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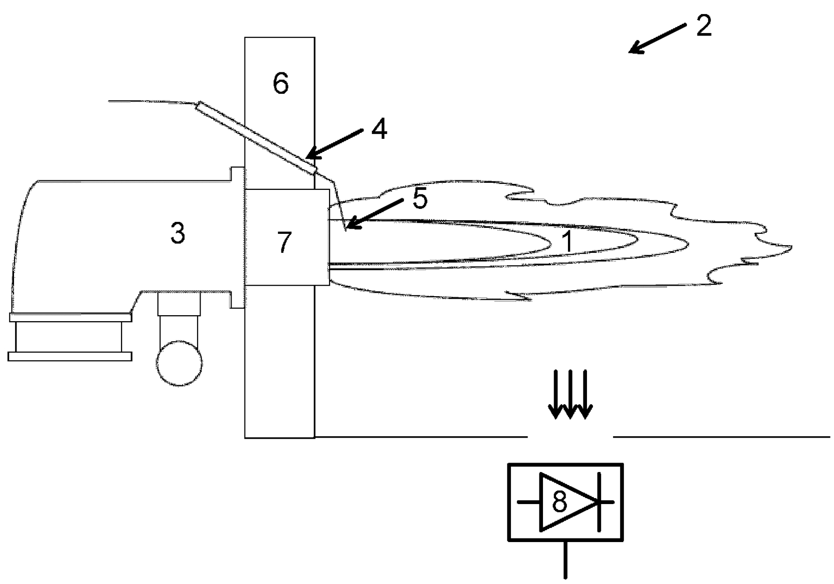
(54) CONTROLLING A MIXING RATIO

(57) Controlling a mixing ratio. A method of controlling a mixing ratio of combustion air and a gaseous fuel comprising more than twenty percent of hydrogen gas, wherein the combustion air and the gaseous fuel are combusted together in a combustion chamber (2), the method comprising the steps: a first optical sensor (8) recording a first raw signal directly originating from a flame (1) inside the combustion chamber (2), producing a first sensor signal from the first raw signal, and sending the first sensor signal to a controller (14); the controller (14) determining a first signal strength of the first sensor signal; after recording the first raw signal, changing a supply of combustion air and/or of gaseous fuel to the combustion chamber (2); the at least one first optical sensor (8) recording a second raw signal directly originating from the flame (1) inside the combustion chamber (2).

FIG 1



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Description

Background

[0001] The present disclosure relates to a mixing ratio between air and combustion gas inside a combustion chamber. More specifically, the present disclosure deals with a mixing ratio inside a combustion apparatus of a heating and/or ventilation and/or air-conditioning system. Gaseous fuels are typically distributed to end customers via a network. Suppliers of gaseous fuels envisage changes in formulations of gaseous fuels such as gaseous fuels additionally comprising hydrogen gas.

[0002] A mixing ratio between combustion air and a gaseous fuel is crucial to clean and complete combustion. An amount of combustion air supplied to a combustion chamber must be sufficient such that all the gaseous fuel will be consumed chemically. A lambda value is commonly used to describe a stochiometric fuel rate and a deviation from that fuel rate. If the mixing ratio lacks combustion air, the value of lambda will be less than unity. If the mixing ratio comprises more than enough combustion air, the value of lambda will exceed unity. Various considerations such as a need to achieve clean combustion result in a lambda value that exceeds unity. The lambda value can, by way of example, be more than 1.1 and be less than 1.3. A combustion apparatus shall maintain a stable value of lambda during combustion. It follows that a control or regulation process maintains that stable value of lambda.

[0003] A German patent application DE3937290A1 was filed on 9 November 1989. The application was published on 17 May 1990. DE3937290A1 claims a priority date of 10 November 1988. DE3937290A1 deals with a mixture of air and combustion air to be used in a combustion process.

[0004] To that end, an ionisation electrode is arranged within a flame zone inside a combustion chamber. The ionisation electrode produces a signal indicative of an electric conductivity within the flame zone. The signal obtained from the ionisation electrode is compared to a set point value. A closed-loop controller maintains the signal such that it remains close to the set point.

[0005] A European patent application EP1154202A2 was filed by SIEMENS BUILDING TECH AG on 27 April 2001. The application claims a priority date of 8 May 2000 and was published on 14 November 2001. EP1154202A2 deals with a control device for a burner.

[0006] A controller of EP1154202A2 produces first and second control signals as a function of an ionisation current obtained from an ionisation electrode. The ionisation electrode is placed in a flame zone of a combustion chamber. The first control signal corresponds to a combustion gas having a relatively low Wobbe index. The second signal corresponds to a combustion having a Wobbe index that is larger than the Wobbe index associated with the first control signal. The controller determines a weighted mean of the first and second control signals. An actuator signal is produced as a function of the weighted mean and is sent to an actuator.

[0007] These and other control methods presume a gaseous fuel having a predetermined Wobbe index or having a Wobbe index that is within a predetermined range. Accordingly, significant changes of the gaseous fuel can require a recalibration of the combustion apparatus. If hydrogen gas is added to a gaseous fuel, the controllers of legacy combustion apparatuses may have to be recalibrated. That recalibration may require on-site maintenance work at the location of the combustion apparatus. Significant changes of gaseous fuels such as added hydrogen gas can also result in incomplete and/or unclean combustion. Those changes can even result in safety hazards.

[0008] That said, signals other than ionisation currents obtained from ionisation electrodes can be used to control combustion processes. For example, a flame within a combustion chamber also emits visible and ultraviolet light. Those signals can be recorded by a sensor arranged at or near the combustion chamber.

[0009] For example, a European patent application EP3339736A1 was filed on 17 November 2017 and was published on 27 June 2018. EP3339736A1 deals with flame detection for combustion appliances.

[0010] The arrangement according to EP3339736A1 harnesses a photodiode connected to a differential amplifier to detect a flame. An amount of light of at least 1.1 Lux is received by the photodiode. An operational amplifier such as a low-noise differential amplifier produces an electric current in response to a signal originating from the photodiode. EP3339736A1 discloses a photodiode having a first spectral sensitivity at $\lambda_{10\%,1}$ = 900 nanometers wavelength and a second spectral sensitivity at $\lambda_{10\%,2}$ = 600 nanometers wavelength. The photodiode of EP3339736A1 can be a silicon diode. The signal obtained from the photodiode is used to detect a flame, but not to control a mixing ratio inside a burner apparatus.

[0011] A European patent application EP3663646A1 was filed by SIEMENS AG on 6 December 2018. The application was published on 10 June 2020. EP3663646A1 deals with flame monitor.

[0012] EP3663646A1 in paragraph [0026] discloses a silicon carbide (SiC) diode or a cadmium sulfide (CdS) device to be employed in combustion processes. Those devices afford detection of ultraviolet light with optical wavelengths below 400 nanometers. The signals obtained from those devices are used to detect flame lift-off. That is, the optical signals obtained from those devices are used to tackle safety hazards. A binary signal in the form off or on can suffice for the purpose of detecting a lift-off of a flame in a combustion apparatus. The signals obtained in accordance with EP3663646A1 are not used to control mixing ratios λ between air and gaseous fuels inside burner apparatuses. What's more, a suitability of such (binary) signals for closed-loop control of mixing ratios λ is not established by EP3663646A1.

[0013] An application for a German utility model

DE202020106475U1 was filed on 11 November 2020. The utility model was published on 25 February 2021. The date of entry in the register of utility models of DE202020106475U1 is 14 January 2021. DE202020106475U1 deals with detecting a flame in a combustion apparatus.

[0014] DE202020106475U1 discloses a sensor that directly couples to an operational amplifier. That is, the sensor of DE202020106475U1 directly connects to the inverting and noninverting input channels of the operational amplifier. The sensor produces an electric signal in response to receiving an amount of light of $1.6 \cdot 10^{-3}$ Watts per square meter. Paragraph [0028] of DE202020106475U1 states that the sensor can be or can comprise a silicon carbide (SiC) diode. According to paragraph [0099] of DE202020106475U1, the sensor preferably operates without a filter.

[0015] DE202020106475U1 is about flame detection. The signals obtained from the silicon carbide (SiC) diode are not used to control mixing ratios λ between air and gaseous fuels inside combustion apparatuses. What's more, the apparatus of DE202020106475U1 generally produces binary signals indicative of the presence or of the absence of a flame. The suitability of such (binary) signals for closed-loop control of mixing ratios λ is not established by DE202020106475U1.

[0016] A European patent application EP3663648A1 was filed by VAILLANT GMBH on 26 November 2019. The application was published on 10 June 2020. A priority date of 5 December 2018 is claimed. EP3663648A1 deals with a method and with a device for regulating the mixing ratio of combustion air and combustion gas in a combustion process.

[0017] EP3663648A1 pertains to a combustion process involving a combustion gas having more than fifty percent of hydrogen gas. EP3663648A1 does not set out whether those fifty percent of hydrogen gas are by mass or by volume. A sensor is employed to record ultraviolet light originating from a combustion process. Before reaching the sensor, the ultraviolet light is selectively filtered to focus on emissions caused by OH-radicals. Unlike paragraph [0018] of the disclosure of the application EP3663648A1, OH-radicals cause ultraviolet emissions in the vicinity of 308 nanometers. The signal recorded by the sensor is eventually employed to control a mixing ratio between combustion air and a gaseous fuel. The apparatus and the method according to EP3663648A1 require one or more optical filters to selectively focus on emissions caused by OH-radicals. Those filters are prone to failure, thereby jeopardising the operation of the entire combustion apparatus.

[0018] A patent US5037291A was granted on 6 August 1991 to Carrier Corporation. US5037291A deals with a method and with an apparatus for optimising fuel-to-air ratio in the combustible gas supply of a radiant burner. The filing date of US5037291A is 25 July 1990.

[0019] It is thus desirable to largely dispense with optical filters when employing optical sensors in combustion apparatuses. More specifically, it is desirable to largely dispense with such filters when controlling a mixing ratio between air and a combustion gas.

Summary

[0020] The present disclosure deals with influencing or controlling a mixing ratio of combustion air and of a gaseous fuel. More specifically, the present disclosure deals with influencing or controlling the mixing ratio in the presence of a gaseous fuel comprising hydrogen gas (H_2 gas). An optical sensor is employed to sense a flame inside a combustion chamber. The optical sensor records a signal that is not only indicative of OH-radicals or of OH*-radicals. Instead, the signal recorded by the optical sensor accommodates various other spectral lines. In so doing, adverse influences due to humidity and/or moisture are mitigated because OH-radicals or of OH*-radicals can indicate humidity and/or moisture. After recording a first optical sensor, the supply of the combustion air and/or the supply of the gaseous fuel changes. Preferably, the supply of the combustion air changes while the supply of the gaseous fuel comprising hydrogen gas (H_2 gas) is maintained. In an alternate embodiment, the supply of the gaseous fuel comprising hydrogen gas (H_2 gas) changes while the supply of the combustion air is maintained. A change of only a single constituent of the combustible fluid affords well-defined technical conditions.

[0021] A second optical signal is recorded after the change in supply. Again, the second optical signal is not only indicative of OH-radicals or of OH*-radicals. Instead, the second optical signal responds to various other spectral lines. In so doing, adverse influences due to humidity and/or moisture are mitigated.

[0022] A change in signal strength is finally determined based on the first and second optical signals. That change in signal strength is caused by the change in supply. It is employed to control or to influence the mixing ratio of the combustion air and/or of the gaseous fuel. Advantageously, only the supply of one constituent selected from

- the combustion air and
- the gaseous fuel

changes. A change of a single constituent affords well-defined technical conditions.

[0023] The optical sensor records an unfiltered, raw signal emitted by a flame inside the combustion chamber. While a window can be arranged between the optical sensor and the flame, no optical filter is arranged in the optical path. The unfiltered and raw signals recorded by the optical sensor result in an inclusion of as many spectral lines as possible in the signal processing.

[0024] Where the signal of the optical sensor is insufficient to suppress adverse influences caused by humidity and/or by moisture, a second sensor can be employed.

The second sensor preferably comprises or is an ionisation electrode. Signals obtained by the two sensors can be processed together. As a signal obtained from an ionisation electrode is influenced to a lesser extent by humidity and/or by moisture, those adverse influences are better mitigated.

Brief description of the drawings

[0025] Various features will become apparent to those skilled in the art from the following detailed description of the disclosed non-limiting embodiments. The drawings that accompany the detailed description can be briefly described as follows:

FIG 1 schematically shows a flame inside a combustion appliance and a sensor for recording signals caused by the flame.

