

PATENT SPECIFICATION

(11) 1364926

1364926

- (21) Application No. 37495/71 (22) Filed 10 Aug. 1971
 (31) Convention Application No. 7029635 (32) Filed 12 Aug. 1970 in
 (33) France (FR)
 (44) Complete Specification published 29 Aug. 1974
 (51) International Classification G06F 15/00
 (52) Index at acceptance G4A 4X
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(54) METHOD OF PROCESSING WELL LOGGING DATA BY COMPUTER

(71) We, SCHLUMBERGER INLAND SERVICES INC., 19 Berkeley Street, London, England, a corporation of Panama, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

This invention relates to a method of operating a composition to process production logging data and more particularly to a method making it possible to determine the flowrate of each phase in the case of a two-phase flow of oil bubbles in a continuous water phase.

The fluid flowing in a production well is generally a mixture of several phases, water, gas and oil, coming from the different producing layers. One of the purposes of production logging is to determine, at different levels of a production well, the nature and the quantity of the phases in the flowing fluid. To solve this problem in the case of two-phase outflows, a conventional method is to measure at each of these levels, the total flowrate of the fluid and also the hold-up of each phase (by "total flowrate" is meant the instantaneous flow of all the produced fluid; the "hold-up" of a phase is the proportion of that phase to the total volume, considered under static conditions).

There are also numerous apparatuses allowing this information to be obtained. To measure the total flowrate one generally uses spinner flowmeters in particular as described in the British Patent No. 1,304,702 and French Patent No. 2,036,200. To obtain the hold-up of each phase, one may for example measure the average density of the flowing fluid either by means of a differential pressure apparatus, called a gradiomanometer, of the type described in the US Patent 3,455,157, or by means of a vibrating densitometer, in particular as described in the US Patent 3,225,588. It is also possible to obtain the composition of the flowing fluid by means of nuclear apparatus of the gamma ray emis-

sion type, or in certain cases by average capacitance measurements. Another known method is to combine two of the above sensors so as to obtain with a single apparatus the total flowrate and the hold-up of each phase.

It may be thought that, from these two quantities, it is simple to determine the relative flowrate of each phase. In fact, in a vertical rising outflow, the phases have different velocities, the lighter phase flowing faster than the heavier phase. Consequently, the "cut" of the phase (i.e. the flowrate of each phase divided by the total flowrate) is different from the measured (static) hold-up. In order to determine the flowrate of each phase, it is necessary to know another quantity, for example the slippage velocity, i.e. the difference in velocity between the two phases. It has hitherto been assumed that this slippage velocity is constant along the entire length of the well, and only a function of the density difference of the two phases. For high flowrates, such a method makes it possible to obtain reasonably accurate results due to the fact that the slippage velocity remains low in relation to total flowrate. On the other hand, in the case of low flowrates, this method leads to erroneous results.

An object of the present invention is to provide a method making it possible to determine with accuracy the flowrate of each phase in a two-phase flow consisting of oil bubbles in a continuous water phase.

A further object of the invention is to provide a method providing an exact representation of the nature and of the composition of the fluid produced at different levels of a well.

According to the invention, a method of operating a computer to process producing logging data in a two-phase water-oil outflow to determine the flowrate of one of the phases at different levels of a producing well, comprises feeding into the computer, for each depth, data representative of the total flowrate Q_t and of the hold-up y of one

of the phases, operating the computer to determine, for each depth, the slippage velocity V_s between the two phases as a function of the hold-up y and of a parameter $\Delta\rho'$ which is a function of the density difference between the two phases, operating the computer to determine the flowrate of one of the phases from the obtained slippage velocity V_s and from the data representative of the total flowrate Q_t and of the hold-up y , and finally operating the computer to present said determined flowrate in physical form.

