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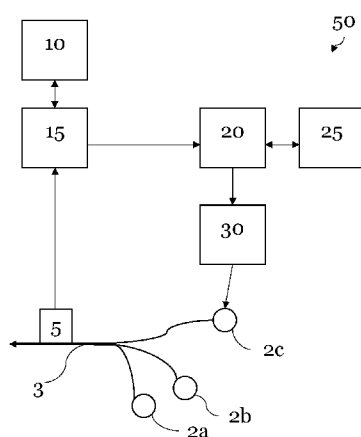


Fig. 2

(57) Abstract: The present invention relates inter alia to a method too for determining at least one hydrocarbon fluid flow rate,  $Q_{iHC}$ , of at least one of a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) with a comingled hydrocarbon fluid flow from the plurality of wells (2a, 2b, 2c) and to adapt at least one operating parameter of at least one well of the plurality of wells (2a, 2b, 2c). The method comprises the step of receiving (110) comingled-flow measurement data from at least one sensor (5). Moreover, the method comprises the step of accessing (120) historical well test data, of the ones of the plurality of wells (2a, 2b, 2c), wherein the well test data are derived from past well tests at the ones of the plurality of wells (2a, 2b, 2c).

## BACK ALLOCATION METHOD

### **1. Technical field**

5 The present disclosure relates to improved methods and a system for determining at least one hydrocarbon fluid flow rate of at least one of a plurality of wells connected to a common pipeline, a computer program for performing said methods and a non-transitory computer readable medium for performing said methods. Further, the present invention relates to a control unit for determining at least one hydrocarbon  
10 fluid flow rate of at least one of a plurality of wells connected to a common pipeline and an oilfield comprising said control unit being operated according to said methods.

### **2. Prior art**

When operating wells of a hydrocarbon reservoir, e.g. an oilfield or gasfield, several wells are regularly connected to a common pipeline such that they have a combined, i.e.  
15 comingled, output which is measured. One of the reasons for this is that hydrocarbon reservoirs are often located in remote regions and the wells share one pipeline for transferring the output, which includes hydrocarbon fluid, to a location of further processing. Another reason is that the wells of a hydrocarbon reservoir often share the same local processing infrastructure which requires the output of the wells to be  
20 merged.

Since several wells are regularly connected, such that they have a combined output, it is difficult to precisely define the output rates of the individual wells. This applies particularly, since most existing wells are not equipped with measuring equipment which would allow for a continuous monitoring of the output of the single wells. Even  
25 further, individual wells often simply cannot be continuously measured, e.g. due to their configuration and/or interdependencies with other wells.

However, it is of high importance to precisely and/or constantly define the output rates of the individual wells. This is as based on these output rates, which, besides hydrocarbon fluid flow rates, may include gas flow rates and/or water flow rates, the  
30 operating parameters of the individual wells are adjusted if necessary. This may serve

to sustain efficiency and/or avoid stress on components of the wells. Further, the precise output rates of the individual wells may be of interest from an economic point of view. Exemplarily, if wells of an oilfield being connected to a common pipeline have different shareholders.

5 Presently, it is regularly practiced conducting tests at the individual wells in regular or irregular time intervals. Based on this historic test data and the often continuously measured combined output of the wells, it is concluded on the output of the individual wells. Thereby interdependencies between different output rates, such as hydrocarbon fluid flow rates, gas flow rates and water flow rates, are regularly not considered.  
10 Thereby significant inaccuracies for the output rates of the individual wells are generated.

Moreover, it has shown that the use of artificial intelligence to define the output rates of the individual wells based on historic individual well test data and the measured combined output of the wells is limited therein that machine learning solutions mostly  
15 rely on accurate training data which often cannot be provided, particularly not in sufficient quantity and/or quality.

Thus, it is an object of the present disclosure to provide at least one method and a system that overcome the aforementioned drawbacks at least partially. It is also an object underlying the present invention to provide a computer program for performing  
20 said method(s) and a non-transitory computer readable medium for performing said method(s). Further, it is also an object underlying the present invention to provide a respective control unit and an oilfield comprising said control unit being operated according to said method(s).

### **3. Summary of the invention**

25 This object is achieved, at least partly, by methods, particularly computer-implemented methods, a system, a computer program, a non-transitory computer readable medium and an oilfield as defined in the independent claims. Further aspects of the present disclosure are defined in the dependent claims. Since the methods and the system relate to determining at least one hydrocarbon fluid flow rate of at least one of a  
30 plurality of wells connected to a common pipeline with a comingled fluid flow from the plurality of wells, it will be understood that advantages and/or features of the methods may also apply to the system and vice versa.

In particular, the object of the present disclosure is at least partly achieved by a first method, which may be a computer implemented method, for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells connected to a common pipeline with a comingled hydrocarbon fluid flow from the plurality of wells to adapt at least one operating parameter of at least one well of the plurality of wells.

The wells of the plurality of wells may be oil wells and/or natural gas wells. The plurality of wells may form part of an oilfield and/or a natural gas field. The common pipeline may comprise a pipe, a tube, a channel, and/or any other flow guiding means. Further, it is understood that the common pipeline may comprise multiple parallel pipes and/or any other flow guiding means. This may be required if a single pipeline has not enough capacity for the comingled hydrocarbon flow.

Throughout the present disclosure an “ $i$ ” within any formula and/or formula symbol represents an integer value which corresponds to one well of the plurality of wells. Exemplarily, the hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the fourth well ( $i = 4$ ) of a plurality of wells may be expressed as  $Q_4^{HC}$ . Moreover, in the present disclosure “ $n_w$ ” represents the total number of wells of the plurality of wells.

Hydrocarbon fluids according to the present disclosure are fluids which comprise at least one type of hydrocarbon. Thereby the hydrocarbon fluids may be in a liquid state. Exemplary hydrocarbon fluids according to the present disclosure may comprise oil, e.g. crude oil, and/or liquid natural gas. Further exemplary hydrocarbon fluids according to the present disclosure may comprise co-produced non-hydrocarbons, such as water.

