Exhaust gas recirculation for large internal combustion engines

An internal combustion engine may comprise an exhaust gas recirculation line (80, 82, 84, 86) with a high temperature cooler (50), an exhaust gas compressor (70), a low temperature cooler (55), and a control unit (60). The control unit (60) may be configured to control the cooling performance of the high temperature cooler (50) in accordance with a cooling performance/engine operation mode information such that a temperature of the extracted exhaust gas at an exit of the high temperature cooler (50) may be maintained at a temperature above a dew point of sulphuric acid independently of the engine operation mode. For low sulphur fuel operation of the engine, operating the high temperature cooler (50) in the proposed manner allows handling severe fouling and blocking issues primarily in the low temperature cooler (55).
Description

Technical Field

[0001] The present disclosure generally refers to using exhaust gas recirculation (EGR) with large internal combustion engines, and more particularly to performing cooling within a high pressure EGR line.

Background

[0002] Due to a recently grown sense of responsibility for the environment and current and prospective emission regulations, it is an objective of engine manufacturers to reduce the amount of air pollutants generated by internal combustion engines. These air pollutants may include particulate matter, nitrogen oxides (NOx), and sulphur components.

[0003] Engine Manufacturers developed various approaches to reduce the generation and/or exhaust of air pollutants to the environment. A well known technique to reduce the generation of NOx is EGR. EGR may be performed by recirculating a portion of the exhaust gas to the combustion unit, thereby lowering the combustion chamber temperature and, thus, reducing the generation of NOx. To guide the exhaust gas to the charge air system, EGR lines may branch off at different positions in the exhaust gas system of an internal combustion engine.

[0004] In the case of a high pressure EGR, the inlet into the EGR line may be arranged upstream of a (high pressure) exhaust gas turbine (the extracted exhaust gas, thus, has a "high pressure" compared to ambient pressure) and the outlet may open into the charge air manifold of the internal combustion engine, for example, downstream of a charge air cooler.

[0005] For an internal combustion engine, WO 2011/066871 A1 discloses inter alia a high pressure EGR line with its own super high temperature (SHT) cooling circuit for cooling the exhaust gas with a coolant of 150°C.

[0006] The present disclosure is directed, at least in part, to improving or overcoming one or more aspects of prior systems.

Summary of the Disclosure

[0007] According to an aspect of the present disclosure, an internal combustion engine may comprise a combustion unit with a charge air inlet and an exhaust gas outlet, an exhaust gas recirculation line for extracting and recirculating exhaust gas to the charge air inlet of the internal combustion engine. The exhaust gas recirculation line may fluidly connect the exhaust gas outlet to the charge air inlet. The internal combustion engine may further comprise a high temperature cooler arranged in the exhaust gas recirculation line configured to use a first coolant within a first preset temperature range for cooling the extracted exhaust gas, an exhaust gas compressor arranged in the exhaust gas recirculation line downstream of the high temperature cooler for compressing the extracted exhaust gas, a low temperature cooler arranged in the exhaust gas recirculation line downstream of the exhaust gas compressor configured to use a second coolant within a second preset temperature range for cooling the compressed extracted exhaust gas, an engine operation mode detecting unit configured to provide a parameter indicating an engine operation mode; and a control unit. The control unit may comprise a cooling performance determination unit configured to control the cooling performance of the high temperature cooler in dependence of the detected parameter such that a temperature of the extracted exhaust gas at an exit of the high temperature cooler may be maintained at a temperature above a dew point of sulphuric acid independently of the engine operation mode.

[0008] Setting the cooling performance of the high temperature cooler according to a cooling performance/engine operation information may prevent a temperature below a dew point of sulphuric acid independently of an engine operation mode.

[0009] In some embodiments, the cooling performance determination unit may comprise cooling performance/engine operation information that may comprise, in dependence of the engine operation mode, a cooling performance that may ensure cooling of the extracted exhaust gas to a temperature above a dew point of sulphuric acid at an exit of the high temperature cooler.

[0010] According to another aspect, a method for cooling extracted exhaust gas within a recirculated exhaust gas line of an internal combustion engine may comprise determining an engine operation mode of a combustion unit of the combustion engine, setting a cooling performance in dependence of the engine operation mode such that a temperature of the extracted exhaust gas may be maintained at a temperature above a dew point of sulphuric acid independently of the engine operation mode, and cooling the extracted exhaust gas according to the set cooling performance.

