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[54] **GAS DENSITOMETER**

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[52] **U.S. Cl.** **356/201,** 356/206, 250/218

[51] **Int. Cl.** **G01n 21/22**

[58] **Field of Search** 356/87, 74, 206, 201; 250/218

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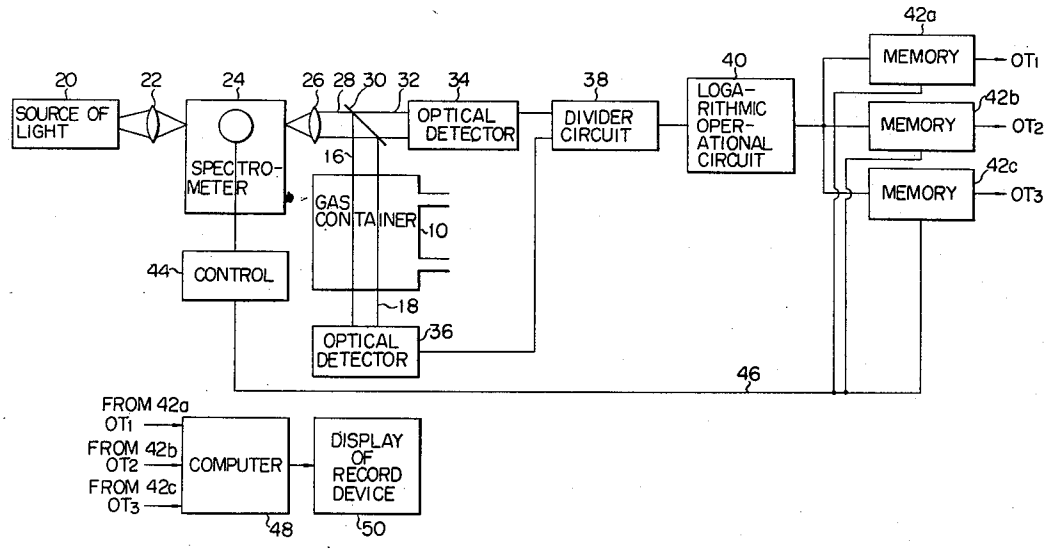
[57] **ABSTRACT**

A beam of light traverses a gas container including three gases whose concentrations are to be successively measured at their absorption wavelengths. The intensity of the traversed light divided by an intensity of a corresponding reference light provides a transmission T of the container with the gases presented to the associated light. A value of $\log_e 1/T$ is calculated by a logarithmic operational circuit and stored in a memory. The above process is repeated in synchronization with a change in wavelength to store the calculated values in respective memories. The stored values of $\log_{e\ 1/Tj}$ where $j=1, 2, 3 \ldots$ are supplied to a computer where the concentrations N's of the gases 1, 2, and 3 . . . are computed following the equations

$$\sum_{i=1}^{n} N_i \sigma_{ij} L \log_e \frac{1}{T_j} \qquad j=1, 2, 3$$

where L = length of container traversed by light σ_{ij} = cross-sectional area for absorption of gas i for light at wavelength λ_j.

