

A SYSTEM FOR IN-SITU GAS ANALYSIS

FIELD

The present disclosure relates to the field of systems for gas analysis. In particular, the present disclosure relates to a gas analysis system for the characterization of flue gases.

BACKGROUND

The background information herein below relates to the present disclosure but is not necessarily prior art.

Recent environmental regulation norms require measurement and control of NO_x and CO in the flue gas from power plants driven on fossil fuel. Control of NO_x emission requires a reduction of NO_x using selective catalytic reduction (SCR) and Selective non-catalytic reduction (SNCR). In both these cases, ammonia (NH_3) is sprayed at a high temperature ($> 300^\circ\text{C}$) to reduce NO_x to nitrogen and water. Due to fluctuations in the combustion processes and loading of the power plants, there are wide variations in both NO_x and NH_3 (ammonia slip) concentrations in the flue gas. The in-situ and real-time measurements of flue gas mixtures are thus required for regulatory requirements and active combustion control of the boilers.

Presently, the measurements are carried out through sampling of the flue gas from the stack (hot/cold extraction) and carrying out the measurement in an analyser installed at a distance of 10-30m from the sampling point. A major drawback of this technique is the change in the stoichiometry of the sampled gas or condensations due to fluctuations in the sampling line temperature. To prevent such changes in stoichiometry, salt formations, or condensations, the sampling line is kept at a constant pre-determined high temperature (based on the dew point of the gas mixtures) using automatic temperature (for tropical climates) or heater power (for cold climates) control. Regular monitoring and adjustments with test gas are required to ensure the fidelity of the measurement process. It leads to higher operational and maintenance costs for this type of system.

To mitigate the challenges due to complex gas sampling and conditioning processes, in-situ probes have been developed to measure the gas species concentrations directly in the gas

flow path. This real-time measurement enables the active control of the combustor in synchronization with the load curve based on power demand.

The existing in-situ system uses tunable diode lasers (TDLs) and direct optical absorption spectroscopy (DOAS) technique for the measurement of gas species concentrations. The flue gas diffuses in the diffusion probe through a set of filters that form the measurement zone of the system. The laser radiation from one end of the probe is reflected at the other end using retro-reflectors, thereby forming a measurement path-length which is approximate twice the length of the probe. There are two major limitations with this method: the first limitation is the measurement of low concentrations at high temperatures. At high flue gas temperatures, the line-strength of the absorbing gas molecules decreases resulting in the decrease in measurement sensitivity of the concentrations and degradation of the signal-to-noise ratio. The second limitation is the reliability of the lasers. This mainly manifests as drift in the laser frequencies due to thermal conduction from the stack wall. Additional cooling mechanisms are required to prevent the laser drifts which results in higher operational costs of the in-situ measurement system.

The existing system for gas analysis is not suitable for deep penetration into large measurement zones (> 5m) due to difficulties in optical alignment. Signal degradation occurs in the existing system due to vibration. The conventional system also needs high-cost corrosion-resistant high-temperature mirrors. Also, the conventional system is not suitable if the laser source needs to be maintained at a fixed temperature.

Therefore, there is a need of a system for in-situ gas analysis that alleviates one or more aforementioned drawbacks.

OBJECTS

Some of the objects of the present disclosure, which at least one embodiment herein satisfies, are as follows:

A primary object of the present disclosure is to provide a system for in-situ gas analysis.

Another object of the present disclosure is to provide a system for in-situ gas analysis, which allows accurate measurement of low gas concentrations at high temperatures.

Yet another object of the present disclosure is to provide a system for in-situ gas analysis, which does not require additional cooling mechanisms.

Another object of the present disclosure is to provide a system for in-situ gas analysis, which does not involve difficulties in optical alignment.

Yet another object of the present disclosure is to provide a system for in-situ gas analysis, which provides real-time measurement.

Another object of the present disclosure is to provide a system for in-situ gas analysis, which measures the gas concentrations directly in the gas flow path.

