

"ANALYSIS OF MULTI-PHASE MIXTURES"

This invention relates generally to a method and apparatus for analysing multiphase mixtures to determine selected properties thereof.

Whilst it will be appreciated by those persons
5 skilled in the art that the method and apparatus of
the invention are readily applicable to the analysis
of a wide variety of multi-phase mixtures, one
particularly advantageous application relates to
the analysis of the oil mixture discharged from an
10 oil well. It will be convenient therefore to
hereinafter describe the invention with reference
to that particular application.

It is often necessary to be able to monitor
and/or determine the various properties of the oil/gas/
15 water mixture being discharged from an oil well.
The properties of the mixture which are particularly
important are the volume rate and density of each
phase. It is the current practice when analysing
the mixture discharged from an oil well to feed a
20 relatively large quantity of the mixture to a "test
separator". The "test separator" separates the
multi-phase mixture into discrete phases before
flow measurement is effected.

Separators of this general type are known and it is not proposed to provide a detailed description here. The major disadvantages of separators of this type are that they are relatively bulky and take up
5 considerable space particularly when used on off-shore platforms. As a result each off-shore platform usually has only one test separator, and this test separator is employed to take measurements from one well at a time. A further disadvantage is that they
10 are relatively expensive.

It is an object of the present invention to provide a relatively simple method and apparatus for analysing multi-phase mixtures and with reference to the specific application referred to above, it is
15 an object to alleviate one or more of the aforementioned disadvantages.

According to one aspect of the present invention a method for continuous analysis of a multiphase mixture flowing along a flow path for determining selected properties of the mixture or of phases of the mixture, comprises the steps of :

- (a) first, determining the pressure, temperature, density and mass flow rate of the mixture at a first point upstream of a characteristic change zone in the flow path;
- (b) causing a change in at least one characteristic of the mixture flow in said characteristic change zone;
- (c) thereafter determining the pressure, temperature, density and mass flow rate at a second point downstream of said characteristic change zone; and
- (d) determining the selected properties of the mixture or of one or more phases of the mixture on the basis of the information collected together with known parameters using algorithms.

The characteristic which is changed may be, for example pressure or temperature or the composition of the mixture caused by at least a partial separation of the phases in the mixture.

- 3 -

The characteristic change may be effected by adding a substance to the mixture between the two points. Such substance may be, for example a chemical to cause a reaction or

5 a side stream of gas. In another arrangement, the characteristic change can be initiated by a change at some other point in the flow path which thereby causes the characteristic change. For example, a pressure differential upstream of the two points
10 may be sufficient to cause a change between the points.

By using the method of the invention, it is possible to determine the properties of the various phases of the mixture such as, for example, the volume and density of each particular phase. To determine these properties
15 it may be necessary to carry out more than two density and/or mass flow measurements or calculations and where two or more measurements are carried out corresponding flow characteristic changes are required between the adjacent measuring points. In some instances not all
20 variables may be required to be determined purely from the mass flow measurement technique. For example, in mixtures such as the oil mixture from oil wells it may be convenient to assume that the density of the water phase and the oil phase remain
25 constant along each pressure differential. From the information collected, it is possible to produce suitable algorithms from which the required properties can be determined.

Thus in the particular example of a mixture
30 discharged from an oil well, a series of equations can be written from which the various properties of the phases of the mixture can be determined.

-4-

In a typical example, it is reasonable to assume that the density of the oil and water remain substantially constant throughout the mixture flow. As such, it is possible to determine these values in any suitable manner. Using the method of the present invention the following properties are measured:

- (a) The density of the mixture at points 1 and 2 (ρ_1 and ρ_2).
- (b) The mass flow rate of the mixture (M_{T1}) (where the characteristic change is a pressure differential, the mass flow rate remains constant).
- (c) The temperature and pressure at points 1 and 2.
- (d) The density of the oil (ρ_o) and water (ρ_w) (As mentioned earlier the density of the oil and water are measured separately).