3 Claims, 3 Drawing Figures



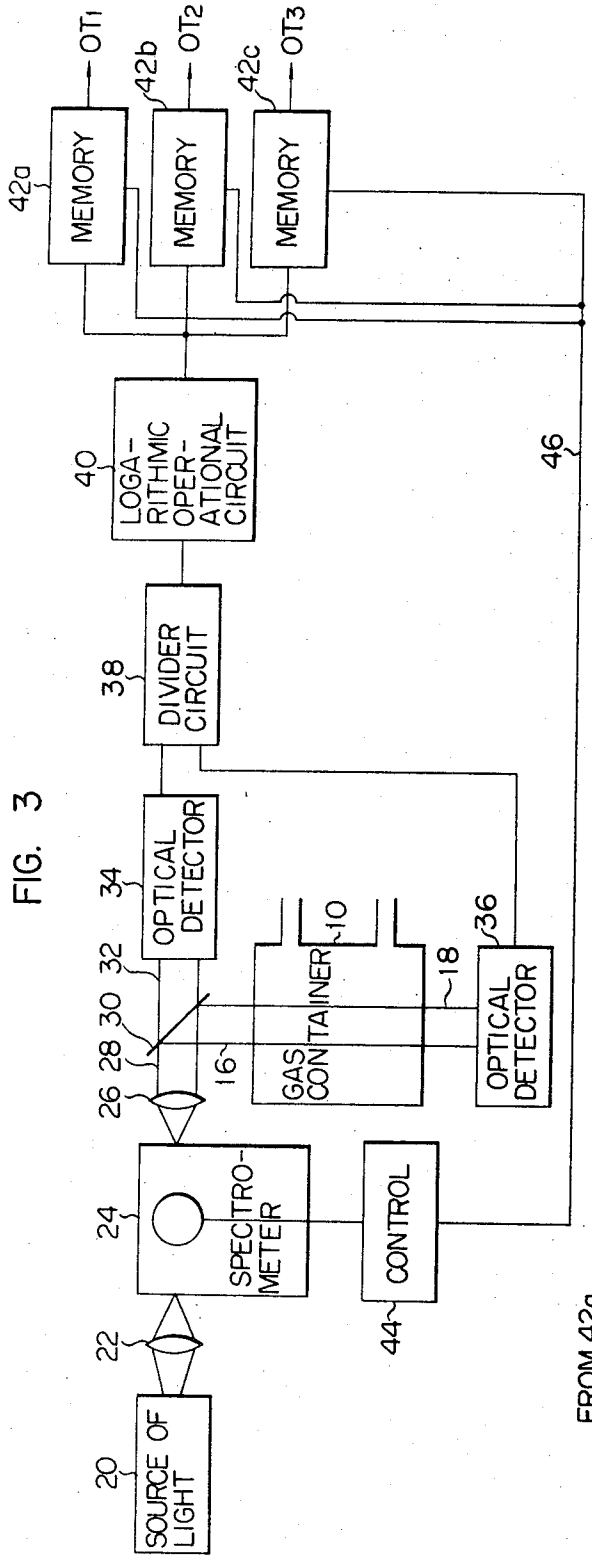

OT1
OT2
OT3
42a
42b
42c
MEMORY
MEMORY
MEMORY
40
LOGA-
RITHMIC
OPER-
ATIONAL
CIRCUIT
46
38
DIVIDER
CIRCUIT
34
OPTICAL
DETECTOR
32
30
28
26
16
GAS
CONTAINER
10
18
36
OPTICAL
DETECTOR
24
SPECTRO-
METER
CONTROL
44
22
20
SOURCE OF
LIGHT
DISPLAY
OF
RECORD
DEVICE
50
48
COMPUTER
FROM 42a
OT1
FROM 42b
OT2
FROM 42c
OT3

FIG. 3

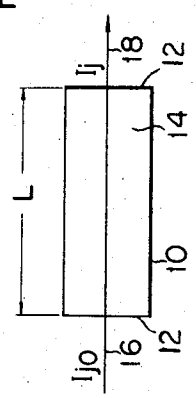
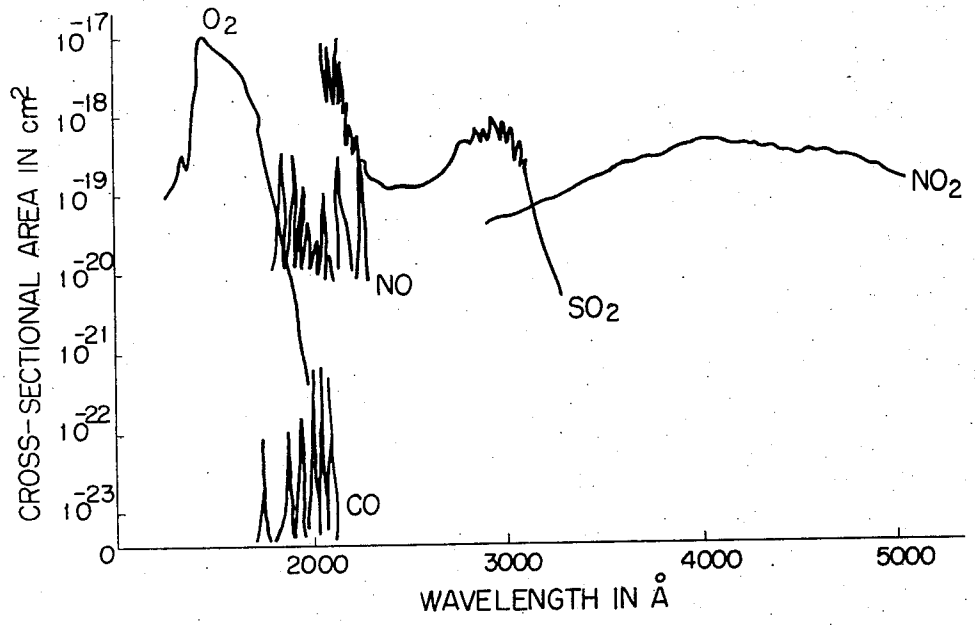