As a value for the parameter $\Delta\rho'$, one may use the density difference between the two phases, corrected if necessary to take the depth into account, in which case one uses average values for the velocity of the phases and the surface tension between the phases. It is also possible to obtain this parameter $\Delta\rho'$ in a zone of the well in which one knows the total flowrate, the flowrate of one of the phases and the hold-up y , by determining from this information, the slippage velocity in this zone, then, from this slippage velocity the parameter $\Delta\rho'$ valid over the entire length of the well. The slippage velocity V_s is obtained by means of the function:

$$V_s = f(y, \Delta\rho'),$$

represented by curves established during laboratory experiments.

The characteristics and advantages of the invention will be better understood through the description to follow given by way of non-limitative example with reference to the accompanying drawings in which:

Figure 1 is a simplified diagram of a two-phase outflow in a producing well;

Figure 2 is a set of curves giving the slippage velocity as a function of the density difference between the two phases of a flowing fluid and also as a function of the relative hold-up of these phases;

Figure 3 is an alignment chart giving a graphical solution of the method of the invention;

Figure 4 is a form of presentation of the results obtained by the method of the invention; and

Figure 5 is the diagram of the circuits for the processing of data in accordance with the method of the invention.

For a proper understanding of the invention we shall first of all establish the equations which relate the different parameters of a two-phase outflow. Referring now to Figure 1, a schematic representation is given of a section of a casing 10 of a producing well. In this casing flows a two-phase fluid produced by underground formations and including a heavy phase 11, for example water, and a light phase 12, for example oil. To per-

mit the equations to be formulated, two separate phases are represented, flowing parallel to each other. In reality, the two phases are mixed, one of these phases generally being in the form of bubbles in suspension in the other phase called the continuous phase. If y is the water hold-up, i.e. the ratio between the volume of water in place and the total volume of the fluid, we see that the water flowrate Q_w and the oil flowrate Q_o are given by the equations:

$$Q_w = yA V_w \quad (1)$$

$$Q_o = (1-y) A V_o \quad (2)$$

in which A is the internal area of the cross-section of the casing and V_w and V_o are the respective velocities of the water phase and the oil phase.

Moreover, the total flowrate Q_t is given by the equation:

$$Q_t = Q_w + Q_o \quad (3)$$

If the quantities Q_t and y can be obtained through measurements in the well, we have three equations with four unknowns, namely Q_w , Q_o , V_w and V_o . To solve this system of equations, we will thus need a fourth equation, for example:

$$V_s = V_o - V_w \quad (4)$$

in which V_s is the slippage velocity between the two phases. If this slippage velocity can be determined, we can in fact solve the system of equations (1) to (4) to obtain Q_w and Q_o .

$$Q_w = y Q_t - y (1-y) A V_s \quad (5)$$

$$Q_o = (1-y) Q_t + y (1-y) A V_s \quad (6)$$

Recent laboratory studies have shown that the slippage velocity V_s is a function of both the hold-up y and of certain physical properties of the phases such as their density, their viscosity, and the surface tension of the bubbles. Figure 2 shows the result of these studies in the case of a two-phase outflow composed of oil bubbles in suspension in a continuous water phase. In this Figure 2, a set of curves 13 to 21 has been plotted, each of these curves representing, for a given water hold-up, the slippage velocity V_s as a function of a parameter $\Delta\rho'$ which is a function of the density difference between the two phases.

Following these experiments, it was possible to make two observations. It was first of all verified that the slippage velocity increases when the density difference increases. It was moreover found that this slippage velocity increases when the water hold-up y

increases. It was hitherto considered that the slippage velocity was constant along the entire length of a producing well, even when the water hold-up varied. The curves of Figure 2 show that this method of interpretation gives erroneous results, especially for low flow-rates in which the slippage velocity is relatively high compared with the average velocity of flow of the fluid.

The curve 13, plotted for a water hold-up $y=1$, corresponds to the speed of an oil bubble in static water. Laboratory experiments have made it possible to verify that the speed of an oil bubble in water depended mainly on the density difference between the water and the oil and on the surface-tension of the bubbles. The viscosity of the oil is also involved, but less significantly, and it is possible to use an average value without effecting substantially the accuracy of the results. The experimental results are moreover very close to those of the theoretical study, which gives a bubble velocity of the form:

$$V=K\left(\frac{g\tau\Delta\rho}{\rho_w^2}\right)^{1/4}$$

in which K is a constant, g the acceleration of gravity, τ the surface tension of the bubbles, $\Delta\rho$ the water-oil density difference, and ρ_w the density of the water. It is seen that the exact determination of the slippage velocity requires theoretically the knowledge of the surface tension τ . In practice, an average value of τ may be used and the curve 13 may be plotted to give the slippage velocity for an apparent density difference $\Delta\rho'$ corresponding to the actual density difference $\Delta\rho$ for average values of viscosity and surface tension.

