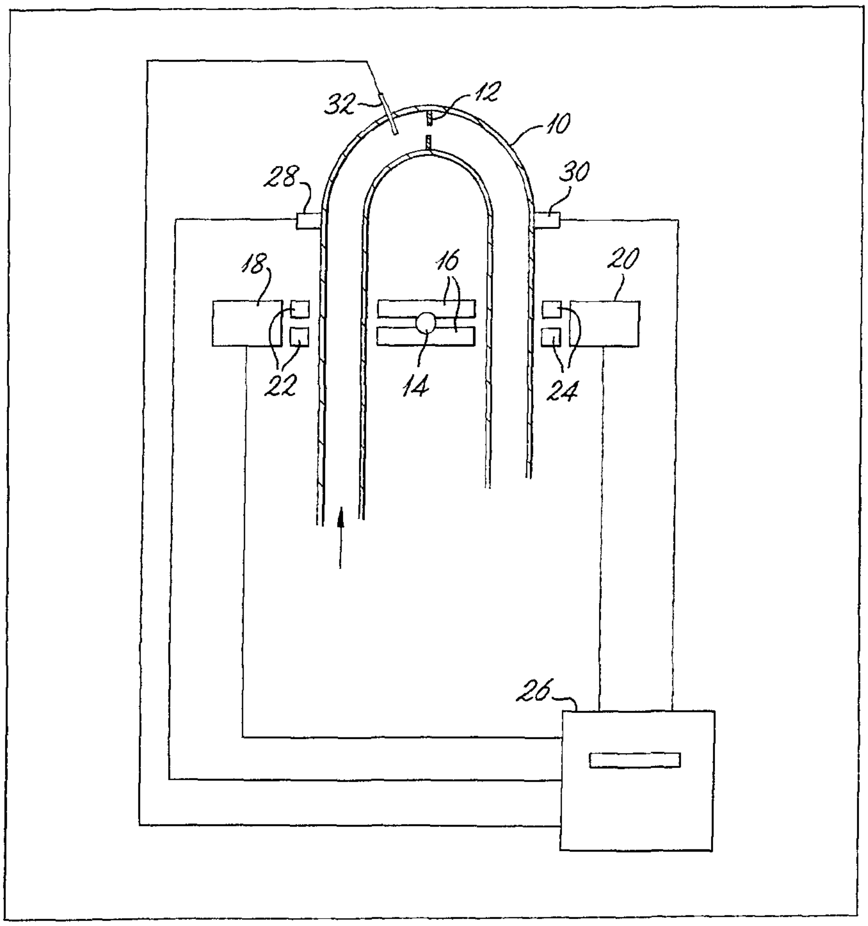
(12) UK Patent Application (19) GB (11) 2 079 465 A

(21) Application No **8116481**
(22) Date of filing **29 May 1981**
(30) Priority data
(31) **80/21717**
(32) **2 Jul 1980**
(33) **United Kingdom (GB)**
(43) Application published
20 Jan 1982
(51) **INT CL³**
G01N 9/32
G01L 13/00
G01N 9/24
(52) Domestic classification
G1N 1A3A 1DX 1M1 3S1A 3S2 7A1 7C 7F AAJ
G1A A4 BA D10 G10 G17 G1 G2 G7 P1 R2 S10 T15 T20 T2 T8
(56) Documents cited
None
(58) Field of search
G1A
G1N
(71) Applicants
National Research Development Corporation,
Kingsgate House,
66-74 Victoria Street,
London, SW1E 6SL.
(72) Inventors
Kenneth Garfield Carr-Brion,
Edward Frank Keen.
(74) Agents
Vivien Irish,
Patent Department,
National Research Development Corporation,
Kingsgate House,
66-74 Victoria Street,
London, SW1E 6SL.

(54) **Measurement of true density**

(57) System for determining the true density of a fluent mixture such as a liquid slurry, containing entrained gas, such as air comprises a restriction 12 in pipe 10 through which at least a part of the mixture is passed. Density measuring means such as gamma-ray detectors 18, 20 and source 14 are of the mixture before and after its passage through the restriction. Solid-state pressure measuring devices 28, 30 are arranged to measure the pressure in the mixture before and after its passage through the restriction. Calculating means, such as a programmed microprocessor 26, determine the true density from these measurements using relationships given in the description.