FIG 2 shows a spectral sensitivity and/or a relative spectral responsivity of at least one first sensor plotted along an optical wavelength.

FIG 3 illustrates a combustion apparatus having a controller and having at least one first sensor for flame monitoring.

Detailed description

[0026] FIG 1 shows a flame 1 inside a combustion chamber 2. A feed conduit 3 directs a gaseous fuel toward the combustion chamber 2. It is envisaged that a gaseous fuel such as methane and/or ethane and/or propane and/or hydrogen or a mixture thereof is conveyed via the feed conduit 3.

[0027] Advantageously, the gaseous fuel comprises at least twenty percent by volume of hydrogen gas (H_2 gas). Preferably, the gaseous fuel comprises at least fifty percent by volume of hydrogen gas (H_2 gas). The gaseous fuel can also comprise at least seventy percent by volume of hydrogen gas (H_2 gas).

[0028] In an alternate embodiment, the gaseous fuel comprises at least twenty percent by mass of hydrogen gas (H_2 gas). Preferably, the gaseous fuel comprises at least fifty percent by mass of hydrogen gas (H_2 gas). The gaseous fuel can also comprise at least seventy percent by mass of hydrogen gas (H_2 gas).

[0029] Hydrogen gas (H_2 gas) can be obtained from electrolysis. Electric power from renewable sources can be used to break water into hydrogen and oxygen using electrolysis. Large percentages of hydrogen gas (H_2 gas) afford a combustion of a gas directly or indirectly obtained from renewable sources.

[0030] In an embodiment, a fluid comprising a mixture of combustion air and a gaseous fuel is conveyed via the feed conduit 3. That fluid can comprise any of the gaseous fuels mentioned above.

[0031] The combustion chamber 2 and the feed conduit 3 are typically part of a combustion appliance. The combustion appliance can, by way of non-limiting example, comprise a gas burner.

[0032] The arrangement optionally comprises an ionisation electrode 4 with a tip 5. The ionisation electrode 4 is arranged such that its tip 5 reaches inside the flame 1. As shown on FIG 1, the ionisation electrode 4 can be mounted to a frame 6 such as a support disc. The frame 6 aligns the ionisation electrode 4 such that its tip 5 will interact with the flame 1.

[0033] The tip 5 of the ionisation electrode 4 advantageously comprises a portion made of an alloy of iron, of aluminum, and of chrome. The alloy can also comprise copper and nickel. Suitable alloys are marketed under the brand Kanthal®. It is envisaged that the tip 5 of the ionisation electrode 4 withstands temperatures above 1173 Kelvin, preferably above 1300 Kelvin, still more preferably above 1500 Kelvin. Higher values of temperature withstand confer advantages in terms of durability.

[0034] Where withstanding elevated levels of temperature is required, the tip 5 of the ionisation electrode can comprise a portion made of silicon carbide. Suitable materials are marketed under the brand Globar®.

[0035] The feed conduit 3 is preferably tubular and provides a nozzle 7 having an injection orifice at its exit. A direction of fluid flow is defined by the nozzle 7. The combustible fluid is conveyed through the feed conduit 3. The combustible fluid is injected into the combustion chamber 2 at the injection orifice. The injection orifice preferably has a circular cross-section. This circular cross-section is perpendicular to the direction of fluid flow through the nozzle 7. It is also envisaged that the cross-section of the injection orifice is quadratic and/or polygonal. According to an aspect, the nozzle 7 provides slots to reduce acoustic emissions.

[0036] FIG 1 also shows that the frame 6 also envelopes the nozzle 7. That is, the ionisation electrode 4 and the nozzle 7 are both mounted to and/or fitted to the frame 6. A flange can be employed to secure the frame 6 relative to the feed conduit 3. Ideally, the flange is employed to mount the frame 6 to the feed conduit 3.

[0037] In addition to the optional ionisation electrode 4, the flame 1 is also monitored via at least one first optical sensor 8. It is envisaged that at least one first optical sensor 8 is a light sensor. In an embodiment, the at least one first optical sensor 8 has a spectral sensitivity $\lambda_{10\%}$ that enables detection of ultraviolet light with optical wavelengths below 400 nanometers. More specifically, the at least one first optical sensor 8 can detect ultraviolet light having an optical wavelength of 306.4 nanometers.

[0038] The at least one first optical sensor 8 can, by way of non-limiting example, be a light receiver such as a UV enhanced Si sensor. The at least one first optical sensor 8 can, by way of another non-limiting example, be a silicon carbide (SiC) diode and/or a cadmium sulfide (CdS) device. The UV enhanced SI sensor can be a SHF530 or a SHF530V photodiode. These enhanced SI sensors typically at temperatures of 298 Kelvin dissipate up to 200 milliWatts of power. At electric voltages of 20 Volts, they exhibit dark currents of less than 10 nanoAmperes. The current gain obtained from these enhanced SI sensors is about 500.

[0039] According to an aspect of the present invention, a silicon carbide (SiC) diode is employed as the at least one first optical sensor 8. The silicon carbide (SiC) diode has a spectral sensitivity and/or has a relative spectral responsivity as illustrated in FIG 2. FIG 2 shows a spectral sensitivity and/or a relative spectral responsivity 9 in relative units along the vertical axis. FIG 2 show an optical wavelength 10 in nanometers along the horizontal axis.

[0040] The spectral sensitivity and/or a relative spectral responsivity 9 generally peaks in the region between 260 nanometers and 290 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 can actually peak at 265 nanometers and/or 270 nanometers and/or at 280 nanometers. The spectral sensitivity and/or a relative spectral responsivity 9 drops to ten percent of its peak value in the region between 200 nanometers and 240 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 can drop to ten percent of its peak value at 210 nanometers and/or at 217 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 can also drop to ten percent of its peak value at 220 nanometers. At the opposite end of the spectrum, the spectral sensitivity and/or the relative spectral responsivity 9 can drop to ten percent of its peak value. That drop occurs in the region between 350 nanometers and 370 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 can drop to ten percent of its peak value at $\lambda_{10\%}$=355 nanometers and/or at $\lambda_{10\%}$=360 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 can also drop to ten percent of its peak value at $\lambda_{10\%}$=365 nanometers.

[0041] Typically, the at least one first optical sensor 8 in the form of a silicon carbide (SiC) diode exhibits a capacitance of approximately 250 picoFarads. That capacitance is measured at a frequency of one MegaHertz and to a temperature of 298 Kelvin. Also, a dark current of approximately 100 femtoAmperes is obtained at temperatures near 298 Kelvin.

[0042] According to another aspect of the present disclosure, the at least one first optical sensor 8 is a photomultiplier tube.

[0043] A careful choice of the spectral sensitivity and/or the relative spectral responsivity 9 of the at least one first optical sensor 8 affords measurements of various optical emissions. OH-radicals are known to emit in the region between 280 nanometers and 320 nanometers. More specifically, OH-radicals are known to emit in the region between 290 nanometers and 310 nanometers. Yet more specifically, OH-radicals can cause emissions at 3064 Angstroms. That is, those radicals cause emissions at 306.4 nanometers.

[0044] Emissions of such OH-radicals are, however, indicative of water vapour. That is, a signal obtained from such OH-radicals is strongly influenced by the partial pressure of water in the combustion air. In other words, the signal obtained from emissions caused by OH-radicals can be a measure of humidity rather than a measure of combustible hydrogen gas (H_2 gas).

[0045] To reduce adverse influences of humidity, emissions other than emissions caused by OH-radicals need be considered. For example, nitrogen molecules (N_2 gas) are present in the air feed to the combustion chamber 2 of FIG 1. The percentage by volume of those nitrogen molecules in the air is typically larger than fifty percent and is likely to be larger than seventy percent. The percentage by volume of those nitrogen molecules in the air can even be larger than seventy-five percent.

[0046] The presence of nitrogen molecules (N_2 molecules) in a combustion process can cause emissions in the region between 310 nanometers and 400 nanometers. More specifically, emissions can occur between 314 nanometers and 318 nanometers such as at 316 nanometers. Emissions causes by nitrogen molecules (N_2 molecules) can also occur between 336 nanometers and 340 nanometers such as at 338 nanometers. Another peak in emissions caused by nitrogen molecules (N_2 molecules) is found between 355 nanometers and 360 nanometers such as at 357 nanometers or at 358 nanometers. Finally, a large peak in such emissions is commonly found in the region between 385 nanometers and 395 nanometers such as at 390 nanometers.

[0047] A choice of the at least one first optical sensor 8 such that the various emissions of nitrogen molecules (N_2 molecules) can be factored in is advantageous. Issues caused by vapour pressure and by humidity of the air fed to the combustion chamber 2 are thereby mitigated. More specifically, the spectral sensitivity and/or the relative spectral responsivity 9 shall overlap with at least some of the emissions of nitrogen molecules (N_2 molecules).

[0048] The spectral sensitivity and/or the relative spectral responsivity 9 can, by way of example, be chosen such that the wavelength $\lambda_{10\%}$ exceeds 338 nanometers. Preferably, this embodiment employs at least one first optical sensor 8 without a filter. That is, the at least one first optical sensor 8 receives raw emissions caused by a flame 1. The spectral sensitivity and/or the relative spectral responsivity 9 then covers the peaks caused by nitrogen molecules (N_2 gas) in the region between 314 and 318 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes some peaks caused by nitrogen molecules (N_2 gas) in the region between 336 and 340 nanometers.

[0049] The spectral sensitivity and/or the relative spectral responsivity 9 can, by way of another example, be chosen such that the wavelength $\lambda_{10\%}$ exceeds 357 nanometers. Preferably, this embodiment employs at least one first optical sensor 8 without a filter. That is, the at least one first optical sensor 8 receives raw emissions caused by a flame 1. The spectral sensitivity and/or the relative spectral responsivity 9 then covers the peaks caused by nitrogen molecules (N_2 molecules) in the region between 314 and 318 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 336 and 340 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 still includes some peaks caused by nitrogen molecules (N_2 molecules) in the region between 355 and 360 nanometers.

[0050] The spectral sensitivity and/or the relative spectral responsivity 9 can, by way of yet another example, be chosen such that the wavelength $\lambda_{10\%}$ exceeds 358 nanometers. Preferably, this embodiment employs at least one first optical sensor 8 without a filter. That is, the at least one first optical sensor 8 receives raw emissions caused by a flame 1. The spectral sensitivity and/or the relative spectral responsivity 9 then covers the peaks caused by nitrogen molecules (N_2 molecules) in the region between 314 and 318 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 336 and 340 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 still includes some peaks caused by nitrogen molecules (N_2 molecules) in the region between 355 and 360 nanometers.

[0051] The spectral sensitivity and/or the relative spectral responsivity 9 can, by way of still another example, be chosen such that the wavelength $\lambda_{10\%}$ exceeds 390 nanometers. Preferably, this embodiment employs at least one first optical sensor 8 without a filter. That is, the at least one first optical sensor 8 receives raw emissions caused by a flame 1. The spectral sensitivity and/or the relative spectral responsivity 9 then covers the peaks caused by nitrogen molecules (N_2 molecules) in the region between 314 and 318 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 336 and 340 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 still includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 355 and 360 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 partially includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 385 and 395 nanometers.

[0052] The spectral sensitivity and/or the relative spectral responsivity 9 can, by way of still another example, be chosen such that the wavelength $\lambda_{10\%}$ exceeds 395 nanometers. Preferably, this embodiment employs at least one first optical sensor 8 without a filter. That is, the at least one first optical sensor 8 receives raw emissions caused by a flame 1. The spectral sensitivity and/or the relative spectral responsivity 9 then covers the peaks caused by nitrogen molecules (N_2 molecules) in the region between 314 and 318 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 336 and 340 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 still includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 355 and 360 nanometers. The spectral sensitivity and/or the relative spectral responsivity 9 also includes the peaks caused by nitrogen molecules (N_2 molecules) in the region between 385 and 395 nanometers.

[0053] FIG 3 shows a combustion apparatus 11 such as a wall-mounted gas burner. During operation a flame of a heat generator burns in the combustion chamber 2 of the combustion apparatus 11. The heat generator exchanges the thermal energy of the hot fuel gases into a different fluid such as water. For example, a hot water heating system is operated and/or drinking water is heated with the warm water. According to a different embodiment, goods, for example in an industrial process, can be heated with the thermal energy of the hot fuels and/or fuel gases. According to a further embodiment, the heat generator is part of a system with combined heat and power generation, for example a motor of such a system. According to a different embodiment, the heat generator is a gas turbine. Furthermore, the heat generator can serve to heat water in a system for the extraction of lithium and/or lithium carbonate. The exhaust gases 10 are discharged, for example via a chimney, from the combustion chamber 2.