It has been found that the curve 13 (for $y=1$) can be expressed mathematically by the function:

$$V_1=K_1\left(\frac{\Delta\rho'}{\rho_w^2}\right)^{1/4}$$

in which the parameter

$$\Delta\rho'=\Delta\rho\frac{\tau}{35}\frac{1}{(1+0.03\text{ Log } \nu)}$$

where K_1 is a constant and ν is the viscosity of the oil. It can be seen that $\Delta\rho'=\Delta\rho$ for $\tau=35$ dynes/cm and $\nu=1$ centipoise, average conditions which are chosen arbitrarily. In practice, the parameter $\Delta\rho'$ is very near to the actual density difference $\Delta\rho$.

Moreover, laboratory experiments have made it possible to show that, knowing the parameter $\Delta\rho'$, it was possible to plot a curve giving the slippage velocity as a function of the water hold-up y , the maximum slippage

velocity corresponding to $y=1$; that is to the points on the curve 13. In the same manner, it was possible to plot curves giving the slippage velocity as a function of the parameter $\Delta\rho'$ for different values of y (curves 14 to 21 of Figure 2).

Using the curves 13 to 21 which define the function

$$V_s=f(y, \Delta\rho'),$$

it is possible, in accordance with the invention, to determine the slippage velocity V_s . In fact, knowing the water hold-up given by a densitometer or a gradiomanometer lowered into the well, one will be able to select one of the curves 13 to 21. Also, knowing the parameter $\Delta\rho'$, one will be able to define a point of the selected curve whose ordinate will be the sought slippage velocity. From the curves of Figure 2, it is also possible to formulate the equation

$$V_s=f(y, \Delta\rho'),$$

with a view to automating the calculations. Once this magnitude V_s has been obtained, it will be easy to determine the flowrates Q_w and Q_o by means of the equations (5) and (6).

It has been found that this function

$$V_s=f(y, \Delta\rho'),$$

can be expressed mathematically by the equation:

$$V_s=K_1\left(\frac{\Delta\rho'y}{\rho_w^2}\right)^{1/4}-K_2(1-y)^{1/3}$$

where K_2 is a constant and $\Delta\rho'$ is given by the equation mentioned previously. It can be seen that V_1 is only a particular case of this general equation V_s , obtained by replacing y by the value 1.

As it is practically impossible to obtain the value of the surface tension, two possibilities exist for determining the parameter $\Delta\rho'$. One can measure the density difference $\Delta\rho$ at the surface and correct this measured value to take into account the temperature and pressure conditions at the considered depth. One can then use this corrected value of the parameter $\Delta\rho'$, knowing that one is implicitly using average values for the surface tension and the viscosity. The other possibility is to determine the value of the parameter $\Delta\rho'$ from surface measurements of the total flowrate Q_t and water flowrate Q_w , and also from a quantity coming from a measurement of y made immediately over the production zone closest to the surface; this measurement y corresponding to the surface flow. From these values, Q_t , Q_w and y one can determine the slippage velocity by using the equation (5). By means of the curves

of Figure 2, knowing y and V_s , one can obtain the value of the parameter $\Delta\rho'$ applicable over the entire length of the well. This value obtained for the parameter $\Delta\rho'$, which then takes into account the surface tension and the viscosity, may not be equal to the actual density difference between the phases.