Yet another object of the present disclosure is to provide a system for in-situ gas analysis, which does not involve condensation of gas.

Another object of the present disclosure is to provide a system for in-situ gas analysis, which incurs low operational and maintenance cost.

Yet another object of the present disclosure is to provide a system for in-situ gas analysis, which is not affected by vibration.

Another object of the present disclosure is to provide a system for in-situ gas analysis, which should be resistant to high temperature.

Yet another object of the present disclosure is to provide a system for in-situ gas analysis, which should be resistance to corrosion.

Other objects and advantages of the present disclosure will be more apparent from the following description, which is not intended to limit the scope of the present disclosure.

SUMMARY

The present disclosure envisages a system for in-situ gas analysis in a flue gas region. The system comprises an enclosure, a laser beam source housed in the enclosure, a tubular probe insertable for probing in the flue gas region, a detector and a processing unit. The laser beam source is configured to generate laser beams. The tubular probe comprises optical waveguides, a dead zone, a measurement zone and a reflection chamber. The optical waveguides are configured to receive and conduct laser beams generated by the laser beam

source. The dead zone configured to support and isolate the optical waveguides contained therein from surrounding flue gases. The optical waveguides extend up to and project the generated laser beams from the farther end of the dead zone. The measurement zone is configured to receive the projected laser beams by the optical waveguides. The measurement
5 zone is configured to allow the flue gas to pass therethrough and get exposed to the projected laser beams. The reflection chamber is located at the farther end of the measurement zone. The reflection chamber comprises a first focusing lens for focusing the projected laser beams that are exposed to the flue gases in the measurement zone and a mirror for reflecting back the focused laser beams towards the optical waveguides. The detector is configured to detect
10 the reflected laser beam and generate at least one corresponding sensed signal. The processing unit is configured to process the sensed signal from the detector for computing composition of the flue gas.

Preferably, the laser beam source is configured to allow tuning of the frequency spectrum of the laser beam generated for identification of particular molecules present in the flue gas
15 being analyzed.

Advantageously, the tubular probe comprises an insulation-cum-support tube along the dead zone for thermally insulating as well as structurally supporting the optical waveguides. Further, preferably, the insulation-cum-support tube consists of a first shield, a second shield and an air jacket defined by the space between the first shield and the second shield. The air
20 jacket is configured to allow compressed air at ambient temperature to flow therethrough.

In an embodiment, the enclosure is temperature-stabilized and is configured to be positioned external to the flue gas region.

Typically, the detector includes a laser-optical sensor.

Preferably, the measurement zone is provided with a diffuser which allows diffusion of flue
25 gases from the surrounding flue gas region into the measurement zone. Alternatively, the measurement zone is an open path cell.

Typically, the optical waveguides include a plurality of transmitting cables for transmitting the generated laser beams and projecting the generated laser beams into the measurement

zone and at least one receiving cable for receiving the reflected laser beam and transmitting the reflecting beam to the detector.

In an embodiment, the optical waveguides include a plurality of sets of transmitting cables and a plurality of receiving cables. The plurality of sets of transmitting cables includes at least a first set of transmitting cables and a second set of transmitting cables for transmitting and projecting first generated laser beams containing a first frequency band and second generated laser beams containing a second frequency band respectively. The plurality of receiving cables includes a first receiving cable and a second receiving cable for receiving and transmitting a corresponding first reflected laser beam and a corresponding second reflected laser beam respectively. Accordingly, the reflection chamber comprises at least two mirrors positioned one after the other along the longitudinal axis of the reflection chamber, wherein a first mirror is configured to reflect the first generated laser beam and a second mirror is configured to reflect the second generated laser beam. Further, the detector comprises a second focusing lens for focusing a plurality of reflected laser beams including the first reflected laser beam and the second reflected laser beam. Accordingly, the dead zone comprises a first collimation lens assembly positioned at the farther end of the dead zone.