-5-

$$P_1 = k_1 \rho_1 T_1 \quad - \quad (1)$$

$$P_2 = k_2 \rho_2 T_2 \quad - \quad (2)$$

$$M_{T1} = M_{T2} \quad - \quad (3)$$

$$M_{T1} = \rho_{g1} V_{g1} + \rho_{w1} V_{w1} + \rho_{o1} V_{o1} \quad - \quad (4)$$

$$5 \quad M_{T2} = \rho_{g2} V_{g2} + \rho_{w2} V_{w2} + \rho_{o2} V_{o2} \quad - \quad (5)$$

$$V_{w1} = V_{w2} \quad - \quad (6)$$

$$V_{o1} = V_{o2} \quad - \quad (7)$$

$$V_{T1} = V_{g1} + V_{o1} + V_{w1} \quad - \quad (8)$$

$$V_{T2} = V_{g2} + V_{o2} + V_{w2} \quad - \quad (9)$$

10 V is volume
 subscript g is gas
 o is oil
 w is water

15 If ρ_{w1} , ρ_{o1} , ρ_{w2} , ρ_{o2} , k_1 , and k_2 are assumed or
 hand measured it is therefore possible to determine
 V_{g1} , V_{g2} , ρ_{g1} , ρ_{g2} , V_{o1} , V_{o2} , V_{w1} , V_{w2} , V_{T1} , V_{T2} .

According to another aspect of the present invention there is provided apparatus for continuous analysis of a multiphase mixture flowing along a flow path for determining selected properties of a mixture or of phases of the mixture, the apparatus comprising:

- a first means for directly measuring the density and mass flow rate at a first point upstream of a characteristic change zone in the flow path;

- means for causing a change in at least one characteristic of the mixture flow in said characteristic change zone; and

- a second means for directly measuring the density and the mass flow rate at a second point downstream of the characteristic change zone, the arrangement being such that selected properties of the mixture or of one or more phases of the mixture can be determined on the basis of the information collected together with known parameters using algorithms.

The apparatus can be interfaced with a suitably programmed computer so that, for example, the properties of the mixture utilizing the equations above can be quickly determined.

The first and second means for measuring density and mass flow may be a mass flow meter. A typical example of a suitable mass flow meter is sold under the trademark Micro Motion and is described in United States patent specification 4,422,338 and reissue patent 31450. Measurement of the temperature and pressure of the mixture can be done in any suitable manner. In another arrangement the density of the mixture can be measured by an on-line density meter one example of which is sold under the trademark SOLARTRON by the company Solartron Schlumberger and the mass flow measured by a separate meter.

If the characteristic change is a pressure change then this can be caused by any suitable device such as a choke or the like.

If the characteristic change is a phase separation then in one preferred form a hydro cyclone or the type which is for example described in International application PCT/AU84/00195 (WO85/01454) which has been specifically developed for the treatment of oily water can be used. In one form the mass flow measurements may be taken at the inlet to the hydro cyclone and at the outlet therefrom.

-7-

for the oil/gas phase which is removed from the oil water mixture. In certain instances it may be necessary to use additional mass flow measurement meters with two or more hydro cyclones in series.

- 5 In the above described arrangements the mass flow measurement is of the total flow. It is possible however to merely take a sample of the flow and pass that sample through a device comprising two mass flow measurement meters with a pressure differential there-
10 between. Using such an arrangement however it is only possible to determine the relative percentage volumes of the phases.

- Preferred embodiments of the invention will hereinafter be described with reference to the
15 accompanying drawings in which:-

Figure 1 is a schematic circuit drawing showing the general principle of the invention;

- Figure 2 is a schematic circuit drawing incorporating one form of device according to the
20 invention;

Figure 3 shows an arrangement by which a sample of the mixture is taken from the main line;

Figures 4 and 5 show a form of the apparatus when used with hydro cyclones;

- 25 Figure 6 is a circuit diagram showing a use of the apparatus in relation to gas optimization;

Figure 7 is a circuit diagram showing a use of apparatus for controlling discharge from an oil well head; and

Figure 8 is a diagram of a test apparatus.

Figure 1 shows schematically what may be required to be measured on-line at points 1 and 2 and with a characteristic change at C to determine the desired properties of the various phases in the mixture.

Referring to Figure 2 of the drawings, there is shown an oil rig 1 comprising oil wells 2, 3 and 4,

-8-

a discharge line 6 for delivering the mixture to a separator (not shown). The device of the present invention comprises a pair of mass flow meters 10 and 11 having a choke 13 therebetween. The mass flow
5 meters can measure the mass flow as well as the density of the mixture.

In Figure 3, there is shown an embodiment where a sample is taken from the main delivery line 6, the sample passing through mass flow meters 10 and 11 and
10 choke 13.

In Figures 4 and 5 there is shown the arrangement of mass flow meters 10, 11 13 and 14 with hydro cyclones 15 and 16. In this particular arrangement the characteristic change is effected by phase
15 separation. For example, in Figure 4 mass flow meter 10 measures the mass flow and density of the mixture in total and mass flow meter 11 measures the mass flow and density of the oil and gas phases. It is therefore possible to devise algorithms to determine the desired
20 properties of each phase.