[0054] The combustion air 12 for the combustion process is supplied via a (motor-) driven fan 13. An open-loop and/or closed-loop controller 14 specifies to the fan 13 via the signal line 15 the air supply V_L which it should convey. The fan rotational speed is thereby a measure of the combustion air 2.

[0055] According to one embodiment, the fan rotational speed is reported to the open-loop and/or closed-loop controller 14 by the fan 13. For example, the open-loop and/or closed-loop controller 14 ascertains the rotational speed of the fan 13 via the signal line 16.

[0056] The open-loop and/or closed-loop controller 14 preferably comprises a microcontroller. The open-loop and/or closed-loop controller 14 ideally comprises a microprocessor. The open-loop and/or closed-loop controller 14 can be a closed-loop facility. Preferably, the closed-loop facility comprises a microcontroller. The closed-loop facility ideally comprises a microprocessor. The closed-loop facility can comprise a proportional and integral regulator. Furthermore, the closed-loop facility can comprise a proportional and integral and derivative regulator.

[0057] Furthermore, the open-loop and/or closed-loop controller 14 can comprise a (logic-) gate array programmable in the field. In addition, the open-loop and/or closed-loop controller 14 can comprise an application-specific integrated circuit.

[0058] In one embodiment, the signal line 15 comprises an optical fibre. For ascertainment of the fan rotational speed the signal line 16 can likewise comprise an optical fibre. In a specific embodiment, the signal lines 15 and 16 are optical fibres. Optical fibres provide advantages in view of galvanic isolation and protection from explosions.

[0059] If the supply of combustion air 12 is set via an air damper and/or via a valve, the damper can be used as a measure of the supply. The valve setting can also be used as a measure of supply. Furthermore, a measured value derived from the signal of a pressure sensors and/or mass flow sensor and/or volume flow sensor can be used. The sensor 17 is advantageously arranged in the duct for the combustion air 12. Advantageously, the sensor 17 provides a signal, which is converted using a suitable signal processing unit into a flow measured value.

[0060] According to one embodiment, the signal of the sensor 17 is reported via a signal line 18. More specifically, a signal can be reported to the open-loop and/or closed-loop controller 14 via of the signal line 18, which signal is a measure of a combustion air 12. A suitable signal processing facility for processing of the signal of the sensor 17 ideally comprises at least one analog-to-digital converter. According to one embodiment, the signal processing facility, in particular the analog-to-digital converter(s), is integrated in the open-loop and/or closed-loop controller 14.

[0061] The signal line 18 can comprise an optical fibre. The signal line 18 can also be an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions.

[0062] The measured value of a pressure sensor and/or a mass flow sensor can also be used as a measure of the air supply V_L. To that end, the pressure sensor and/or the mass flow sensor can be arranged in a side duct of the duct for the combustion air 12. A combustion apparatus with supply duct and side duct is disclosed, for example, in the European patent EP3301364B1. European patent EP3301364B1 was applied for on 7 June 2017 and granted on 7 August 2019. A combustion apparatus with supply duct and side duct is claimed, wherein a mass flow sensor protrudes into the supply duct.

[0063] A pressure sensor and/or a mass flow sensor in the side duct ascertains a signal. That signal corresponds to the pressure value and/or the air flow (particle and/or mass flow) in the side duct. That signal and/or the pressure value and/or the air flow depend on the air supply V_L. Advantageously, the sensor provides a signal, which is converted via a suitable signal processing facility into a measured value. According to a further advantageous embodiment, the signals of a plurality of sensors are converted into a shared measured value. A suitable signal processing facility ideally comprises at least one analog-to-digital converter. According to one embodiment, the signal processing facility, in particular the analog-to-digital converter(s), is integrated in the open-loop and/or closed-loop controller 14. According to a different embodiment, the signal processing facility, in particular the analog-to-digital converter(s), is integrated in the pressure sensor and/or mass flow sensor. The sensor signals are preferably transmitted to the open-loop and/or closed-loop controller 14 with a specified communications bus protocol via a communications interface. It is envisaged that the specified communication bus protocol comprises a digital communication bus protocol. It is also envisaged that the specified communication bus protocol is a digital communication bus protocol.

[0064] According to one embodiment, the air supply V_L is the value of the current flow rate of combustion air 12. The flow rate of combustion air 12 can be measured and/or given in cubic meters of air per hour. The air supply V_L can be measured and/or given in cubic meters of air per hour.

[0065] Mass flow sensors allow measurement in the case of large flow speeds, specifically in connection with combustion apparatuses during operation. Typical values of such flow speeds lie in ranges between 0.1 meters per second and 5 meters per second, and 10 meters per second. Typical values of such flow speeds are also 15 meters per second, 20 meters per second, or even 100 meters per second. Mass flow sensors, which are suitable for the present disclosure, are for example OMRON® D6F-W or SENSOR TECHNICS® WBA type sensors. The useful range of these sensors typically begins at speeds between 0.01 meters per second and 0.1 meters per second. The useful range of these sensors typically ends at a speed such as, for example 5 meters per second, 10 meters per second, or 15 meters per second. The useful range of these sensors can also end at a speed such as 20 meters per second, or even 100 meters per second. In other words, lower limits such as 0.1 meters per second can be combined with upper limits such as 5 meters per second. The lower limits can also be combined with upper limits such as 10 meters per second, 15 meters per second, or 20 meters per second. The lower limits can even be combined with an upper limit such as 100 meters per second.

[0066] The supply V_B of gaseous fuel 20 is set and/or adjusted by the open-loop and/or closed-loop controller 14 with the aid of a fuel actuator and/or a (motor-) settable valve 19. In the embodiment in FIG 3, the fuel 20 is a gaseous fuel. A combustion apparatus 11 can then connect to different fuel gas sources, for example to sources with a high methane content. The combustion apparatus 11 can, by way of another example, also connect to sources with a high propane content. Similarly, it is provided that the combustion apparatus 11 connects to a source of a gas or a gas mixture. The gas or the gas mixture can comprise hydrogen gas (H_2 gas). In FIG 3 the quantity of gaseous fuel is set by the open-loop and/or closed-loop controller 14 by way of a (motor-) settable fuel valve 19. The actuation value, for example a pulse width-modulated signal, of the gas valve is a measure of the quantity of fuel gas. It is also a value for the supply V_B of gaseous fuel 20.

[0067] If a gas valve is used as the fuel actuator 19, its position can be used as a measure of the quantity of fuel gas. According to a specific embodiment, a fuel actuator 19 and/or fuel valve 19 is set via a stepper motor. In that case the step position of the stepper motor is a measure of the quantity of gaseous fuel 20. More specifically, the step position can be a quantitative measure of an amount of gaseous fuel 20, the gaseous fuel 20 comprising hydrogen gas (H_2 gas).

[0068] The fuel valve 19 can also be integrated in a unit with at least one or more safety shut-off valve(s). A signal line 21 connects the fuel actuator 19 to the open-loop and/or closed-loop controller 14. In a specific embodiment, the signal line 21 comprises an optical fibre. In a yet more specific embodiment, the signal line 21 is an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions.

[0069] Furthermore, the fuel valve 19 can be an integrated valve operated with closed-loop control via a flow and/or pressure sensor. It receives a setpoint value and regulates the actual value of the flow and/or pressure sensor to the setpoint value. The flow and/or pressure sensor can be implemented as a volume flow sensor for example as a turbine flowmeter. The flow and/or pressure sensor can also be implemented as a bellows-type gas flowmeter or as a differential pressure sensor. The flow and/or pressure sensor can still be configured as a mass flow sensor, for example as a thermic mass flow sensor.

[0070] Another signal line can connect that flow and/or pressure sensor to the open-loop and/or closed-loop controller 14. In a specific embodiment, the other signal line comprises an optical fibre. In a yet more specific embodiment, the other signal line is an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions. The signal line for that sensor can be the same signal line as for the valve 19.

[0071] In a further embodiment, a flow and/or pressure sensor 22 is arranged in the fuel supply duct separately from the fuel valve 19. The flow rate sensor 22 can be implemented as a volume flow sensor, for example as a turbine flowmeter. The flow and/or pressure sensor can also be implemented bellows-type gas flowmeter or as a differential pressure sensor. The flow and/or pressure sensor 22 can still be configured as a mass flow sensor, for example as a thermic mass flow sensor.

[0072] A signal line 23 connects the flow and/or pressure sensor 22 to the open-loop and/or closed-loop controller 14. In a specific embodiment, the signal line 23 comprises an optical fibre. In a yet more specific embodiment, the signal line 23 is an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions.

[0073] That flow and/or pressure sensor 22 generates a signal, which is converted via a suitable signal processing facility into a flow measured value. The measured value can be a measured value of the particle flow and/or of mass flow and/or of volume flow. A suitable signal processing facility ideally comprises at least one analog-to-digital converter. According to one embodiment, the signal processing facility, in particular the analog-to-digital converter(s), is integrated in the open-loop and/or closed-loop controller 14.

[0074] According to a different embodiment, the signal processing facility, in particular the analog-to-digital converter(s), is integrated in the flow and/or pressure sensor 22. The sensor signals are preferably transmitted to the open-loop and/or closed-loop controller 14 via a communications interface with a specified communications bus protocol. It is envisaged that the specified communication bus protocol comprises a digital communication bus protocol. It is also envisaged that the specified communication bus protocol is a digital communication bus protocol.

[0075] FIG 3 likewise shows a combustion apparatus 11 with an optional combustion sensor 4 for detection of a mixing ratio λ. The combustion sensor 4 can comprise, for example, an ionisation electrode such as the ionisation electrode shown in FIG 1. The combustion sensor 4 can also be an ionisation electrode such as the ionisation electrode shown in FIG 1.

[0076] The combustion sensor 4 is preferably arranged in the combustion chamber 2. The combustion sensor 4 is advantageously arranged in a flame area and/or in a flame zone within the combustion chamber 2.

[0077] Typically, the combustion sensor 4 is connected via an impedance to a voltage source. The impedance to the connection to the voltage source can comprise an electrical resistance such as an electric and ohmic resistance.

[0078] A signal line 24 connects the combustion sensor 4 to the open-loop and/or closed-loop controller 14. A suitable signal processing facility for processing of the signal of the combustion sensor 4 ideally comprises at least one analog-to-digital converter. According to one embodiment, the signal processing facility, especially the at least one analog-to-digital converter, is integrated in the open-loop and/or closed-loop controller 14.

[0079] In a specific embodiment, the signal line 24 comprises an optical fibre. In a yet more specific embodiment, the signal line 24 is an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions.

[0080] FIG 3 likewise shows a combustion apparatus 11 with an optical sensor 8. The optical sensor 8 can comprise, by way of non-limiting example, a UV enhanced Si sensor as described in the notes on FIG 1. More specifically, the optical sensor 8 can be a UV enhanced Si sensor as described in the notes on FIG 1. The optical sensor 8 can comprise, by way of another non-limiting example, a silicon carbide (SiC) diode as described in the notes on FIG 1. More specifically, the optical sensor 8 can be a silicon carbide (SiC) diode as described in the notes on FIG 1. The optical sensor 8 can comprise, by way of yet another non-limiting example, a cadmium sulfide (CdS) device as described in the notes on FIG 1. More specifically, the optical sensor 8 can be a cadmium sulfide (CdS) device as described in the notes on FIG 1. The optical sensor 8 can comprise, by way of still another non-limiting example, a photomultiplier tube as described in the notes on FIG 1. More specifically, the optical sensor 8 can be a photomultiplier tube as described in the notes on FIG 1.

[0081] The combustion chamber 2 typically comprises a flame area and/or a flame zone. The flame area and/or the flame zone are arranged inside the combustion chamber 2. The optical sensor 8 is advantageously arranged outside the flame area and/or outside the flame zone.

[0082] A signal line 25 connects the optical sensor 8 to the open-loop and/or closed-loop controller 14. A suitable signal processing facility for processing of the signal of the optical sensor 8 ideally comprises at least one analog-to-digital converter. According to one embodiment, the signal processing facility, especially the at least one analog-to-digital converter, is integrated in the open-loop and/or closed-loop controller 14.