[0011] The cooling method for cooling extracted exhaust gas in an EGR line may ensure cooling of the extracted exhaust gas to a temperature above a dew point of sulphuric acid independently of an engine operation mode.

[0012] According to another aspect, a high temperature cooler for an exhaust gas recirculation line may comprise a cooling surface that is configured to be adjustable in its size in dependence of a cooling performance that is required to ensure a temperature of the extracted exhaust gas to be maintained at a temperature above a dew point of sulphuric acid.

[0013] In some embodiments, a high temperature cooler may be arranged in a high temperature cooling circuit together with a combustion engine, thereby providing an economically reasonable solution.

[0014] According to another aspect, a high temperature cooler for an exhaust gas recirculation line may comprise a cooling surface, and may be configured to adjust
a size of the cooling surface in dependence of a required cooling performance.

[0015] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[0016] Fig. 1 shows a schematic diagram of an internal combustion engine with an exhaust gas recirculation line;

Fig. 2 shows a schematic diagram of a high temperature cooling circuit;

Fig. 3 shows an exemplary diagram of cooling performance/engine operation mode information; and

Fig. 4 shows a flow diagram illustrating a method for cooling an extracted exhaust gas flow within an exhaust gas recirculation line.

Detailed Description

[0017] The following is a detailed description of exemplary embodiments of the present disclosure. The exemplary embodiments described therein and illustrated in the drawings are intended to teach the principles of the present disclosure, enabling those of ordinary skill in the art to implement and use the present disclosure in many different environments and for many different applications. Therefore, the exemplary embodiments are not intended to be, and should not be considered as, a limiting description of the scope of patent protection. Rather, the scope of patent protection shall be defined by the appended claims.

[0018] The present disclosure may be based in part on the realization that, for example, low sulfur marine diesel oil (LSMDO) with a fuel sulphur content of, for example, 1000 ppm may affect EGR systems of internal combustion engines as the exhaust gas may contain sulphur components and particulate matter.

[0019] For EGR, a certain amount of the exhaust gas may be branched off and recirculated to the combustion unit. When cooling the extracted exhaust gas below the dew point of sulphuric acid, condensation may occur within the cooler, which may lead - in combination with particulate matter - to, for example, a blockage and fouling of the cooler. As a result an increased pressure drop may occur across the cooler. Additionally, the condensed sulphuric acid may cause corrosion within piping and devices arranged on the downstream side of the cooler.

[0020] Accordingly, it is proposed to operate the high temperature cooler within an EGR line to reliably prevent the condensation of sulphuric acid within a high temperature cooler. For low sulphur fuel operation of the engine, operating the high temperature cooler in the proposed manner allows handling stronger fouling and blocking issues primarily in the low temperature cooler.

[0021] An exemplary embodiment of an internal combustion engine with an EGR line comprising a high temperature cooler, an exhaust gas compressor, and a low temperature cooler is described in the following with reference to Fig. 1.

[0022] An internal combustion engine 100 may comprise a combustion unit 10 with one or more cylinders and associated combustion chambers 15 and an EGR system 17. Combustion unit 10 may be, for example, a diesel, heavy fuel, and/or gas powered combustion unit. The cylinders may be arranged, for example, in an inline, V, W, or any other known configuration.

[0023] Combustion unit 10 may further comprise an air inlet 20 (for example, configured as an intake manifold). Air inlet 20 may be connected to a charge air system 30. Charge air system 30 may comprise one or more stages of a charger system (not shown), which may compress fresh air prior charging combustion chambers 15 of combustion unit 10.

[0024] Combustion engine 100 may further comprise an exhaust gas outlet 25 (for example, configured as an outlet manifold). Via exhaust gas line 35, exhaust gas outlet 25 may be connected to an exhaust gas system (not shown) that may, for example, include turbines of the charger system and additional exhaust gas treatment devices.

