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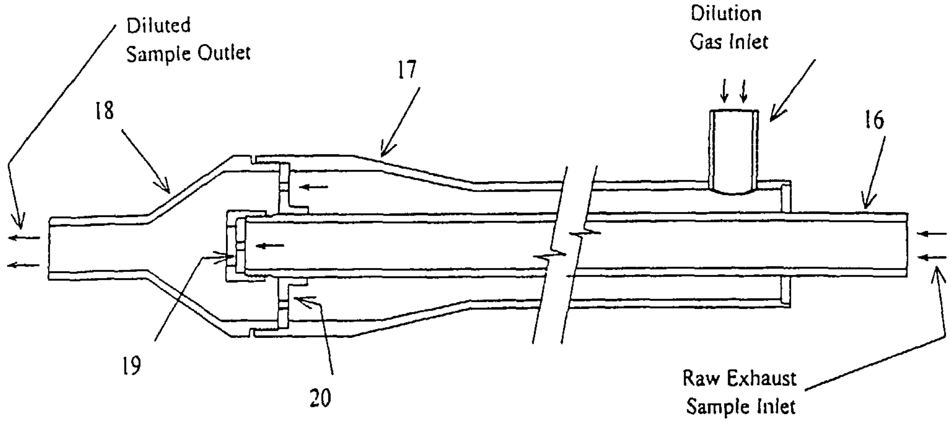
(54) **Title:** ASSEMBLY AND METHOD FOR MIXING GASES



(57) **Abstract:** A method of raw exhaust drawn from a raw exhaust stream (16) is mixed with a diluting gas in a predetermined constant proportion by introducing the raw exhaust sample and diluting gas into respective inlet means and passing the raw exhaust sample and the diluting gas through a plurality of apertures (19, 20) into outlet means for receiving the mixture. The proportion of raw exhaust sample to diluting gas is determined by the ratio of the total area of the apertures through which the raw exhaust sample is passed to the total area of the apertures through which the diluting gas is passed.

WO 02/070116 A1

"ASSEMBLY AND METHOD FOR MIXING GASES"

Technical field

This invention relates to a method of and an assembly for mixing gases.

The invention has particular application to a method of and an assembly for mixing gases when sampling, pre-conditioning and measuring the concentrations and mass flow of gases and/or fine particle levels in a fluid stream.

The invention has particular but not exclusive application to the mixing of raw exhaust and a diluting gas in the measurement of concentrations and mass flow of gases and/or fine particles in the exhaust stream of a combustion process.

It is to be understood that reference to gas and gases herein includes reference to gases carrying particulate material.

For illustrative purposes the invention will be described with reference to internal combustion engines.

Background of Invention

Over recent years, health and environmental authorities around the world have placed increased emphasis on reducing the adverse health impacts of airborne particulate and gaseous pollutants.

Research has shown that exhaust emissions from motor vehicles and other equipment using internal combustion engines are a dominant source of many pollutants of concern. Most notable of these are fine particulates and a range of chemical substances that combine to precipitate the formation of photochemical smog.

Industrial processes, domestic and industrial heating systems, electrical power generation plants and other processes involving combustion or the release of chemicals to the atmosphere also contribute to undesirable levels of airborne pollutants.

Particulate emissions, most commonly from diesel internal combustion engines, have been widely acknowledged to be one of the most significant pollutant health threats to humans. Diesel particulate emissions, comprising a mixture of very finely divided carbonaceous matter, sulfates and highly toxic compounds, are carcinogenic and can affect the neurological and reproductive systems of humans.

Although research-grade laboratory instrumentation and test methods for diesel emissions have been developed, they are very expensive and time-consuming, making them unsuitable for use or adaptation to the low-cost, high volume measurements required to rapidly assess the emissions performance of in-use vehicles and industrial plant.

To accurately and repeatably measure gaseous and particulate emission rates in an exhaust flow, it is preferable, inter alia that:

- total exhaust mass flow rate be accurately measured or controlled;
- the exhaust sample be pre-conditioned to meet specified temperatures in order to achieve correct particulate formation; and
- vapour-to-liquid condensation in sample lines and/or measuring equipment be avoided.