The first method comprises the step of receiving commingled-flow measurement data from at least one sensor, wherein the commingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ . The at least one sensor may be a flow sensor. Thereby the at least one sensor may be attached to the common pipeline. Optionally, the at least one sensor may be configured to determine when a reservoir with a specified volume is filled up to a predefined volume.

The term wherein “data are representative of” particular values according to the present disclosure describes that from the data the respective values can be determined. Hence, the commingled-flow measurement data may exemplarily comprise a volume of a hydrocarbon fluid and a time interval during which this volume

passed through a portion of the common pipeline. Thus, these data are representative of the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ .

Flow rates according to the present disclosure may be described in volume per time unit. Further, flow rates according to the present disclosure may be described in mass  
 5 per time unit. Exemplary time units for flow rates are a year, a month, a week, a day, an hour, a minute, and/or a second.

The comingled-flow measurement data are optionally further representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ . Gas according to the present invention is gaseous. Exemplary, gas  
 10 according to the present disclosure may be natural gas. Particularly, gas according to the present disclosure may comprise methane, ethane, propane, butane, pentane, carbon dioxide, and/or nitrogen. Water according to the present disclosure may comprise sediments, sand, sludge, and/or any other soil components.

Further, the first method comprises the step of accessing historical well test data,  
 15 wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells, wherein the well test data are optionally further representative of at least one of the following: test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells, wherein the well test data are derived from past well tests at the ones  
 20 of the plurality of wells.

The historical well test data may be derived from a historical test data storage means, such as a test database. Further, the past well tests may be experiments which were conducted at the individual wells. Moreover, the past well tests at the ones of the plurality of wells may be at least partially based on well simulations. Preferably, the  
 25 historical well test data comprise test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , for each well of the plurality of wells.

The test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , may describe a volume of hydrocarbon fluid, e.g. oil, which is derived from one of the plurality of wells per time unit. The time  
 30 unit underlying the test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , may be the duration of a past well test.

The test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , may be represented by a test gas flow rate,  $Q_i^{test\ Gas}$ , and the test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Hence, the test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , may be obtained by dividing the test gas flow rate,  $Q_i^{test\ Gas}$ , by the test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . However, the test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , may be also directly measured.

The test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , may be exemplarily represented by a test water flow rate,  $Q_i^{test\ Water}$ , and the test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Hence, the test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ , may be obtained by dividing the test water flow rate,  $Q_i^{test\ Water}$ , by the test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . However, the test water-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , may also be directly measured.

The data representative of the test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , the test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and/or the test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , may be obtained from one well test. This allows for an accurate relationship between said values.

Moreover, the first method comprises the step of determining, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells using the received commingled-flow measurement data and the accessed historical well test data.

Typically, the hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of each well of the plurality of wells are determined. However, also the hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of a part of the plurality of wells may be determined. Moreover, the step of determining may be conducted using an optimizer unit adapted to run an optimization program based on Lagrange multipliers.

The use of Lagrange multipliers is a strategy for finding the local maxima and/or minima of at least one function, i.e. an objective function, subject to at least one equality constraint, i.e. a constraint function. Hence, the use of Lagrange multipliers may serve to minimize the difference between the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Thereby, the use of Lagrange multipliers allows to take into account relations between hydrocarbon fluid flow rates,  $Q_i^{HC}$ , gas-to-hydrocarbon-fluid ratios,  $GOR_i$ , and/or water-to-hydrocarbon-

fluid ratios,  $WOR_i$ . Accordingly, the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may be determined with improved accuracy.

In summary, the use of Lagrange multipliers allows to link hydrocarbon fluid flow data with secondary well-test data, such as gas-to-hydrocarbon-fluid ratios and/or water-to-hydrocarbon-fluid ratios. Hence, more accurate values may be obtained. Further, values being more consistent with the test values may be obtained.

Furthermore, the first method comprises the step of adapting at least one operating parameter of at least one well of the plurality of wells, wherein adapting is at least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells.

Adapting at least one operating parameter of at least one well means that the at least one well is controlled. For example, based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , a pumping rate of the at least one well may be adjusted to increase efficiency and/or to reduce stress on components of the well. Moreover, a gas injection rate for a gas lift well may be adapted to improve efficiency of the utilized gas. Furthermore, the wellhead pressure may be adjusted to reduce stress on components of the well. Hence, since the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , can be determined with improved accuracy, also the efficiency may be improved more accurately. Moreover, the stress on the components of the well may be precisely reduced. This allows resources to be used more efficiently and/or repairs to be avoided.

Further particular, the object of the present disclosure is at least partly achieved by a second a method, which may be a computer-implemented method, for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells connected to a common pipeline with a comingled hydrocarbon fluid flow from the plurality of wells. It will be understood that the details described in reference to the first method may also apply for the second method.

The second method comprises the step of receiving commingled-flow measurement data from at least one sensor, wherein the commingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , wherein the commingled-flow measurement data are further representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ . Further, the second method comprises the step of accessing historical well test data,

wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells, wherein the well test data are further representative of at least one of the following: test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells, wherein the well test data are derived from past well tests at the ones of the plurality of wells. Furthermore, the second method comprises the step of determining, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells using the received commingled-flow measurement data and the accessed historical well test data.

It is to be understood, that individual method steps of the first and the second method can be combined. For example, a method step described with respect to the first method can be part of the second method, or vice versa. The following description refers to the first and the second method.

The methods described above may further comprise the step of identifying the ones of the plurality of wells for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value. Thus, it is possible to identify wells which exhibit significant deviations between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . This allows for improved monitoring of the plurality of wells. Exemplarily, the identified wells may be selected for further investigation and/or operating parameter adaption.

