Title: MULTI-MODEL FRACTION VERIFICATION FOR MULTIPHASE FLOW

Abstract: The present invention relates to a flow monitoring system and method for monitoring the content of a multiphase flow by monitoring at least one characteristic of the flow. The characteristic being influenceable by at least three different properties of the flow where the properties are related to the flow content. The monitoring system is adapted to calculate an indication of the content of the flow in three different calculation modes and compare new values with previous values providing three pairs of parameters, where the first calculation mode being adapted to calculate the flow content from said flow measurements, the first of said parameter pair indicating a change in the flow content, the second calculation mode being adapted to calculate the content of the flow under the assumption that a first of said three properties is constant, the second pair indicating the change in flow content under the first assumption, and the third calculation mode being adapted to calculate the content of the flow under the assumption that a second of said three properties is constant, the third pair indicating the change in flow content under the second assumption. The system and method, at an event defined as a detected change in said characteristic or said parameter pairs of the flow, is adapted to indicate the cause of the event based on the comparison between the new and previous values in each pair of parameters.
MULTI-MODEL FRACTION VERIFICATION FOR MULTIPHASE FLOW

The present invention relates to the use of a multiphase meter measuring real time oil, water and gas flow rates. A full version meter consist of a multi-electrode electrical impedance sensor, a single or dual beam gamma radiation density meter and a venturi differential pressure meter, along with sensors for measuring pressure and temperature. A water salinity sensor can also be added.

A basic version, with some reduced performance and functionality, consist of only the multi-electrode impedance sensor, utilizing cross-correlation technique for flow velocity measurements, and interpretation of the tomometric information from the multi-electrode sensor for phase fraction measurements. The system approach is modular, allowing versions at cost and performance between the basic and full version meters, by adding gamma, venturi and/or pressure and temperature sensors.

The multiphase meter requires some input parameter for optimum operation, e.g. electrical and density properties of the oil and water. The full version meter require less input, and is less sensitive to changes in these input parameters than the stripped down basic version. On the other hand, all meter versions will be more or less affected by such changes, which could in example result from water injection or gas lift operations. Additionally, the meter will be influenced by deposits, e.g. scale, wax or asphaltene, however the different version will be influenced to varying degree.

Several systems exist for monitoring the content of multi fluid flows, such as WO/2005/045371, US 2005/0193832, EP 1862781 and US 2014137642. WO/2006/094669 describes a system for measuring the flow rates of the different phases in a flow, but while providing the measurements it does not suggest a way to interpret the measurements so as to indicate the cause of the measured changes.
Operators of oil wells want to optimize production, and may use wellhead choke or downhole zone control for achieving this. Additionally, the operator can use artificial lift techniques like downhole pump or gas lift, or he could use water injection for maintaining reservoir pressure or for reservoir sweep operations. The operator also want to optimize production by producing the best producing well, or by selecting wells and production rates for best match with the downstream separator and water handling capacity. For many such control and optimization purposes the main interest of the operator will be monitoring the result of his control actions, e.g. increased production, or the operator may be interested to discover changes in well behavior as early as possible. In other words, in many such applications, the main interest will be in monitoring trends and detecting sudden changes in flow composition or rates, rather than measuring produced volumes at best possible accuracy.

The objective of this invention is an improved operator tool for monitoring well behavior. The operator tool is based on measurement of the multiphase flow fractions and flowrates, preferably combined with operator input on a-priori knowledge of well, reservoir and process, and it is based on combining results of alternative sensor combinations and calculation models. The present invention is more precisely defined in the claims.

The invention thus utilizes the multiphase measurements by making certain assumptions regarding the conditions in the flow and using at least two different assumptions to find the cause of a change in the measurements. Thus the purpose of the present invention is not finding the exact values related to the monitored changes, but based on the indicated changes to be able to find the cause of those changes based on the knowledge about how different types of changes in the flow will lead to different types of changes in the measurements performed by the sensors.