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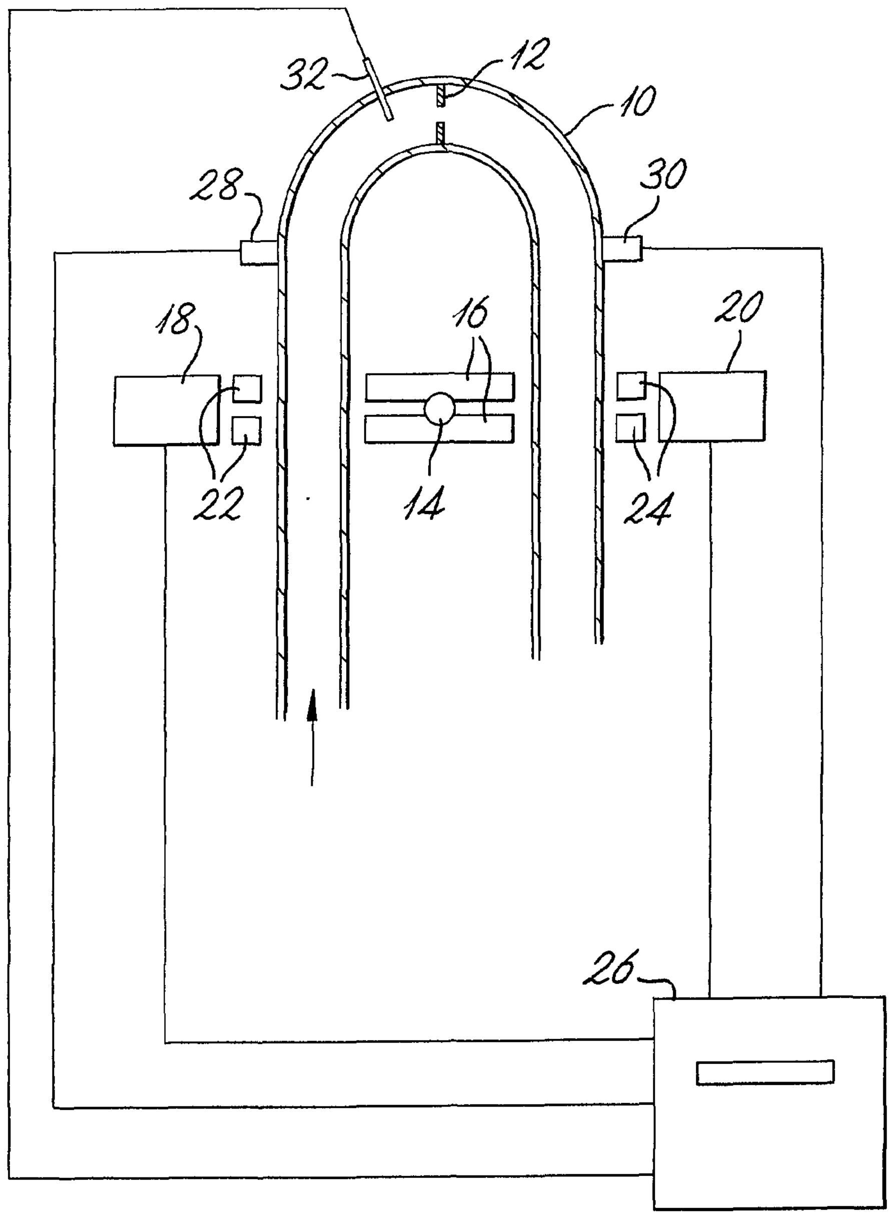
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SPECIFICATION

On-line measurement of density

This invention relates to the measurement of the true density of a mixture, such as a gas/liquid/solid mixture, in which a gas is entrained and cannot settle out. An example is a solid/liquid slurry in which air is inadvertently entrained. A measurement of the density of the slurry by a conventional density meter such as a gamma ray density gauge will give a measure of the apparent density; the presence of the air therefore causes an error and any process control system based on the measured density value will be inaccurate.

