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Application No. 36457/93

NOTICE OF ENTITLEMENT

I, Joram Agar , of Agar Corporation Limited, PO Box 1764, Grand Cayman, Cayman Islands being authorised by the Applicant(s)/Nominated Person(s) in respect of Application No 36457/93 state the following:-

The Applicant(s)/Nominated Person(s) has/have entitlement from the actual inventor(s) as follows:-

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The Applicant(s)/Nominated Person(s) is/are entitled to rely on the application(s) listed in the Declaration under Article 8 of the PCT as follows:

The Applicant(s)/Nominated Person(s) is/are the assignee(s) of the basic applicant(s).

The basic application(s) listed on the Declaration under Article 8 of the PCT is/are the first application(s) made in a Convention country in respect of the invention.

DATED this 23RD day of FEBRUARY 1994

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APPARATUS AND METHOD FOR MEASURING TWO- OR THREE PHASE FLUID FLOW UTILIZING ONE OR MORE MOMENTUM FLOW METERS AND A VOLUMETRIC FLOW METER

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(56) Prior Art Documents
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WO 9115738
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(57) Claim

1. An apparatus for measuring flow rates of gas and liquid components in a fluid flowing in a flow path, comprising:

volumetric flow meter means arranged to measure a total flow rate for said fluid and to output a corresponding total flow rate signal;

momentum flow meter means coupled in series in said flow path with said volumetric flow meter means for measuring the momentum flux of said fluid at first and second points in said flow path and for outputting respective first and second momentum signals;

processor means coupled to said volumetric flow meter means and said momentum flow meter means arranged to determine the flow rate of said gas component and the

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flow rate of said liquid component by solving predetermined equations for total flow and momentum or energy utilizing said total flow rate signal and said first and second momentum signals.

13. A method of measuring flow rates of gas and liquid components in a fluid flowing in a series flow path, comprising the steps of:

measuring a total flow rate in said flow path and outputting a corresponding total flow rate signal;

measuring the momentum flux of said fluid at first and second points in said series flow path and outputting respective first and second momentum signals; and

determining the flow rate of said gas component and the flow rate of said liquid component by solving predetermined equations for total flow and momentum or energy utilizing said total flow rate signal and said first and second momentum signals.

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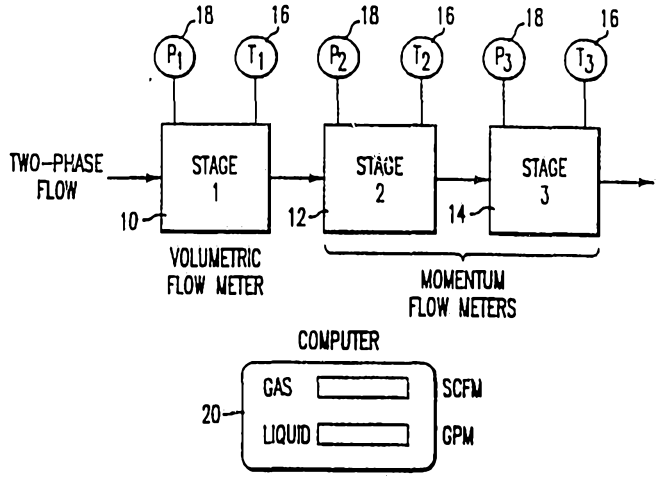
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(54) Title: APPARATUS AND METHOD FOR MEASURING TWO- OR THREE PHASE FLUID FLOW UTILIZING ONE OR MORE MOMENTUM FLOW METERS AND A VOLUMETRIC FLOW METER



(57) Abstract

An apparatus and method for measuring the flow rates of each component of two-phase flow consisting of a gas and a liquid or three-phase flow consisting of water, oil and gas, including a first volumetric flow meter stage, and second and third momentum flow meter stages coupled in a series flow path with the volumetric flow meter stage and in which a velocity ratio between the gas and the liquid in the series flow path is maintained to be one. A processor calculates flow rates of the components of flow by solving volumetric flow and momentum or energy equations defining flow through the first through third stages utilizing a volumetric flow output from the first stage and momentum flux outputs from said second and third stages, and an indicator displays flow of liquid and gas or oil, water and gas components of the flow. To measure three-phase flow, a water-cut meter is provided to determine the amount of water flow, which is then used by the processor to determine the flow of the rest of the liquid. The second and third momentum flow meter stages can be implemented by two separate momentum flow meters or by a single momentum flow meter, such as a venturi flow meter having a venturi nozzle including pressure taps for obtaining at least two differential pressure measurements. In the event that the density of the liquid component is known, a single momentum flow meter stage is sufficient.

This invention relates to an apparatus and method for measuring two-phase flow (liquid/gas) or three-phase flow (liquid/liquid/gas) of fluids.

The measurement of oil, water and gas flow finds application in various fields. In oil production, it is required for reservoir control and fiscal reasons. High accuracy of measurement is necessary as well as small instrumentation space requirements. Additional applications exist in petrochemical, nuclear and other industries.

In the past, three principal methods have been utilized for flow measurements.

As disclosed in U.S. Patent 4,760,742, the gas in a liquid is physically separated from the liquid, and each fluid is measured separately. A water-cut monitor is used to measure the amount of the water and the oil in the liquid phase. Two conventional single-phase flow meters are used to measure the gas and the liquid flow rates. This method can

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yield high accuracy, but requires gas-separating devices which are either very large or are very sensitive to flow rates and the liquid's viscosity, surface tension, etc.

A second approach is described in U.S. Patents 4,168,624 and 4,050,896, wherein the total flow is measured at two different flow conditions (for example: different temperatures and different pressures along the pipeline). The changing of the gas volume during the change of this condition makes it possible to calculate the flow rates of the gas and the liquid. To achieve high accuracy in this method, a large difference in flow conditions between the two flow meters is required. This requires a large pressure drop, which is costly in terms of pumping energy.

A third technique as described by Baker, "Measuring Multi-Phase Flow", Chemical Engineer, No. 453, pp. 39-45, October, 1988, and Reimann et al, "Measurement of Two-Phase Mass Flow Rate: A Comparison of Different Techniques", Int. J. of Multi-Phase Flows, Vol. 8, No. 1, pp. 33-46, 1982, measures the total momentum flux, total density, total volumetric flow rate, and the water cut. All are required to calculate the amount of gas, oil and water. One such device uses the combination of a turbine flow meter, a venturi flow meter, a gamma ray densitometer or void fraction meter and a water-cut monitor. The advantage of this method is that it enables the use of venturies which have low pressure drops. The weak link in this technique is the densitometer, which is

sensitive to the flow characteristics and the fluid's contaminants (heavy metals, etc.).