Further, determining the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may comprise using at least one uncertainty value for at least one of the plurality of wells, wherein preferably the at least one uncertainty value is at least partially based on a measurement error of the well test data. The use of uncertainty values allows a weighing of test data in dependence of an increased uncertainty. Hence, accuracy may be increased. The increased uncertainty may exemplarily arise from test data whose acquisition already lies longer in the past. Further, the at least one uncertainty value,  $w_i$ , may be defined as  $\frac{1}{\sigma^2}$ , wherein  $\sigma^2$  represents a measurement error. Further, at least one uncertainty value,  $w_i^{HC}$ , may relate to a test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Moreover, at least one uncertainty value,  $w_i^{Gas}$ , may relate to a test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ . Furthermore, at least one uncertainty value,  $w_i^{Water}$ , may relate to a test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ . Thereby differences in uncertainties for

the different test values may be considered which allows to further increase the accuracy of determining the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ . Hence, also the adaption of at least one operating parameter of the at least one well may be conducted more precisely.

- 5 Moreover, determining the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells may be based on a Lagrangian function that comprises at least one objective function and at least one constraint function, wherein the Lagrangian function optionally comprises two objective functions and at least two constraint functions, wherein the Lagrangian function further optionally comprises at  
10 least three objective functions and at least three constraint functions, wherein the Lagrangian function even further optionally comprises exactly three objective functions and exactly three constraint functions.

- By means of at least two objective functions and at least two constraint functions the relation between at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and at least one gas-to-  
15 hydrocarbon-fluid ratio,  $GOR_i$ , or at least one water-to-hydrocarbon-fluid ratio,  $WOR_i$ , may be taken into account. Hence, the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may be determined more accurately. Further, by means of at least three or exactly three objective functions and at least three or exactly three constraint functions the relation  
20 between at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and at least one gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and/or at least one water-to-hydrocarbon-fluid ratio,  $WOR_i$ , may be considered. Hence, the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may be determined even more accurately. As above, an accurate determination of the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may also allow for a more accurate adaption of at least one operating parameter of the at least one well.

- 25 The Lagrangian function may comprise a hydrocarbon fluid flow rate objective function. The hydrocarbon fluid flow rate objective function may be referred to as *HCOF*. Thereby the hydrocarbon fluid flow rate objective function may be configured to minimize the difference between a well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and a respective well specific test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Said difference may be  
30 minimized for each well. Further the hydrocarbon fluid flow rate objective function optionally comprises the sum of the squared differences of each well's hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Moreover, each squared difference may be multiplied with a respective uncertainty

value,  $w_i^{HC}$ . An exemplary hydrocarbon fluid flow rate objective function,  $HCOF$ , may be

$$HCOF = \sum_{i=1}^{n_w} \frac{w_i^{HC}}{2} (Q_i^{HC} - Q_i^{test\ HC})^2.$$

It will be understood that other hydrocarbon fluid flow rate objective functions,  $HCOF$ , being configured to minimize the difference between a well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and a respective well specific test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , may be used. Further it will be understood that the well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the hydrocarbon fluid flow rate objective function,  $HCOF$ , may be the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , to be determined by the methods according to the present disclosure.

By reducing the difference between the well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , it is ensured that the well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$  are interrelated. Thereby the uncertainty value,  $w_i^{HC}$ , may allow for considering the uncertainty associated with the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Thus, inaccuracies may be avoided or at least reduced.

The Lagrangian function may comprise a gas-to-hydrocarbon-fluid ratio objective function. The gas-to-hydrocarbon-fluid ratio objective function may be referred to as  $GOF$ . Thereby the gas-to-hydrocarbon-fluid ratio objective function may be configured to minimize the difference between a well specific gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and a respective well specific test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ . Said difference may be minimized for each well. Further the gas-to-hydrocarbon-fluid ratio objective function optionally comprises the sum of the squared differences of each well's gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and the respective test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ . Moreover, each squared difference may be multiplied with a respective uncertainty value,  $w_i^{Gas}$ . An exemplary gas-to-hydrocarbon-fluid ratio objective function,  $GOF$ , may be

$$GOF = \sum_{i=1}^{n_w} \frac{w_i^{Gas}}{2} (GOR_i - GOR_i^{test})^2.$$

It will be understood that other gas-to-hydrocarbon-fluid ratio objective functions,  $GOF$ , being configured to minimize the difference between a well specific gas-to-

hydrocarbon-fluid ratio,  $GOR_i$ , and a respective well specific test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , may be used.

By reducing the difference between the well specific gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and the respective test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , it is ensured that  
 5 said ratios are interrelated. Thereby the uncertainty value,  $w_i^{Gas}$ , may allow for considering the uncertainty associated with the respective test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ . Thereby, inaccuracies may be avoided or at least reduced.

The Lagrangian function may comprise a water-to-hydrocarbon-fluid ratio objective function. The water-to-hydrocarbon-fluid ratio objective function may be referred to as  
 10  $WOF$ . Thereby the water-to-hydrocarbon-fluid ratio objective function may be configured to minimize the difference between a well specific water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and a respective well specific test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ . Said difference may be minimized for each well. Further the water-to-hydrocarbon-fluid ratio objective function optionally comprises the sum of the squared  
 15 differences of each well's water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and the respective test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ . Moreover, each squared difference may be multiplied with a respective uncertainty value,  $w_i^{Water}$ . An exemplary water-to-hydrocarbon-fluid ratio objective function,  $WOF$ , may be

$$WOF = \sum_{i=1}^{n_w} \frac{w_i^{Water}}{2} (WOR_i - WOR_i^{test})^2.$$

20 It will be understood that other water-to-hydrocarbon-fluid ratio objective functions,  $WOF$ , being configured to minimize the difference between a well specific water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and a respective well specific test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ , may be used.

By reducing the difference between the well specific water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and the respective test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ , it is ensured  
 25 that said ratios are interrelated. Thereby the uncertainty value,  $w_i^{Water}$ , may allow for considering the uncertainty associated with the respective test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ . Thus, inaccuracies may be avoided or at least reduced.

The Lagrangian function may comprise a hydrocarbon fluid flow constraint function  
 30 being multiplied with a hydrocarbon fluid flow Lagrange multiplier. The hydrocarbon fluid flow constraint function may be referred to as  $HCCF$ . Thereby the hydrocarbon

fluid flow constraint function optionally comprises the difference between the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells.