In an embodiment, the enclosure houses a plurality of gas cells provided for calibration, with one gas cell per laser beam source.

Preferably, the optical waveguides are made of chalcogenic cylindrical raw material such as As-Se, As-Se-Te, or Ge-Sb-Se, or are hollow waveguides.

The first focusing lens is formed by a group of lens which includes convex lens and fresnel lens.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWING

The system for in-situ gas analysis of the present disclosure will now be described with the help of the accompanying drawing, in which:

Figure 1 shows a schematic view of the proposed system for in-situ gas analysis of the present disclosure in accordance with an embodiment;

Figure 2 shows a sectional view of the tubular probe of the system for in-situ gas analysis of the present disclosure;

Figure 3 shows a side sectional view of the tubular probe revealing the reflection chamber, the dead zone and the measurement zone of the system of Figure 1;

- 5 **Figure 4A** shows a sectional view of the tubular probe for in-situ gas analysis of the present disclosure in accordance with another embodiment;

Figure 4B shows a side sectional view of the reflection chamber in accordance with the embodiment of Figure 4A; and

- 10 **Figure 5** shows a sectional view of the detector in accordance with the embodiment of Figures 4A-4B.

LIST OF REFERENCE NUMERALS USED IN DETAILED DESCRIPTION AND DRAWING

- | | | |
|----|------|---|
| | 1000 | System for in-situ gas analysis of the present disclosure |
| | 10 | Enclosure |
| 15 | 20 | Laser beam source |
| | 22 | Gas cell |
| | 24 | Parabolic mirror |
| | 26 | Probe head |
| | 30 | Dead zone |
| 20 | 32 | Insulation-cum-support tube |
| | 32a | Inner shield |
| | 32b | Outer shield |
| | 32c | Air jacket |
| | 34 | First collimation lens assembly |

- 40 Measurement zone
- 42 Diffuser
- 50 Reflection chamber
- 52 First focusing lens
- 5 54 Mirror
 - 54a First mirror
 - 54b Second mirror
- 60 Optical waveguide
 - 60a Transmitting cables
 - 10 60b Receiving cable
 - 601a First set of transmitting cables
 - 602a Second set of transmitting cables
 - 601b First receiving cable
 - 602b Second receiving cable
- 15 65 Flue gas region
 - 70 Detector
 - 72 Laser-optical sensor
 - 74 Second focusing lens
 - 75 Mounting flange

20 DETAILED DESCRIPTION

Embodiments, of the present disclosure, will now be described with reference to the accompanying drawing.

Embodiments are provided so as to thoroughly and fully convey the scope of the present disclosure to the person skilled in the art. Numerous details are set forth, relating to specific components, and methods, to provide a complete understanding of embodiments of the present disclosure. It will be apparent to the person skilled in the art that the details provided
5 in the embodiments should not be construed to limit the scope of the present disclosure. In some embodiments, well-known processes, well-known apparatus structures, and well-known techniques are not described in detail.

The terminology used, in the present disclosure, is only for the purpose of explaining a particular embodiment and such terminology shall not be considered to limit the scope of the
10 present disclosure. As used in the present disclosure, the forms “a”, “an” and “the” may be intended to include the plural forms as well, unless the context clearly suggests otherwise. The terms “comprises”, “comprising”, “including” and “having” are open-ended transitional phrases and therefore specify the presence of stated features, integers, steps, operations, elements, modules, units and/or components, but do not forbid the presence or addition of
15 one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The particular order of steps disclosed in the method and process of the present disclosure is not to be construed as necessarily requiring their performance as described or illustrated. It is also to be understood that additional or alternative steps may be employed.

When an element is referred to as being “mounted on”, “engaged to”, “connected to” or
20 “coupled to” another element, it may be directly on, engaged, connected or coupled to the other element. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed elements.

The terms first, second, third, etc., should not be construed to limit the scope of the present disclosure as the aforementioned terms may be only used to distinguish one element,
25 component, region, layer or section from another component, region, layer or section. Terms such as first, second, third etc., when used herein do not imply a specific sequence or order unless clearly suggested by the present disclosure.