[0083] In a specific embodiment, the signal line 25 comprises an optical fibre. In a yet more specific embodiment, the signal line 25 is an optical fibre. Optical fibres provide advantages in view of galvanic isolation and protection against explosions.

[0084] A first control concept can be summarised as follows: A first pilot control characteristic stored in the closed-loop controller 14 describes an actuator setting and a signal strength of the light emitted by a flame. The first pilot control characteristic has preferably been recorded under reference conditions. The actuator 13, 19 is advantageously set via a signal comprising at least one of

- a signal sent to the (motor-) driven fan 13,
- a signal sent to the fuel valve 19 and/or gas valve 19.

The actuator 13, 19 is ideally set via a signal selected from

- a signal sent to the (motor-) driven fan 13,
- a signal sent to the fuel valve 19 and/or gas valve 19.

The closed-loop controller 14 adjusts the setting of the actuator 13, 19 so that the desired signal strength of the light emitted by the flame 1 is achieved. To that end, a signal is obtained by the closed-loop controller 14 from the optical sensor 8. The signal obtained from the optical sensor 8 can then be compared to a set point. The set point is ideally chosen in accordance with the first pilot control characteristic. The signal to be sent to the actuator 13, 19 is ideally determined based on a deviation of the signal obtained from the sensor from the set point. Eventually, combustion takes place with the desired mixing ratio between combustion air and combustion gas.

[0085] A calibration process can check and adapt the first pilot control characteristic. Checking and adaption preferably take place with reference to the current combustion conditions. Those conditions can be characterised at least by

- a composition of the gaseous fuel 20,
- a density of the supplied gaseous fuel 20,
- a density of the combustion air 12,
- a humidity of the combustion air 12.

The result of the calibration process can, for example, be a first correction factor. The first pilot control characteristic is then corrected using the first correction factor. The result of the calibration process can, for example, also be a first inflection point. The first pilot control characteristic is then corrected using the first inflection point. Also, the mixing ratio is influenced or controlled based on the first inflection point.

[0086] The result of the calibration process can, for example, also be a first maximum value. The first pilot control characteristic is then corrected using the first maximum value. Also, the mixing ratio is influenced or controlled based on the first maximum value.

[0087] In an embodiment, the first pilot control characteristic comprises a first pilot control curve. It is envisaged that the first pilot control characteristic is a first pilot control curve.

[0088] A second control concept closely relates to the first control concept. The second control concept can be summarised as follows: A second pilot control characteristic stored in the closed-loop controller 14 describes an actuator setting and a combustion signal. The combustion signal will be described in detail below. The second pilot control characteristic has preferably been recorded under reference conditions. The actuator 13, 19 is advantageously set via a signal comprising at least one of

- a signal sent to the (motor-) driven fan 13,
- a signal sent to the fuel valve 19 and/or gas valve 19.

The actuator 13, 19 is ideally set via a signal selected from

- a signal sent to the (motor-) driven fan 13,
- a signal sent to the fuel valve 19 and/or gas valve 19.

The closed-loop controller 14 adjusts the setting of the actuator 13, 19 so that the desired signal strength of the combustion signal.

[0089] To that end, a first signal is obtained by the closed-loop controller 14 from the optical sensor 8. A second signal is obtained by the closed-loop controller 14 from the combustion sensor 4. The second signal is preferably obtained from an ionisation electrode 4 as described above.

[0090] The closed-loop controller 14 merges the first signal obtained from the optical sensor 8 and the second signal obtained from the combustion sensor 4. As a result of the merging, the closed-loop controller 14 produces the combustion signal. That is, the closed-loop controller 14 produces the combustion signal as a function of the first and second signals.

[0091] According to an aspect of the present disclosure, the closed-loop controller 14 produces the combustion signal as a weighted mean of the first and second signals. The weighted mean can be a weighted arithmetic mean. The weighted mean can also be a weighted geometric mean.

[0092] The combustion signal preferably is a scalar signal.

[0093] The combustion signal is then preferably compared to a set point. The set point is ideally chosen in accordance with the second pilot control characteristic. The signal to be sent to the actuator 13, 19 is determined based on a deviation of the combustion signal from the set point. The signal to be sent to the actuator 13, 19 can also be calculated based on that deviation. Eventually, combustion takes place with the desired mixing ratio between combustion air and combustion gas.

[0094] A calibration process can check and adapt the second pilot control characteristic. Checking and adaption preferably take place with reference to the current combustion conditions. Those conditions can be characterised at least by

- a composition of the gaseous fuel 20,
- a density of the supplied gaseous fuel 20,
- a density of the combustion air 12,
- a humidity of the combustion air 12.

The result of the calibration process can, for example, be a second correction factor. The second pilot control characteristic is then corrected using the second correction factor. The result of the calibration process can, for example, also be a second inflection point. The second pilot control characteristic is then corrected using the second inflection point. Also, the mixing ratio is influenced or controlled based on the second inflection point.

[0095] The result of the calibration process can, for example, also be a second maximum value. The second pilot control characteristic is then corrected using the second maximum value. Also, the mixing ratio is influenced or controlled based on the second maximum value.

[0096] In an embodiment, the second pilot control characteristic comprises a second pilot control curve. It is envisaged that the second pilot control characteristic is a second pilot control curve.

[0097] As described in detail herein, the present disclosure deals with a method of influencing or of controlling a mixing ratio of combustion air (12) and a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, wherein the combustion air (12) and the gaseous fuel (20) are combusted together in a combustion chamber (2), the method comprising the steps of:

at least one first optical sensor (8) recording a first raw signal directly originating from a flame (1) inside the combustion chamber (2), producing a first sensor signal from the first raw signal, and sending the first sensor signal to a controller (14);
the controller (14) determining a first signal strength of the first sensor signal;
after recording the first raw signal, changing a supply of the combustion air (12) and/or of the gaseous fuel (20) to the combustion chamber (2);
after the change in supply, the at least one first optical sensor (8) recording a second raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a second sensor signal from the second raw signal, and sending the second sensor signal to the controller (14);
the controller (14) determining a second signal strength of the second sensor signal;
the controller (14) determining a change in signal strength as a function of the first signal strength and as a function of the second signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20); and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength.

[0098] The instant disclosure also deals with any of the aforementioned methods, the method comprising the steps of:

the at least one first optical sensor (8) being a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 290 nanometers, the silicon carbide (SiC) diode recording the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 338 nanometers; and
after the change in supply, the silicon carbide (SiC) diode recording the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 338 nanometers.

[0099] The present disclosure further deals with any of the aforementioned methods, the method comprising the steps of:

the flame (1) inside the combustion chamber (2) emitting the first raw signal having a first spectral density;
the at least one first optical sensor (8) recording the first raw signal directly originating from the flame (1) inside the combustion chamber (2) such that the first raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 260 nanometers and 400 nanometers substantially the same first spectral density as the first spectral density of the first raw signal as emitted by the flame (1);
after the change in supply, the flame (1) inside the combustion chamber (2) emitting the second raw signal having a second spectral density; and
the at least one first optical sensor (8) recording the second raw signal directly originating from the flame (1) inside the combustion chamber (2) such that the second raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths be-

tween 260 nanometers and 400 nanometers substantially the same second spectral density as the second spectral density of the second raw signal as emitted by the flame (1).

[0100] The instant disclosure still deals with any of the aforementioned methods, the method comprising the steps of:

at least one second sensor (4, 5) within a flame zone of the combustion chamber (2) recording a third electric signal, producing a third sensor signal from the third electric signal, and sending the third sensor signal to the controller (14);
the controller (14) determining a third signal strength of the third sensor signal;
after the change in supply, the at least one second sensor (4, 5) within the flame zone of the combustion chamber (2) recording a fourth electric signal, producing a fourth sensor signal from the fourth electric signal, and sending the fourth sensor signal to the controller (14);
the controller (14) determining a fourth signal strength of the fourth sensor signal; and
the controller (14) determining the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0101] The present disclosure still further deals with any of the aforementioned methods involving a fourth sensor signal, the method comprising the step of:
the controller (14) determining the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0102] The instant disclosure still deals with any of the aforementioned methods, the method comprising the steps of:

at least one second sensor (4, 5) within a flame zone of the combustion chamber (2) recording a third electric signal, producing a third sensor signal from the third electric signal, and sending the third sensor signal to the controller (14);
the controller (14) determining a third signal strength of the third sensor signal;
after the change in supply, the at least one second sensor (4, 5) within the flame zone of the combustion chamber (2) recording a fourth electric signal, producing a fourth sensor signal from the fourth electric signal, and sending the fourth sensor signal to the controller (14);
the controller (14) determining a fourth signal strength of the fourth sensor signal;
the controller (14) calculating a first ratio r_1 between the second signal strength and the first signal strength and calculating a second ratio r_2 between the fourth signal strength and the third signal strength; and
the controller (14) determining the change in signal strength as a function of the first ratio r_1 and the second ratio r_2, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0103] In an embodiment, the first ratio r_1 reads:

$$r_1 = \frac{\text{second signal strength}}{\text{first signal strength}}$$

[0104] Accordingly, the second ratio r_2 reads:

$$r_2 = \frac{\text{fourth signal strength}}{\text{third signal strength}}$$

[0105] In an alternate embodiment, the first ratio r_1 reads:

$$r_1 = \frac{\text{first signal strength}}{\text{second signal strength}}$$

[0106] Accordingly, the second ratio r_2 reads:

$$r_2 = \frac{\text{third signal strength}}{\text{fourth signal strength}}$$

[0107] The instant disclosure also deals with any of the aforementioned methods, the method comprising the steps of:

starting a combustion inside the combustion chamber (2) with an excess supply in the combustion air (12);
after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, throttling the excess supply of the combustion air (12);
after the throttling, the at least one first optical sensor

(8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further throttling the excess supply of the combustion air (12);
after the further throttling, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further throttling the excess supply of the combustion air (12);
after the yet further throttling, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal;
the controller (14) determining an inflection point as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0108] It is envisaged that a combustion inside the combustion chamber (2) with an excess supply in the combustion air (12) is started by sending a third actuation signal to at least one actuator (13, 19), the third actuation signal causing an excess supply in the combustion air (12) to the combustion chamber (2).

[0109] The present disclosure still deals with any of the aforementioned methods, the method comprising the steps of:

starting a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, throttling the supply of the combustion air (12);
after the throttling, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further throttling the supply of the combustion air (12);
after the further throttling, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further throttling the supply of the combustion air (12);
after the yet further throttling, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal; the controller (14) determining an inflection point as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0110] It is envisaged that a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20) is started by sending a third actuation signal to at least one actuator (13, 19), the third actuation signal causing an excess supply in the combustion air (12) to the combustion chamber (2).

[0111] The instant disclosure still further deals with any of the aforementioned methods, the method comprising the steps of:
starting a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);

after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, enriching the mix-

ing ratio of the combustion air (12) and the gaseous fuel (20);

after the enrichment, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);

the controller (14) determining a sixth signal strength of the sixth sensor signal;

after recording the sixth raw signal, further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);

after the further enrichment, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);

the controller (14) determining a seventh signal strength of the seventh sensor signal;

after recording the seventh raw signal, yet further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);

after the yet further enrichment, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);

the controller (14) determining an eighth signal strength of the eighth sensor signal;

the controller (14) determining an inflection point as a function of the fifth to eighth signal strengths; and

the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0112] The instant disclosure also deals with any of the aforementioned methods, the method comprising the steps of:

starting a combustion inside the combustion chamber (2) with an excess supply in the combustion air (12);

after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);

the controller (14) determining a fifth signal strength of the fifth sensor signal;

after recording the fifth raw signal, throttling the excess supply of the combustion air (12);

after the throttling, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);

the controller (14) determining a sixth signal strength of the sixth sensor signal;

after recording the sixth raw signal, further throttling the excess supply of the combustion air (12);

after the further throttling, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);

the controller (14) determining a seventh signal strength of the seventh sensor signal;

after recording the seventh raw signal, yet further throttling the excess supply of the combustion air (12);

after the yet further throttling, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);

the controller (14) determining an eighth signal strength of the eighth sensor signal;

the controller (14) determining a maximum value as a function of the fifth to eighth signal strengths; and

the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the maximum value.

[0113] It is envisaged that a combustion inside the combustion chamber (2) with an excess supply in the combustion air (12) is started by sending a third actuation signal to at least one actuator (13, 19), the third actuation signal causing an excess supply in the combustion air (12) to the combustion chamber (2).