The most commonly used known method of meeting the above criteria is to entrain the full exhaust stream (or a known portion of the stream) with a flow of dilution air, and to draw the sample/diluent mixture through a critical flow venturi such that the sum of the instantaneous exhaust flow, plus the dilution air flow, remains constant. This is known as a Constant Volume Sampler. Depending on the level of dilution required, a two-stage, or secondary dilution tunnel is frequently employed, together with its own mass-flow controllers and measurement systems.

FIG 1 schematically illustrates a known Constant Volume Sampling Emissions Measuring System. Note that, for ease of understanding, details of the emissions measuring instrumentation and any mass flow controllers and sensors associated with the primary and secondary dilution tunnels have been omitted from FIG 1.

Although the total flow through the venturi remains constant, the flow rate of the raw exhaust gas stream entering the dilution tunnel may vary considerably over the sampling period. Hence this arrangement can be characterised as a "constant volume, variable dilution" system.

The known method achieves three outcomes:

- the critical flow (sonic) venturi maintains a nominally constant (and known) total flow of sample/diluent mixture;
- if the sample exhaust is hot (as is often the case) the dilution air can reduce the temperature of the mixture to a level that published standards require for valid measurements to be obtained (ie, below 52deg Celsius for diesel particulate matter measurement); and
- provided the dilution air is relatively dry and the dilution ratio is sufficiently high, the sample mixture will remain above the dew point of water vapour and thus avoid water condensation in the sample lines.

After suitable pre-conditioning as outlined above, the sample mixture may be analysed using known gaseous and particulate measuring systems to determine the concentration of each emission of interest. Multiplying the total exhaust/diluent flow rate by the concentration of pollutant, either on a second-by-second basis or integrated over a period of time, delivers a mass emission rate for the whole exhaust stream.

Alternatively, a sample of the diluted exhaust stream may be drawn off, at a constant volumetric rate, into a bag or similar receptacle over the required total sampling period. In this case, the concentration of emissions measured as a homogenous mixture in the sample bag, multiplied by the total flow through the venturi over the sampling period, delivers the total emissions of each pollutant over the same period.

Summary of Invention

The present invention aims to provide an alternative to known methods of and apparatus for mixing raw exhaust with a diluting gas.

In one aspect this invention resides broadly in an assembly for mixing a sample of raw exhaust drawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, the assembly including:-

respective inlet means for receiving the raw exhaust sample and the diluting gas and outlet means for receiving the mixed raw exhaust sample and diluting gas, and

a plurality of apertures for having passed through respective ones thereof the raw exhaust sample and the diluting gas;

wherein the predetermined proportion is the ratio of the total area of the apertures for having passed through the raw exhaust sample to the total area of the apertures for having passed through the diluting gas.

In another aspect this invention resides broadly in a method of mixing a sample of raw exhaust drawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, the method including:-

introducing the raw exhaust sample and diluting gas into respective inlet means, and

passing the raw exhaust sample and the diluting gas through a plurality of apertures into outlet means for receiving the mixed raw exhaust sample and diluting gas;

the proportion of raw exhaust sample to diluting gas being determined by the ratio of the total area of the apertures through which the raw exhaust sample is passed to the total area of the apertures through which the diluting gas is passed.

It is preferred that the apertures are substantially identical.

It is also preferred that the assembly includes baffle plate means the apertures forming passages therethrough.

It is preferred that the baffle plate means separates the inlet means and the outlet means.

It is preferred that the number of apertures through which the raw exhaust sample and diluting gas are respectively passed is in the proportion in which the raw exhaust sample and diluting gas are to be mixed.

It is preferred that the inlet and outlet means comprise coaxial pipes or the like whereby the temperature of the raw exhaust sample and diluting gas is substantially equalised prior to mixing.

It is preferred that the assembly includes flow rate control means for controlling the flow rate of the mixed raw exhaust sample and diluting gas.

It is also preferred that the flow rate control means includes pump means for applying a negative pressure to the mixed raw exhaust sample and diluting gas.