One application of the invention relates to gas optimization of oil wells. To bring the oil water mixture to the surface of a well, gas is delivered down the well and thereby reduces the mass of the mass
25 of the column of mixture within the production tubing. As a result of this mass reduction, the reservoir pressure causes the column to rise to the surface.

The amount of gas fed down the well will affect the oil/water/gas mixture delivered to the surface. Thus,
30 by controlling the gas flow the desired oil/water/gas mixture can be controlled. Figure 6 is one example of how the gas flow can be controlled using the method and apparatus of the present invention.

- 9 -

Gas is fed under pressure along line 30 through throttling valve 20 down the well where it mixes with the column of oil/water and sometimes gas to bring the mixture to the surface. The properties of the mixture are determined through mass flow meters 10 and 11 and choke valve 13 and the information fed to controller C. The controller then opens or closes throttling valve 20 as required.

In figure 7 there is shown an arrangement whereby well flow is controlled by the control of the well head choke. In this installation, two mass flow meters 10 and 11 are operatively connected to the well output line, the meters being disposed on opposite sides of the choke 13. The instrumentation provided at each point consists of a temperature transmitter, a pressure transmitter and a mass flow density transmitter.

The transmitter measurements are adapted to be fed to a processor P such as a computer containing data and algorithms regarding characterization of gas pressure/temperature/volume/density relationships, mass balance relationships and data regarding oil and water properties as a function of temperature and pressure. The processor P uses this data and the transmitter signals to determine oil, water and gas mass and volumetric flow rates. This information is used as a basis for controlling the position of the choke. This may be done automatically or manually.

By employing the multi-phase analysis system of the invention, for example, on an off-shore platform with multiple wells, continuous measurement of production from each well can be achieved. This can lead to improved reservoir management. The analysis also provides for a more representative flow measurement from the well head due to an improved

-10-

response time compared to the "test separator" discussed earlier.

In the particular example given above, the system is likely to be able to monitor slugging flow whereas the "test separator" cannot effectively
5 owing to its poor response time.

An example of multi-phase measurement according to the present invention is given below for measurement of a distillate fuel oil/water/air
10 mixture, the measurement being done in a laboratory.

Fig.8 shows the layout of a test installation. This installation is only used as a simulator of the apparatus of the invention and is not constructed in accordance with the apparatus claims herein.

The mixture tested was a mixture of diesel, water and air. The water, diesel and air were fed into the system via flow meters M_1 , M_2 and M_3 and through gate valves V_8 , V_9 and V_{10} respectively. M_1 was a Fisher and Porter Rotameter M_2 a VAF positive displacement vane meter and M_3 a Fisher and Porter Purge Rotameter. The gate valves were used to vary the inlet flows.

The flow of the various phases passed to a static flow mixer 1 which provided for a homogeneous three phase flow. A clear pipe section 2 was provided for enabling visual inspection.

The mixture passed to the test circuit section of the installation where measurement of the flow rate was made by meter M_4 which was a Micrometer D40 mass flow meter with the DT7 density and temperature and DT10 flow rate and flow stabilization units. The flow meters M_1 , M_2 and M_3 were calibrated against meter M_4 before the test and the meter M_4 was volumetrically calibrated before the test.

The pressure gauge PG measured the pressure at the meter M_4 and the pressure gauge PA was used in conjunction with meter M_3 to give the inlet air flow.

-11-

The valves V_1 , V_2 , V_3 , V_4 , V_5 and V_6 were arranged to control the direction of flow and V_7 was the pressure dropping gate valve. This valving arrangement was used to simulate upstream and downstream of the pressure dropping valve V_7 . As such, it was only necessary to use one meter M_4 rather than two.

Initial readings were taken of the three inlet flows and upstream conditions at the meter M_4 thereafter the system was reversed to simulate downstream conditions and further readings were taken. Table 1 sets out the results of four tests conducted.

The mathematics involved with test number 2 are given below.

Initial Known Data

15	Density of water (ρ_w)	1.00s.g.
	Density of diesel (ρ_d)	0.828s.g.
	Density of air (ρ_g)	1.29×10^{-3} (0°C 1 Atmos)

Before Valve V_7 (UPSTREAM)			After Valve V_7 (DOWNSTREAM)	
	M_{T1}	19.2 Kg/min	M_{T2}	19.2
20	P_1	330 KPa	P_2	265
	T_1	19.4 °C	T_2	19.4
	ρ_{T1}	.825 s.g.	ρ_{T2}	.812

-12-

Inlet Conditions

$$V_d' \quad 10.7 \text{ l/min} : V_w' \quad 10.4 \text{ l/min} : V_g' \quad 2.2 \text{ l/min}$$

The above flows were corrected to calibrated flows from original readings.