In many multi-phase flow applications it is desirable to predict the pressure drops which will occur in various piping apparata with different combinations of multi-phase fluids. This information is critical to piping design, pump sizing, etc. While information has been compiled on the pressure drops of a two-phase fluid comprising of water and air, it has not been possible to predict the pressure drops for other, more unique multi-phase fluids.

US-A-3,488,996 discloses a method of determining the oil content of a flowing stream of oil and water by measuring, during a test period, the total volume of liquid, total mass of liquid and the specific gravity of both the oil and the water separately at operating temperature and thereafter effecting calculation of the percentage oil constituent from the measurements.

JP-A-56125621 discloses a two-phase flow measuring device which can measure the two-phase flow under high temperature and high pressure highly accurately by combining a diaphragm type density meter and a drag disc type current meter.

An object of the invention is to provide a new and improved apparatus and method for measuring multi-phase flow by means of simple, low cost, compact equipment which has high flow rate measuring accuracy.

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Another object is to provide a novel apparatus and method for measuring multi-phase flow and which entails small pressure drops and therefore requires little pumping energy.

Preferably flow measurement is to be achieved in gas separating which devices or densitometers or measurement of a void fraction is not necessary.

It is also desirable to provide a novel apparatus and method capable of developing a table predicting the pressure drops which will occur in piping apparata for different multi-phase fluids.

According to the invention there is provided an apparatus for measuring flow rates of gas and liquid components having the features recited in claim 1.

The second and third momentum flow meter stages can be implemented by two separate momentum flow meters or by a single momentum flow meter having a venturi nozzle including at least three pressure taps for obtaining at least two differential pressure measurements.

To measure three-phase (oil, water, gas) flow a water-cut meter may be provided to determine the amount of water flow, which is then used by the processor to determine the amount of oil flow. The flow rates of oil, water and gas are then displayed.

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Where prediction of multi-phase fluid pressure drops in various flow apparata is required, a differential pressure measurement is taken across the first through third (and optionally fourth) stages, and means are provided to calculate and display ratios of the pressure drops of multi-phase fluids relative to the known pressure drops of fluids comprising water and air.

Further according to the invention there is provided a method of measuring flow rates of gas and liquid components comprising the operational steps as recited in claim 13.

Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a block diagram of one embodiment for two-phase flow measurement;

Figure 2 is a schematic diagram of one preferred embodiment for two-phase flow measurement, utilizing two venturi tubes and an ultra-sonic flow meter;

Figure 3 is a schematic diagram of another preferred embodiment for measuring two-phase flow, using a combination of a single

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modified venturi meter with a positive displacement flow meter;

Figure 4 is a schematic diagram of an embodiment of the present invention for three-phase flow with the flow meter shown in Figure 3 and a water-cut-monitor;

Figure 5 is a schematic diagram illustrating how the flow meter shown in Figure 4 can be used to measure the relative pressure drop of a three-phase fluid; and

Figure 6 is a flow chart of the overall process in accordance with one embodiment of the present invention for measuring three-phase flow and determining pressure drop ratios, according to the apparata described in relation to Figs. 2-5.

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to Figure 1 thereof, there is shown schematically an embodiment of the apparatus of the invention, including a volumetric flowmeter 10 serving as a first stage in which a mixture of gas and liquid flows through the volumetric flow meter 10. This flow meter 10 measures the total flow rate for the mixture. The mixture then flows through second and third stages, consisting of two momentum flow meters 12 and 14 with different dimensions (for example, two venturi flow meters with different throat diameters). Momentum flow meters are flow meters that measure

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the momentum flux of the fluid (M = mv). In order to avoid using a void fraction meter, this embodiment of the present invention forces the velocity ratio between the gas and the liquid (slip ratio) inside the apparatus to be a known value, a slip ratio of one being conveniently enforced. This is achieved through using either static or dynamic mixers or a positive displacement meter. In each stage the absolute pressure and temperature are measured by means of temperature transducers 16 and pressure transducers 18. One momentum flow meter can also be used by itself, in the instance that the liquid component's density is known. The data from Stages 1, 2 and 3 is transferred to a computer 20 that calculates the flow rates of the liquid and the gas components by solving equations presented hereinafter.

Figure 2 shows an example of a more concrete embodiment of the invention for two-phase flow measurement. Stage 1 is an ultra-sonic flow meter 10_1 installed between two static mixers 22 and 24. The ultrasonic flow meter measures volumetric flow. Other volumetric flow meters can also be used, such as turbine, vortex shedding, magnetic, heat transfer, variable area, paddle and Coriolis volumetric flow meter. In this modification the static mixers 22, 24 are used to force a unitary velocity ratio between the phases. Instead of measuring the absolute pressure independently in each stage, the absolute pressure is measured with a pressure

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transducer 18 in stage 1, and is calculated using differential pressure transducers 26 and 28 in stages 2 and 3.

The two momentum flow meters shown in Figures 1 and 2 can be reduced to one, by drilling one more pressure tap along the venturi nozzle, as shown in Figure 3. Such a modified venturi flowmeter is designated by numeral 31 in Fig. 3. Here the volumetric flow meter 10_2 is a positive displacement (P.D.) type. The advantage of using a P.D. flow meter is that it provides an exact measurement of the sum of the liquid and gas flow rates, with no slip between the gas and liquid phases inside the meter or immediately after the meter. Thus, the P.D. flow meter forces the slip ratio to a known amount, i.e., unity, and permits dispensing with the static mixers of the Fig. 2 embodiment.

The embodiments shown in Figure 1-3 are above-described using one or two venturi-type momentum flow meters. However, it should be understood that other momentum flow meters can be used to practice the present invention. For example, a target or drag-disk-type flow meter having different paddle dimensions can also be utilized to obtain sufficient parametric data to solve the energy and momentum equations of the fluids. For more detail about particular instrumentation described herein, see Hewitt, G.F., "Measurement of Two Phase Flow Parameters", Whitstable Litho Ltd., Whitstable, Kent, Great Britain, 1978, and Holman, J.P., "Experimental Methods for Engineers", McGraw-Hill Book Company, 1978.