More specific the multiphase meter may according to a preferred embodiment now be set to run in three different calculation modes:
calculate the multiphase fractions and flowrates from only its in-built sensors and online input data providing a first estimate of a first and second content ratio parameter, e.g. Gas/Oil Ratio (GOR) and Water/Liquid Ratio (WLR);

ii. assume the first of said content ratio parameters, (the GOR) to be constant, and calculate the fractions and flowrates from this basis, providing a second estimate of said second content ratio parameter (the WLR); and

iii. assume the second of said content ratio parameters (the WLR), to be constant, and then calculate the fractions and flowrates from this basis, providing a second estimate of said first content ratio parameter (the GOR).

The invention will be discussed below with reference to the accompanying drawings, illustrating the invention by way of examples. The invention is exemplified using an impedance sensor as the primary method for determining the flow composition, and in the examples below it will be assumed that the impedance sensor is in capacitance mode.

Figure la-d and 2a-d illustrates the indications found under different assumptions and how the different calculated constant ratios varies over time in two different incidents.

Figure 3 illustrates the display presented to an operator in a stable situation and after a certain incident.

In the example illustrated in figure 1 and 2 the measurements from a multiphase meter is shown in the case where the capacitance of the flow is monitored. Similar results may be obtained by measuring the impedance, conductance or density. As can be seen from the illustrations the standard measuring mode illustrated in figures 1a,b and 2a,b use known calculation means for calculating the properties of the flow, and in the present example illustrated in figure 1a, 1b finds that an increase in capacitance may give an indication of a stable gas/oil ratio (GOR) and an increased water cut (WLR). A fall in the measured capacitance may indicate an increase in the GOR while the WLR is stable. In other words Figure 1a and 1b illustrates that the standard mode calculation in this case predicts the step change to be resulting from a step change in the water cut (lb),
while the average gas to oil ratio remained unchanged (la).

The trend curves in figure 1c and 2c are calculated based on an assumption that the water cut is fixed, and will respond to the increased capacitance by calculating a drop in gas/oil ratio. The trend curves in figure 1d and 2d, are assuming a fixed gas/oil ratio, and will respond to the increased capacitance by calculating an increase in water cut.

The content ratios or properties of the flow are monitored until at a time t where one or more of the monitored content ratios or the measured characteristic of the flow deviates more than a predetermined limit from an initial value. The predetermined limit could be a fixed value, it could be relative to previous measurement(s), e.g. detecting a step change as illustrated, or other suitable measure for determining trends or events in the production profile. Further, the step change in content ratios illustrated in figure 1 and 2 are the calculated response to a step increase or decrease in the measured capacitance.

In addition to be triggered by a step change, a change in the variation rate of the characteristic, e.g. from a slow change to a fast change, may also be used.

Now, by simple voting based on the calculated changes as represented by figure 1a-d and 2a-d, one can determine that the cause for the observed step is a sudden water break-through, which could of course also have been determined directly from the standard mode calculation. While the advantage of the fixed GOR and WLR modes, and the voting, may therefore not be immediately apparent in this ideal case, then one should be aware that often such shift in fractions may cause increased measurement uncertainty in multiphase meters, e.g. due to flow regime changes. While the standard mode calculation is still expected to move in the right direction, the calculated step in content ratios may therefore not be completely correct, and moreover, the water breakthrough could also result in a change in the GOR calculated by the standard mode. Then, taking into account that GOR and WLR are independent characteristics (although not always the case), the fixed GOR mode can now be decided to be the best option until next set-point calibration.
The monitored properties of the flow may be calculated sequentially or in parallel depending on the situation and the expected rate of change, as e.g. slow flow changes may not require continuous monitoring of all parameters. Also the evaluation of the event may be triggered by any change in the calculated properties or parameter pairs monitored by the system, or by a change in the measured characteristics, such as the measured capacitance or permittivity of the flow.

Once the event has been detected the content ratios of the flow may be calculated, and/or compared with previous content ratios for use in the voting to find the cause of the event.