In another aspect this invention resides broadly in an assembly for mixing a sample of raw exhaust drawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, the assembly including:-

respective inlet means for receiving the raw exhaust sample and the diluting gas and outlet means for receiving the mixed raw exhaust sample and diluting gas;

baffle plate means separating the inlet means and the outlet means, and

a plurality of substantially identical apertures in the baffle plate means for having passed through respective ones thereof the raw exhaust sample and the diluting gas;

wherein the predetermined proportion is the ratio of the number of apertures through which the raw exhaust sample and diluting gas are respectively passed.

Description of Drawings

In order that this invention may be more easily understood and put into practical effect, reference will now be made to the accompanying drawings which illustrate a preferred embodiment of the invention, wherein:-

- **FIG 2** is a schematic diagram showing the elements of the invention connected to an internal combustion engine exhaust system

- **FIG 3** is a sectioned diagram of an example of a diluter for mixing a controlled portion of the raw exhaust stream with a controlled amount of diluent gas.

Description of Preferred Embodiment of Invention

Referring to FIG 2, in this example the internal combustion engine exhaust pipe (1) is connected via a gas-tight sleeve (2) to a length of flexible hose (3). This hose is, in turn, connected to a circular duct (4), of sufficient length to minimise turbulence and to establish substantially laminar flow of the exhaust stream.

Towards the outlet end of the duct an averaging pitot-static tube assembly (5) is positioned to sense the stagnation and static pressures in the duct created by flow of the exhaust gases. The pitot-static outputs are in turn connected to a differential pressure transducer (6), which measures the difference between the stagnation and static pressures in the duct.

A fast-response thermocouple and associated signal conditioning assembly (7) measures the temperature of the exhaust stream in the duct.

Both the differential pressure transducer and the thermocouple outputs are transmitted to a computer (not shown), which uses the measurements to calculate the instantaneous average velocity of the exhaust stream and hence, as the diameter of the duct is known, the mass flow of exhaust in the duct.

A sample line (8) allows a portion of the exhaust stream to be directed to the various analysers and instruments used to measure emissions of interest. This sample line may be heated or insulated, as required, to prevent precipitation of water in the line through condensation due to cooling of the sample.

A known exhaust opacity meter (9) may optionally be connected to the sample line to continuously or periodically measure opacity (visible smoke) levels of the exhaust stream.

Known low-cost gas analysers (11), suitable for measuring gaseous concentrations of specific gases in a raw exhaust stream, may also be arranged to communicate with the sample line. In this example, the sample for gaseous analysis is first passed through a filter (10) to remove smoke and particulates which could contaminate the optical systems in the gas analyser(s). An arrangement for drying or de-watering the gaseous sample (not shown) may optionally be fitted in series with the filter.

For measurements of fine particulate matter in the exhaust stream, a sample of the exhaust stream is drawn through a diluter assembly (12) described in more detail below with reference to FIG 3. The diluted stream is then conducted to a known means of measuring particulate matter concentration (14).

Dilution of the raw exhaust sample is achieved using a suitable, substantially non-reactive gas such as dry nitrogen or dried and filtered air. If ambient air is at low relative humidity levels, it is feasible to only filter the air to remove background particulate contamination.

A pump (15), optionally a vane or diaphragm type, draws both the dilution gas and the exhaust sample through the diluter assembly, wherein the two streams are mixed in a known predetermined proportion.

Reference is now made to FIG 3 in order to more readily understand the operation of the diluter assembly. FIG 3 is a sectioned diagram of one embodiment of a diluter for mixing a controlled portion of the raw exhaust stream with a controlled amount of diluent gas.

Inner rigid tube (16) is connected to the raw gas sample line. An outer casing (17), is located substantially coaxial with the inner tube and is fitted with an inlet tube (23) for dilution gas towards the end in closest proximity to the raw exhaust sample inlet. A threaded cap (18) is connected to the outer casing (17) such that the assembly comprises a chamber, which is closed except for the two inlet tubes and one outlet tube.