The differential pressure transducers 26 and 28 measure the pressure difference along the venturi nozzle. A three-phase flowmeter in which a mixture of oil, water and gas can be measured is constructed with the addition of a fourth stage water-cut meter. Figure 4 shows a water-cut meter 32 (such as described in U.S. Patents 4,503,383 and 4,771,680) that measures the water concentration c of the mixture. Absolute pressure and temperature are measured in this stage by transducers 16 and 34, respectively. Reference numeral 31 designates the modified venturi flowmeter having the pressure taps 1-3 and associated transducers shown in Fig. 3. Because of the change in the specific volume of the gas ($v = p/RT$), measurement of the absolute pressure and temperature at all stages is necessary.

Next described is the analytical basis by which the flow measurements are performed utilizing momentum equations. In the following analysis, the following English and Greek letters and subscripts are used and have the noted meanings:

English letters

A - cross sectional area

c - percent of water

d - longitude differential

g - gravity constant

m - total mass flux

M - momentum flux

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p - pressure

P - circumference

Q - volumetric flow rate

R - gas constant

s - velocity ratio between the gas and the liquid ("slip")

T - absolute temperature

v - specific volume

x - quality

Greek letters

α - void fraction

B - slope of the instrumentation

ρ - density

τ - wall shear

Subscripts

G - gas

O - oil

PD - positive displacement

TOTAL - sum of all the fluid components

TP - two-phase

W - water

In performing a two-phase flow measurement, Q_L and Q_G are unknowns, but not the only unknowns.

The density of the liquid is also unknown (other unknown properties of the liquid and the gas have only a minor effect on the present method, and are therefore ignored here). The three equations that need to be solved for the three unknowns are the following:

1) The volumetric flow meter equation for stage 1:

$$Q_{PD} = Q_L + Q_G \quad (1)$$

Q_{PD} is derived from the volumetric flow meter output.

2) The momentum equation for stage 2 (for example the venturi meter shown in Figure 3 from tap 1 to tap 2):

$$\rho_1 - \rho_2 = f_1(Q_L, Q_G, \rho_L) \quad (2)$$

where $\rho_1 - \rho_2$ is the differential pressure derived from transducer 28 in Figure 3.

3) The momentum equation for stage 3 (for example the venturi meter shown in Figure 3 from tap 1 to tap 3):

$$\rho_1 - \rho_3 = f_2(Q_L, Q_G, \rho_L) \quad (3)$$

where $\rho_1 - \rho_3$ is the differential pressure derived from transducer 30 in Figure 3.

Certain assumptions must be made for the equations to be solvable:

1) The expansion of the gas along the venturi nozzle is isothermal.

2) Evaporation and dissolution of vapor and gas are negligible.

3) The ideal gas equation holds, and the liquid is incompressible.

4) The velocity ratio between the gas and the liquid = 1, or can be found experimentally as a function of the liquid and the gas flow rates.

Equations 2 and 3, shown here in general form, are in fact integral equations derived from the full expression of the momentum equation (see Hetsroni, G., "Handbook of Multi-Phase Systems", Chaps. 1.2, 2.1, 2.3, Hemisphere Publishing Corporation, U.S.A., 1982).

The momentum equation can be simplified to a model for one-dimensional, steady-state flow based on the Separated Two-Phase Flow model (see Hetsroni, G., supra) and can integrate from the first tap of the venturi to the second tap:

$$\rho_1 - \rho_2 = \int_1^2 \left(g\rho_{TP}\sin\beta - \frac{\tau_o P}{A} + m^2 \frac{d}{dz}\left[\frac{(1-x)^2}{\rho_L(1-\alpha)} + \frac{x^2}{\rho_G \alpha} \right] \right) dz \qquad (4)$$

and from the first tap of the venturi to the third tap:

$$\rho_1 - \rho_3 = \int_1^3 \left(g\rho_{TP}\sin\beta + \frac{\tau_o P}{A} + m^2 \frac{d}{dz}\left[\frac{(1-x)^2}{\rho_L(1-\alpha)} + \frac{x^2}{\rho_G \alpha} \right] \right) dz \qquad (5)$$

In equations 4 and 5 ρ_{TP}, m, x and α are functions of Q_G, Q_L and ρ_L:

$$\rho_{TP} = (1-\alpha)\rho_L + \alpha\rho_G \qquad (6)$$

$$m = \frac{Q_L\rho_L - Q_G\rho_G}{A} \qquad (7)$$

$$\alpha = \frac{Q_G}{Q_G + sQ_L} \qquad (8)$$

$$x = \frac{Q_G\rho_G}{Q_L\rho_L + Q_G\rho_G} \qquad (9)$$

Substituting equations 6, 7, 8 and 9 into equations 4 and 5, and then solving with equation 1, provides solutions for Q_L, Q_G and ρ_L since we have three equations and three unknowns.

Equations 4 and 5 are solved using known numerical analysis techniques. The selection of a particular numerical analysis technique is based on a trade-off between accuracy and speed of execution, and is a function also of the availability of fast and economic computation devices. The relative merits of some techniques are discussed in Scheid, "Theory and Problems of Numerical Analysis", Schaum's Outline Series, McGraw-Hill Book Co., 1968. The technique most appropriate for equations 4 and 5, today, is the Runge-Kutta method described in Chapter 19 of Scheid, supra. It is anticipated, however, that the development of cheaper and faster computation devices, or more efficient or more accurate

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methods of solving integral equations, will suggest other techniques to be utilized in the future. Similarly, a method well suited for solving the set of equations 1, 4 and 5 is the Newton method described in Chapter 25 of Scheid.

More or less detailed, and different types of models can be written as well, depending on the required accuracy of the meter. Applying the momentum equations provides a much more accurate solution than the energy equations, since the momentum equations only have to take into account the friction on the wall (easy to estimate), as compared with the energy equations which have to take into account the energy losses (very difficult to estimate). Generally, it is considered that embodiments of the present invention utilize conservation equations, which can be either momentum or energy equations (see Hetsroni, supra).

The equation for deriving three-phase flow (oil/water/gas) by the addition of a water-cut meter in stage 4 is:

$$c = \frac{Q_W}{Q_W + Q_O + Q_G} \qquad (10)$$

The liquid flow rate is the sum of the water and the oil flow rates:

$$Q_L = Q_O + Q_W \qquad (11)$$

Therefore, the equation for determining the water flow rate can be written as:

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$$Q_W = (Q_L + Q_G)C \qquad (12)$$

and then Q_O can be derived from equation 12 once Q_W is known.

Figure 5 shows how the multi-phase flow meter can also be used to predict pressure drops for different multi-phase fluids in different piping devices. The addition of differential pressure transducer (36) provides measurement of the pressure drop across the meter. In the calibration process a look-up table is generated, which contains the measured pressure drop across the meter when different proportions and rates of water and air are flowed through it. In effect the look-up table is a matrix of values of $\Delta p_{water/air}$ for different values of Q_{air} and Q_{water}.