Figure 3 illustrates the visualization of the measurements and calculations where figure 3 illustrates a stable condition. The solid line in figure 3 marks the deviations from an initial starting point, e.g. the previous calibration, and in the stable condition is close to zero. In this example there are two content related parameters that are monitored by the three calculation modes, these are the local water to liquid ratio (WLR) and the local gas area fraction (GAF), which is the area occupied by gas, relative to the total pipe area. Threshold indicating allowed deviations are shown above and below the measurements for the fixed GOR and WLR assumptions, and as indicated in figure 3 an incident is registered and evaluated as the calculations for each of the fixed GOR and WLR show if the deviation is negative or positive.

More in detail, a multiphase meter/monitor could initially, and at intervals to be determined, be set to, or tuned to, a starting point that is assumed to be correct. Operator input and available reference information will determine the absolute accuracy of this initial calibration point, however, for the purpose of this invention, the important feature will be the accuracy and robustness of the trending from the starting point until next calibration.

When monitoring the three calculation modes during production from an oil well, the resulting content ratio parameters will now react differently to changes in the flow composition, e.g. as a result of gradual or sudden increase in produced water.
Mode i. would detect and monitor the changing watercut, and should produce measurements of fractions and flowrates to the accuracy possible with the actual meter.

Mode ii., having a fixed GOR, would also detect and monitor the changing watercut, and accuracy could be expected higher than mode i. provided GOR is in fact constant.

Mode iii., have a fixed WLR, would naturally not detect the changing watercut. However, in this mode, in the example of using the electrical impedance sensor, the increasing watercut would wrongly be measured as a decrease in GOR.

The first and second estimates of the content ratio parameters will thus react differently as a result of the change, due to the differences in algorithms and a-priori assumptions. This may give an indication of the event type without accurately measuring the size of the change, and provide a useful information to the operator.

The internal voting system then may use the information as the standard/full multiphase code with the first estimate of the content ratio parameters, and the fixed GOR mode with the second estimate of the content ratio parameters, now pull in the same direction, while the estimates of the third mode deviates in the opposite direction, determining that the change is a result of a water breakthrough. Thereby the operator can continue monitoring the well using the two first modes, while flagging that setting a new starting point is required at earliest possible time.

Using the same example as above, it could in an example situation further be known that the well monitor is installed in a production line from a well in a thick oil zone, not using gas injection for artificial lift, and the oil of the reservoir having a known GOR, not assumed to change. In this case the fixed GOR mode will provide the highest performance measurements. Operating the meter in this mode, and assuming now that the multiphase meter reports a drop in watercut; In many production scenarios a drop in watercut would be a non-expected behavior, and certainly the operator would know if
this was the case. The operator would then suspect gas from a different source than what is free gas originating from the reservoir oil.

The above are examples of how the use of parallel running calculation modes, combined with operator knowledge, can be used in a rule based monitoring system for accurate and robust monitoring of trends and sudden changes in well behavior.

The method is not limited to running different modes based on the same set of sensors, but could also be based on different sensors or combination of sensors. As an example the meter could include two methods for measuring the velocity of the flow; e.g. cross correlation based on the multiple electrode impedance sensor and differential pressure across a venturi. For certain flow regimes the cross correlation will be mostly sensitive to the gas flow velocity, while the venturi will mostly be sensitive to the liquid velocity. The full multiphase code could make use of both these measurements in the flowrate calculations, thereby taking into account the slip between the liquid and gas. Two additional calculation modes can then run in parallel; a first mode using only the venturi, and a second mode using only the cross correlation, both with a slip as recorded from the calibration point. A deviation between these codes can be indicative of deposits either on walls of the sensor or in the venturi impulse lines. And similar to the previous example, voting and operator knowledge can be used to determine cause, and to determine which mode to trust until next time it is possible to set a new starting point.