Terms such as “inner”, “outer”, “beneath”, “below”, “lower”, “above”, “upper” and the like,
30 may be used in the present disclosure to describe relationships between different elements as depicted from the figures.

Conventional methods of measurement of the concentration of gases involve sampling of gases from the source and transporting them to the analyser located 10-30m away. The stoichiometry of the sample gas, salt formations, or condensation changes due to fluctuations in the sampling line temperature. In order to counteract such a change, the sampling line is
5 kept at a constant pre-determined high temperature. Such systems incur high operating and maintenance costs for regular monitoring and adjustment with a test gas, which is necessary to ensure the accuracy of the measuring process. To mitigate these challenges, in-situ gas analysis is proposed.

While in-situ analysis of flue gases in combustion chambers and the like using LASER is
10 known, the desired accuracy of the analysis of flue gases could not be achieved due to the depth of the chambers at which the gases are desired to be analyzed. When the light moves to depths of 3 m and beyond, the light is subject to scattering, diffraction, etc. by the vibrating gas molecules, which are produced at high temperatures, i.e., 500°C and above. Moreover, it is also desired to keep the light source at room temperature. Hence, the source cannot be
15 exposed to the high temperatures within or in direct contact with the combustion chamber. Thus, a system for in-situ gas analysis is required, which has improved accuracy and which eliminates or mitigates the aforementioned issues.

The preferred embodiment of the present invention will now be described with reference to Figures 1-3. The present disclosure envisages a system 1000 for in-situ gas analysis in a flue
20 gas region 65. The system 1000 comprises an enclosure 10, a laser beam source 20 housed in the enclosure 10, a tubular probe insertable for probing in the flue gas region 65, at least one detector 70 and a processing unit. The laser beam source 20 is configured to generate laser beams. Thus, the enclosure 10 is positioned external to the flue gas region 65. The tubular probe comprises optical waveguides 60, a dead zone 30, a measurement zone 40 and a
25 reflection chamber 50. The optical waveguides 60 are configured to receive and conduct laser beams generated by the laser beam source 20. The dead zone 30 configured to support and isolate the optical waveguides 60 contained therein from surrounding flue gases. The optical waveguides 60 extend up to and project the generated laser beams from the farther end of the dead zone 30. The measurement zone 40 is configured to receive the projected laser beams by
30 the optical waveguides 60. The measurement zone 40 is configured to allow the flue gas to pass therethrough and get exposed to the projected laser beams. The reflection chamber 50 is located at the farther end of the measurement zone 40. The reflection chamber 50 comprises a

first focusing lens 52 for focusing the projected laser beams that are exposed to the flue gases in the measurement zone 40 and a mirror 54 for reflecting back the focused laser beams towards the optical waveguides 60. The detector 70, typically placed in a probe head 26, is configured to detect the reflected laser beam and generate at least one corresponding sensed signal. The processing unit is configured to process the sensed signal from the detector 70 for computing composition of the flue gas.

Preferably, the laser beam source 20 is configured to allow tuning of the frequency spectrum of the laser beam generated, using direct optical absorption spectroscopy (DOAS) or wavelength modulation spectroscopy (WMS) or frequency modulation spectroscopy (FMS), for identification of particular molecules present in the flue gas being analyzed.

In an embodiment, the enclosure 10 is temperature-stabilized and is configured to be positioned external to the flue gas region. In an embodiment, the enclosure 10 houses a plurality of gas cells 22 provided for calibration, with one gas cell 22 per laser beam source 20.

A plurality of parabolic mirrors 24 can be used to direct the laser beam emanating from the laser beam sources 20 into each of the optical waveguides 60. Preferably, each of the laser beam sources 20 is a QCL, i.e., quantum cascade laser or tunable diode lasers (TDLs).

Typically, the first focusing lens 52 formed by a group of lens which includes convex lens and fresnel lens.

