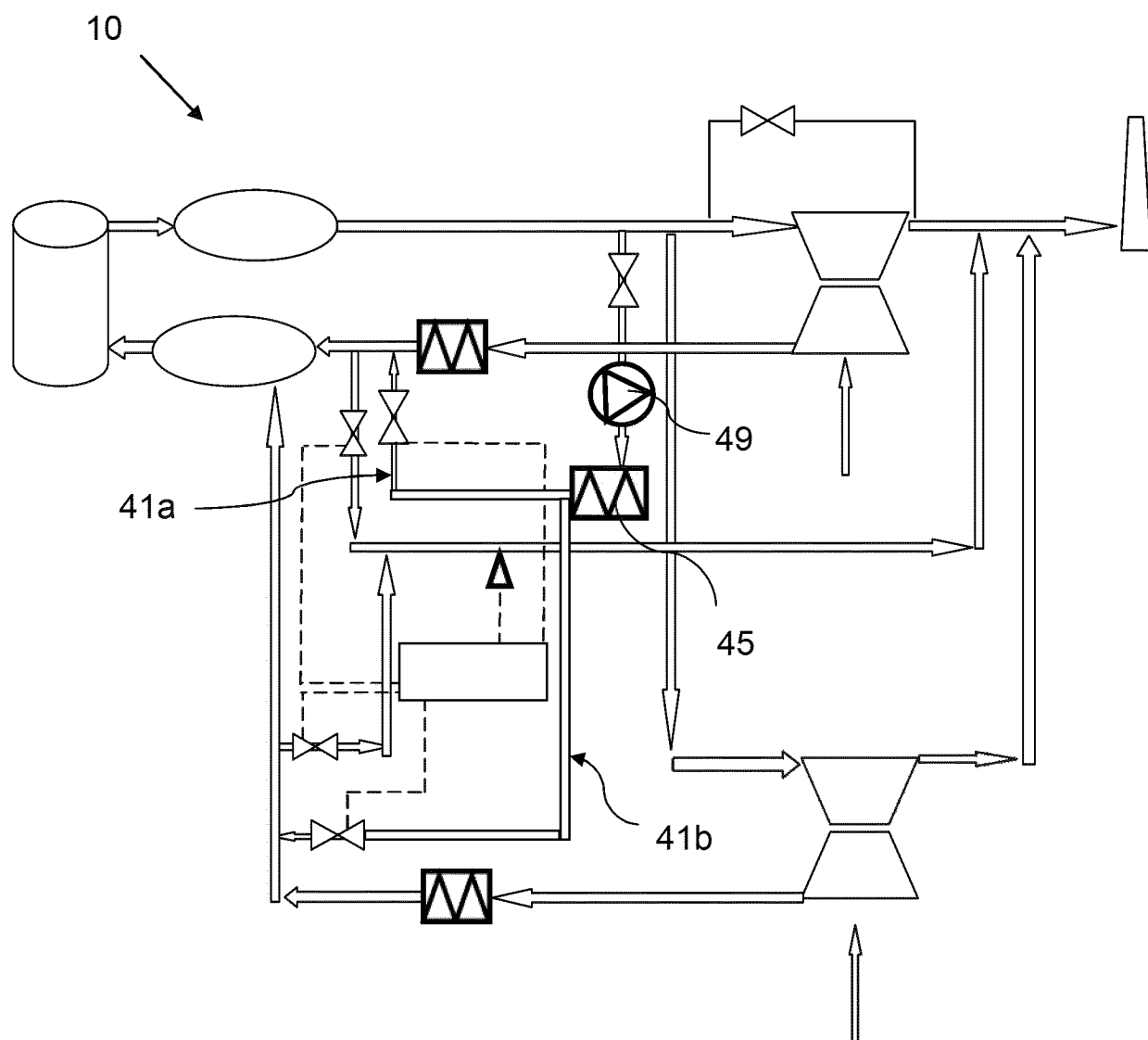


Fig. 8

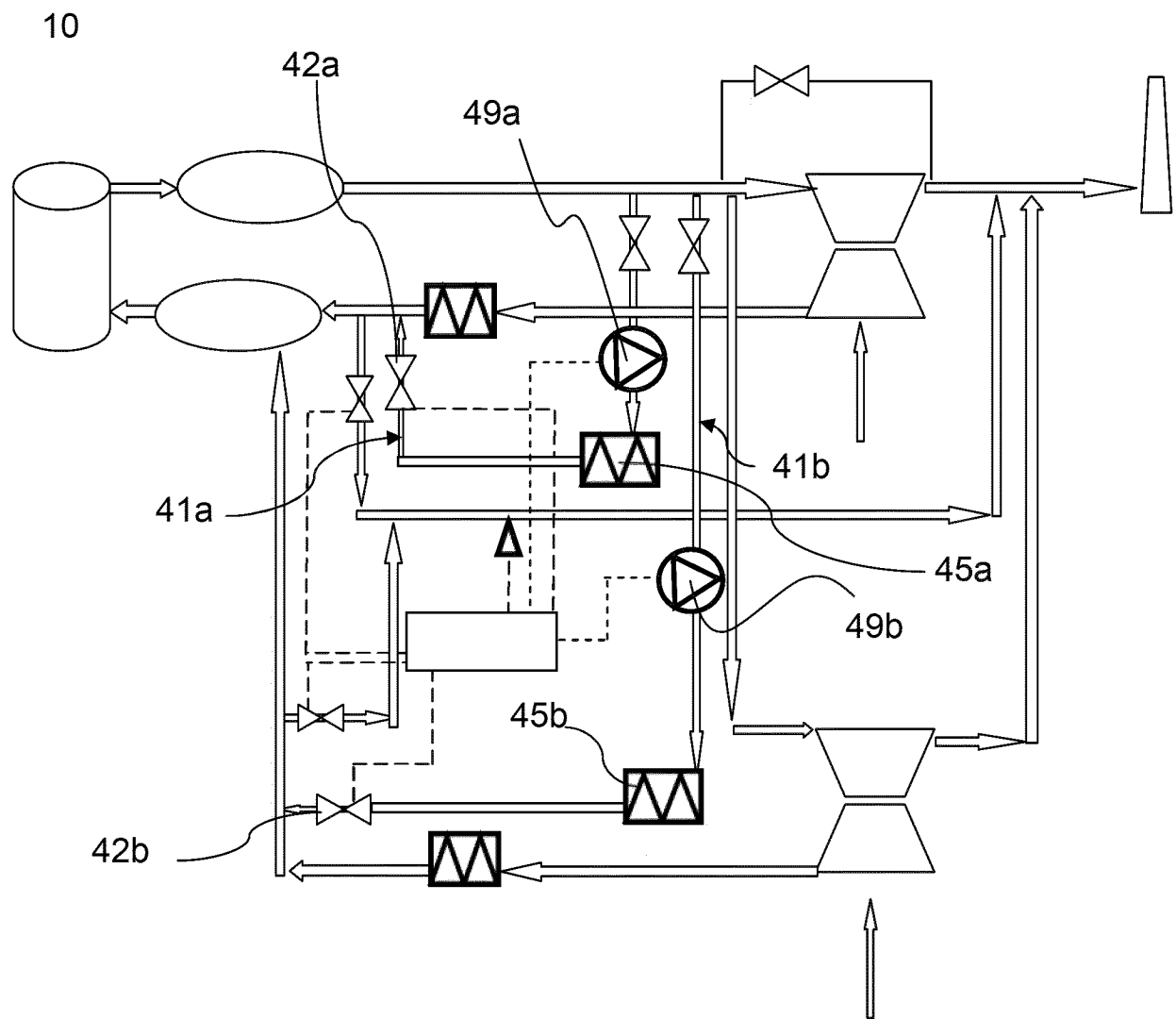


Fig. 9



EUROPEAN SEARCH REPORT

Application Number

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			F02B F02M
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 7 October 2022	Examiner Kolodziejczyk, Piotr
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