The threaded cap and the outer casing locate and engage an orifice plate (20), which, through the use of appropriate seals (not shown) permits the axial flow of dilution gas only through a number of small holes (21) normal to the face of orifice plate (20). The orifice holes (21) may optionally be arranged in a circular pattern coaxial with the body of the diluter assembly.

At the downstream end of the raw exhaust sample tube, a second orifice plate (19) is retained by a threaded cap and again sealed to only permit the axial passage of exhaust sample through one or more small orifice holes (22) normal to the face of orifice plate (19).

This arrangement allows ready dismantling and cleaning, as necessary, of any components likely to require maintenance.

It is convenient, but not essential, that both orifice plates are of the same thickness and that all orifice holes are of substantially the same diameter and finish.

Both the dilution gas line and the raw exhaust sample line are arranged such that they are maintained at substantially ambient atmospheric pressure.

In operation, a negative pressure is applied to the diluted sample outlet of the diluter assembly, using a suitable pumping means (15). Because this negative pressure acts on both orifice plates (19 & 20) and their corresponding orifice holes (22 and 21), an axial flow of raw exhaust sample and dilution gas is induced.

Because in this example the differential pressure applied to each orifice plate, the thickness of each orifice plate, and the orifice hole geometry in each plate are all substantially the same, the flow rate of dilution gas relative to the flow rate of exhaust sample will be predetermined and in the ratio of the number of orifice holes in each plate, respectively. This predetermined dilution ratio will be maintained regardless of the actual level of pressure differential applied.

To minimise the potential for differences in temperature between the dilution and sample streams to cause differences in flow rates across the orifice holes, the dilution and sample streams in this example run coaxially for a suitable distance prior to passing through the orifices. This technique promotes temperature equalisation between the two streams.

If operating circumstances dictate, insulation or external heating, or both, may be applied to the sample tubes, dilution gas tubes and/or diluter body to avoid the exhaust sample from reaching a temperature lower than its dew point.

It will thus be appreciated that the present invention in the above described preferred embodiments:

- controls diluent and raw exhaust sample flow rates using passive flow control devices capable of operating at low pressure differential, thereby avoiding the need for a venturi and high-pressure generating devices, and

provides a constant and predetermined dilution ratio between the raw exhaust sample and the diluent gas.

For the measurement of particulate concentrations a tubular sample probe, or the like, is arranged in the emissions measuring apparatus to conduct a portion of the exhaust stream to a means of diluting the exhaust stream with a known proportion of suitable dilution gas.

The dilution means is arranged such that the predetermined ratio of diluent to exhaust sample remains substantially constant regardless of the temperature and/or pressure of the diluent and the exhaust sample.

The means for controlling the flow of both exhaust sample and diluent gas also includes means for mixing the exhaust sample and the diluent in such a manner as to achieve a substantially homogenous mixture that is at a temperature consistent with that prescribed in applicable standards or regulations pertaining to the measurement of particles in an exhaust stream.

The predetermined ratio of diluent gas to exhaust sample is controlled at a rate such that the dew point temperature of the mixture is lower than the actual temperature of the mixture as it passes into and through the particulate measuring instrument. This ensures that particulates in the sample stream are not entrapped by condensed vapours in the sample line, nor can small condensed water particles entrained in the sample stream lead to erroneous particle concentration measurements.

The total volumetric flow rate of diluent/exhaust sample mixture is limited to only what is required for correct operation of the known particulate emissions measuring instrument or apparatus.

It will be appreciated that the present invention, which provides a reliable and accurate measurement of emission rates of fine particulates in the exhaust stream of combustion processes, has a number of advantages over known systems and methods.

The present invention provides a significant advance in the performance/cost ratio of emissions measuring equipment by enabling the use of both raw and diluted exhaust stream measurement in a single unit.

The system and its principal components described above constitute a compact, simple, reliable and low cost alternative to existing arrangements for measuring, controlling and pre-conditioning the flow of exhaust constituents prior to determining the concentration of emissions in the stream using known emission measuring instruments.

For example, the present invention does not require the use of large, bulky and expensive ducts, fans and venturi as are commonly employed in existing systems utilised for similar tasks.