Just as it is possible, from the curves of Figure 2, to find the equation which relates the slippage velocity to the apparent density difference and to the water hold-up, one can also solve the equations (5) and (6) graphically. In order for this graphical solution to be applicable to all the casings of the well, irrespective of their internal area A , one

uses a parameter $\bar{V}$, called the "superficial velocity", and defined, as the flow per unit area. This superficial velocity is then independent of the dimensions of the casing, and we have:

$$\bar{V}_t = Q_t / A$$

$$\bar{V}_w = Q_w / A$$

$$\bar{V}_o = Q_o / A$$

The superficial velocities of the water and of the oil are then given by the equations:

$$\bar{V}_w = y \bar{V}_t - (1-y) V_s \quad (7)$$

$$\bar{V}_o = (1-y) \bar{V}_t + y (1-y) V_s \quad (8)$$

Figure 3 represents an alignment chart permitting the graphical solution of the equations (7) and (8) without passing in an explicit manner through the intermediate value V_s . This figure represents, from left to right, three axes 23, 24 and 25, on which are

located respectively the values $\bar{V}_t$, $\bar{V}_w$ and $\bar{V}_o$. A family of curves 26, corresponding to the different values of $\Delta\rho'$, is intersected by vertical lines 27 corresponding to the different values of the water hold-up y . To each value of $\Delta\rho'$ there thus corresponds a curve of the family 26 and to each value of y a point on this curve. If we know the total superficial velocity $\bar{V}_t$, we need only join this value, located on the axis on the left, to the previously defined point of the curve of the family 26. This line intersects the axes 24 and 25 at two points which give respectively the sought values of $\bar{V}_w$ and $\bar{V}_o$. By way of example is shown the graphical solution obtained for a total superficial velocity

$\bar{V}_t = 7.1$ m/min, a water hold-up $y = 0.6$ and an apparent density difference $\Delta\rho' = 0.25$. To do this, one draws a line 32 joining the point 30 on the axis 23 whose ordinate is equal to 7.1 to the point 31 defined on the curve family 26 by the values $y = 0.6$ and $\Delta\rho' = 0.25$. This line intersects the lines 24 and 25

at two points whose ordinates are $\bar{V}_w = 3.2$ m/min and $\bar{V}_o = 3.9$ m/min.

Conversely, by means of the alignment chart of Figure 3, it is possible to determine the value of the parameter $\Delta\rho'$ applicable over the entire length of the well if one knows the values of $\bar{V}_t$, $\bar{V}_w$ and y corresponding to the same outflow. As the values $\bar{V}_t$ and $\bar{V}_w$ are known for the flow at the surface of the well, one need only carry out a measurement of y in the part of the casing located immediately over the perforations closest to the surface. The line joining the values $\bar{V}_t$ and $\bar{V}_w$ measured on the surface will intersect the vertical line of abscissa y at a point defining a curve of the family 26 which corresponds to the sought value of $\Delta\rho'$.

The method of the invention thus makes it possible to determine at different depths the flowrate of the water and the flowrate of the oil flowing in the well for oil bubbles in suspension in a continuous water phase. In simple cases, these values may be determined manually, either by calculation, or graphically, as indicated above, although such manual determination falls outside the scope of the present patent. On the other hand, for more complex cases, it will be necessary to use automatic computation methods in accordance with the present invention. The method of the invention is a method of operating a computer to perform automatic calculations. In fact, as one knows all the relationships between the different parameters, they can be transformed into program form by specialists. The computer can be either a general purpose computer or a dedicated computer, in which case the calculations are carried out by means of electronic circuits adapted to automatically process signals representative of the total flowrate Q_t and of the water hold-up y .

Figure 5 represents such circuits. A signal representative of y is applied to a calculation circuit 33 to which is also applied a signal representative of $\Delta\rho'$. The circuit 33 delivers an output signal proportional to

$$V_s = f(y, \Delta\rho'),$$

the function f being defined by the curves of Figure 2. The signal y is also applied to a calculation circuit 34 adapted to deliver an output signal proportional to $y(1-y)$.
 5 The circuits 33 and 34 are connected to the inputs of another calculation circuit 35 to which is applied the value of the area A so as to generate a signal representative of $y(1-y)V_sA$. The signal y and a signal
 10 representative of Q_t are also applied to a multiplication circuit 36 whose output signal is proportional to yQ_t . The outputs of the circuits 35 and 36 are connected to the input of a subtraction circuit 37 which gives the
 15 difference of these two signals; that is,

$$Q_w = yQ_t - y(1-y)V_sA.$$

The signal Q_w and the signal Q_t are applied to a recorder 38 whose movement is a function of the depth.