Ij
18
12
14
L
10
16
12
Ijo

FIG. 1

FIG. 2


O_2
NO
SO_2
NO_2
CO
CROSS-SECTIONAL AREA IN cm^2
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
0
2000
3000
4000
5000
WAVELENGTH IN Å

GAS DENSITOMETER

BACKGROUND OF THE INVENTION

This invention relates to a gas densitometer for selectively sensing several types of gases and detecting their concentrations.

In the past, there have been developed various types of devices for measuring a concentration of a particular gaseous ingredient contained in any gas. Among them there is representatively known the infrared non-dispersion type of gas densitometers utilizing the absorption bands appearing in the infrared region of the radiation spectrum. As this type of gas densitometer includes no wavelength selective means, it is very stable in operation unless the particular gas includes any disturbing gaseous ingredient having an absorption band at least overlapping an absorption band of that gaseous ingredient to be detected. However, the presence of such a disturbing gaseous ingredient in the gas causes an error in measurement or detection. In general, infrared absorption bands are spread over different ranges of infrared wavelengths and each band is relatively broad. This has resulted in an increase in a probability of overlapping the absorption bands of different gases on each other. Also gas detectors of the prior art type have been designed to detect special gases prescribed thereto respectively. Therefore each of those gas detectors is prevented from simultaneously detecting several gaseous ingredients in a gaseous mixture.

On the other hand, public attention has been lately directed to the fact that gaseous sulfur dioxide, nitrogen oxides etc. contained in the flue gas cause contamination of the atmosphere leading to the necessity of measuring concentrations of those gases. Thus it has been forced to simultaneously use a plurality of infrared gas densitometers one for each of gaseous ingredients because each of the densitometers is enabled to detect a single gas inherent thereto as above described.

SUMMARY OF THE INVENTION

Accordingly it is an object of the invention to provide a new and improved gas densitometer device free from the cumbersomeness as above described and enabled to detect a plurality of different gases.

It is a special object of the invention to provide a new and improved gas densitometer device particularly effective for simultaneously detecting gaseous sulfur dioxide, nitric oxide and nitrogen dioxide contained in the atmosphere to contaminate it.

The invention accomplishes these objects by the provision of a gas densitometer device comprising a source of light for emitting a beam of light having a continuous radiation spectrum, optical separator means for receiving the beam of light from the source to selectively deliver beams of light at different wavelengths, collimator lens means for forming the beam of light delivered by the optical separator means into a parallel beam of light, beam splitter means for dividing the parallel beam of light from the collimator lens means into two beam portions. A gas container having circulating therethrough a gaseous mixture including a plurality of gaseous ingredients overlapping in resonant absorption bands one another, the gas container being disposed at its position where one of the split portions from the beam splitter means traverses the container with the gaseous ingredients, optical detector means responsive

to the beam portion coming out from the gas container to provide an electrical signal representative of an intensity thereof, another optical detector means responsive to the other beam portion from the beam splitter means to provide an electrical signal representative of an intensity thereof, and means applied with the electrical signals from both optical detector means to measure a transmission of the gas container with the gaseous ingredients presented to the associated light on the basis of a ratio of magnitude between both electrical signals, characterized by control means operatively coupled to the optical separator means to control the wavelength of the beam delivered therefrom, a plurality of memory means connected to the transmission measuring means one for each of the gaseous ingredients to be measured, the plurality of memory means being controlled by the control means to successively store the outputs from the measuring means corresponding to different wavelengths selected by the control means, and computer means connected to the plurality of memory means to compute the concentrations of the gaseous ingredients from the outputs from the plurality of memory means.