[0114] The maximum value m is preferably calculated as a function of the fifth to eighth signal strengths s_5, s_6, s_7, and s_8:

$$m = \max(s_5, s_6, s_7, s_8).$$

[0115] A calibration based on a maximum value improves on detection of anomalies. The signal obtained from the at least one first optical sensor (8) normally increases or decreases as a function of the mixing ratio. A calibration based on a maximum value enables detection of deviations from such expected changes.

[0116] The present disclosure still deals with any of the aforementioned methods, the method comprising the steps of:

starting a combustion inside the combustion cham-

ber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, throttling the supply of the combustion air (12);
after the throttling, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further throttling the supply of the combustion air (12);
after the further throttling, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further throttling the supply of the combustion air (12);
after the yet further throttling, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal; the controller (14) determining a maximum value as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the maximum value.

[0117] It is envisaged that a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20) is started by sending a third actuation signal to at least one actuator (13, 19), the third actuation signal causing an excess supply in the combustion air (12) to the combustion chamber (2).

[0118] The instant disclosure still further deals with any of the aforementioned methods, the method comprising the steps of:
starting a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);

after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the enrichment, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the further enrichment, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the yet further enrichment, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal;
the controller (14) determining a maximum value as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the maximum value.

[0119] The present disclosure also deals with a combustion apparatus (11) comprising at least one first optical sensor (8), a combustion chamber (2), at least one actuator (13, 19) acting on a supply to the combustion chamber (2) of combustion air (12) and/or of a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, a controller (14) in operative communication with the at least one first optical sensor (8) and with the at least one actuator (13, 19), the at least one first optical sensor (8) being configured to:

record a first raw signal directly originating from a flame (1) inside the combustion chamber (2), produce a first sensor signal from the first raw signal, and send the first sensor signal to the controller (14); the controller (14) being configured to:

determine a first signal strength of the first sensor signal;
after recording the first raw signal, send a first actuation signal to the at least one actuator (13, 19), the first actuation signal causing the at least one actuator (13, 19) to change the supply of the combustion air (12) and/or of the gaseous fuel (20);

the at least one first optical sensor (8) being configured to:

after the change in supply, record a second raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a second sensor signal from the second raw signal, and send the second sensor signal to the controller (14);
determine a second signal strength of the second sensor signal;
determine a change in signal strength as a function of the first signal strength and as a function of the second signal strength, the change in signal strength being caused by the change in supply; and
produce a second actuation signal as a function of the change in signal strength and send the second actuation signal to the at least one actuator (13, 19), the second actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) to the combustion chamber (2).

[0120] Advantageously, the gaseous fuel (20) comprises at least twenty percent by volume of hydrogen gas (H_2 gas). Preferably, the gaseous fuel (20) comprises at least fifty percent by volume of hydrogen gas (H_2 gas). The gaseous fuel (20) can also comprise at least seventy percent by volume of hydrogen gas (H_2 gas).
[0121] In an alternate embodiment, the gaseous fuel (20) comprises at least twenty percent by mass of hydrogen gas (H_2 gas). Preferably, the gaseous fuel (20) comprises at least fifty percent by mass of hydrogen gas (H_2 gas). The gaseous fuel (20) can also comprise at least seventy percent by mass of hydrogen gas (H_2 gas).
[0122] The present disclosure also deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:

produce a first signal strength from the first sensor signal; and
produce a second signal strength from the second sensor signal.

[0123] The instant disclosure still deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:
determine a change in signal strength by subtracting the first signal strength from the second signal strength or by subtracting the second signal strength from the first signal strength.
It is also envisaged that the controller (14) calculates a change in signal strength by subtracting the first signal strength from the second signal strength or by subtracting the second signal strength from the first signal strength.
[0124] The present disclosure still further deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:
determine a change in signal strength as an absolute value of a difference between the first signal strength and the second signal strength.
It is also envisaged that the controller (14) calculates a change in signal strength as an absolute value of a difference between the first signal strength and the second signal strength.
[0125] The instant disclosure still further deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:
determine a change in signal strength as a square value of a difference between the first signal strength and the second signal strength.
[0126] It is also envisaged that the controller (14) calculates a change in signal strength as a square value of a difference between the first signal strength and the second signal strength.
[0127] No optical filters are arranged between the flame (1) and the at least one first optical sensor (8). The at least one first optical sensor (8) can be separated from the flame (1) by a window in a wall of the combustion chamber (2) such that the at least one first optical sensor (8) can still record a first raw signal directly originating from the flame (1) inside the combustion chamber (2). To that end, the combustion chamber (2) comprises a flame zone for the flame (1).
[0128] The at least one first optical sensor (8) can also be arranged inside a feed duct (3) such as a feed duct (3) for the combustion air (12) and/or for the gaseous fuel (20). An arrangement of the at least one first optical sensor (8) inside the feed duct (3) affords cooling of the at least one first optical sensor (8). An arrangement of the at least one first optical sensor (8) inside the feed duct (3) also affords protection of the at least one first optical sensor (8) from the flame (1). More specifically, the combustion apparatus (11) comprises a feed duct (3) for supplying the combustion air (12) and/or the gaseous fuel (20) to the combustion chamber (2), the at least one first optical sensor (8) being arranged inside the feed duct

(3). Yet more specifically, the combustion apparatus (11) comprises a feed duct (3) for supplying the combustion air (12) and the gaseous fuel (20) to the combustion chamber (2), the at least one first optical sensor (8) being arranged inside the feed duct (3).

[0129] The at least one first optical sensor (8) is preferably in the vicinity of a flame (1) inside the combustion chamber (2) such that the at least one first optical sensor (8) can record the first and second raw signals directly originating from the flame (1). More specifically, no optical filters are arranged between the flame (1) and the at least one first optical sensor (8). The at least one first optical sensor (8) can be separated from the flame (1) by a window in a wall of the combustion chamber (2) such that the at least one first optical sensor (8) can still record a first raw signal directly originating from the flame (1) inside the combustion chamber (2). To that end, the combustion chamber (2) comprises a flame zone for the flame (1).

[0130] The present disclosure also deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 290 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 338 nanometers; and
after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 338 nanometers.

[0131] The present disclosure also deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 280 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 338 nanometers; and
after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 338 nanometers.

[0132] The instant disclosure still deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 290 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 357 nanometers; and
after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 357 nanometers.

[0133] The present disclosure further deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 280 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 357 nanometers; and
after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 357 nanometers.

[0134] The instant disclosure still further deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 290 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 390 nanometers; and
after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 390 nanometers.

[0135] The present disclosure yet further deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is a silicon carbide (SiC) diode having a peak in spectral sensitivity and/or a peak in a relative spectral responsivity (9) at optical wavelengths between 260 nanometers and 280 nanometers, wherein the at least one first optical sensor (8) is configured to:

record the first raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to an optical wavelength $\lambda_{10\%}$ of 390 nanometers; and

after the change in supply, record the second raw signal directly originating from the flame (1) inside the combustion chamber (2) at least up to the optical wavelength $\lambda_{10\%}$ of 390 nanometers.

[0136] The at least one first optical sensor (8) has a spectral sensitivity and/or a relative spectral responsivity (9) and the spectral sensitivity and/or the relative spectral responsivity (9) has a peak. At the optical wavelength $\lambda_{10\%}$, the spectral sensitivity and/or the relative spectral responsivity (9) drops to ten percent of its peak. More specifically, the at least one first optical sensor (8) has a spectral sensitivity and/or a relative spectral responsivity (9) and the spectral sensitivity and/or the relative spectral responsivity (9) has a peak value. At the optical wavelength $\lambda_{10\%}$, the spectral sensitivity and/or the relative spectral responsivity (9) drops to ten percent of its peak value. Still more specifically, the silicon carbide (SiC) diode has a spectral sensitivity and/or a relative spectral responsivity (9) and the spectral sensitivity and/or the relative spectral responsivity (9) has a peak. At the optical wavelength $\lambda_{10\%}$, the spectral sensitivity and/or the relative spectral responsivity (9) drops to ten percent of its peak. Yet more specifically, the silicon carbide (SiC) diode has a spectral sensitivity and/or a relative spectral responsivity (9) and the spectral sensitivity and/or the relative spectral responsivity (9) has a peak value. At the optical wavelength $\lambda_{10\%}$, the spectral sensitivity and/or the relative spectral responsivity (9) drops to ten percent of its peak value.

[0137] The instant disclosure also deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is configured to:

in response to the flame (1) inside the combustion chamber (2) emitting the first raw signal having a first spectral density, record the first raw signal such that the first raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 260 nanometers and 400 nanometers substantially the same first spectral density as the first spectral density of the first raw signal as emitted by the flame (1); and

in response to the flame (1) inside the combustion chamber (2) emitting the second raw signal having a second spectral density, record the second raw signal such that the second raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 260 nanometers and 400 nanometers substantially the same second spectral density as the second spectral density of the second raw signal as emitted by the flame (1).

[0138] The instant disclosure also deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is configured to:

in response to the flame (1) inside the combustion chamber (2) emitting the first raw signal having a first spectral density, record the first raw signal such that the first raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 260 nanometers and 400 nanometers the same first spectral density as the first spectral density of the first raw signal as emitted by the flame (1);

in response to the flame (1) inside the combustion chamber (2) emitting the second raw signal having a second spectral density, record the second raw signal such that the second raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 260 nanometers and 400 nanometers the same second spectral density as the second spectral density of the second raw signal as emitted by the flame (1).

[0139] The present disclosure still deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is configured to:

in response to the flame (1) inside the combustion chamber (2) emitting the first raw signal having a first spectral density, record the first raw signal such that the first raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 270 nanometers and 340 nanometers substantially the same first spectral density as the first spectral density of the first raw signal as emitted by the flame (1); and

in response to the flame (1) inside the combustion chamber (2) emitting the second raw signal having a second spectral density, record the second raw signal such that the second raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 270 nanometers and 340 nanometers substantially the same second spectral density as the second spectral density of the second raw signal as emitted by the flame (1).

[0140] The instant disclosure further deals with any of the aforementioned apparatuses (11), wherein the at least one first optical sensor (8) is configured to:

in response to the flame (1) inside the combustion chamber (2) emitting the first raw signal having a first spectral density, record the first raw signal such that the first raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 270 nanometers and 340 nanometers the same first spectral density as the first spectral density of the first raw signal as emitted by the flame (1); and

in response to the flame (1) inside the combustion chamber (2) emitting the second raw signal having a second spectral density, record the second raw signal such that the second raw signal as recorded by the at least one first optical sensor (8) has at optical wavelengths between 270 nanometers and 340 nanometers the same second spectral density as the second spectral density of the second raw signal as emitted by the flame (1).

[0141] Substantially the same spectral density means that deviations between the spectral densities are less than three decibels. Those deviations can, for example, be caused by a window shielding the at least one first optical sensor (8) from the flame (1). Whilst that window does not function as a filter, minor distortions of the spectral density of a signal emitted by a flame (1) may occur. A signal recorded by the at least one first optical sensor (8) can directly originate from the flame (1) despite that window.

[0142] The present disclosure also deals with any of the aforementioned apparatuses (11), the apparatus (11) additionally comprising at least one second sensor (4, 5) arranged within a flame zone of the combustion chamber (2) and in operative communication with the controller (14), the at least one second sensor (4, 5) being configured to:

record a third electric signal, produce a third sensor signal from the third electric signal, and send the third sensor signal to the controller (14);
the controller (14) being configured to:
determine a third signal strength of the third sensor signal;
the at least one second sensor (4, 5) being configured to:
after the change in supply, record a fourth electric signal, produce a fourth sensor signal from the fourth electric signal, and send the fourth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fourth signal strength of the fourth sensor signal; and
determine the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0143] The present disclosure also deals with any of the aforementioned apparatuses (11) processing third and fourth signals, the controller (14) being configured to:

produce a third signal strength from the third sensor signal; and
produce a fourth signal strength from the fourth sensor signal.

[0144] It is envisaged that the controller (14) calculates the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0145] The at least one second sensor (4, 5) preferably comprises an ionisation electrode. The at least one second sensor (4) ideally is an ionisation electrode. The at least one second sensor (4, 5) is different from the at least one first optical sensor (8).