[0025] EGR system 17 may provide an exhaust gas recirculation path from exhaust gas outlet 25 to air inlet 20. As shown in Fig. 1, the exhaust gas recirculation path may comprise (in flow direction) a high temperature cooler 50, an exhaust gas compressor 70, and low temperature cooler 55. EGR system 17 may further comprise one or more valves, sensors (such as temperature and pressure sensors), and a control unit 60. Control unit 60 may be configured to communicate with the various components of the exhaust gas recirculation path via communication lines indicated by solid lines in Fig. 1.

[0026] Specifically, an exhaust gas recirculation line 80 may be branched off from exhaust gas line 35 such that high pressure exhaust gas directly from the combustion chambers may be returned to the charge air inlet 20.

[0027] A first valve 40 may be disposed in exhaust gas recirculation line 80 to open or shut off the exhaust gas recirculation as controlled by control unit 60. High temperature cooler 50 may be arranged downstream of first valve 40 and may be controlled as described below by control unit 60.

[0028] An exhaust gas recirculation line 82 may fluidly connect high temperature cooler 50 and exhaust gas compressor 70. Exhaust gas compressor 70 may be driven, for instance, by an electric motor or a drivingly coupled exhaust gas turbine (both not shown).

[0029] Low temperature cooler 55 may be arranged downstream of exhaust gas compressor 70 and may be connected to exhaust gas compressor 70 through an exhaust gas recirculation line 84. An outlet of low temperature cooler 55 may be fluidly connected via exhaust gas recirculation 86 with air inlet 20, whereby a second valve 45 may be arranged within exhaust gas recirculation line 86 to open or shut off the recirculated exhaust gas.
In general, first valve 40 and second valve 45 determine whether action is required. For example, instructions and data stored in memory or input by a user, other appropriate circuitry. Control unit 60 may analyze final-conditioning circuitry, communication circuitry, and with control unit 60, including power supply circuitry, signal conditioning circuitry, communication circuitry, and other appropriate circuitry. Control unit 60 may analyze and compare received and stored data, and, based on instructions and data stored in memory or input by a user, determine whether action is required. For example, control unit 60 may compare received values with target values stored in memory, and based on the results of the comparison, control unit 60 may transmit signals to one or more components to alter the operation status thereof. Control unit 60 may include any memory device known in the art for storing data relating to operation of the internal combustion engine 100 and its components. The data may be stored in the form of one or more maps that describe and/or relate, for example, injection timing. Each of the maps may be in the form of tables, graphs, and/or equations, and include a compilation of data collected from lab and/or field operation of the combustion engine. The maps may be generated by performing instrumented tests on the operation of the internal combustion engine 100 under various operating conditions while varying parameters associated therewith. Control unit 60 may reference those maps and control operation of one component in response to the desired operation of another component.

During operation of internal combustion engine 100, combustion unit 10, for example, the cylinder liners and cylinders may be heated by the combustion process. To limit the temperature, usually a so-called high temperature cooling circuit is provided. Also compressing the charge air results in heating the same and thus requires cooling the charge air if combustion unit 10 is intended to be charged with charge air at a temperature at about 40 °C. Accordingly, high temperature coolers of high temperature cooling circuit may be provided within the charge air system. In addition, a low temperature cooling circuit may be provided to further cool down the charge air.

Also high temperature cooler 50 and low temperature cooler 55 of the exhaust gas recirculation path may need to dissipate heat when cooling the passing exhaust gas and, thus, may be integrated in the high temperature cooling circuit and the low temperature cooling circuit, respectively.

In Fig. 2, a high temperature cooling circuit 300 of a cooling system of an engine is schematically shown. High temperature cooling circuit 300 may comprise a pump 390 to pump a coolant (e.g. water) through the various components for dissipating the heat acquired by those components. In the embodiment shown in Fig. 2, high temperature cooling circuit 300 may pump the coolant through high temperature EGR cooler 350, combustion unit 310, and main high temperature cooler 352. In some embodiments, high temperature EGR cooler 350 and combustion unit 310 may correspond to high temperature EGR cooler 350 and combustion unit 310, respectively.

Main high temperature cooler 352 may be part of an external cooling circuit comprising external pump 392 pumping an external coolant through the external cooling circuit. Additionally, external cooling circuit may comprise temperature sensors 346A-B and valves (not shown). External coolant may be ambient air in land applications such as power plants, or sea water in marine
applications on ships/vessels.