In a preferred embodiment of the invention, the transmission measuring means may include a divider circuit for producing an output representative of the magnitude of the electrical signal from the first mentioned optical detector divided by the magnitude of the electrical signal from the second optical detector means, and a logarithmic operational circuit connected to the divider circuit to calculate $\log_e 1/T_j$ where T_j is a transmission of the gas container with the gaseous ingredients presented to that light at a wavelength λ_j where $j=1, 2, 3, \ldots$ The computer means is adapted to compute the respective concentrations N_i of the gaseous ingredients following the equations

$$\sum_{i=1}^{n} N_i \sigma_{ij} l = \log_e \frac{1}{T_j} \qquad j=1,2,\ldots,n$$

where L is a length of the gas container traversed by light and σ_{ij} is a cross-sectional area for absorption of the ith gaseous ingredient for light a wavelength λ_j.

BRIEF DESCRIPTION OF THE DRAWING

The invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatic view of a gas container useful in explaining the principles of the invention;

FIG. 2 is a graph illustrating cross-sectional areas for resonant absorption of some gases plotted against a wavelength of radiation; and

FIG. 3 is a block diagram of a gas densitometer constructed in accordance with the principles of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawings, it is seen that an arrangement disclosed herein comprises a gas container **10** closed at the opposite ends with a pair of end plates **12** of any suitable light transparent material and having a longitudinal dimension of L. The container **10** is filled with a gaseous mixture **14** consisting of; three gaseous ingredients having respective concentrations of N_1, N_2 and N_3. Under these circumstances, a beam of light **16** having a wavelength of λ_j falls upon

one of the end plates **12** for example, the lefthand end plate as viewed in FIG. **1**, and passes through the container **10** with the gaseous mixture **14** until it appears from the other or righthand end plate **12** as an exit beam **18.** Assuming that the incident beam of light has an intensity of I_{j0}, the exit beam will decrease to its intensity I_j due to the absorption by the gaseous mixture **14.**

For the purpose of illustration it is assumed that the beam of light is not absorbed by nor reflected from both end plates **12** of the container **10.** Under the assumed condition the gas container **10** with the gaseous mixture **14** has a transmission or a penetrating power T_j expressed by the following equation:

$$T_j = \frac{I_j}{I_{j0}} = \exp\left(-\sum_{i=1}^{3} N_i \sigma ijL\right) \quad (1)$$

were σ_{ij} is a cross-sectional area for resonant absorption at a wavelength λ_j exhibited by the ith gaseous ingredient having the concentration of N_i. The equation (1) results from the Lambert-Beer's equation well known in the art and can be transformed into the equation

$$\sum_{i=1}^{n} N_i \sigma_{ij} l = \log_e \frac{1}{T_j} \quad (2)$$

In the equation (2), the σ_{ij} and L can be preliminarily measured and therefore they are known. After the σ_{ij} and L have been measured, the measurement of the transmission T_j at three wavelengths λ_j where j=1, 2, 3) permits the concentration N_i where i=1, 2, 3) to be calculated in accordance with the equation (2). This calculation is to solve three simultaneous linear equations with respect to T_j and therefore an analog computation circuit can be used to obtain the solution in easy manner. If desired, a digital computer may be used for the same purpose.

As above described, public attention has been lately directed to causes from which the atmosphere is contaminated. It is well known that the flue gas includes nitrogen, oxygen, carbon dioxide, carbon monoxide, water vapor, sulfur dioxide nitric oxide, nitrogen dioxide etc. in the form of gases. Among them, the carbon monoxide, gaseous sulfur dioxide, nitric oxide, nitrogen dioxide are desirable to be measured in concentration in view of the standpoint of contaminating the atmosphere.