[0146] The present disclosure also deals with any of the aforementioned apparatuses (11) involving a fourth signal strength, the controller (14) being configured to: determine the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

[0147] The instant disclosure still deals with any of the aforementioned apparatuses (11) processing third and fourth signals, the controller (14) being configured to:

determine a first difference between the first signal strength and the second signal strength;
determine a second difference between the third signal strength and the fourth signal strength; and
determine the change in signal strength as a function of the first difference and as a function of the second difference.

[0148] According to an aspect of the instant disclosure, the change in signal strength is determined as a function of a weighted arithmetic mean of the first difference and of the second difference.

[0149] It is also envisaged that the controller (14) calculates a first difference between the first signal strength and the second signal strength and calculates a second difference between the third signal strength and the fourth signal strength and calculates the change in signal strength as a function of the first difference and as a function of the second difference. According to an aspect of the instant disclosure, the change in signal strength is calculated as a function of a weighted arithmetic mean of the first difference and of the second difference.

[0150] Let s_1 be the first signal strength, s_2 be the second signal strength, s_3 be the third signal strength, s_4 be the fourth signal strength, d_1 be the first difference, d_2 be the second difference, and c be the change in signal strength. The first difference d_1 can then be expressed as:

$$d_1 = s_1 - s_2$$

[0151] In an alternate embodiment, the first difference d_1 is expressed as:

$$d_1 = s_2 - s_1$$

[0152] The second difference d_2 can be expressed as:

$$d_2 = s_3 - s_4$$

[0153] In an alternate embodiment, the second difference d_2 is expressed as:

$$d_2 = s_4 - s_3$$

[0154] The change c in signal strength then is a function of the first difference d_1 and a function of the second difference d_2:

$$c = f(d_1, d_2)$$

[0155] The present disclosure still further deals with any of the aforementioned apparatuses (11) processing third and fourth signals, the controller (14) being configured to:

determine a first difference between the first signal strength and the second signal strength;
determine a second difference between the third signal strength and the fourth signal strength;
determine a first absolute value of the first difference;
determine a second absolute value of the second difference; and
determine the change in signal strength as a function of the first absolute value and as a function of the second absolute value.

[0156] According to an aspect of the instant disclosure, the change in signal strength is determined as a function of a weighted arithmetic mean of the first absolute value and of the second absolute value.

[0157] It is also envisaged that the controller (14) calculates a first difference between the first signal strength and the second signal strength and calculates a second difference between the third signal strength and the fourth signal strength and calculates a first absolute value of the first difference and calculates a second absolute value of the second difference and calculates the change in signal strength as a function of the first absolute value and as a function of the second absolute value.

[0158] According to an aspect of the instant disclosure, the change in signal strength is calculated as a function of a weighted arithmetic mean of the first absolute value and of the second absolute value.

[0159] Let s_1 be the first signal strength, s_2 be the second signal strength, s_3 be the third signal strength, s_4 be the fourth signal strength, d_1 be the first difference, d_2 be the second difference, a_1 be the first absolute value, a_2 be the second absolute value, and c be the change in signal strength. The first difference d_1 can then be expressed as:

$$d_1 = s_1 - s_2$$

[0160] The second difference d_2 can be expressed as:

$$d_2 = s_3 - s_4$$

[0161] The first absolute value a_1 thus reads:

$$a_1 = | d_1 |$$

and the second absolute value a_2 reads:

$$a_2 = | d_2 |$$

[0162] The change c in signal strength then is a function of the first absolute value a_1 and a function of the second absolute value a_2:

$$c = f(a_1, a_2)$$

[0163] The present disclosure still further deals with any of the aforementioned apparatuses (11) processing third and fourth signals, the controller (14) being configured to:

determine a first difference between the first signal strength and the second signal strength;
determine a second difference between the third signal strength and the fourth signal strength;
determine a first square value of the first difference;
determine a second square value of the second difference; and
determine the change in signal strength as a function of the first square value and as a function of the second square value.

[0164] According to an aspect of the instant disclosure, the change in signal strength is determined as a function of a weighted arithmetic mean of the first square value and of the second square value.

[0165] It is also envisaged that the controller (14) calculates a first difference between the first signal strength and the second signal strength and calculates a second difference between the third signal strength and the fourth signal strength and calculates a first square value of the first difference and calculates a second square value of the second difference and calculates the change in signal strength as a function of the first square value and as a function of the second square value.

[0166] According to an aspect of the instant disclosure, the change in signal strength is calculated as a function of a weighted arithmetic mean of the first square value and of the second square value.

[0167] Let s_1 the first signal strength, s_2 be the second signal strength, s_3 be the third signal strength, s_4 be the fourth signal strength, d_1 be the first difference, d_2 be the second difference, q_1 be the first square value, q_2 be the second square value, and c be the change in signal strength. The first difference d_1 can then be expressed as:

$$d_1 = s_1 - s_2$$

[0168] The second difference d_2 can be expressed as:

$$d_2 = s_3 - s_4$$

[0169] The first square value q_1 thus reads:

$$q_1 = d_1^2$$

and the second square value q_2 reads:

$$q_2 = d_2^2$$

[0170] The change c in signal strength then is a function of the first square value q_1 and a function of the second square value q_2:

$$c = f(q_1, q_2)$$

[0171] The present disclosure also deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:

send a third actuation signal to the at least one actuator (13, 19), the third actuation signal causing an excess supply in the combustion air (12);
the at least one first optical sensor (8) being configured to:
after sending the third actuation signal, record a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a fifth sensor signal from the fifth raw signal, and send the fifth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, send a fourth actuation signal to the at least one actuator (13, 19), the fourth actuation signal causing the at least one actuator (13, 19) to throttle the excess supply of the combustion air (12);

the at least one first optical sensor (8) being configured to:
after the fourth actuation signal, record a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a sixth sensor signal from the sixth raw signal, and send the sixth sensor signal to the controller (14);
the controller (14) being configured to:

determine a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, send a fifth actuation signal to the at least one actuator (13, 19), the fifth actuation signal causing the at least one actuator (13, 19) to throttle the excess supply of the combustion air (12) further;

the at least one first optical sensor (8) being configured to:
after the fifth actuation signal, record a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a seventh sensor signal from the seventh raw signal, and send the seventh sensor signal to the controller (14);
the controller (14) being configured to:

determine a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, send a sixth actuation signal to the at least one actuator (13, 19), the sixth actuation signal causing the at least one actuator (13, 19) to throttle the excess supply of the combustion air (12) yet further;

the at least one first optical sensor (8) being configured to:
after the sixth actuation signal, record an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce an eighth sensor signal from the eighth raw signal, and send the eighth sensor signal to the controller (14);
the controller (14) being configured to:

determine an eighth signal strength of the eighth sensor signal;
determine an inflection point as a function of the fifth to eighth signal strengths; and
produce a seventh actuation signal and send the seventh actuation signal to the at least one

actuator (13, 19), the seventh actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0172] It is envisaged that the controller (14) calculates an inflection point as a function of the fifth to eighth signal strengths.

[0173] The instant disclosure still deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:

send a third actuation signal to the at least one actuator (13, 19), the third actuation signal causing a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:
after sending the third actuation signal, record a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a fifth sensor signal from the fifth raw signal, and send the fifth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, send a fourth actuation signal to the at least one actuator (13, 19), the fourth actuation signal causing the at least one actuator (13, 19) to throttle the supply of the combustion air (12);

the at least one first optical sensor (8) being configured to:
after the fourth actuation signal, record a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a sixth sensor signal from the sixth raw signal, and send the sixth sensor signal to the controller (14);
the controller (14) being configured to:

determine a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, send a fifth actuation signal to the at least one actuator (13, 19), the fifth actuation signal causing the at least one actuator (13, 19) to throttle the supply of the combustion air (12) further;

the at least one first optical sensor (8) being configured to:
after the fifth actuation signal, record a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a seventh sensor signal from the seventh raw signal, and send the seventh sensor signal to the controller (14);
the controller (14) being configured to:

determine a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, send a sixth actuation signal to the at least one actuator (13, 19), the sixth actuation signal causing the at least one actuator (13, 19) to throttle the supply of the combustion air (12) yet further;

the at least one first optical sensor (8) being configured to:
after the sixth actuation signal, record an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce an eighth sensor signal from the eighth raw signal, and send the eighth sensor signal to the controller (14);
the controller (14) being configured to:

determine an eighth signal strength of the eighth sensor signal;
determine an inflection point as a function of the fifth to eighth signal strengths; and
produce a seventh actuation signal and send the seventh actuation signal to the at least one actuator (13, 19), the seventh actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0174] It is still envisaged that the controller (14) calculates an inflection point as a function of the fifth to eighth signal strengths.

[0175] The present disclosure still further deals with any of the aforementioned apparatuses (11), the controller (14) being configured to:

send a third actuation signal to the at least one actuator (13, 19), the third actuation signal causing a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:
after sending the third actuation signal, record a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a fifth sensor signal from the fifth raw signal, and send the fifth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, send a fourth actuation signal to the at least one actuator (13, 19), the fourth actuation signal causing the at

least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20);

the at least one first optical sensor (8) being configured to:
after the fourth actuation signal, record a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a sixth sensor signal from the sixth raw signal, and send the sixth sensor signal to the controller (14);
the controller (14) being configured to:

determine a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, send a fifth actuation signal to the at least one actuator (13, 19), the fifth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) further;

the at least one first optical sensor (8) being configured to:
after the fifth actuation signal, record a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a seventh sensor signal from the seventh raw signal, and send the seventh sensor signal to the controller (14);
the controller (14) being configured to:

determine a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, send a sixth actuation signal to the at least one actuator (13, 19), the sixth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) yet further;

the at least one first optical sensor (8) being configured to:
after the sixth actuation signal, record an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce an eighth sensor signal from the eighth raw signal, and send the eighth sensor signal to the controller (14);
the controller (14) being configured to:

determine an eighth signal strength of the eighth sensor signal;
determine an inflection point as a function of the fifth to eighth signal strengths; and
produce a seventh actuation signal and send the seventh actuation signal to the at least one actuator (13, 19), the seventh actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

[0176] The instant disclosure also deals with a computer program comprising instructions to cause any of the aforementioned apparatuses (11) to execute the steps of any of the aforementioned methods not involving at least one second sensor (4, 5).

[0177] The instant disclosure also deals with a computer program product comprising instructions to cause any of the aforementioned apparatuses (11) not involving at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods not involving at least one second sensor (4, 5).

[0178] The present disclosure further deals with a computer program comprising instructions to cause the controller (14 of any of the aforementioned apparatuses (11) not involving at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods not involving at least one second sensor (4, 5).

[0179] The instant disclosure still deals with a computer program product comprising instructions to cause the controller (14) of any of the aforementioned apparatuses (11) not involving at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods not involving at least one second sensor (4, 5).

[0180] The present disclosure also deals with a computer program comprising instructions to cause any of the aforementioned apparatuses (11) having at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods involving at least one second sensor (4, 5).

[0181] The instant disclosure also deals with a computer program product comprising instructions to cause any of the aforementioned apparatuses (11) having at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods involving at least one second sensor (4, 5).

[0182] The present disclosure further deals with a computer program comprising instructions to cause the controller (14) of any of the aforementioned apparatuses (11) having at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods involving at least one second sensor (4, 5).

[0183] The instant disclosure still deals with a computer program product comprising instructions to cause the controller (14) of any of the aforementioned apparatuses (11) having at least one second sensor (4, 5) to execute the steps of any of the aforementioned methods involving at least one second sensor (4, 5).

[0184] The instant disclosure also deals with a computer-readable data carrier having stored thereon any of the aforementioned computer programs.

[0185] The present disclosure also deals with a computer-readable data carrier having stored thereon any of the aforementioned computer program products.

[0186] It should be understood that the foregoing relates only to certain embodiments of the disclosure. Numerous changes can be made therein without departing from the scope of the disclosure as defined by the following claims. It should also be understood that the disclosure is not restricted to the illustrated embodiments. Various modifications can be made within the scope of the claims.