[0043] High temperature cooling circuit 300 may further be used for dissipating heat of one or more air intake coolers 354, 356, which is indicated in Fig. 2 by dashed lines and dashed-line boxes. In some embodiments, one or more air intake coolers 354 may be arranged in line (upstream or downstream) or parallel to each other. Moreover, one or more air intake coolers 354 may be arranged in line (upstream or downstream) or in parallel to combustion unit 310 and/or high temperature EGR cooler 350.

[0044] In addition, a valve 342 may be arranged in high temperature cooling circuit 300 and be configured to adjust a volume flow of the coolant. For controlling the volume flow of the coolant, valve 342 and one or more temperature sensors 344A, 344B, 344C may be connected to a control unit (not shown), which may correspond to control unit 60 of Fig. 1. For example, valve 342 in the bypass of main high temperature cooler 352 may be configured to direct all or a certain amount of the coolant to main high temperature cooler 352, thereby adjusting the amount of heat taken out of high temperature cooling circuit 300 by the external coolant of the external cooling circuit.

[0045] For example, in marine applications, the highest temperature of the coolant pumped through the high temperature cooling circuit 300 may be measured by temperature sensor 344A that may be positioned downstream of the combustion unit 310 and may be, for example, about 90°C. The temperature of the coolant downstream of high temperature EGR cooler 350 may be, for example, about 80°C, which may be measured by temperature sensor 344B.

[0046] The advantage of integrating high temperature EGR cooler 350 into high temperature cooling circuit 300 may be that the EGR cooling circuit may be integrated into and combined with the existing high temperature engine cooling circuit.

Industrial Applicability

[0047] In the following, the basic operation of the above exemplary embodiment of internal combustion engine 100 will be described with reference to Fig. 1 and 3.

[0048] During normal operation of an internal combustion engine 100, fuel and combustion air may be supplied to and burned in combustion unit 10. Exhaust gas may leave combustion unit 10 through exhaust gas outlet 25 to exhaust gas line 35. A partial flow of the exhaust gas may be branched off (extracted) to be guided into exhaust gas recirculation line 80.

[0049] The extracted exhaust gas may flow through exhaust gas line 80 and may enter high temperature exhaust gas cooler 50. High temperature exhaust gas cooler 50 may be connected to and controlled by control unit 60. Control unit 60 may set a cooling performance parameter dependent on an engine operation mode of the internal combustion engine 100 such that a temperature of the extracted exhaust gas may be maintained above a preset minimum temperature at an exit of high temperature cooler 50 independently of the load at which the engine may be operated. For example, the temperature of the exhaust gas at the exit of high temperature cooler 50 may be above a dew point of sulphuric acid.

[0050] Therefore, condensation of sulphuric acid within high temperature cooler 50, exhaust gas recirculation line 82, and exhaust gas compressor 70 may be prevented or at least reduced. As a result, effects such as corrosion, blocking, and unacceptable fouling within high temperature cooler 50, exhaust gas recirculation line 82, and exhaust gas compressor 70 may be reduced. Severe fouling and blocking in those components may occur because condensed sulphuric acid together with the particulate matter within the exhaust gas may form deposits in the respective component.

[0051] Control unit 60 may control high temperature cooler 50 in accordance with cooling performance/engine operation mode information.

[0052] An exemplary embodiment of cooling performance/engine operation mode information is described with reference to Fig. 3.

[0053] The axis of abscissa indicates an absolute exhaust gas pressure in bar. In some embodiments, an engine operation mode detection unit may comprise an exhaust gas pressure sensor. Measured values for the exhaust gas pressure may be utilized by control unit 60 as parameter to indicate an engine operation mode. Control unit 60 may set a cooling performance in accordance to the indicated engine operation mode.

[0054] The axis of ordinate indicates a dew point of sulphuric acid in °C. To illustrate the wide range of dew points of sulphuric acid as a function of exhaust gas pressure, fuel sulphur content, and ambient conditions (such as ambient temperature and ambient humidity) four exemplary graphs are shown in Fig. 3. Using such cooling performance/engine operation mode information, the cooling performance of high temperature cooler 50 may be controlled within a wide range parameters (such as exhaust gas pressure, fuel sulphur content, ambient temperature, ambient humidity).