When a multi-phase fluid consisting of different components than water and air flows through the meter, stages 1, 2 and 3 measure Q_G and Q_L, while stage 5 measures the differential pressure across the meter (Δp_{fluid}). The $\Delta p_{water/air}$ that corresponds to the equivalent air and water values for the measured Q_G and Q_L of the working fluid is then looked up in the above-noted look-up table, and the pressure drop ratio is calculated.

The equation for the pressure drop ratio of the working multi-phase fluid relative to an equivalent water/air mixture is:

$$\frac{\Delta p_{fluid}}{\Delta p_{water/air}} = \text{const}\Big|_{\text{same flow conditions}} \qquad (13)$$

Once this ratio has been calculated, it can be applied to obtain an accurate prediction of the pressure drop of multi-phase fluids in other devices in the line, where the pressure drop of an equivalent water/air mixture is known.

For example, to obtain the pressure drop in a vertical pipe in a field pipe line where crude oil, water and natural gas are flowing, a priori knowledge of the pressure drop for an air/water mixture in the same vertical pipe at the same flow rate is needed. This can be found in field handbooks (see Perry et al, "Chemical Engineer's Handbook", McGraw-Hill Book Co., 1973, pp. 5.40-5.47). Multiplication of this number with the pressure drop ratio calculated according to this embodiment of the present invention provides an accurate prediction of the pressure drop across the vertical pipe for the working fluid.

Figure 6 shows a flow chart that summarizes the process in accordance with this embodiment of the present invention.

In Figure 6, in step 100, the output of the volumetric flow meter 10, Q_{PD}, is measured. In step 110, differential pressure, p_1-p_2, is measured. In step 120, the differential pressure p_1-p_3 is measured. In step 130, the water-cut, c, is measured. The outputs of the steps 100. 110, 120 and 130 are fed to the computer 20 which then at step 140 calculates Q_L, Q_G and ρ_L, solving equations 1, 4 and 5 and utilizing equations 6-9. In step 150, Q_{water} and Q_{oil} are calculated utilizing equations 10-12, and in step 160, the results of the various calculations

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performed as thus far described, Q_G, Q_{water} and Q_{oil} are displayed.

Figure 6 also illustrates steps by which the ratio $\Delta p_{fluid}/\Delta p_{water/air}$ is determined. In step 170, Δp_{fluid} is measured by means of the sensor 36 shown in Figure 5. In step 180, a look-up table is utilized to determine $\Delta p_{water/air}$, based on the values of Q_L and Q_G determined in step 140. In step 190 the ratio of Δp_{fluid}, determined in step 170 and $\Delta p_{water/air}$, determined in step 180, is determined and likewise displayed in step 160.

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CLAIMS:

1. An apparatus for measuring flow rates of gas and liquid components in a fluid flowing in a flow path, comprising:

volumetric flow meter means arranged to measure a total flow rate for said fluid and to output a corresponding total flow rate signal;

momentum flow meter means coupled in series in said flow path with said volumetric flow meter means for measuring the momentum flux of said fluid at first and second points in said flow path and for outputting respective first and second momentum signals;

processor means coupled to said volumetric flow meter means and said momentum flow meter means arranged to determine the flow rate of said gas component and the flow rate of said liquid component by solving predetermined equations for total flow and momentum or energy utilizing said total flow rate signal and said first and second momentum signals.

2. An apparatus as claimed in claim 1, comprising forcing means arranged to force a known velocity ratio between said gas component and said liquid component in said flow path.

3. An apparatus as claimed in claim 2, wherein

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in that said forcing means comprises one or more static mixer and/or dynamic mixer.

4. An apparatus as claimed in claim 3, wherein said forcing means comprises first and second mixers respectively coupled in series at an input and an output of said volumetric flow meter means.

5. An apparatus as claimed in claim 2, wherein said volumetric flow meter means and said forcing means comprise a positive displacement flow meter.

6. An apparatus as claimed in any preceding claim comprising indicator means for displaying the determined flow rates of said gas and liquid components.

7. An apparatus as claimed in any preceding claim, wherein said momentum flow meter means comprises first and second venturi flow meters having different throat dimensions.

8. An apparatus as claimed in any one of claims 1 to 6, wherein said momentum flow meter means comprises a venturi flow meter having a venturi nozzle including plural pressure measuring taps for obtaining at least two differential pressure measurements.

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9. An apparatus as claimed in claim 1, wherein said momentum flow meter means comprise drag-disk flow meters having different paddle dimensions.

10. An apparatus as claimed in any preceding claim comprising:

water-cut meter means for measuring an amount of water in said liquid component and for outputting a corresponding water-cut signal;

said processor means being adapted to determine flow rates of a gas constituent, a water constituent, and a further constituent of said liquid in said fluid component based on said water-cut signal and the determined liquid and gas flow rates.

11. An apparatus as claimed in claim 10 comprising indicator means for displacing the determined flow rates of said water constituent and said further constituent.

12. An apparatus as claimed in any one of claims 1 to 11, comprising means for measuring a pressure drop across the series flow path of said volumetric flow meter means and said momentum flow meter means and producing a corresponding pressure drop signal; memory means adapted to store a table of differential pressure drops as a function of plural values of air flow rate and water

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flow rate through said series flow path; means adapted to select from said table stored in said memory means a corresponding differential pressure drop based on the measured gas and liquid flow rates; means adapted to calculate a pressure drop ratio of said pressure drop signal and the selected differential pressure drop and outputting a corresponding pressure drop ratio signal; and means adapted to multiply said pressure drop ratio signal with a predetermined signal indicative of a pressure drop of an air/water mixture through a different flow path to determine a pressure drop of said fluid in said different flow path.

13. A method of measuring flow rates of gas and liquid components in a fluid flowing in a series flow path, comprising the steps of:

measuring a total flow rate in said flow path and outputting a corresponding total flow rate signal;

measuring the momentum flux of said fluid at first and second points in said series flow path and outputting respective first and second momentum signals; and

determining the flow rate of said gas component and the flow rate of said liquid component by solving predetermined equations for total flow and momentum or energy utilizing said total flow rate signal and said first and second momentum signals.

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14. A method as claimed in claim 13 comprising the step of displaying the determined flow rates of said liquid and gas components.

15. A method as claimed in claim 13 or 14, comprising the step of forcing a known velocity ratio between said gas component and said liquid component in said flow path.