Reference numerals

[0187]

1 flame
2 combustion chamber
3 feed conduit
4 ionisation electrode
5 tip
6 frame
7 nozzle
8 sensor
9 spectral sensitivity and/or a relative spectral responsivity
10 optical wavelength in nanometers
11 combustion apparatus
12 air supply, combustion air
13 fan
14 controller
15 signal line
16 signal line
17 sensor
18 signal line
19 valve
20 fuel, gaseous fuel
21 signal line
22 sensor
23 signal line
24 signal line

Claims

1. A method of influencing or of controlling a mixing ratio of combustion air (12) and a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, wherein the combustion air (12) and the gaseous fuel (20) are combusted together in a combustion chamber (2), the method comprising the steps of:

at least one first optical sensor (8) recording a first raw signal directly originating from a flame (1) inside the combustion chamber (2), producing a first sensor signal from the first raw signal, and sending the first sensor signal to a controller (14);
the controller (14) determining a first signal strength of the first sensor signal;
after recording the first raw signal, changing a supply of the combustion air (12) and/or of the gaseous fuel (20) to the combustion chamber (2);
after the change in supply, the at least one first optical sensor (8) recording a second raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a second sensor signal from the second raw signal, and sending the second sensor signal to the controller (14);
the controller (14) determining a second signal strength of the second sensor signal;
the controller (14) determining a change in signal strength as a function of the first signal strength and as a function of the second signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20); and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength;
characterised in that the method further comprises the steps of:

at least one second sensor (4, 5) within a flame zone of the combustion chamber (2) recording a third electric signal, producing a third sensor signal from the third electric signal, and sending the third sensor signal to the controller (14);
the controller (14) determining a third signal strength of the third sensor signal;
after the change in supply, the at least one second sensor (4, 5) within the flame zone of the combustion chamber (2) recording a fourth electric signal, producing a fourth sensor signal from the fourth electric signal, and sending the fourth sensor signal to the controller (14);
the controller (14) determining a fourth signal strength of the fourth sensor signal; and
the controller (14) determining the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

2. The method according to claim 1, the method comprising the step of:
the controller (14) determining the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function

of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

3. The method according to any of the claims 1 to 2, the method comprising the steps of:

starting a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the enrichment, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the further enrichment, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the yet further enrichment, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal;
the controller (14) determining an inflection point as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

4. A combustion apparatus (11) comprising at least one first optical sensor (8), a combustion chamber (2), at least one actuator (13, 19) acting on a supply to the combustion chamber (2) of combustion air (12) and/or of a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, a controller (14) in operative communication with the at least one first optical sensor (8) and with the at least one actuator (13, 19), the at least one first optical sensor (8) being configured to:

record a first raw signal directly originating from a flame (1) inside the combustion chamber (2), produce a first sensor signal from the first raw signal, and send the first sensor signal to the controller (14);
the controller (14) being configured to:

determine a first signal strength of the first sensor signal;
after recording the first raw signal, send a first actuation signal to the at least one actuator (13, 19), the first actuation signal causing the at least one actuator (13, 19) to change the supply of the combustion air (12) and/or of the gaseous fuel (20);

the at least one first optical sensor (8) being configured to:

after the change in supply, record a second raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a second sensor signal from the second raw signal, and send the second sensor signal to the controller (14);
determine a second signal strength of the second sensor signal;
determine a change in signal strength as a function of the first signal strength and as a function of the second signal strength, the change in signal strength being caused by the change in supply; and
produce a second actuation signal as a function of the change in signal strength and send the second actuation signal to the at least one actuator (13, 19), the second actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) to the combustion chamber (2);
characterised in that

the apparatus (11) additionally comprises at least one second sensor (4, 5) arranged within a flame zone of the combustion chamber (2) and in operative communication with the controller (14), the at least one second sensor (4, 5) being configured to:
record a third electric signal, produce a third sensor signal from the third electric signal, and send the third sensor signal to the controller (14);
the controller (14) being configured to:
determine a third signal strength of the third sensor signal;
the at least one second sensor (4, 5) being configured to:
after the change in supply, record a fourth electric signal, produce a fourth sensor signal from the fourth electric signal, and send the fourth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fourth signal strength of the fourth sensor signal; and
determine the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

5. The apparatus (11) according to claim 4, the controller (14) being configured to:
determine the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

6. The apparatus (11) according to any of the claims 4 to 5, the controller (14) being configured to:

send a third actuation signal to the at least one actuator (13, 19), the third actuation signal causing a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:
after sending the third actuation signal, record a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a fifth sensor signal from the fifth raw signal, and send the fifth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, send a fourth actuation signal to the at least one actuator (13, 19), the fourth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20);

the at least one first optical sensor (8) being configured to:
after the fourth actuation signal, record a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a sixth sensor signal from the sixth raw signal, and send the sixth sensor signal to the controller (14);
the controller (14) being configured to:

determine a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, send a fifth actuation signal to the at least one actuator (13, 19), the fifth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) further;

the at least one first optical sensor (8) being configured to:
after the fifth actuation signal, record a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a seventh sensor signal from the seventh raw signal, and send the seventh sensor signal to the controller (14);
the controller (14) being configured to:

determine a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, send a sixth actuation signal to the at least one actuator (13, 19), the sixth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) yet further;

the at least one first optical sensor (8) being configured to:
after the sixth actuation signal, record an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce an eighth sensor signal from the eighth raw signal, and send the eighth sensor signal to the controller (14);
the controller (14) being configured to:

determine an eighth signal strength of the

eighth sensor signal;
determine an inflection point as a function of the fifth to eighth signal strengths; and
produce a seventh actuation signal and send the seventh actuation signal to the at least one actuator (13, 19), the seventh actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

7. A computer program comprising instructions to cause the apparatus (11) of claim 4 to execute the steps of any of the methods according to claims 1 to 3.

8. A computer-readable data carrier having stored thereon the computer program of claim 7.

Amended claims in accordance with Rule 137(2) EPC.

1. A method of influencing or of controlling a mixing ratio of combustion air (12) and a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, wherein the combustion air (12) and the gaseous fuel (20) are combusted together in a combustion chamber (2), the method comprising the steps of:

at least one first optical sensor (8) recording a first raw signal directly originating from a flame (1) inside the combustion chamber (2), producing a first sensor signal from the first raw signal, and sending the first sensor signal to a controller (14);
at least one second sensor (4, 5) within a flame zone of the combustion chamber (2) recording a third electric signal, producing a third sensor signal from the third electric signal, and sending the third sensor signal to the controller (14);
the controller (14) determining a first signal strength of the first sensor signal;
the controller (14) determining a third signal strength of the third sensor signal;
after recording the first raw signal, changing a supply of the combustion air (12) and/or of the gaseous fuel (20) to the combustion chamber (2);
after the change in supply, the at least one first optical sensor (8) recording a second raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a second sensor signal from the second raw signal, and sending the second sensor signal to the controller (14);
the controller (14) determining a second signal strength of the second sensor signal;
after the change in supply, the at least one second sensor (4, 5) within the flame zone of the combustion chamber (2) recording a fourth electric signal, producing a fourth sensor signal from the fourth electric signal, and sending the fourth sensor signal to the controller (14);
the controller (14) determining a fourth signal strength of the fourth sensor signal;
the controller (14) determining a change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20); and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength.

2. The method according to claim 1, the method comprising the step of:
the controller (14) determining the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

3. The method according to any of the claims 1 to 2, the method comprising the steps of:

starting a combustion inside the combustion chamber (2) with a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
after starting the combustion, the at least one first optical sensor (8) recording a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a fifth sensor signal from the fifth raw signal, and sending the fifth sensor signal to the controller (14);
the controller (14) determining a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the enrichment, the at least one first optical sensor (8) recording a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a sixth sensor signal from the sixth raw signal, and sending the sixth

sensor signal to the controller (14);
the controller (14) determining a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the further enrichment, the at least one first optical sensor (8) recording a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), producing a seventh sensor signal from the seventh raw signal, and sending the seventh sensor signal to the controller (14);
the controller (14) determining a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, yet further enriching the mixing ratio of the combustion air (12) and the gaseous fuel (20);
after the yet further enrichment, the at least one first optical sensor (8) recording an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), producing an eighth sensor signal from the eighth raw signal, and sending the eighth sensor signal to the controller (14);
the controller (14) determining an eighth signal strength of the eighth sensor signal;
the controller (14) determining an inflection point as a function of the fifth to eighth signal strengths; and
the controller (14) controlling or setting the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

4. A combustion apparatus (11) comprising at least one first optical sensor (8), a combustion chamber (2), at least one actuator (13, 19) acting on a supply to the combustion chamber (2) of combustion air (12) and/or of a gaseous fuel (20) comprising more than twenty percent of hydrogen gas, a controller (14) in operative communication with the at least one first optical sensor (8) and with the at least one actuator (13, 19), the at least one first optical sensor (8) being configured to:

record a first raw signal directly originating from a flame (1) inside the combustion chamber (2), produce a first sensor signal from the first raw signal, and send the first sensor signal to the controller (14);
the apparatus (11) additionally comprises at least one second sensor (4, 5) arranged within a flame zone of the combustion chamber (2) and in operative communication with the controller (14), the at least one second sensor (4, 5) being configured to:

record a third electric signal, produce a third sensor signal from the third electric signal, and send the third sensor signal to the controller (14);
the controller (14) being configured to:

determine a first signal strength of the first sensor signal;
determine a third signal strength of the third sensor signal;
after recording the first raw signal, send a first actuation signal to the at least one actuator (13, 19), the first actuation signal causing the at least one actuator (13, 19) to change the supply of the combustion air (12) and/or of the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:

after the change in supply, record a second raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a second sensor signal from the second raw signal, and send the second sensor signal to the controller (14);
the at least one second sensor (4, 5) being configured to:

after the change in supply, record a fourth electric signal, produce a fourth sensor signal from the fourth electric signal, and send the fourth sensor signal to the controller (14);
the controller (14) being configured to:

determine a second signal strength of the second sensor signal;
determine a fourth signal strength of the fourth sensor signal;
determine a change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of a further signal strength selected from the third and the fourth signal strengths, the change in signal strength being caused by the change in

supply of the combustion air (12) and/or of the gaseous fuel (20); and
produce a second actuation signal as a function of the change in signal strength and send the second actuation signal to the at least one actuator (13, 19), the second actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) to the combustion chamber (2).

5. The apparatus (11) according to claim 4, the controller (14) being configured to:
determine the change in signal strength as a function of the first signal strength and as a function of the second signal strength and as a function of the third signal strength and as a function of the fourth signal strength, the change in signal strength being caused by the change in supply of the combustion air (12) and/or of the gaseous fuel (20).

6. The apparatus (11) according to any of the claims 4 to 5, the controller (14) being configured to:

send a third actuation signal to the at least one actuator (13, 19), the third actuation signal causing a lean mixing ratio of the combustion air (12) and the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:

after sending the third actuation signal, record a fifth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a fifth sensor signal from the fifth raw signal, and send the fifth sensor signal to the controller (14);
the controller (14) being configured to:

determine a fifth signal strength of the fifth sensor signal;
after recording the fifth raw signal, send a fourth actuation signal to the at least one actuator (13, 19), the fourth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20);
the at least one first optical sensor (8) being configured to:

after the fourth actuation signal, record a sixth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a sixth sensor signal from the sixth raw signal, and send the sixth sensor signal to the controller (14);
the controller (14) being configured to:

determine a sixth signal strength of the sixth sensor signal;
after recording the sixth raw signal, send a fifth actuation signal to the at least one actuator (13, 19), the fifth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) further;
the at least one first optical sensor (8) being configured to:

after the fifth actuation signal, record a seventh raw signal directly originating from the flame (1) inside the combustion chamber (2), produce a seventh sensor signal from the seventh raw signal, and send the seventh sensor signal to the controller (14);
the controller (14) being configured to:

determine a seventh signal strength of the seventh sensor signal;
after recording the seventh raw signal, send a sixth actuation signal to the at least one actuator (13, 19), the sixth actuation signal causing the at least one actuator (13, 19) to enrich the mixing ratio of the combustion air (12) and the gaseous fuel (20) yet further;
the at least one first optical sensor (8) being configured to:

after the sixth actuation signal, record an eighth raw signal directly originating from the flame (1) inside the combustion chamber (2), produce an eighth sensor signal from the eighth raw signal, and send the eighth sensor signal to the controller (14);
the controller (14) being configured to:

determine an eighth signal strength of the eighth sensor signal;
determine an inflection point as a function of the fifth to eighth signal strengths; and
produce a seventh actuation signal and send the seventh actuation signal to the at least one actuator (13, 19), the seventh actuation signal causing the at least one actuator (13, 19) to control or to set the supply of the combustion air (12) and/or of the gaseous fuel (20) as a function of the change in signal strength and as a function of the inflection point.

7. A computer program comprising instructions to cause the apparatus (11) of claim 4 to execute the steps of any of the methods according to claims 1 to 3.