- 5 Calculating volume flows from above

$$V_{T1} = \frac{M_{T1}}{A_{T1}} \quad V_{T2} = \frac{M_{T2}}{A_{T2}}$$

$$= 23.2 \text{ l/min} \quad = 23.6 \text{ l/min}$$

$$\Delta V_T = V_{T2} - V_{T1} = 0.4 \text{ l/min}$$

$$V_{T1} = V_d' + V_w' + V_g' = 23.3 \text{ l/min}$$

- 10 The expected change in V_T due to the change in gas volume induced across V_T can be calculated from $PV = nRT$ (ideal gas).

For this case nRT is constant.

$$\therefore V_{g2} = \frac{P_1}{P_2} \cdot V_{g1} \text{ (using } V_g' = 1.7 \text{ l/min @ 470 KPng)}$$

- 15 $V_{g1} = 2.2 \text{ l/min} \quad V_{g2} = 2.6 \text{ l/min}$

$$\Delta V_g = V_{g2} - V_{g1} = 0.4 \text{ l/min}$$

(This result compares with ΔV_T as measured by M_4 of 0.4 l/min).

- 20 Given that the volume flow rates of diesel and water will remain constant across V_7 ; that is

$$V_{d1} + V_{w1} = V_{d2} + V_{w2}$$

then the measured change in volume flow rate across V_7 is the flow rate change in the gas phase; that is

-13-

$$V_{T2} - V_{T1} = V_{g2} + V_{d2} + V_{w2} - V_{g1} + V_{d1} - V_{w1}$$

$$= V_{g2} - V_{g1}$$

$$= \Delta V_g = 0.4 \text{ l/min}$$

Using the ideal gas law in this instance

$$\begin{aligned} 5 \quad V_{g2} &= V_{g1} + \Delta V_g \\ &= n \frac{RT_1}{P_1} + \Delta V_g = n \frac{RT_2}{P_2} \end{aligned}$$

$$\begin{aligned} nR &= \frac{\Delta V_g}{\frac{T_2}{P_2} - \frac{T_1}{P_1}} \end{aligned}$$

$$\begin{aligned} \text{From the above result} \quad \Delta V_g &= 0.4 \text{ l/min} \\ T_1 &= T_2 = 19.4^\circ \text{C} \\ 10 \quad P_1 &= 330 \text{ KPag} \\ P_2 &= 265 \text{ KPag} \end{aligned}$$

$$nR = 3.3$$

At meter M₃ Pa = 470 KPag T = 20°C

$$V_g = \frac{3.3 \times 293}{571} = 1.7 \text{ l/min}$$

15 This compares with the calibrated inlet volume of 1.7 l/min. Changing the above flow rate to the flow rates at the upstream and downstream

$$V_{g1} = 2.2 \text{ l/min}$$

$$V_{g2} = 2.6 \text{ l/min}$$

20 To find the gas density at the above conditions it is necessary to know its molecular weight
M = 29 kg/kmol

- 14 -

$$\rho_{g1} = 5.1 \text{ g/l}$$

$$\rho_{g2} = 4.3 \text{ g/l}$$

The calculation of the water and diesel flow rates can be found from the following equations

$$5 \quad V_w = \frac{M_{T1} - M_{g1} + \rho_d (V_{g1} - V_{T1})}{\rho_w - \rho_d}$$

$$V_d = \frac{M_{T1} - M_{g1} + \rho_w (V_{g1} - V_{T1})}{\rho_d - \rho_w}$$

Substituting values into the above

$$V_w = 10.5$$

$$V_d = 10.5$$

10 These are comparable to the inlet flows

-15-

TABLE 1

BEFORE VALVE (UPSTREAM)					AFTER VALVE (DOWNSTREAM)					INLET CONDITIONS				
M_{T1} kg/min	P_1 kPag	T_1 °C	Density ρ_{T1}	V_{T1}	M_{T2}	P_2	T_2	Density ρ_{T2}	V_{T2}	Diesel V_d'	Water V_w'	Air V_{a1}	$M_{T1} \sim \rho_{T1} V_{d1} + \rho_{T1} V_{w1}$	
(1) 19.0	325	19.5	.873	21.8	19.0	260	19.4	.863	22.0	10.8	9.9	.91	21.5	~ 18.7
(2) 19.2	330		.825	23.2	19.2	265		.812	23.6	10.7	10.4	1.72	22.8	~ 19.3
(3) 19.0	360		.775	24.3	19.0	295		.759	25.1	10.8	9.8	3.7	24.4	~ 18.7
(4) 17.4	325		.751	23.2	17.4	215		.719	24.3	14.5	5.2	3.4	23.1	~ 17.2

$V_T = \frac{M_T}{\rho_T}$

$\Delta V_T = V_{T2} - V_{T1}$

$\Delta V_g = V'_{g1} - V'_{g2}$

$V_{g1.2}$

calculated from gas law
and pressures at measurement points.