The present invention can, if required, be packaged into a compact, lightweight container capable of being lifted readily by a human and is thus highly suitable for remote site testing or on-vehicle measurements of emissions.

In addition, because the present invention has no moving parts except for a simple and rugged pump, the system is much more amenable to transportation than other arrangements that are simply miniaturised versions of the full-scale prior art described above.

Known equipment is expensive, complex, and can consume high levels of power to move large volumes of exhaust/diluent while generating a pressure differential across the venturi sufficient to achieve sonic conditions at the choke point.

Known systems are also, in general, physically large and typically require a laboratory at least 6 meters in length and several highly skilled operators. As a result, such systems are not readily adapted for use in mobile or on-site emission measurements. Miniaturised, partial flow versions have been developed, using the same physical principles, but these also are complex, expensive and have only very limited portability.

It will of course be realised that whilst the above has been given by way of an illustrative example of this invention, many modifications and variations thereto will be apparent to persons skilled in the art. For example the dilution gas and exhaust stream orifices may be arranged in alternative configurations to FIG 3. For instance the dilution orifices may be located on a cylindrical or conical section of the outer casing, such that their axes are directed towards the axis of revolution of the outer casing.

This and all such and other modifications and variations thereto, as would be apparent to persons skilled in the art, are deemed to fall in the broad scope and ambit of this invention as is hereinafter claimed.

The claims defining the invention are as follows:-

1. An assembly for mixing a sample of raw exhaust drawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, said assembly including:-

respective inlet means for receiving the raw exhaust sample and the diluting gas and outlet means for receiving the mixed raw exhaust sample and diluting gas, and

a plurality of apertures for having passed through respective ones thereof the raw exhaust sample and the diluting gas;

wherein the predetermined proportion is the ratio of the total area of the apertures for having passed through the raw exhaust sample to the total area of the apertures for having passed through the diluting gas.

2. An assembly as claimed in claim 1, wherein the apertures are substantially identical.

3. An assembly as claimed in claim 2, wherein the number of apertures through which the raw exhaust sample and diluting gas are respectively passed is in the proportion in which the raw exhaust sample and diluting gas are to be mixed.

4. An assembly as claimed in claim 3, wherein the inlet and outlet means comprise coaxial pipes or the like whereby the temperature of the raw exhaust sample and diluting gas is substantially equalised prior to mixing.

5. An assembly as claimed in claim 4, and including baffle plate means the apertures forming passages therethrough.

6. An assembly as claimed in claim 5, wherein the baffle plate means separates the inlet means and the outlet means.

7. An assembly as claimed in claim 6, and including:-

flow rate control means for controlling the flow rate of the mixed raw exhaust sample and diluting gas.

8. An assembly as claimed in claim 7, wherein the flow rate control means includes pump means for applying a negative pressure to the mixed raw exhaust sample and diluting gas.

9. A method of mixing a sample of raw exhaust drawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, said method including:-

introducing the raw exhaust sample and diluting gas into respective inlet means, and

passing the raw exhaust sample and the diluting gas through a plurality of apertures into outlet means for receiving the mixed raw exhaust sample and diluting gas;

the proportion of raw exhaust sample to diluting gas being determined by the ratio of the total area of the apertures through which the raw exhaust sample is passed to the total area of the apertures through which the diluting gas is passed.

10. An assembly for mixing a sample of raw exhaust withdrawn from a raw exhaust stream with a diluting gas in a predetermined constant proportion, said assembly including:-

respective inlet means for receiving the raw exhaust sample and the diluting gas and outlet means for receiving the mixed raw exhaust sample and diluting gas;

baffle plate means separating the inlet means and the outlet means, and

a plurality of substantially identical apertures in the baffle plate means for having passed through respective ones thereof the raw exhaust sample and the diluting gas;

wherein the predetermined proportion is the ratio of the number of apertures through which the raw exhaust sample and diluting gas are respectively passed.