16. A method as claimed in any one of claims 13 to 15, comprising the steps of measuring an amount of water in said liquid component and outputting a corresponding water-cut signal; and determining flow rates of a gas constituent, a water constituent, and a further constituent of said liquid component in said fluid based on said water-cut signal and the determined liquid and gas flow rates.

17. A method as claimed in claim 16 comprising the step of displaying the determined flow rates of said water constituent and said further constituent.

18. A method as claimed in any one of claims 13 to 16, comprising the steps of measuring a pressure drop across said series flow path and producing a corresponding pressure drop signal; storing a table of differential pressure drops as a function of plural values of air flow rate and water flow rate through said

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series flow path; selecting from the stored table a corresponding differential pressure drop based on the measured gas and liquid flow rates; calculating a pressure drop ratio of said pressure drop signal and the selected differential pressure drop and outputting a corresponding pressure drop ratio signal; and multiplying said pressure drop ratio signal with a predetermined signal indicative of a pressure drop of an air/water mixture through a different flow path to determine a pressure drop of said fluid in said different flow path.

19. A method as claimed in any one of claims 13 to 18, comprising the step of by forcing a known velocity ratio between said gas component and said liquid component in said flow path.

20. An apparatus for measuring flow rates of gas and liquid components in a fluid flowing in a flow path substantially as hereinbefore described with reference to and as illustrated in any of the accompanying drawings.

21. A method of measuring flow rates of gas and liquid components in a fluid flowing in a series path substantially as hereinbefore described with reference to any of the accompanying drawings.

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Dated 5 March, 1996
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Patent Attorneys for the Applicant/Nominated Person
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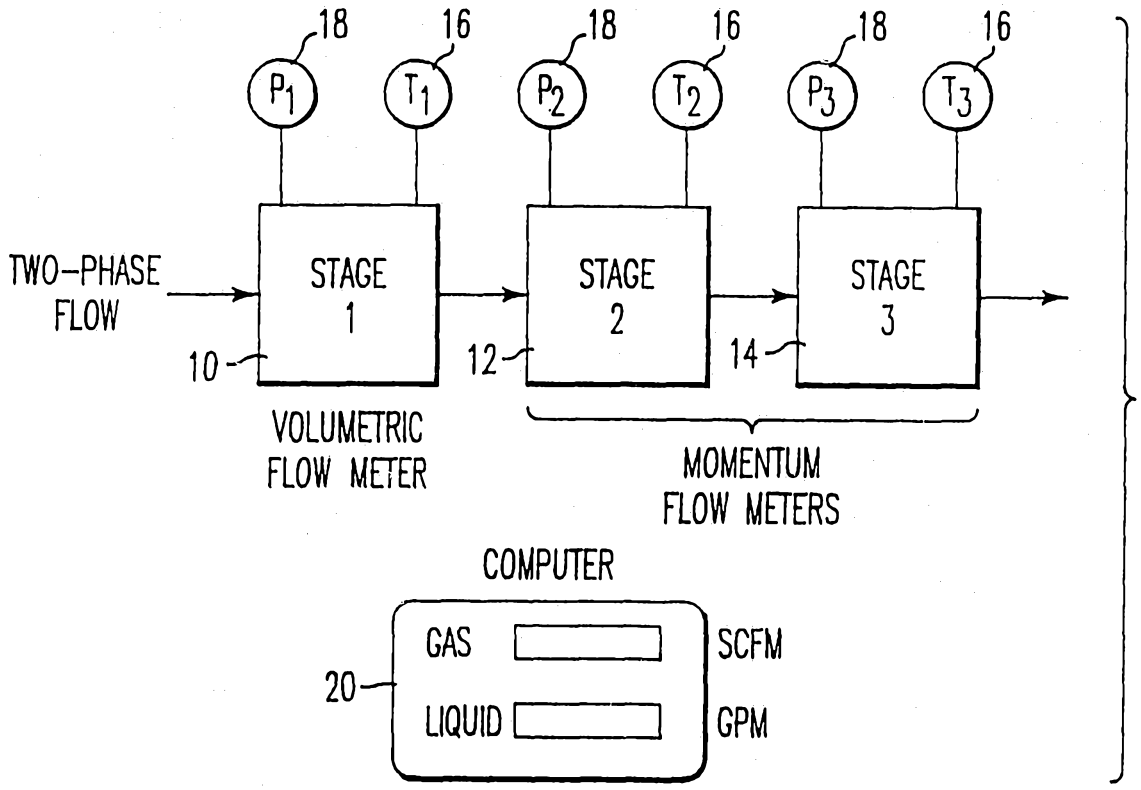