FIG. **2** shows absorption spectra exhibited by oxygen (O_2), carbon monoxide (CO), nitric oxide (NO), gaseous sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). As shown in FIG. **2,** carbon monoxide and oxygen have individual absorption bands very low in absorbing power in a wavelength band around 2,000A. This is true in the case of nitrogen, gaseous carbon dioxide and water vapor. On the contrary, gaseous sulfur dioxide, nitric oxide and nitrogen dioxide have respective absorption bands relatively high in absorbing power in the wavelength band around 2,000A. However carbon monoxide is small in cross-sectional area and has absorption wavelengths short enough to make it difficult to provide a suitable source of radiation at such short wavelengths. Thus in some cases carbon monoxide may be difficult to be measured in concentration.

With the particular gaseous mixture including nitrogen dioxide (NO_2), gaseous sulfur dioxide (SO_2) and nitric oxide (NO) to be measured in concentration, it is assumed that in the above equation (2) the NO_2, SO_2 and NO are identified by the i's having values of 1, 2 and 3 respectively. Under the assumed condition, it is apparent from FIG. **2** that if a wavelength at which absorption is measured is selected to be of about 4,000A that the measured absorption results only from the NO_2 but not from the SO_2 and NO. Alternatively if such a wavelength is selected to be of about 3,000A at which the SO_2 gives the absorption effect then absorption by the NO does not occur. Therefore the σ's can be selected such that σ_{21}, σ_{31}, and σ_{32} all are null. This results in the simplification of an analog computation circuit used to compute concentrations of gaseous ingredients.

Referring now to FIG. **3,** there is illustrated a gas densitometer constructed in accordance with the principles of the invention. The arrangement illustrated comprises a source of light **20** for emitting a beam of light having wavelengths at which gases to be measured exhibites resonant absorption lines or bands. The beam of light is incident upon a lens **22** which focuses it upon a spectrometer **24** serving as a light separator for selectively extracting beams of light having wavelengths of resonant absorption for gases involved. The extracted beam falls upon a collimator lens **26** to be formed into a parallel beam of monochromatic light **28** which, in turn, goes to a beam splitter shown as being a semitransparent mirror **30** where the beam is split into two portions. More specifically one portion of the beam is reflected from the mirror **30** to form a beam of light **16** to be measured arranged to fall upon a gas container **10** such as shown in FIG. **1** having circulating therethrough a gaseous mixture including gaseous ingredients to be measured. The other portion of the beam passes through the mirror **30** to form a reference beam of light **32.**

The reference beam of light **32** passes to an optical detector **34** to be converted to an electrical signal representing an intensity thereof. The beam of light **16** traverses the gas container **10** to be absorbed by the particular gaseous ingredient within the container, until it leaves the latter as a beam of light **18** decreased in intensity. This beam of light **18** falls upon another optical detector **36** to be converted to an electrical signal representative of the decreased intensity thereof.

Then the electrical signals from both optical detectors **34** and **36** are applied to a divider circuit **38** which produce a ratio of magnitude therebetween. It is here noted that the intensities of the reference beam **32** and beam **16** to be measured and the sensitivities of the optical detectors **34** and **36** should be preliminarily selected to render that ratio of magnitude to equal to the T_j expressed by the equation (1). The output from the divider circuit **38** is applied to a logarithmic operational circuit **40** where $\log_e 1/T_j$ on the righthand side of the equation (2) is computed. The output of the logarithmic operational circuit **40** is connected to three memory circuits **42***a*, **42***b* and **42***c*.