5 Since the individual wells of the plurality of wells may be flowing only during a fraction of the time during which the comingled flow rates,  $Q_{field}^{HC}$ ,  $Q_{field}^{Gas}$ ,  $Q_{field}^{Water}$ , are determined, i.e. measured, the respective flow rates of the individual wells may be multiplied with a factor,  $L_i$ . Exemplarily, if the comingled flow rates,  $Q_{field}^{HC}$ ,  $Q_{field}^{Gas}$ ,  $Q_{field}^{Water}$ , were determined during one week and an individual well was flowing only one day, the factor  $L_i$  would be 1/7.

10 An exemplary hydrocarbon fluid flow constraint function,  $HCCF$ , may be

$$HCCF = Q_{field}^{HC} - \sum_{i=1}^{n_w} (L_i Q_i^{HC}).$$

Thus, by means of the above exemplary hydrocarbon fluid flow constraint function,  $HCCF$ , it is ensured that the objective functions described above are optimized under the constraint that the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells equals the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ . Hence, it may be ensured that the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , is accurate. This improves the accuracy of the step of determining of the methods described above.

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The Lagrangian function may comprise a gas flow rate constraint function being multiplied with a gas flow rate Lagrange multiplier. The gas flow rate constraint function may be referred to as  $GCF$ . Thereby the gas flow rate constraint function optionally comprises the difference between the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells, wherein each hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the ones of the plurality of wells is multiplied with a respective gas-to-hydrocarbon-fluid ratio,  $GOR_i$ .

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25 An exemplary gas flow rate constraint function,  $GCF$ , may be

$$GCF = Q_{field}^{Gas} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} GOR_i).$$

Thus, by means of the above exemplary gas flow rate constraint function,  $GCF$ , it is ensured that the objective functions described above are optimized under the constraint that the sum of gas flow rates,  $Q_i^{Gas} = Q_i^{HC} GOR_i$ , of the ones of the plurality of wells equals the comingled gas flow rate,  $Q_{field}^{Gas}$ . Hence, it may be ensured that the sum of gas flow rates,  $Q_i^{Gas}$ , is accurate. This further improves the accuracy of the step of determining of the methods described above. Further, accuracy may be improved by taking the relation between hydrocarbon fluid flow to gas flow into account by  $Q_i^{Gas} = Q_i^{HC} GOR_i$ .

The Lagrangian function may comprise a water flow rate constraint function being multiplied with a water flow rate Lagrange multiplier. The water flow rate constraint function may be referred to as  $WCF$ . Thereby the water flow rate constraint function optionally comprises the difference between the comingled water flow rate,  $Q_{field}^{Water}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells, wherein each hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the ones of the plurality of wells is multiplied with a respective water-to-hydrocarbon-fluid ratio,  $WOR_i$ .

An exemplary water flow rate constraint function,  $WCF$ , may be

$$WCF = Q_{field}^{Water} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} WOR_i).$$

Thus, by means of the above exemplary water flow rate constraint function,  $WCF$ , it is ensured that the objective functions described above are optimized under the constraint that the sum of water flow rates,  $Q_i^{Water} = Q_i^{HC} WOR_i$ , of the ones of the plurality of wells equals the comingled water flow rate,  $Q_{field}^{Water}$ . Hence, it may be ensured that the sum of water flow rates,  $Q_i^{Water}$ , is accurate. This improves the accuracy of the step of determining of the methods described above. Further, accuracy may be improved by taking the relation between hydrocarbon fluid flow to water flow into account by  $Q_i^{Water} = Q_i^{HC} WOR_i$ .

The Lagrangian function with the above objective functions and constraint functions may be formulated as

$$F = HCOF + GOF + WOF + \lambda_{HC} HCCF + \lambda_G GCF + \lambda_W WCF.$$

Thereby the Lagrange multipliers are represented by  $\lambda$ . In more detail, the Lagrangian function with the above objective functions and constraint functions may be formulated as

$$\begin{aligned}
 F = & \sum_{i=1}^{n_w} \frac{w_i^{HC}}{2} (Q_i^{HC} - Q_i^{test\ HC})^2 + \sum_{i=1}^{n_w} \frac{w_i^{Gas}}{2} (GOR_i - GOR_i^{test})^2 \\
 & + \sum_{i=1}^{n_w} \frac{w_i^{Water}}{2} (WOR_i - WOR_i^{test})^2 + \lambda_{HC} \left[ Q_{field}^{HC} - \sum_{i=1}^{n_w} (L_i Q_i^{HC}) \right] \\
 & + \lambda_G \left[ Q_{field}^{Gas} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} GOR_i) \right] + \lambda_W \left[ Q_{field}^{Water} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} WOR_i) \right]
 \end{aligned}$$

The Lagrangian function may be minimized by solving

$$\nabla F = 0 = \left( \frac{\partial F}{\partial Q_i^{HC}}, \frac{\partial F}{\partial GOR_i}, \frac{\partial F}{\partial WOR_i}, \frac{\partial F}{\partial \lambda_{HC}}, \frac{\partial F}{\partial \lambda_G}, \frac{\partial F}{\partial \lambda_W} \right).$$

In detail,

$$\frac{\partial F}{\partial Q_i^{HC}} = w_i^{HC} (Q_i^{HC} - Q_i^{test\ HC}) - \lambda_{HC} L_i - \lambda_G L_i GOR_i - \lambda_W L_i WOR_i,$$

$$\frac{\partial F}{\partial GOR_i} = w_i^{Gas} (GOR_i - GOR_i^{test}) - \lambda_G L_i Q_i^{HC},$$

$$\frac{\partial F}{\partial WOR_i} = w_i^{Water} (WOR_i - WOR_i^{test}) - \lambda_W L_i Q_i^{HC},$$

$$\frac{\partial F}{\partial \lambda_{HC}} = \left[ Q_{field}^{HC} - \sum_{i=1}^{n_w} (L_i Q_i^{HC}) \right],$$

$$\frac{\partial F}{\partial \lambda_G} = \left[ Q_{field}^{Gas} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} GOR_i) \right],$$

$$\frac{\partial F}{\partial \lambda_W} = \left[ Q_{field}^{Water} - \sum_{i=1}^{n_w} (L_i Q_i^{HC} WOR_i) \right].$$

The above equations assume that  $Q_i^{HC}$ ,  $GOR_i$  and  $WOR_i$  are constant over time. For even further increased accuracy, a decline rate may be included. Exemplarily,  $Q_i^{HC}$  may be

replaced by  $Q_{ij}^{HC} = Q_{i1}^{HC} e^{-c}$ , wherein  $Q_{i1}^{HC}$  is a single rate and  $c$  is a decline constant for all time periods  $j$ .