The tubular probe is mounted using a mounting flange 75. The mounting flange 75 is provided with a circumferential sealing means.

The laser beam projected from the optical waveguides 60 interacts with the high-temperature flue gases in the measurement zone 40. Further, the first focusing lens 52 of the reflection chamber 50 collimates the laser beam traveling within the measurement zone 40. The mirror 54 of the reflection chamber 50 reflects the laser beam towards the optical waveguides 60 parallel to the incident light. The optical waveguides 60 transmit the light coming from the measurement zone 40 into the detector 70. The detector 70 generates signals corresponding to the light and transmits to the processing unit. The processing unit analyses the signals thus received for identifying contents of the flue gases that are analyzed. The processing unit is preferably disposed within the temperature-controlled optical source enclosure 10.

In an advantageous embodiment, as shown in **Figure 2**, the tubular probe comprises an insulation-cum-support tube 32 along the dead zone for thermally insulating as well as structurally supporting the optical waveguides 60. The insulation-cum-support tube 32 consists of a first shield 32a, a second shield 32b and an air jacket 32c defined by the space
5 between the first shield 32a and the second shield 32b. Compressed air at ambient temperature is made to flow through air jacket 32c.

The dead zone 30 comprises a first collimation lens assembly 34 positioned at the farther end of the dead zone 30. The first collimation lens assembly 34 aligns each of the beams in its intended direction of impingement on the first focusing lens 52.

- 10 Preferably, the measurement zone 40 is provided with a diffuser 42 which allows diffusion of flue gases from the surrounding flue gas region into the measurement zone 40. Alternatively, the measurement zone 40 is an open path cell.

Typically, the detector 70 includes a laser-optical sensor 72.

- Typically, as shown in **Figure 2**, the optical waveguides 60 include a plurality of transmitting
15 cables (60a) for transmitting the generated laser beams and projecting the generated laser beams into the measurement zone 40 and at least one receiving cable 60b for receiving the reflected laser beam and transmitting the reflecting beam to the detector 70.

- In an embodiment, as shown in **Figure 4**, the optical waveguides 60 include a plurality of sets of transmitting cables and a plurality of receiving cables. The plurality of sets of transmitting
20 cables includes at least a first set of transmitting cables 601a and a second set of transmitting cables 602a. The first set of transmitting cables 601a transmits and projects first generated laser beams containing a first frequency band. The second set of transmitting cables 602a transmits and projects second generated laser beams containing a second frequency band. The plurality of receiving cables includes a first receiving cable 601b and a second receiving
25 cable 602b. The first receiving cable 601b receives and transmits a first reflected laser beam corresponding to the first frequency band. The second receiving cable 602b receives and transmits a second reflected laser beam corresponding to the second frequency band.

- Accordingly, as shown in **Figure 5**, the reflection chamber 50 comprises at least two mirrors 54a, 54b positioned one after the other along the longitudinal axis of the reflection chamber
30 50. A first mirror 54a is configured to reflect the first generated laser beam and a second

mirror 54b is configured to reflect the second generated laser beam. Further, the detector 70 comprises a second focusing lens 74 for focusing a plurality of reflected laser beams including the first reflected laser beam and the second reflected laser beam. In an embodiment, the detector 70 may include a second collimation lens assembly (not shown).

- 5 The positioning and the stability of the various components within the tubular probe, including the cables, the lenses, the mirror can be provided using clamps, brackets, and the like, known in the art.

Preferably, the optical tubes 60 of the tubular probe of the present disclosure have a reflective internal surface. The optical tubes 60 are hollow fiber/glass tubes having silver coating on the
10 internal surface. In another embodiment, the optical tubes 60 are hollow waveguide made of chalcogenic cylindrical raw material such as As-Se, As-Se-Te or Ge-Sb-Se, or are hollow waveguides. The property of having a reflective internal surface prevents the distortion due to diffraction, scattering, and so on, of the light that is transmitted through the optical tubes 60 due to any surrounding gases. Due to the low attenuation factor (measured in dB/m) of the
15 optical tubes 60, the range of the tubular probe of the in-situ gas analysis system 1000 of the present disclosure increases significantly as compared to in-situ gas analysis systems of the prior art. Accurate analysis of flue gases produced in chambers having depths of 10m and beyond can be done using the in-situ gas analysis system 1000 of the present disclosure.