As shown in FIG. **3,** a control device **44** is operatively coupled to the spectrometer **24** to control the wavelength of the beam coming out from the latter. Each time the wavelength of the beam emerging from the spectrometer **24** is successively equal to the desired absorption wavelengths, λ_j where j=1, 2, 3, the control device **44** delivers a control signal **46** to a corresponding one of the memories circuit **42***a*, **42***b* and **42***c*. At

the same time that value of $\log_e 1/T_j$, calculated at the wavelength λ_j by the circuit **40** is applied to that corresponding memory circuit to be stored therein. For example, when the spectrometer **24** provides a beam of light at a wavelength λ_1 as controlled by the control device **44**, a corresponding value of $\log_e 1/T_1$ from the logarithmic operational circuit **40** is applied to the memory **42***a* while at the same time the control device **44** applies the control signal to the memory circuit **42***a* with the result that that value of $\log_e 1/T_1$ is stored in the memory **42***a*. Similarly the memory circuit **42***b* stores a value of $\log_e 1/T_2$ corresponding to a wavelength of λ_2 and then the memory circuit **42***c* stores a value of $\log_e 1/T_3$ corresponding to a wavelength of λ_3.

Thereafter the outputs OT_1, OT_2 and OT_3 from the memory circuits **42***a*, **42***b* and **42***c* are supplied to a computer circuit **48** which may be of the analog type. The computer circuit **48** is operative to solve the simultaneous liner equations (2) with respect to the concentration N_1, N_2 and N_3 of the gaseous ingredients whereupon the computation is completed to determine the concentrations. The result of the computation can be displayed and also recorded by a combined display and record device **50**.

While the invention has been illustrated and described in conjunction with a single preferred embodiment thereof it is to be understood that numerous changes in the details of construction and the form and arrangement of parts may be resorted to without departing from the spirit and scope of the invention. For example, the spectrometer may be replaced by an interference filter. The invention is equally applicable to any of gaseous mixtures including gaseous ingredients of any desired number other than three.

What is claimed is:

1. A gas densitometer device for measuring a concentration of at least two of the gases sulfur dioxide (SO_2) nitric oxide (NO) and nitrogen dioxide (NO_2) contained in a flue gas comprising, in combination, a source of light for emitting a beam of light having a continuous radiation spectrum, optical separator means for receiving the beam of light from said source to selectively extract beams of light at least at two wavelengths of resonance absorption selected from three wavelengths of about 3000A, about 2000A and about 4000A of peak absorption respectively for sulfur dioxide (SO_2), nitric oxide (NO) and nitrogen dioxide (NO_2) to be measured, a collimator optical system for forming the beam of light extracted by said optical separator means into a parallel beam of light, beam splitter means dividing the parallel beam of light from said collimator system into two equal beam portions, a gas container having circulating therethrough gases to be measured and having absorption bands overlapping each other, said gas container being disposed at a position where one of the split beam portions from said beam splitter means traverses axially said gas container, optical detector means responsive to the beam portion emitting from said gas container to produce an electrical signal representative of an intensity thereof, another optical detector means responsive to the other beam portion from said beam splitter means to produce an electrical signal representative of an intensity thereof, measuring means applied with the electrical signals from both said optical detector means to measure a transmission of said gas container with the gases to be measured at each of said wavelengths of resonance absorption for the gases to be measured on the basis of a ratio of intensity between both said electrical signals, three memory means one for each of the gases to be measured to individually store the measured magnitudes of the transmission from said measuring means in response to the wavelengths of resonance absorption for the gases to be measured, control means connected to said optical separator means and said three memory means for controlling the wavelength of the beam of light extracted by said optical separator means and for enabling each of said memory means in synchronism with changes in wavelength of the beam of light extracted by said optical separator means for storing the measured transmission of the flue gas measured at each of said wavelengths of resonance absorption and computation means connected to said plurality of memory means to compute concentrations of the gases to be measured by the following equation:

$$\left[\sum_{i=1}^{3} N_i \lambda_{ij} l = \log_e \frac{1}{T_j}\right], j = \text{number of wavelengths}$$

$$\sum_{i=1}^{3} N_i \sigma_{ij} l = \log \frac{1}{T_j}$$

where T_j is a transmission of said gas container with said gases to be measured at a *j*th wavelength of resonance absorption for each of said gases, N_i a concentration of one of said gases, σ_{ij} a cross sectional area for absorption of the *i*th gas to be measured, and L is a length of said gas container traversed by light.

2. A gas densitometer device as claimed in claim **1**, wherein said optical separator means is a spectrometer.

3. A gas densitometer device as claimed in claim **1**, wherein said optical separator means is interference filter means.

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