8. A computer-readable data carrier having stored thereon the computer program of claim 7.

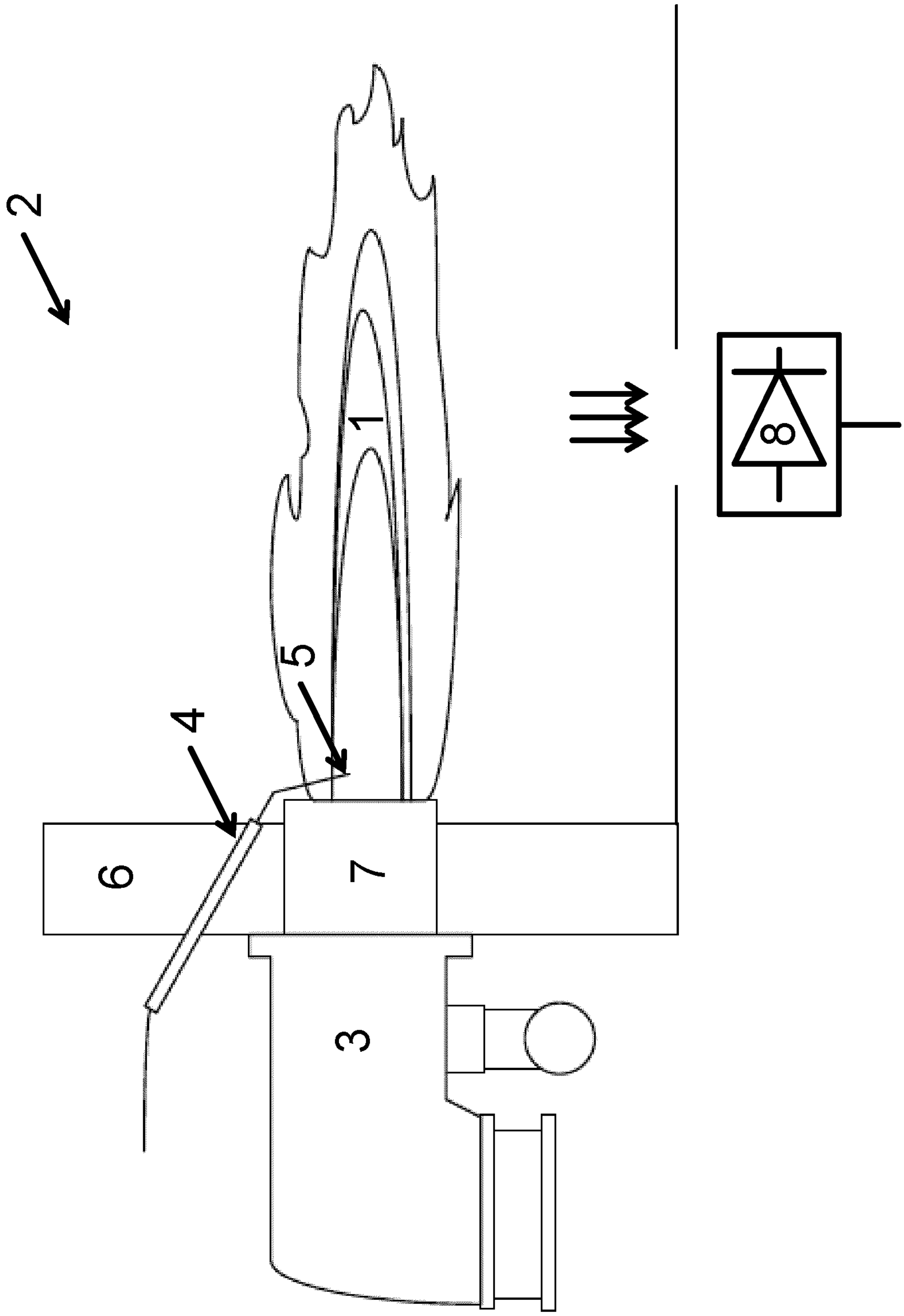
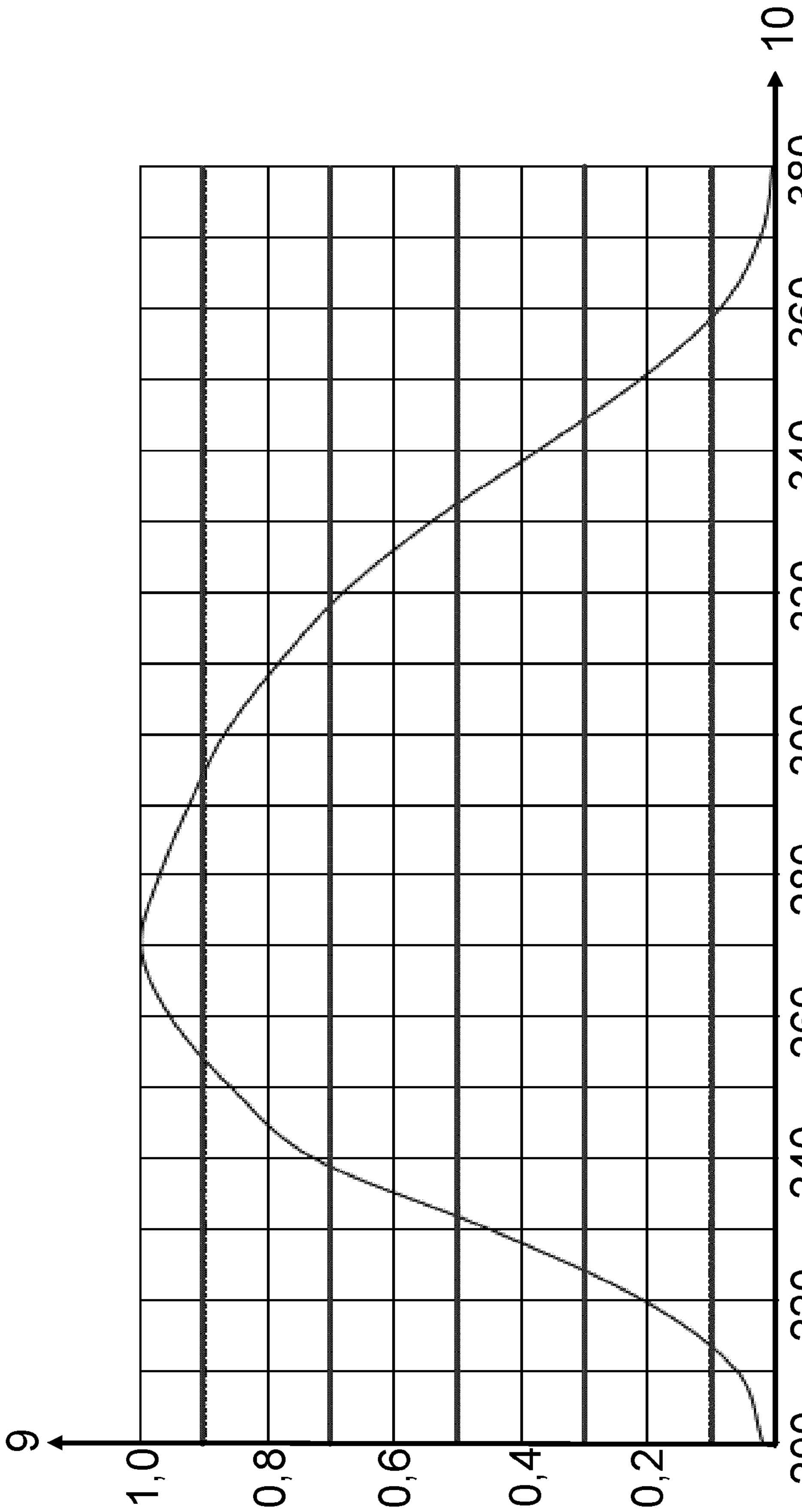


FIG 1

FIG 2



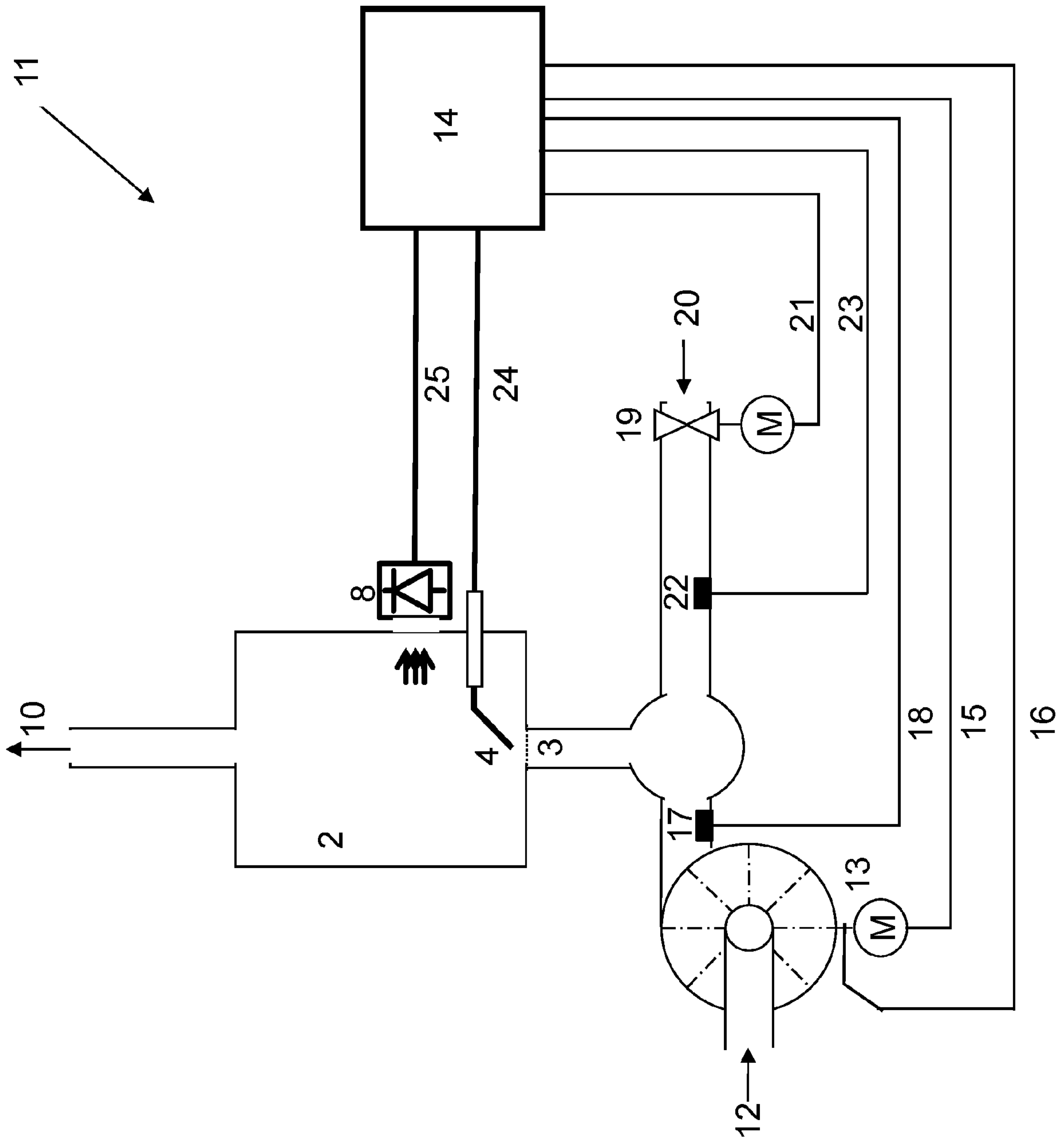


FIG 3

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 4564

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 5 037 291 A (CLARK DANIEL R [US]) 6 August 1991 (1991-08-06) * column 2, line 5 - column 7, line 12; figures 1-5 * -----	1-8	INV. F23N1/02 F23N5/08
A	DE 10 2019 101329 A1 (VAILLANT GMBH [DE]) 23 July 2020 (2020-07-23) * the whole document * -----	1-8	
A	US 2017/314989 A1 (MAZZILLO MASSIMO CATALDO [IT] ET AL) 2 November 2017 (2017-11-02) * paragraph [0078]; figure 5 * -----	1-8	
			TECHNICAL FIELDS SEARCHED (IPC)
			F23N F23C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	26 September 2023	Theis, Gilbert

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 23 15 4564

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26-09-2023

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REFERENCES CITED IN THE DESCRIPTION

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