In another technical field, a stable foam may be manufactured from a liquid and a gas. A measure of density is required which allows the proportions of the components to be controlled; a conventional density meter cannot give such a measure. In a related problem, a measure of the true volume fraction of the gas at a standard temperature and pressure may be required; in a variation of the invention, such a measurement can be provided.

In a publication by Windle, Beazley and Burr in the Proceedings of the 13th EUCEPA conference 1970 on pages 787-790, a measurement of the true density of a mixture containing an entrained gas was obtained by taking a sample of the mixture and measuring its apparent density at two pressures, the second pressure being double the first pressure, and calculating the true density D using a simple equation.

The disadvantages of this method are that a sample of the mixture must be taken with the associated risk of altering the gas content during the sampling process, the need to apply precisely double the pressure during the second density measurement, and the fact that the measurement could not be made continuously or on-stream.

According to the invention, a method of determining the true density of a flowable mixture which contains an entrained gas comprises passing at least a part of the mixture through a restriction which alters the pressure of that part; measuring both the apparent density and the pressure before and after said passage; and from the measurements determining the true density.

The restriction may be, for example, an orifice plate having an orifice of suitable dimensions, and the method may be applied to the whole of a flowing mixture or to a continuously diverted sample which is then returned to the main body of the flowing mixture.

Further according to the invention the temperature of the mixture in the region of the restriction is measured, and the volume fraction of the gas entrained in the mixture is determined.

Also according to the invention, apparatus for determining the true density of a flowable mixture which contains an entrained gas comprises a restriction through which at least a part of the mixture can be passed; density measuring means arranged to measure the apparent density of the mixture before and after passage through the restriction; pressure measuring means arranged to measure the pressure in the mixture before and after passage through the restriction; and calculating means arranged to determine the true density from the measurements. The calculating means may be a micro-processor which may also be programmed to determine the volume fraction of the entrained gas at a predetermined temperature and pressure using the measured temperature of the mixture in the region of the orifice.

The invention will now be described by way of example with reference to the accompanying drawing in which a flow pipe 10 shaped as an inverted "U" contains an orifice plate or restriction 12 between two density gauges. A slurry or liquid is pumped through the pipe in the direction shown by the arrow, and through the orifice plate.

Between the arms of the "U" pipe is a gamma ray source 14 in a soure collimator 16 which allows a beam of gamma rays to pass towards each arm of the pipe. Beyond each arm lies a gamma ray detector 18, 20 each with an associated detector collimator 22, 24 which allow narrow beams of gamma rays to pass to the respective detectors. Such a device is well known. By previous calibration, each detector 18, 20 provides an output signal indicating the apparent density of the slurry in the arms of the pipe respectively before and after passage through the orifice plate 12; the detectors supply the signals to a microprocessor 26.

References 28, 30 indicate solid state pressure sensors arranged to measure the pressure in the pipe 10 on both sides of the orifice plate 12. These sensors are also connected to the microprocessor 26, as is a temperature sensor 32 which is in contact with the slurry adjacent the orifice plate.

In the aforementioned paper by Windle et al, equations are given relating the values of apparent density at atmospheric pressure and at twice atmospheric pressure d_1 and d_2 respectively, the true density D, and the percentage by volume of entrained air *x*, giving

$$d_1 = D(1 - \frac{x}{100}) \qquad (1)$$

$$d_2 = \frac{D(1 - \frac{x}{100})}{(1 - \frac{x}{200})} \qquad (2)$$

Using the simplification that for x less than 5%,

$$d_2 = D(1 - \frac{x}{200}) \qquad (3)$$

then $D = 2d_2 - d_1$ (4)

These simple equations relate to special case of using densities measures at atmospheric and twice atmospheric pressure and are limited to $x < 5\%$.