20 Figure 4 represents a recording which may be given by the recorder 38. This presentation may also be obtained by marking on a diagram the value of Q_w and Q_t obtained graphically by means of the alignment chart of
 25 Figure 3. On the left part is a schematic representation of the production well consisting of a casing 40, perforated opposite two production zones 41 and 42. On the upper part of the casing 40 is fixed the lower end of a
 30 production string 43. To the right of this schematic representation there is a zone whose ordinate is graduated in depths and whose abscissa is graduated in flowrate units (m^3/h , for example). In this zone a first curve 44
 35 has been plotted, representing the total flowrate Q_t , given for example by a spinner flowrate. A second curve 45 represents the water flowrate Q_w calculated in accordance with the
 40 method of the invention from the measurements of the flowmeter and a gradiomanometer for example. The zone located between the curves 44 and 45 thus represents the oil production of the well. By means of
 45 such curves, one immediately sees the nature and the composition of the fluid produced by each zone. Thus, for example, the zone 42 is composed of a lower part which produces only water, a middle part which does
 50 not produce any fluid and an upper part which produces both water and oil in the proportions of 20% water and 80% oil. These curves thus give precise quantitative information which is directly utilizable and which
 55 in particular makes it possible to determine the operations to be performed to improve the production and the yield of the well.

WHAT WE CLAIM IS:—

1. A method of operating a computer to process well logging data in order to determine, in a two-phase, water-oil, outflow, the flowrate of one of the phases at different
 60 depths of a production well, comprising feed-

ing into the computer for each depth first data representative of the total flowrate Q_t and second data representative of the hold-up y of one of the phases, operating the
 65 computer to determine for each depth a value of the slippage velocity V_s between the two phases, as a function of the said second data y and of a parameter $\Delta\rho'$ which
 70 is a function of the density difference between the two phases, operating the computer to determine the flowrate of one phase from the obtained value of the slippage velocity
 75 V_s and from the first and second data representative respectively of the total flowrate Q_t and of the hold-up y , and finally operating the computer to present said determined flowrate in physical form.

2. A method according to claim 1 characterized in that the said value of the slippage velocity V_s is obtained by operating the computer to solve the equation

$$V_s = f(y, \Delta\rho'),$$

f being a function represented by the curves of Figure 2. 85

3. A method according to claim 2 characterized in that the parameter $\Delta\rho'$ is the value of the density difference between the phases measured on the surface and corrected if
 90 necessary to take into account the temperature and pressure conditions of the well.

4. A method according to claim 2 characterized in that the parameter $\Delta\rho'$ is obtained by determining a value of the slippage velocity V_s in a zone of the well where the total
 95 flowrate Q_t , the flowrate of one of the phases, and the hold-up y are known, and by using this value of the slippage velocity to obtain the said parameter $\Delta\rho'$ by operating the
 100 computer to solve the said equation

$$V_s = f(y, \Delta\rho').$$

5. A method according to any one of claims 1 to 4 characterized in that the determination of the flowrate of the water phase
 105 Q_w is accomplished by operating the computer to solve the equation:

$$Q_w = yQ_t - y(1-y)V_sA,$$

in which A is the area of the internal cross-section of the production well. 110

6. A method according to any one of claims 1 to 4 characterized in that the determination of the oil flowrate Q_o is accomplished by operating the computer to solve the equation: 115

$$Q_o = (1-y)Q_t + y(1-y)V_sA,$$

in which A is the area of the internal cross-section of the production well.