[0055] In the following, the term "ISO conditions" may refer to an ambient barometric pressure of 1 bar, an ambient temperature of 25°C and an ambient relative humidity of 30 % according to ISO 3046-1: 2002 (E) and ISO 15550: 2002 (E) . In contrast, the term "tropical conditions" may refer to an ambient barometric pressure of 1 bar, an ambient temperature of 45°C and an ambient relative humidity of 60 % according to IACS rule M28.

[0056] In Fig. 3, the dotted line relates to tropical conditions and a low sulphur content and, thus, represents a dew point of sulphuric acid within an exhaust gas flow at tropical conditions. Specifically, the dotted line relates to burning fuel with a fuel sulphur content of 100 ppm at an air-fuel ratio (AFR) of 1.8.

[0057] In Fig. 3, the dashed/dotted line relates to ISO conditions and a low sulphur content and, thus, the
dashed/dotted line represents a dew point of sulphuric acid within an exhaust gas flow at ISO conditions. Specifically, the dashed/dotted line relates to burning fuel with a fuel sulphur content of 100 ppm at an AFR of 1.8.

In Fig. 3, the solid line relates to tropical conditions and a high sulphur content and, thus, represents the dew point of sulphuric acid within an exhaust gas flow at tropical humid conditions. Specifically, the solid line relates to burning fuel with a fuel sulphur content of 1000 ppm at an AFR of 1.8.

In Fig. 3, the dashed line relates to ISO conditions and a high sulphur content and, thus, represents a dew point of sulphuric acid within an exhaust gas flow at ISO conditions. Specifically, the solid line relates to burning fuel with a fuel sulphur content of 100 ppm at an AFR of 1.8.

The cooling performance of high temperature cooler 50 may be set by control unit 60 such that a temperature of the extracted exhaust gas may be maintained above a correspondent line indicative of the aforementioned parameters at an exit of high temperature cooler 50. Therefore, it may be ensured that the temperature of the exhaust gas leaving high temperature cooler 50 may be above a dew point temperature of sulphuric acid and condensation of sulphuric acid within the cooler may be prevented or reduced.

In some embodiments, an exhaust gas pressure may be measured by a pressure sensor, which may be arranged in or downstream of exhaust gas outlet 25. Engine operation mode may be determined on basis of the measured exhaust gas pressure.

In some embodiments, engine operation mode may be determined on basis of one or more parameters of internal combustion engine 100. These parameters may be engine speed, turbine speed of super- or turbochargers, fuel rack position and/or charge air pressure. To measure those parameters, an engine operation mode may comprise an engine speed sensor, turbine speed sensors, fuel rack position sensor, and/or a charge air pressure sensor, which may be arranged in or downstream of exhaust gas outlet 25. Engine operation mode may be determined on basis of the measured exhaust gas pressure.

In some embodiments, an ambient temperature, ambient humidity, and/or fuel sulphur content may be measured by sensors and/or input in a user interface by a user. Sensors and/or user interface may be connected to control unit 60.

As already outlined above, control unit 60 may control the cooling performance of high temperature cooler 50. The cooling performance may be adjusted by increasing or decreasing a cooling surface size, and/or increasing or decreasing a volume flow of a coolant acquiring the heat of high temperature cooler 50, and/or other techniques of varying the cooling performance of a cooler known by a skilled person.

The extracted exhaust gas may leave high temperature cooler 50 with a temperature above a dew point of sulphuric acid and enter exhaust gas compressor 70 through exhaust gas recirculation line 82. Exhaust gas compressor 70 may compress the extracted exhaust gas to a predetermined pressure, thereby also increasing a temperature of the extracted exhaust gas. The compressed and extracted exhaust gas may be guided into exhaust gas recirculation line 84.

Exhaust gas recirculation line 84 may guide the extracted exhaust gas into low temperature cooler 55, which may cool the compressed exhaust gas to a temperature below a dew point of sulphuric acid. Low temperature cooler 55 may be connected to and controlled by control unit 60.