The commingled-flow measurement data may be representative of the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the comingled water flow rate,  $Q_{field}^{Water}$ . Thus, interdependencies between all three rates may be taken into account which serves to further increase the accuracy of the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ .

The well test data may be representative of test hydrocarbon fluid flow rates,  $Q_i^{test HC}$ , test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells. By taking the test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and the test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells into account, interdependencies between the hydrocarbon fluid flow, the gas flow, and the water flow may be taken into account which serves to further increase the accuracy of the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ .

The step of determining may further comprise determining gas-to-hydrocarbon-fluid ratios,  $GOR_i$ , and/or water-to-hydrocarbon-fluid ratios,  $WOR_i$ , of individual ones of the plurality of wells. Thus, further information may be provided which may be used to adapt at least one operating parameter of at least one well of the plurality of wells. Hence, accuracy may be further improved.

It is to be understood, that the method described above, can be a computer implemented method. The entire method may be computer implemented or only some of the method steps. The method may be carried out on a single data processing means, such as a computer, or may be distributed in a computing environment, including multiple (at least two) data processing means. Further, additional devices and/or specific data processing means, particularly specific control units, may be utilized to carry out the above-described method/method steps.

Further, the object of the present disclosure is at least partly achieved by a system for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells connected to a common pipeline with a comingled hydrocarbon fluid flow from the plurality of wells.

As mentioned above, since the methods and the system relate to determining at least one hydrocarbon fluid flow rate of at least one of a plurality of wells connected to a common pipeline with a comingled hydrocarbon fluid flow from the plurality of wells, it will be understood that advantages and/or features of the methods may also apply to the system and vice versa. Further, the system according to the present disclosure may serve to perform one of the methods as described above.

The system comprises a data storing means, such as a database, configured to store historical well test data, wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells, wherein the well test data are optionally further representative of at least one of test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells, wherein the well test data are derived from past well tests at the ones of the plurality of wells.

Moreover, the system comprises a data acquisition unit configured to receive commingled-flow measurement data, wherein the commingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , wherein the commingled-flow measurement data are optionally further representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ .

The data acquisition unit is further configured to access historical well test data from the data storing means.

Even further, the system comprises an optimizer unit being able to receive data from the data acquisition unit. The optimizer unit is configured to determine, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells using the received commingled-flow measurement data and the accessed historical well test data.

Furthermore, the system may comprise at least one sensor disposed on the pipeline with the comingled hydrocarbon fluid flow from a plurality of wells. Thereby the data acquisition unit may be configured to receive commingled-flow measurement data from the sensor.

The system may further comprise a signal transmission unit being configured for adapting at least one operating parameter of at least one well of the plurality of wells.

Thereby adapting is optionally at least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells.

The system may further comprise means for identifying the ones of the plurality of wells for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value.

Thus, it is possible to identify wells which exhibit significant deviations between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . This allows for improved monitoring of the plurality of wells. The identified wells may be selected for further investigation and/or operating parameter adaption.

Determining the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , may comprise using at least one uncertainty value for at least one of the plurality of wells, wherein preferably the at least one uncertainty value of the ones of the plurality of wells is at least partially based on a measurement error of the well test data of the ones of the plurality of wells.

The use of uncertainty values allows a weighing of test data in dependence of an increased uncertainty. Hence, accuracy may be increased. The increased uncertainty may exemplarily arise from test data whose acquisition already lies longer in the past. Further, the at least one uncertainty value,  $w_i$ , may be defined as  $\frac{1}{\sigma^2}$ , wherein  $\sigma^2$  represents a measurement error. Further, at least one uncertainty value,  $w_i^{HC}$ , may relate to a test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ . Moreover, at least one uncertainty value,  $w_i^{Gas}$ , may relate to a test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ . Furthermore, at least one uncertainty value,  $w_i^{Water}$ , may relate to a test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ .

The commingled-flow measurement data may be representative of the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the comingled water flow rate,  $Q_{field}^{Water}$ . Thus, interdependencies between all three rates may be taken into account which may serve to further increase the accuracy of the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ .

The well test data may be representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid

ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells. By taking the test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and the test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells into account, interdependencies between the hydrocarbon fluid flow, the gas flow, and the water flow may be taken into account  
5 which serves to further increase the accuracy of the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ .

Furthermore, the object of the present disclosure is at least partly achieved by a computer program, comprising instructions that when carried out by at least one processor, cause the at least one processor to perform for performing a method as  
10 described above.

Further, the object of the present disclosure is at least partly achieved by a non-transitory computer readable medium having stored thereon software instructions that, when carried out by at least one processor, cause the processor to perform for performing a method as described above.

Moreover, the object of the present disclosure is at least partly achieved by a control unit for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells connected to a common pipeline with a comingled hydrocarbon fluid flow from the plurality of wells, the control unit comprising at least one processor and a memory coupled with the at least one processor; the at least one processor and memory  
15 20 configured to perform a method as described above.

Even further, the object of the present disclosure is at least partly achieved by an oilfield comprising a plurality of wells connected to a common pipeline and a control unit as described above, operated to perform a method as also described above.