7. A method of operating a computer to

the function f being defined by the curves of Figure 2. The signal y is also applied to a calculation circuit 34 adapted to deliver an output signal proportional to $y(1-y)$. The circuits 33 and 34 are connected to the inputs of another calculation circuit 35 to which is applied the value of the area A so as to generate a signal representative of $y(1-y)V_sA$. The signal y and a signal representative of Q_t are also applied to a multiplication circuit 36 whose output signal is proportional to yQ_t . The outputs of the circuits 35 and 36 are connected to the input of a subtraction circuit 37 which gives the difference of these two signals; that is,

$$Q_w = yQ_t - y(1-y)V_sA.$$

The signal Q_w and the signal Q_t are applied to a recorder 38 whose movement is a function of the depth.

Figure 4 represents a recording which may be given by the recorder 38. This presentation may also be obtained by marking on a diagram the value of Q_w and Q_t obtained graphically by means of the alignment chart of Figure 3. On the left part is a schematic representation of the production well consisting of a casing 40, perforated opposite two production zones 41 and 42. On the upper part of the casing 40 is fixed the lower end of a production string 43. To the right of this schematic representation there is a zone whose ordinate is graduated in depths and whose abscissa is graduated in flowrate units (m^3/h , for example). In this zone a first curve 44 has been plotted, representing the total flowrate Q_t , given for example by a spinner flowrate. A second curve 45 represents the water flowrate Q_w calculated in accordance with the method of the invention from the measurements of the flowmeter and a gradiomanometer for example. The zone located between the curves 44 and 45 thus represents the oil production of the well. By means of such curves, one immediately sees the nature and the composition of the fluid produced by each zone. Thus, for example, the zone 42 is composed of a lower part which produces only water, a middle part which does not produce any fluid and an upper part which produces both water and oil in the proportions of 20% water and 80% oil. These curves thus give precise quantitative information which is directly utilizable and which in particular makes it possible to determine the operations to be performed to improve the production and the yield of the well.

WHAT WE CLAIM IS:—

1. A method of operating a computer to process well logging data in order to determine, in a two-phase, water-oil, outflow, the flowrate of one of the phases at different depths of a production well, comprising feed-

ing into the computer for each depth first data representative of the total flowrate Q_t and second data representative of the hold-up y of one of the phases, operating the computer to determine for each depth a value of the slippage velocity V_s between the two phases, as a function of the said second data y and of a parameter $\Delta\rho'$ which is a function of the density difference between the two phases, operating the computer to determine the flowrate of one phase from the obtained value of the slippage velocity V_s and from the first and second data representative respectively of the total flowrate Q_t and of the hold-up y , and finally operating the computer to present said determined flowrate in physical form.

2. A method according to claim 1 characterized in that the said value of the slippage velocity V_s is obtained by operating the computer to solve the equation

$$V_s = f(y, \Delta\rho'),$$

f being a function represented by the curves of Figure 2.

3. A method according to claim 2 characterized in that the parameter $\Delta\rho'$ is the value of the density difference between the phases measured on the surface and corrected if necessary to take into account the temperature and pressure conditions of the well.

4. A method according to claim 2 characterized in that the parameter $\Delta\rho'$ is obtained by determining a value of the slippage velocity V_s in a zone of the well where the total flowrate Q_t , the flowrate of one of the phases, and the hold-up y are known, and by using this value of the slippage velocity to obtain the said parameter $\Delta\rho'$ by operating the computer to solve the said equation

$$V_s = f(y, \Delta\rho').$$

5. A method according to any one of claims 1 to 4 characterized in that the determination of the flowrate of the water phase Q_w is accomplished by operating the computer to solve the equation:

$$Q_w = yQ_t - y(1-y)V_sA,$$

in which A is the area of the internal cross-section of the production well.

6. A method according to any one of claims 1 to 4 characterized in that the determination of the oil flowrate Q_o is accomplished by operating the computer to solve the equation:

$$Q_o = (1-y)Q_t + y(1-y)V_sA,$$

in which A is the area of the internal cross-section of the production well.

7. A method of operating a computer to

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process well logging data in order to determine, in a two-phase, water-oil outflow, the flowrate of one of the phases at different depths of a production well, substantially as described hereinbefore with reference to and

as illustrated in the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1974.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY; from which copies may be obtained.



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