Using the general forms of the equations, it can be shown that:-

$$D = \frac{d_N d_1 (N - 1)}{N d_1 - d_N} \qquad (5)$$

where:-

D is the true density of the gas-containing mixture;

d_N is the apparent density of the mixture at N units pressure;

and

d_1 is the apparent density of the mixture at unit pressure.

It can also be shown that:-

$$V = \frac{1 - \frac{d_1}{d_N}}{1 - \frac{1}{N}} \qquad (6)$$

where V is the volume fraction of gas at unit pressure.

Wendell chose unit pressure as atmospheric pressure, and set $N = 2$. To achieve this change in pressure, a sample of the mixture was pressurised in a pressure chamber.

It is believed that it has not previously been realised that it is not necessary to have such a large change in pressure in order to measure the true density. Use of an orifice plate gives a pressure differential of about 0.2, and it has been found that this relatively small pressure change is adequate for the calculation of true density.

In the method and apparatus according to the present invention, unit pressure is the pressure after passage through the orifice, and N is the ratio of the pressure before passage to the pressure after passage. Similarly, d_1 is the apparent density after passage and d_N is the apparent density before passage through the orifice.

The four sensors 18, 20, 28, 30 supply the sensed values to the microprocessor which applies equation [1] and computes true density. The microprocessor also applies equation [2] and, using the temperature sensed by sensor 32, computes the volume fraction of the gas at any required temperature and pressure, usually STP.

The use of a microprocessor allows the values of D and/or N to be calculated sufficiently rapidly for the measurements to be used by a process control system. The values can also be displayed if required.

In the Figure, the pipe 10 may be the main slurry transport pipe through which a slurry travels during processing, or it may be a bypass pipe which taps off part of the main flow, then returns the sample after passage through the orifice plate.

It is to be understood that the types of sensors used to measure the pressure and the apparent density are not limited to those described; any sensor giving the required accuracy of measurement may be used. For example, when the gas concentration is low, a conventional vibrating tube type density gauge, which has high precision, is particularly advantageous.

In an example from a test rig a slurry flows through a pipe of diameter 3.8 cm and through an orifice of diameter 0.95 cm. A liquid flow rate of 30 litres per minute with entrained air corresponding to 30 cubic centimetres per minute causes a pressure drop across the orifice of 15.2 cm of mercury.

A measurement of true density according to the invention may be aplied to a solid/liquid slurry which typically contains up to 5% of accidentally entrained air. A measurement of volume fraction of gas according to the invention may be required during manufacture of a foam which comprises up to 99% of gas in a liquid.

CLAIMS

1. A method of determining the true density of a flowable mixture which contains an entrained gas comprising passing at least a part of the mixture through a restriction which alters the pressure of that part; measuring both the apparent density and the pressure before and after said passage; and from the measurement determining the true density.

2. A method according to Claim 1 in which the restriction is an orifice in an orifice plate through which at least a part of the mixture is passed.

3. A method according to Claim 1 or Claim 2 comprising passing the whole of the flowing mixture through the restriction;

4. A method according to Claim 1 or Claim 2 comprising continuously diverting a part of the flowing mixture through the restriction, and returning the part to the main body of the flowing mixture.

5. A method according to any preceding claim further comprising the temperature of the mixture in the region of the restriction, and further determining the volume fraction of the gas entrained in the mixture.

6. Apparatus for determining the true density of a flowable mixture which contains an entrained gas comprises a restriction through which at least a part of the mixture can be passed; density measuring means arranged to measure the apparent density of the mixture before and after passage through the restriction; pressure measuring means arranged to measure the pressure in the mixture before and after passage through the restriction; and calculating means arranged to determine the true density from the measurements.

7. Apparatus according to Claim 6 in which the restriction is an orifice in an orifice plate.

8. Apparatus according to Claim 6 or Claim 7 further comprising means to measure the temperature of the mixture in the region of the restriction, the calculating means being arranged to further determine the volume fraction of the gas entrained in the mixture.

9. Apparatus according to any one of Claims 6 to 8 in which the density measuring means comprises a gamma ray density gauge.

10. Apparatus for determining the true density of a flowable mixture substantially as hereinbefore described with reference to the accompanying drawing.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1982.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.