The cooled and compressed extracted exhaust gas may leave low temperature cooler 55 through exhaust gas recirculation line 86 and may be fed into air inlet 20. The recirculated exhaust gas may further be mixed with charge air from charge air system 30. The charge air may have passed one or more compressors of a one or more stage charging system (not shown) prior to enter air inlet 20.

In the following, a method for cooling exhaust gas within an exhaust gas recirculation line will be described with reference to Fig. 4. The method's beginning and end is indicated by a rounded box 410 and a rounded box 490, respectively.

In a step 420, an engine operation mode may be determined. This may be done based on a pressure value of the exhaust gas and/or on values for engine speed, turbine speed of a turbocharger, and/or charge air pressure.

In a step 430, a cooling performance of a cooler may be set in dependence of the determined engine operation mode of step 420. The cooling performance may be set to maintain a temperature of the passing exhaust gas above a dew point of sulphuric acid after cooling independently of a load at which the engine may be operated.

In a step 440, the cooling of the exhaust gas may be performed in accordance with the set cooling performance of step 430.

According to some embodiments of the present disclosure, the exhaust gas may be further compressed in a step 450, thereby increasing its temperature.

In a step 460, the exhaust gas may be cooled down to a low temperature below a dew point of sulphuric acid. This temperature may correspond to a charge air temperature and may be, for example, about 45°C.

Furthermore, the cooled and compressed recirculated exhaust gas may be mixed with cooled and compressed charge air (step 470) and may be provided together with the cooled and compressed charge air to the combustion process (step 480), for example, to an air inlet of the combustion unit.

In some embodiments, the exhaust gas pressure sensor (90) may be arranged in the exhaust gas recirculation line (80, 82, 84, 86) upstream of the high temperature cooler (50).

In some embodiments, the cooling performance/engine operation unit may comprise a table, a map,
An internal combustion engine (100) comprising:

- a combustion unit (10) with a charge air inlet (20) and an exhaust gas outlet (25);
- an exhaust gas recirculation line (80, 82, 84, 86) for extracting and recirculating exhaust gas to the charge air inlet (20) of the internal combustion engine (100), the exhaust gas recirculation line (80, 82, 84, 86) fluidly connecting the exhaust gas outlet (25) to the charge air inlet (20);
- a high temperature cooler (50) arranged in the exhaust gas recirculation line (80, 82, 84, 86) configured to use a first coolant within a first preset temperature range for cooling the extracted exhaust gas;
- an exhaust gas compressor (70) arranged in the exhaust gas recirculation line (80, 82, 84, 86) downstream of the high temperature cooler (50) for compressing the extracted exhaust gas;
- a low temperature cooler (55) arranged in the exhaust gas recirculation line (80, 82, 84, 86) downstream of the exhaust gas compressor (70) configured to use a second coolant within a second preset temperature range for cooling the compressed extracted exhaust gas;
- an engine operation mode detecting unit configured to provide a parameter indicating an engine operation mode; and
- a control unit (60) comprising a cooling performance/engine operation mode information comprising a cooling performance of the high temperature cooler (50) in dependence of the detected parameter such that a temperature of the extracted exhaust gas at an exit of the high temperature cooler (50) is maintained at a temperature above a dew point of sulphuric acid independently of the engine operation mode.

The internal combustion engine (100) of claim 1, wherein the cooling performance determination unit comprises cooling performance/engine operation mode information comprising, in dependence of the engine operation mode, a cooling performance that ensures cooling of the extracted exhaust gas to a temperature above a dew point of sulphuric acid at the exit of the high temperature cooler (50).

The internal combustion engine (100) of claim 1 or 2, wherein the cooling performance/engine operation mode information comprises a cooling performance parameter in dependence of the engine operation mode, and optionally at least one of an ambient temperature, an ambient humidity, and a fuel sulphur content.

The internal combustion engine (100) of any one of claims 1 to 3, wherein the engine operation mode detecting unit comprises an exhaust gas pressure sensor (90), which is connected to the control unit (60) and configured to measure a pressure of the exhaust gas, and the engine operation mode detecting unit is further configured to provide the measured exhaust gas pressure as the parameter indicating the engine operation mode to the control unit (60).

The internal combustion engine (100) of claim 4, wherein the exhaust gas pressure sensor (90) is arranged in the exhaust gas recirculation line (80, 82, 84, 86) upstream of the exhaust gas compressor (70).