FIG. 1

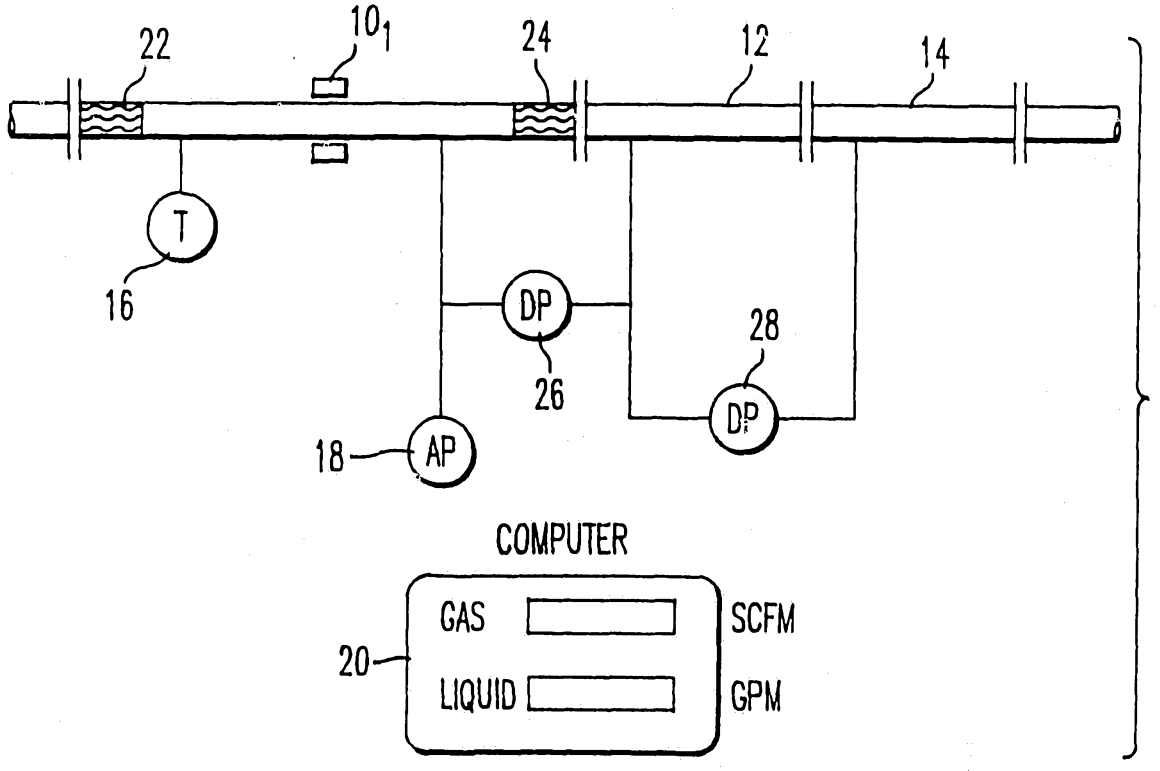


FIG. 2

SUBSTITUTE SHEET

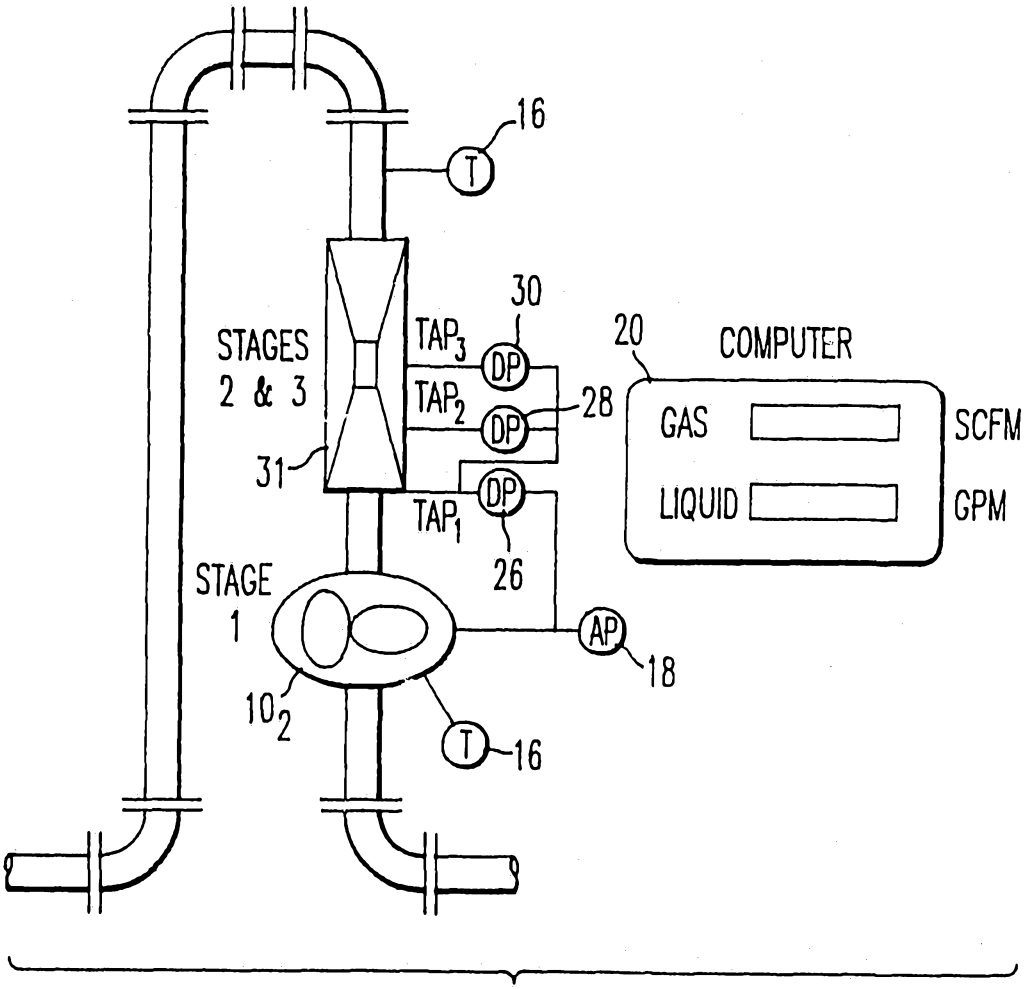

16
T
30
STAGES
2 & 3
TAP3
DP
20
COMPUTER
TAP2
DP
28
GAS
SCFM
31
DP
LIQUID
GPM
TAP1
26
STAGE
1
AP
18
10
2
T
16

FIG. 3

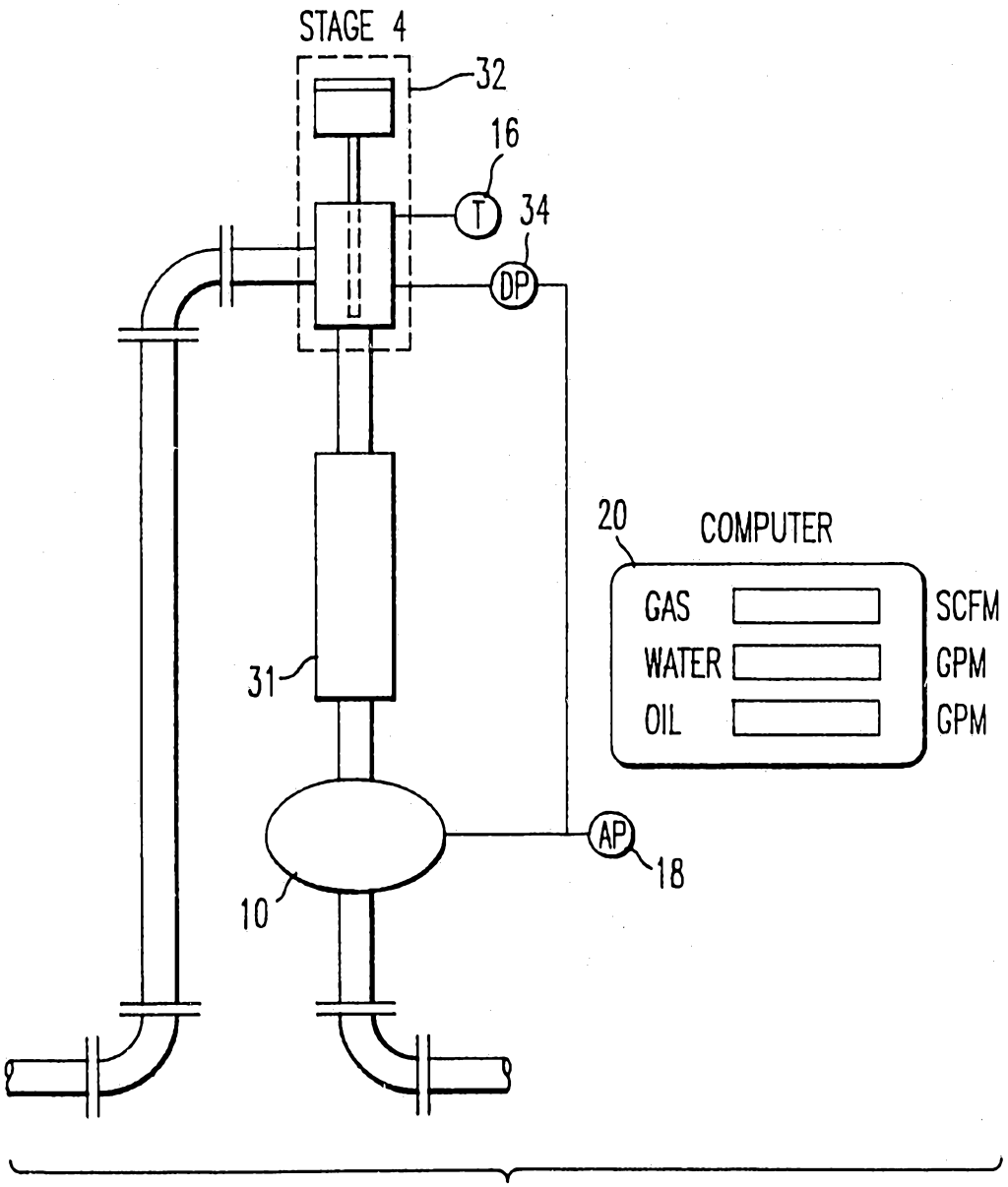

STAGE 4
32
16
T
34
DP
20
COMPUTER
GAS
SCFM
WATER
GPM
OIL
GPM
31
AP
18
10

FIG. 4

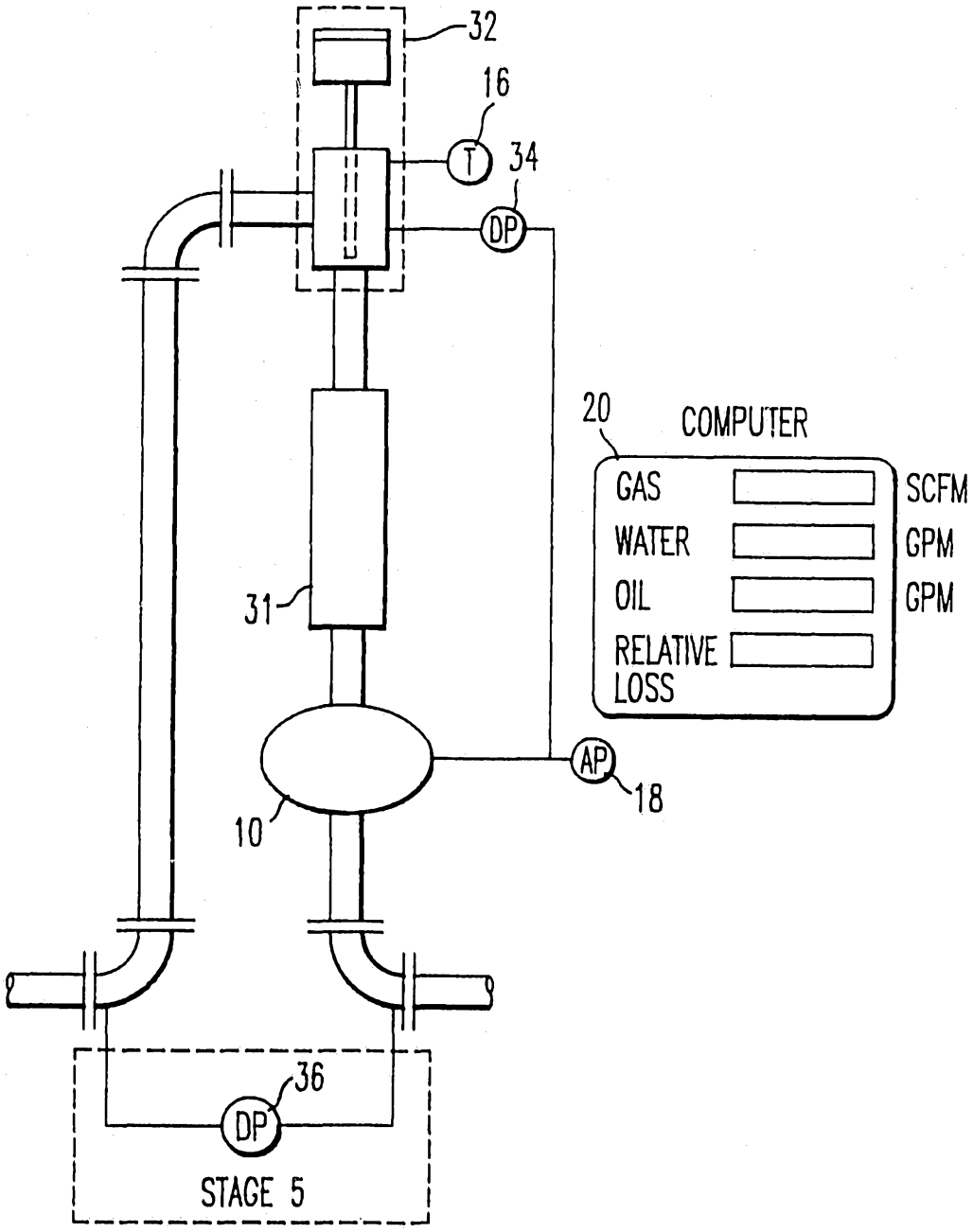

32
16
T
34
DP
20
COMPUTER
GAS
SCFM
WATER
GPM
OIL
GPM
RELATIVE LOSS
31
AP
18
10
36
DP
STAGE 5

FIG. 5

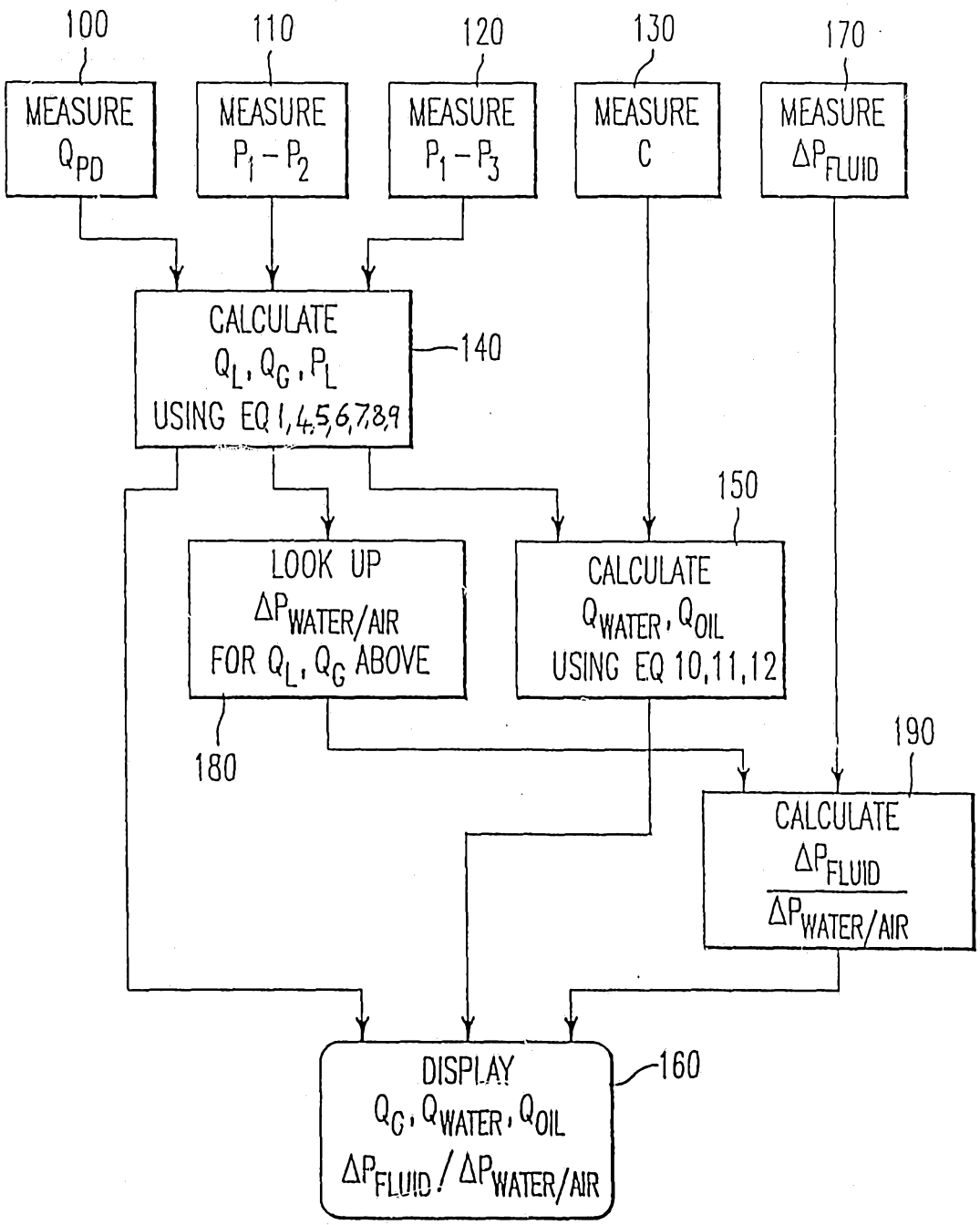

100
MEASURE Q_{PD}
110
MEASURE $P_1 - P_2$
120
MEASURE $P_1 - P_3$
130
MEASURE C
170
MEASURE ΔP_{FLUID}
CALCULATE Q_L, Q_G, P_L USING EQ 1,4,5,6,7,8,9
140
150
LOOK UP $\Delta P_{WATER/AIR}$ FOR Q_L, Q_G ABOVE
180
CALCULATE Q_{WATER}, Q_{OIL} USING EQ 10,11,12
190
CALCULATE $\frac{\Delta P_{FLUID}}{\Delta P_{WATER/AIR}}$
DISPLAY Q_G, Q_{WATER}, Q_{OIL} $\Delta P_{FLUID} / \Delta P_{WATER/AIR}$
160

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 93/00516

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01F1/74