To summarize the invention thus relates to a method or system for monitoring the content of a multiphase flow. At least one characteristics of the flow is influenceable or may be affected by at least three different properties of the flow related to the flow content, e.g by being an electrical characteristic of the flow that is affected by variations in the gas, oil or water content of the flow. The properties will preferably be mutually independent content ratios between the first and second, first and third or the second and third calculated content indications of the flow, such as content related properties like phase area fractions of the multiphase flow or ratios between phase area fractions of the multiphase flow, or they may flow related such as phase flow rates of the multiphase flow or the ratios between phase flow rates of the multiphase flow.
The monitoring system is adapted to calculate an indication of the content of the flow in
three different calculation modes and compare new values with previous values
providing three pairs of parameters. Each pair of parameters may include one parameter
calculated before a certain event and the second parameter calculated after the event, or
may also indicate two possible values of a parameter after the event.

The first calculation mode being adapted to calculate the flow content from said flow
measurements, the first of said parameter pairs indicating a change in the flow content.
This may for example be a change in watercut after an event calculated in the standard
calculation mode or an indication of the calculated values or changes in the watercut
and GVF after the event.

The second calculation mode is adapted to calculate the content of the flow under the
assumption that a first of said three properties is constant, the second pair indicating the
change in flow content under the first assumption. As an example the GVF may be
calculated assuming that the watercut is fixed.

The third calculation mode is adapted to calculate the content of the flow under the
assumption that a second of said three properties is constant, the third pair indicating the
change in flow content under the second assumption. For example the Watercut may be
calculated assuming that the GVF is constant.

Based on these parameter pairs the system may, at the detection of a change in the flow,
indicate the cause of the change in monitored characteristic. This is performed by a
comparison between the new and previous values in each pair of parameters.

As explained above the detected change may be registered when a change in the
monitored characteristic exceeds a chosen threshold or when the rate of change in the
monitored characteristic exceeds a chosen threshold.
The monitored characteristic is one of the following: impedance, capacitance, conductance or density, and may provide an indication of the flow conditions such as flow rate or flow content.

In the latter case the system calculates the watercut or gas/oil fraction of the flow in the first mode. The second mode calculates the gas/oil fraction of the flow under the assumption that the watercut is constant, and the third mode calculates the watercut under the assumption that the gas/oil fraction is constant. Thus the system is able to provide a reliable indication of the content ratios of the flow.
Claim 1. Flow monitoring system for monitoring the content of a multiphase flow by monitoring at least one characteristic of the flow, said characteristic being influencable by at least three different properties of the flow, the properties being related to the flow content, the monitoring system being adapted to calculate an indication of the content of the flow in three different calculation modes and compare new values with previous values providing three pairs of parameters, the first calculation mode being adapted to calculate the flow content from said flow measurements, the first of said parameter pair indicating a change in the flow content, the second calculation mode being adapted to calculate the content of the flow under the assumption that a first of said three properties is constant, the second pair indicating the change in flow content under the first assumption, the third calculation mode being adapted to calculate the content of the flow under the assumption that a second of said three properties is constant, the third pair indicating the change in flow content under the second assumption, and the system at an event defined as a detected change in said characteristic or said parameter pairs of the flow being adapted to indicate the cause of the event based on the comparison between the new and previous values in each pair of parameters.

2. System according to claim 1, where the event is registered when a change in the monitored characteristic or property exceeds a chosen threshold.

3. System according to claim 1, where the event is registered when the rate of change in the monitored characteristic or property exceeds a chosen threshold.

4. System according to claim 1, wherein the monitored characteristic is one of the following: impedance, capacitance, conductance or density.

5. System according to claim 4, wherein the first mode calculates the watercut and gas/oil fraction of the flow, the second mode calculating the gas/oil
fraction of the flow under the assumption that the watercut is constant, and the third mode calculating the watercut under the assumption that the gas/oil fraction is constant.

6. System according to claim 1, wherein said properties are mutually independent ratios between the first and second, first and third and the second and third calculated content parameter of the flow.

7. System according to claim 1, wherein said content related properties are phase area fractions of the multiphase flow.

8. System according to claim 1, wherein said content related properties are ratios between phase area fractions of the multiphase flow.

9. System according to claim 1, wherein said content related properties are phase flow rates of the multiphase flow.

10. System according to claim 1, wherein said content related properties are ratios between phase flow rates of the multiphase flow.