#### **4. Brief description of the accompanying figures**

25 In the following, the accompanying figures are briefly described:

Fig. 1 shows an exemplary method according to the present invention,

Fig. 2 shows an exemplary system according to the present invention, and

Fig. 3 shows an exemplary oilfield according to the present invention.

## **5. Detailed description of the figures**

According to the present invention, Fig. 1 shows a method 100 for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells 2a, 2b, 2c connected to a common pipeline 3 with a comingled hydrocarbon fluid flow from the plurality of wells 2a, 2b, 2c to adapt at least one operating parameter of at least one well of the plurality of wells 2a, 2b, 2c.

The depicted method comprises the step of receiving 110 commingled-flow measurement data from at least one sensor 5, wherein the commingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ . Further, the commingled-flow measurement data are representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ .

The method of Fig. 1 further comprises the step of accessing 120 historical well test data, exemplarily from a historical test data storing means, such as a database. Thereby the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells 2a, 2b, 2c. Moreover, the well test data are representative of at least one of the following: test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells 2a, 2b, 2c. The well test data are derived from past well tests at the ones of the plurality of wells 2a, 2b, 2c.

The depicted method further comprises determining 130, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells 2a, 2b, 2c using the received commingled-flow measurement data and the accessed historical well test data. Determining 130 may be conducted by using an optimizer unit adapted to run an optimization program.

The illustrated exemplary method further comprises identifying 140 the ones of the plurality of wells 2a, 2b, 2c for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value.

The depicted exemplary method further comprises adapting 150 at least one operating parameter of at least one well of the plurality of wells 2a, 2b, 2c. Said adapting 150 is at

least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells 2a, 2b, 2c.

Further according to the present invention, Fig. 2 shows a system 50 for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells 2a, 2b, 2c connected to a common pipeline 3 with a comingled hydrocarbon fluid flow from the plurality of wells 2a, 2b, 2c.

The exemplary system 50 comprises a data storing means 10 being configured to store historical well test data. Said well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells 2a, 2b, 2c. Further, the well test data are representative of at least one of test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells 2a, 2b, 2c. The well test data are derived from past well tests at the ones of the plurality of wells 2a, 2b, 2c.

The exemplary system 50 of Fig. 2 further comprises a data acquisition unit 15 which is configured to receive commingled-flow measurement data. Said commingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ . Further, the commingled-flow measurement data are representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ .

The data acquisition unit 15 is further configured to access historical well test data from the data storing means 10.

Moreover, the system illustrated in Fig. 2 comprises an optimizer unit 20 being able to receive data from the data acquisition unit 15. Said optimizer unit 20 is configured to determine, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells 2a, 2b, 2c, using the received commingled-flow measurement data and the accessed historical well test data.

The system 50 of Fig. 2 further comprises a signal transmission unit 30 being configured for adapting at least one operating parameter of at least one well of the plurality of wells 2a, 2b, 2c. Thereby adapting is at least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells 2a, 2b, 2c.

Even further the exemplary system 50 comprises means for identifying 25 the ones of the plurality of wells 2a, 2b, 2c for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value.

- 5 Fig. 3 of shows an oilfield 1 according to the present disclosure. The oilfield 1 comprises a plurality of wells 2a, 2b, 2c connected to a common pipeline 3 and a control unit 1000. The control unit 1000 is operated to perform a method as described within the present disclosure.

## 10 **List of reference signs**

- |            |                          |
|------------|--------------------------|
| 1          | oilfield                 |
| 2a, 2b, 2c | plurality of wells       |
| 3          | common pipeline          |
| 5          | sensor                   |
| 10         | data storing means       |
| 15         | data acquisition unit    |
| 20         | optimizer unit           |
| 25         | means for identifying    |
| 30         | signal transmission unit |
| 50         | system                   |
| 100        | method                   |
| 110        | receiving                |
| 120        | accessing                |
| 130        | determining              |
| 140        | identifying              |
| 150        | adapting                 |
| 1000       | control unit             |

**CLAIMS 1 to 28**

1. A method (100) for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) with a comingled hydrocarbon fluid flow from the plurality of wells (2a, 2b, 2c) and to adapt at least one operating parameter of at least one well of the plurality of wells (2a, 2b, 2c), the method comprising the following steps:
  - receiving (110) comingled-flow measurement data from at least one sensor (5), wherein the comingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ ;
  - accessing (120) historical well test data, wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells (2a, 2b, 2c), wherein the well test data are derived from past well tests at the ones of the plurality of wells (2a, 2b, 2c);
  - determining (130) based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells (2a, 2b, 2c) using the received comingled-flow measurement data and the accessed historical well test data, and
  - adapting (150) at least one operating parameter of at least one well of the plurality of wells (2a, 2b, 2c), wherein adapting (150) is at least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells (2a, 2b, 2c).
2. A method (100) for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) with a comingled hydrocarbon fluid flow from the plurality of wells (2a, 2b, 2c), the method comprising the following steps:
  - receiving (110) comingled-flow measurement data from at least one sensor (5), wherein the comingled-flow measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ ;
  - accessing (120) historical well test data, wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells (2a, 2b, 2c), wherein the well test data are derived from past well tests at the ones of the plurality of wells (2a, 2b, 2c);

determining (130), based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells (2a, 2b, 2c) using the received comingled-flow measurement data and the accessed historical well test data.