In a typical embodiment, the length of the measurement zone 40 is 0.5m, whereas the length
20 of the dead zone can be extended significantly due to the low attenuation factor of the optical tubes 60. Thus, the in-situ gas analysis system 1000 of the present disclosure requires optical alignment to be maintained only in a measurement zone of typically 0.5m. Also, the optical source 20 can be arranged at a sufficient distance from the combustion chamber so that no system for cooling the light sources is required. Moreover, low-cost mirrors can be used in
25 the reflection chamber 50, thereby avoiding the use of the corrosion-resistant mirrors used in the prior art and saving almost three times the cost.

The processing unit may include a repository for storing information such as chemical formulae of gaseous and suspended solid components expected to be detected in the flue gases. The processing unit may include an analog-to-digital convertor, a digital filter module,
30 a time-domain-to-frequency-domain conversion module, a crawler-and-extractor module and so on. The digital filter module may be configured to subject the detected signal to a band-

pass filter, an anti-aliasing filter, a noise removal filter and the like. The time-domain-to-frequency-domain conversion module is configured to convert the data from time domain to frequency domain. The crawler-and-extractor module is configured to compare processed data to the information stored in the memory and identify composition of the flue gas,
5 including contained gases, their proportions by weight and so on.

The foregoing description of the embodiments has been provided for purposes of illustration and not intended to limit the scope of the present disclosure. Individual components of a particular embodiment are generally not limited to that particular embodiment, but, are interchangeable. Such variations are not to be regarded as a departure from the present
10 disclosure, and all such modifications are considered to be within the scope of the present disclosure.

TECHNICAL ADVANCEMENTS

The present disclosure described hereinabove has several technical advantages including, but not limited to, the realization of a system for in-situ gas analysis, which:

- 15 • prevents drop in accuracy due to vibration, diffraction, and scattering (x10);
- requires optical alignment to be maintained only in measurement zone typically 0.5 meters;
- uses lower-cost optical element instead of corrosion resistance mirrors;
- allows placement of the source far from the high-temperature zone;
- 20 • does not require transportation of sampling of gases from the source to the analyser located 10-30m away and hence does not lead to change in the stoichiometry of gases due to sampling; and
- does not require conditioning of the gases to be analyzed.

The foregoing disclosure has been described with reference to the accompanying
25 embodiments which do not limit the scope and ambit of the disclosure. The description provided is purely by way of example and illustration.

The embodiments herein and the various features and advantageous details thereof are explained with reference to the non-limiting embodiments in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended
5 merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

The foregoing description of the specific embodiments so fully reveal the general nature of
10 the embodiments herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is
15 for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

The use of the expression “at least” or “at least one” suggests the use of one or more elements
20 or ingredients or quantities, as the use may be in the embodiment of the disclosure to achieve one or more of the desired objects or results.

Any discussion of documents, acts, materials, devices, articles or the like that has been included in this specification is solely for the purpose of providing a context for the disclosure. It is not to be taken as an admission that any or all of these matters form a part of
25 the prior art base or were common general knowledge in the field relevant to the disclosure as it existed anywhere before the priority date of this application.

While considerable emphasis has been placed herein on the components and component parts of the preferred embodiments, it will be appreciated that many embodiments can be made and that many changes can be made in the preferred embodiments without departing from the
30 principles of the disclosure. These and other changes in the preferred embodiment as well as other embodiments of the disclosure will be apparent to those skilled in the art from the

disclosure herein, whereby it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the disclosure and not as a limitation.

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