The internal combustion engine (100) of any one of the preceding claims, wherein the engine operation mode detecting unit further comprises at least one of an engine speed sensor connected to the control unit (60) and configured to measure an engine speed of the internal combustion engine (100); a turbine speed sensor connected to the control unit (60) and configured to measure a turbine speed of a turbocharger; and a fuel rack position sensor connected to the control unit (60) and configured to measure a position of the fuel rack, a charge air pressure sensor connected to the control unit (60) and configured to measure a pressure of the charge air, wherein the engine operation mode detecting unit is config-
ured to provide the measured engine speed, and/or
the measured turbine speed, and/or the measured
charge air pressure as the parameter indicating the
engine operation mode to the control unit (60).

7. The internal combustion engine (100) of any one of
the preceding claims, comprising
at least one sensor for measuring an ambient tem-
perature, an ambient humidity, and/or a fuel sulphur
content, and/or
a user interface for receiving input values for at least
one of the ambient temperature, the ambient humid-
ity, and/or the fuel sulphur content.

8. The internal combustion engine (100) of any one of
the preceding claims, wherein the control unit is con-
figured to adjust the cooling performance of the high
temperature cooler (50) by adjusting a volume flow
of the first coolant through the high temperature cool-
er (50), and/or adjusting a cooling surface size of the
high temperature cooler (50).

9. The internal combustion engine (100) of any one of
the preceding claims, wherein the high temperature
cooler (50, 350) is part of a high temperature cooling
circuit (300) that is configured to cool the internal
combustion engine (100) by pumping the first coolant
through an engine cooling channel system.

10. The internal combustion engine (100) of claim 9,
wherein the high temperature cooling circuit (300)
further comprises at least one charge air cooler (354,
356).

11. A high temperature cooler (50) for an exhaust gas
recirculation line (80, 82, 84, 86), comprising
a cooling surface that is configured to be adjustable
in its size in dependence of a cooling performance
that is required to ensure a temperature of the ex-
ttracted exhaust gas to be maintained at a tempera-
ture above a dew point of sulphuric acid.

12. A method for cooling extracted exhaust gas within a
recirculated exhaust gas line of an internal combus-
tion engine (100), the method comprising:

determining an engine operation mode of the
combustion engine (100);
setting a cooling performance in dependence of
the engine operation mode such that a tempera-
ture of the extracted exhaust gas is maintained
at a temperature above a dew point of sulphuric
acid independently of the engine operation
mode; and
cooling the extracted exhaust gas according to
the set cooling performance.

13. The method of claim 12, wherein the engine opera-
tion mode is determined based on at least one of an
exhaust gas pressure, an engine speed, a rotational
speed of a turbocharger, a fuel rack position, and/or
a charge air pressure.

14. The method of claim 12 or 13, wherein the cooling
performance is further determined based on an am-

15. The method of any one of claims 12 to 14, further
comprising:

compressing the extracted exhaust gas that was
cooled according to the set cooling perform-
ance;
further cooling the compressed extracted ex-
thast gas; and
supplying the cooled and compressed extracted
exhaust gas to an air inlet (20) of the internal
combustion engine (100).
The present search report has been drawn up for all claims.

The European Patent Office has searched the following cited documents:

  - Abstract
  - Paragraph [0029] - Paragraph [0037]
  - Figures 1, 2

  - Abstract
  - Figures 2, 3, 5, 6, 7
  - Column 1, line 34 - Line 54
  - Column 3, line 15 - Line 24
  - Column 4, line 64 - Column 6, line 2
  - Column 6, line 51 - Line 65
  - Column 8, line 7 - Line 19
  - Column 10, line 39 - Line 52
  - Column 11, line 46 - Line 53

  - Abstract
  - Figure 1
  - Paragraph [0004] - Paragraph [0007]
  - Paragraphs [0045], [0096], [0105], [0108], [0122], [0145], [0160]

- **EP 0 740 065 A1** (DAF TRUCKS NV [NL]) 30 October 1996 (1996-10-30)
  - The whole document

**Relevant to Claim:** 1-10, 15

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**Technical Fields Searched (IPC):** F02M
This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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REFERENCES CITED IN THE DESCRIPTION

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