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G01F ; F17D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	US,A,3 488 996 (R.H. PFREHM) 13 January 1970 see column 2, line 25 - column 3, line 49; figure 1 ---	1
A	US,A,4 236 406 (P.W. REED) 2 December 1980 see column 3, line 31 - line 32; figure 1 ---	2
A	PATENT ABSTRACTS OF JAPAN vol. 5, no. 202 (P-95)(874) 22 December 1981 & JP,A,56 125 621 (ESU TEE KENKYUSHO K.K.) 2 October 1981 see abstract --- -/--	8

° Special categories of cited documents : [10]

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

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"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

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
09 JUNE 1993	08.07.93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	HEINSIUS R.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	WO,A,9 115 738 (J. AGAR) 17 October 1991 see page 5, paragraph 2 - page 9, last paragraph; figures 1-3	1,9-11, 13,18, 20,22
A	US,A,4 760 742 (G.J. HATTON) 2 August 1988 cited in the application see column 1, line 47 - column 2, line 55; figure	1-32
A	US,A,4 168 624 (D.PICHON) 25 September 1979 cited in the application see column 6, line 6 - column 7, line 4; figure 2	1-32
A	US,A,4 050 896 (R. RAFFEL) 27 September 1977 cited in the application see column 3, line 61 - column 6, line 15; figures 1-4	1-32
A	US,A,4 503 383 (J. AGAR) 5 March 1985 cited in the application see column 6, line 59 - column 7, line 16; figure 8	9-11,18, 22,26,31
A	THE CHEMICAL ENGINEER October 1988, pages 39 - 45 R. BAKER 'MEASURING MULTIPHASE FLOW' cited in the application see the whole document	1-32
A	INT. JOURNAL OF MULTIPHASE FLOW vol. 8, no. 1, 1982, GB pages 33 - 46 J. REIMANN, E.A. 'MEASUREMENTS OF TWO-PHASE MASS FLOW RATE: A COMPARISON OF DIFFERENT TECHNIQUES' cited in the application see the whole document	1-32

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 9300516
SA 71574

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 09/06/93

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