11. Method for monitoring the content of a multiphase flow by monitoring at least one characteristics of the flow, said characteristic being influencable by at least three different properties of the flow, the properties being related to the flow content, the monitoring system being adapted to calculate an indication of the content of the flow in three different calculation modes and compare new values with previous values providing three pairs of parameters,

   in the first mode calculating the flow content from said flow measurements, the first of said parameter pair indicating a change in the flow content.

   in the second mode calculating the content of the flow under the assumption that a first of said three properties is constant, the second pair indicating the change in flow content under the first assumption,
in the third calculation calculating the content of the flow under the assumption that a second of said three properties is constant, the third pair indicating the change in flow content under the second assumption, and

at an event defined as a detected change in said characteristic or said parameter pairs of the flow indicating the cause of the event based on the comparison between the new and previous values in each pair of parameters.

12. Method according to claim 11, where the event is registered when a change in the monitored characteristic exceeds a chosen threshold.

13. Method according to claim 11, where the event is registered when the rate of change in the monitored characteristic exceeds a chosen threshold.

14. Method according to claim 11, wherein the monitored characteristic is one of the following: impedance, capacitance, conductance or density,

15. Method according to claim 14, wherein the first mode calculates the watercut or gas/oil fraction of the flow, the second mode calculating the gas/oil fraction of the flow under the assumption that the watercut is constant, and the third mode calculating the watercut under the assumption that the gas/oil fraction is constant.

16. Method according to claim 11, wherein said properties are mutually independent ratios between the first and second, first and third or the second and third calculated content parameter of the flow.

17. Method according to claim 11, wherein said content related properties are phase area fractions of the multiphase flow.

18. Method according to claim 11, wherein said content related properties are ratios between phase area fractions of the multiphase flow.
19. Method according to claim 11, wherein said content related properties are phase flow rates of the multiphase flow.

20. Method according to claim 1, wherein said content related properties are ratios between phase flow rates of the multiphase flow.
FIG. 3
INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/072807

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01F1/74
ADD. G01N33/28

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
G01F E21B G01N

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 2016/076926 A1 (MCCANN DOMINIC PATRICK [GB] ET AL) 17 March 2016 (2016-03-17) paragraphs [0001] - [0003], [0010], [0020], [0054], [0067], [0123] - [0129], [0149]; figures 2, 3</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :
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Date of the actual completion of the international search
28 November 2017

Date of mailing of the international search report
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Name and mailing address of the ISA/
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<td>Y</td>
<td>US 2011/290035 AI (WEE ARNSTEIN [NO] ET AL) 1 December 2011 (2011-12-01) paragraphs [0002], [0051] - [0052], [0086]; figure 2</td>
<td>4, 14</td>
</tr>
<tr>
<td>A</td>
<td>WO 2006/094669 AI (SCHLUMBERGER SERVICES PETROL [FR]; SCHLUMBERGER TECHNOLOGY BV [NL]; SC) 14 September 2006 (2006-09-14) cited in the application on the whole document</td>
<td>1-20</td>
</tr>
<tr>
<td>A</td>
<td>WO 2005/045371 AI (ABB AS [NO]; BRINGEDAL BJØRNE ØYVIND [NO]; BI RKEMØE EGIIL [NO]; MØRUD) 19 May 2005 (2005-05-19) cited in the application on the whole document</td>
<td>1-20</td>
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<tr>
<td>Patent document cited in search report</td>
<td>Publication date</td>
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<td>WO 2008104750 Al</td>
<td>04-09-2008</td>
<td>EA 200901181 Al</td>
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<td>EP 2115270 Al</td>
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<td>EP 2495392 A2</td>
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<td>US 2008234939 Al</td>
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<td>US 2012209529 Al</td>
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<td>US 2013166216 Al</td>
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<td>WO 2008104750 Al</td>
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<td>US 2016076926 Al</td>
<td>17-03-2016</td>
<td>EP 2992364 Al</td>
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<td>WO 2014177654 Al</td>
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<td>WO 2010068117 Al</td>
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<tr>
<td>WO 2006094669 Al</td>
<td>14-09-2006</td>
<td>GB 2437904 A</td>
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