- 5        3.        The method (100) according to claim 1 or 2, wherein the comingled-flow measurement data are further representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ .
- 10       4.        The method (100) according to one of claims 1 to 3, wherein the well test data are further representative of at least one of the following: test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells (2a, 2b, 2c).
- 15       5.        The method (100) according to one of claims 1 to 4, further comprising identifying (140) the ones of the plurality of wells (2a, 2b, 2c) for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value.
- 20       6.        The method (100) according to one of the preceding claims, wherein determining (130) the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , comprises using at least one uncertainty value for at least one of the plurality of wells (2a, 2b, 2c), wherein preferably the at least one uncertainty value is at least partially based on a measurement error of the well test data.
- 25       7.        The method (100) according to one of the preceding claims, wherein determining (130) the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells (2a, 2b, 2c) is based on a Lagrangian function that comprises at least one objective function and at least one constraint function, wherein the Lagrangian function optionally comprises two objective functions and at least two constraint functions, wherein the Lagrangian function further optionally comprises at least three objective functions and at least three constraint functions, wherein the Lagrangian function even further optionally comprises exactly three objective functions and exactly three constraint functions.
- 30
- 35

8. The method (100) according to the preceding claim, wherein the Lagrangian function comprises a hydrocarbon fluid flow rate objective function, wherein the hydrocarbon fluid flow rate objective function is configured to minimize the difference between a well specific hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and a respective well specific test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , wherein the difference may be minimized for each well, and wherein optionally the hydrocarbon fluid flow rate objective function comprises the sum of the squared differences of each well's hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ .
9. The method (100) according to one of claims 7 or 8, wherein the Lagrangian function comprises a gas-to-hydrocarbon-fluid ratio objective function, wherein the gas-to-hydrocarbon-fluid ratio objective function is configured to minimize the difference between a well specific gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and a respective well specific test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ , wherein the difference may be minimized for each well, and wherein optionally the gas-to-hydrocarbon-fluid ratio objective function comprises the sum of the squared differences of each well's gas-to-hydrocarbon-fluid ratio,  $GOR_i$ , and the respective test gas-to-hydrocarbon-fluid ratio,  $GOR_i^{test}$ .
10. The method (100) according to one of claims 7 to 9, wherein the Lagrangian function comprises a water-to-hydrocarbon-fluid ratio objective function, wherein the water-to-hydrocarbon-fluid ratio objective function is configured to minimize the difference between a well specific water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and a respective well specific test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ , wherein the difference may be minimized for each well, and wherein optionally the water-to-hydrocarbon-fluid ratio objective function comprises the sum of the squared differences of each well's water-to-hydrocarbon-fluid ratio,  $WOR_i$ , and the respective test water-to-hydrocarbon-fluid ratio,  $WOR_i^{test}$ .
11. The method (100) according to one of claims 7 to 10, wherein the Lagrangian function comprises a hydrocarbon fluid flow constraint function being multiplied with a hydrocarbon fluid flow Lagrange multiplier, wherein the hydrocarbon fluid flow constraint function optionally comprises the difference between the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells (2a, 2b, 2c).

12. The method (100) according to one of claims 7 to 11, wherein the Lagrangian function comprises a gas flow rate constraint function being multiplied with a gas flow rate Lagrange multiplier, wherein the gas flow rate constraint function optionally  
5 comprises the difference between the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells (2a, 2b, 2c), wherein each hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the ones of the plurality of wells (2a, 2b, 2c) is multiplied with a respective gas-to-hydrocarbon-fluid ratio,  $GOR_i$ .
- 10 13. The method (100) according to one of claims 7 to 12, wherein the Lagrangian function comprises a water flow rate constraint function being multiplied with a water flow rate Lagrange multiplier, wherein the water flow rate constraint function optionally comprises the difference between the comingled water flow rate,  $Q_{field}^{Water}$ , and the sum of hydrocarbon fluid flow rates,  $Q_i^{HC}$ , of the ones of the plurality of wells (2a,  
15 2b, 2c), wherein each hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the ones of the plurality of wells (2a, 2b, 2c) is multiplied with a respective water-to-hydrocarbon-fluid ratio,  $WOR_i$ .
14. The method (100) according to one of the preceding claims, wherein the  
20 comingled-flow measurement data are representative of the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the comingled water flow rate,  $Q_{field}^{Water}$ .
15. The method (100) according to one of the preceding claims, wherein the well test  
25 data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells (2a, 2b, 2c).
16. The method (100) according to one of the preceding claims, wherein the step of  
30 determining (130) further comprises determining gas-to-hydrocarbon-fluid ratios,  $GOR_i$ , and/or water-to-hydrocarbon-fluid ratios,  $WOR_i$ , of individual ones of the plurality of wells (2a, 2b, 2c).
17. A system (50) for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at  
35 least one of a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) with a

comingled hydrocarbon fluid flow from the plurality of wells (2a, 2b, 2c), the system (50) comprising:

a data storing means (10) configured to:

store historical well test data, wherein the well test data are  
 5 representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , of the ones of the plurality of wells (2a, 2b, 2c), wherein the well test data are derived from past well tests at the ones of the plurality of wells (2a, 2b, 2c);

a data acquisition unit (15) configured to:

receive comingled-flow measurement data, wherein the comingled-flow  
 10 measurement data are representative of a comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ ; and

access historical well test data from the data storing means (10); and

an optimizer unit (20) being able to receive data from the data acquisition unit (15), the optimizer unit (20) configured to:

15 determine, based on Lagrange multipliers, at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of the plurality of wells (2a, 2b, 2c) using the received comingled-flow measurement data and the accessed historical well test data.

18. The system (50) according to the preceding claim, wherein the well test data are  
 20 further representative of at least one of test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells (2a, 2b, 2c).

19. The system (50) according to one of the preceding claims, wherein the  
 25 comingled-flow measurement data are further representative of at least one of the following: a comingled gas flow rate,  $Q_{field}^{Gas}$ , and a comingled water flow rate,  $Q_{field}^{Water}$ .

20. The system (50) according to one of the preceding claims, wherein the system (50) further comprises

30 a signal transmission unit (30) being configured for adapting at least one operating parameter of at least one well of the plurality of wells (2a, 2b, 2c), wherein adapting is at least partially based on the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of the at least one of the plurality of wells (2a, 2b, 2c).

35 21. The system (50) according to one of the preceding claims, wherein the system (50) further comprises

means for identifying (25) the ones of the plurality of wells (2a, 2b, 2c) for which the difference between the at least one determined hydrocarbon fluid flow rate,  $Q_i^{HC}$ , and the respective test hydrocarbon fluid flow rate,  $Q_i^{test\ HC}$ , exceeds a predefined threshold value.