11. An assembly as claimed in claim 10, wherein the inlet and outlet means comprise coaxial pipes or the like whereby the temperature of the raw exhaust sample and diluting gas is substantially equalised prior to mixing.

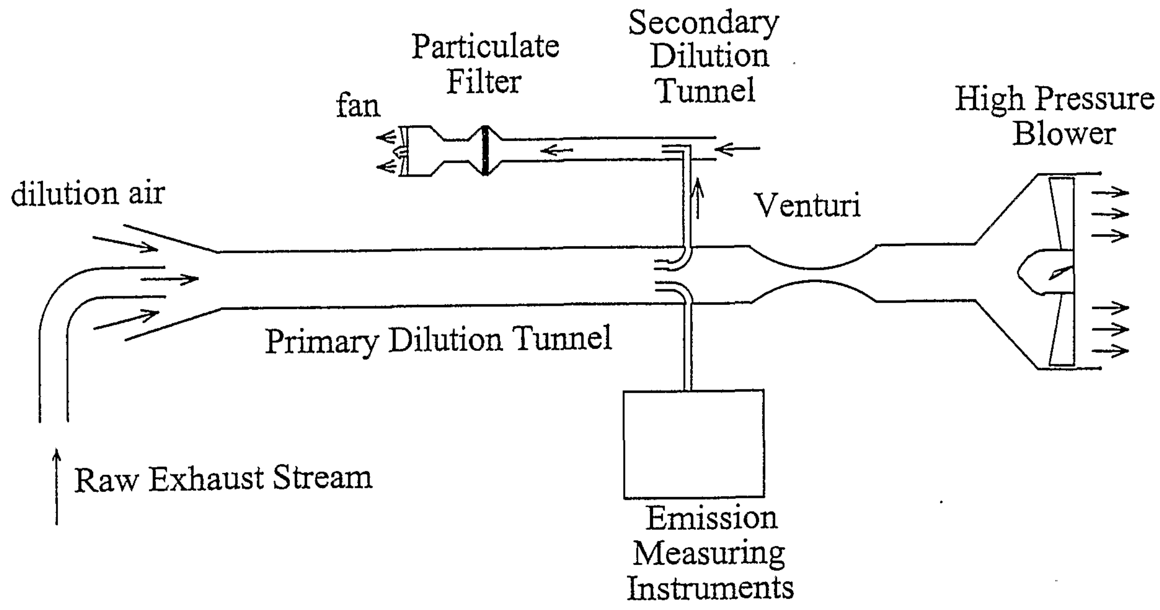


FIG 1 (PRIOR ART)