(1)	0.2	0.2
(2)	0.4	0.4
(3)	0.6	0.6
(4)	1.1	1.2

CLAIMS

1. A method for continuous analysis of a multiphase mixture flowing along a flow path for determining selected properties of the mixture or of phases of the mixture, the method including the steps of :
 - (a) first, determining the pressure, temperature, density and mass flow rate of the mixture at a first point upstream of a characteristic change zone in the flow path;
 - (b) causing a change in at least one characteristic of the mixture flow in said characteristic change zone;
 - (c) thereafter determining the pressure, temperature, density and mass flow rate at a second point downstream of said characteristic change zone; and
 - (d) determining the selected properties of the mixture or of one or more phases of the mixture on the basis of the information collected together with known parameters using algorithms.
2. A method according to claim 1 wherein the characteristic which is changed is pressure.
3. A method according to claim 1 wherein the characteristic which is changed is temperature.
4. A method according to claim 1 wherein the characteristic which is changed is the composition of the mixture caused by at least a partial separation of the phases in the mixture.
5. A method according to claim 1 wherein said characteristic change is initiated by a change other than between said two points which causes said characteristic change.



6. A method according to any preceding claim including the step of utilizing an interfaced computer to determine the selected properties.

7. Apparatus for continuous analysis of a multiphase mixture flowing along a flow path for determining selected properties of the mixture or of phases of the mixture, the apparatus comprising:

a first means for directly measuring the density and mass flow rate at a first point upstream of a characteristic change zone in the flow path;

means for causing a change in at least one characteristic of the mixture flow in said characteristic change zone; and

a second means for directly measuring the density and the mass flow rate at a second point downstream of the characteristic change zone, the arrangement being such that selected properties of the mixture or of one or more phases of the mixture can be determined on the basis of the information collected together with known parameters using algorithms.

8. Apparatus according to claim 7 including a computer arranged so that the properties of the mixture can be determined from the information obtained from the other parts of the apparatus.

9. Apparatus according to claim 7 or claim 8 wherein the characteristic is a pressure differential caused by a choke valve.

10. Apparatus according to claim 7 or claim 8 wherein the characteristic changed is the composition of the mixture caused by phase separation by a hydro cyclone.



11. Apparatus according to any one of claims 7 to 10, wherein said first and second means are mass flow meters.

12. A method of controlling discharge from a well head comprising the steps of analysing the multi-phase mixture being discharged from the well head in accordance with any one of claims 1 to 6 and from the results obtained controlling the discharge conditions in a selected manner.

13. A method according to claim 12 wherein the discharge of the mixture from the well is controlled by a choke, the method including operating the choke in response to the results obtained.

14. A method according to claim 12 wherein the discharge of the mixture from the well is controlled by the delivery of gas to the well the method including controlling the delivery of the gas in response to the results obtained.

15. Apparatus for controlling discharge from a well head the apparatus being characterised by multi-phase analysis apparatus for analysing multi-phase mixtures according to any one of claims 7 to 11, having a choke operatively connected to the discharge line from the well head and control means for controlling opening and closing of said choke said control means being operable in response to information received from said multi-phase analysis apparatus.



16. Apparatus for controlling discharge from a well head, the apparatus being characterised by multi-phase analysis apparatus according to any one of claims 7 to 11, means for delivering gas to the well having valve means controlling the quantity of gas delivered and control means for controlling opening or closing of said valve means said control means being operable in response to information received from said multi-phase analysis apparatus.

17. A method according to claim 1 substantially as described herein.

18. Apparatus according to claim 7 substantially as described herein with reference to Figs. 1 to 5 of the drawings.

19. A method according to claim 13 substantially as described herein with reference to Fig. 6 of the drawings.

20. A method according to claim 14 substantially as described herein with reference to Fig. 7 of the drawings.

21. Apparatus according to claim 15 substantially as described herein with reference to Fig. 6 of the drawings.

22. Apparatus according to claim 16 substantially as described herein with reference to Fig. 7 of the drawings.