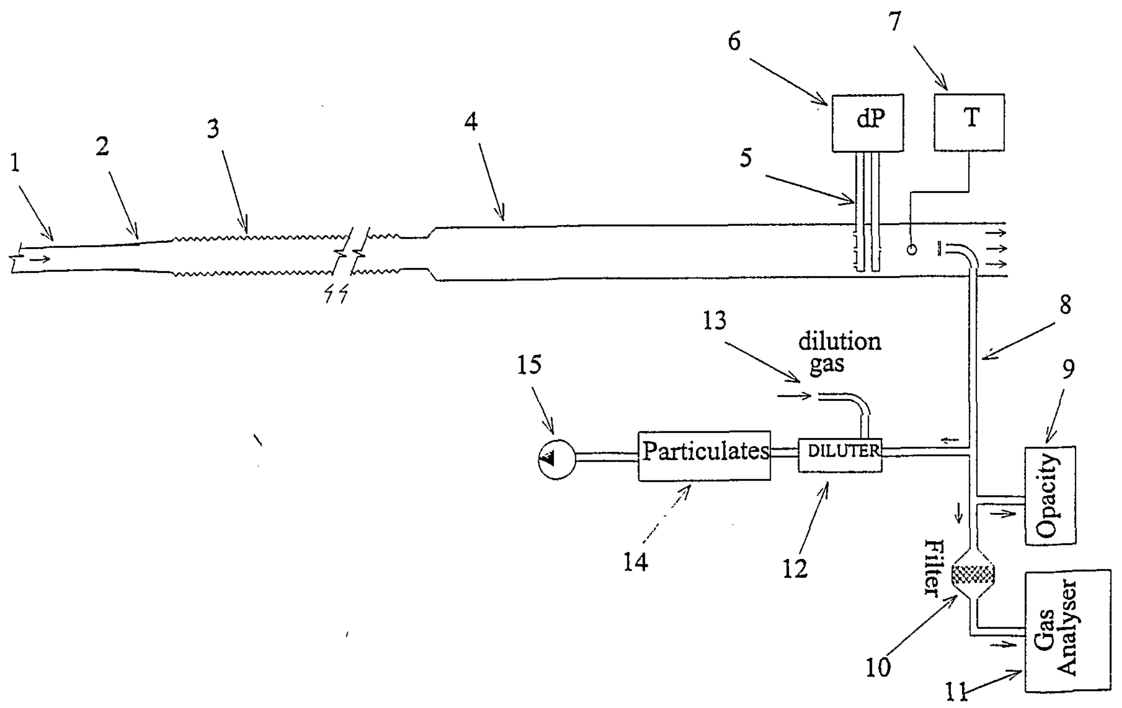


FIG 2

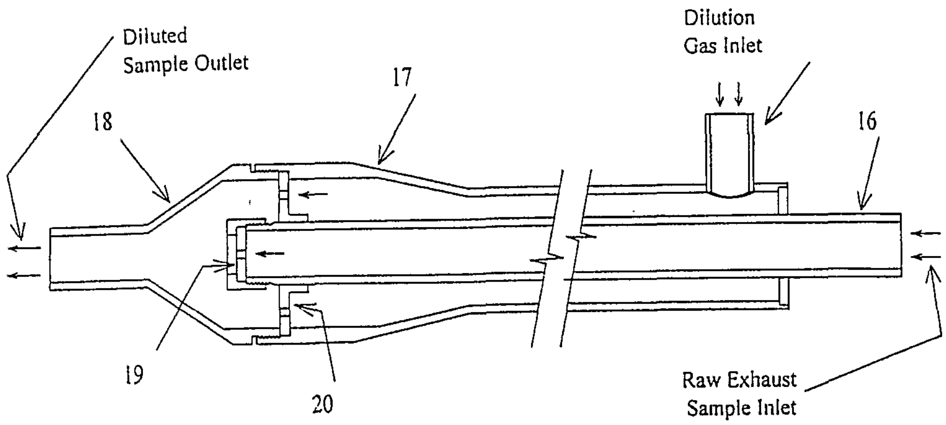

Diluted
Sample Outlet
Dilution
Gas Inlet
17
18
16
19
20
Raw Exhaust
Sample Inlet

FIG 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/00231

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: B01F 3/02, 5/06, 15/04, F01N 11/00, G01N 1/22, 1/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI, JAPIO: Int. Cl. 7 and keywords: G01N 1/-, G01M 15/-, G05D 11/-, B01F 3/-, 5/-, 15/-, F01N 11/00, exhaust, waste gas, dilut+, mix+, ratio, proportion, fraction, percentage, sample, aperture, opening, hole, orifice, perforation.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4498496 A (BARCELLONA et al) 12 February 1985 See figure 1 and description thereof, column 4 lines 16-17, column 4 line 66 - column 5 line 7	1-11
X	WO 97/31265 A (HORIBA INSTRUMENTS, INC) 28 August 1997 See page 4 lines 11-16, page 5 lines 9-12, page 9 lines 8-10, page 10 lines 16-19, page 13 lines 4-8	1-11
X	US 5846831 A (SILVIS) 8 December 1998 See column 3 lines 31-42, lines 53-54, figure 3	1-11

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 6 May 2002	Date of mailing of the international search report 21 MAY 2002
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **ZOE BRADY** Telephone No : (02) 6283 7947

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU02/00231

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	4498496	DE	3227242	GB	2103498	IT	1144417
WO	9731265	EP	882227	US	6200819	EP	871855
		US	5756360	WO	9712221		
US	5846831	EP	972181	WO	9844332	US	5968452

END OF ANNEX