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22. The system (50) according to one of the preceding claims, wherein determining the at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , comprises using at least one uncertainty value for at least one of the plurality of wells (2a, 2b, 2c), wherein preferably the at least one uncertainty value of the ones of the plurality of wells (2a, 2b, 2c) is at least partially based on a measurement error of the well test data of the ones of the plurality of wells (2a, 2b, 2c).

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23. The system (50) according to one of the preceding claims, wherein the comingled-flow measurement data are representative of the comingled hydrocarbon fluid flow rate,  $Q_{field}^{HC}$ , the comingled gas flow rate,  $Q_{field}^{Gas}$ , and the comingled water flow rate,  $Q_{field}^{water}$ .

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24. The system (50) according to one of the preceding claims, wherein the well test data are representative of test hydrocarbon fluid flow rates,  $Q_i^{test\ HC}$ , test gas-to-hydrocarbon-fluid ratios,  $GOR_i^{test}$ , and test water-to-hydrocarbon-fluid ratios,  $WOR_i^{test}$ , of the ones of the plurality of wells (2a, 2b, 2c).

20

25. A computer program, comprising instructions that when carried out by at least one processor, cause the at least one processor to perform for performing a method (100) accruing to any one of claims 1 to 16.

25

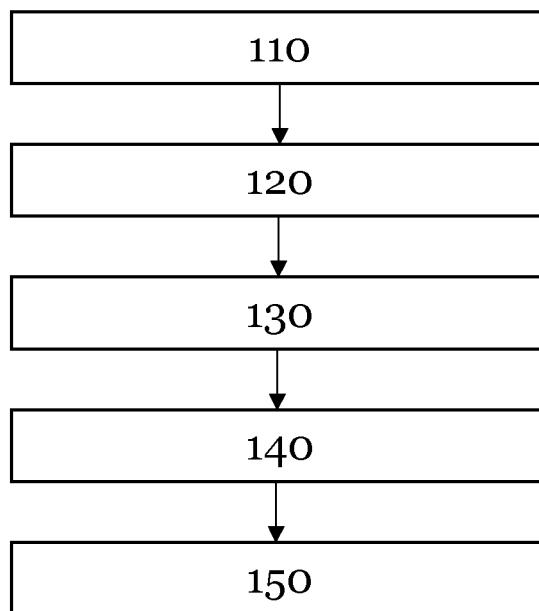
26. A non-transitory computer readable medium having stored thereon software instructions that, when carried out by at least one processor, cause the processor to perform for performing a method (100) accruing to any one of claims 1 to 16.

30

27. A control unit (1000) for determining at least one hydrocarbon fluid flow rate,  $Q_i^{HC}$ , of at least one of a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) with a comingled hydrocarbon fluid flow from the plurality of wells (2a, 2b, 2c), the control unit (1000) comprising at least one processor and a memory coupled with the

at least one processor; the at least one processor and memory configured to perform a method (100) accruing to any one of claims 1 to 16.

- 5      28.    An oilfield (1) comprising a plurality of wells (2a, 2b, 2c) connected to a common pipeline (3) and a control unit (1000) according to claim 27 operated to perform a method (100) accruing to any one of claims 1 to 16.

**Figures**100**Fig. 1**

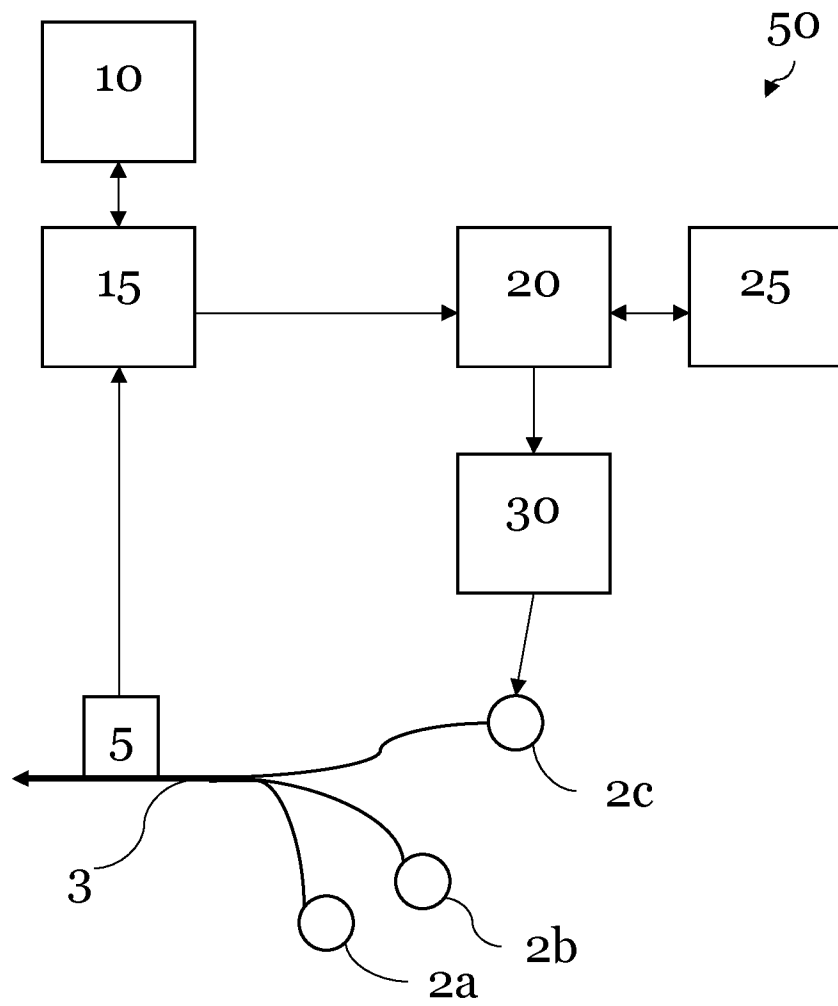


Fig. 2

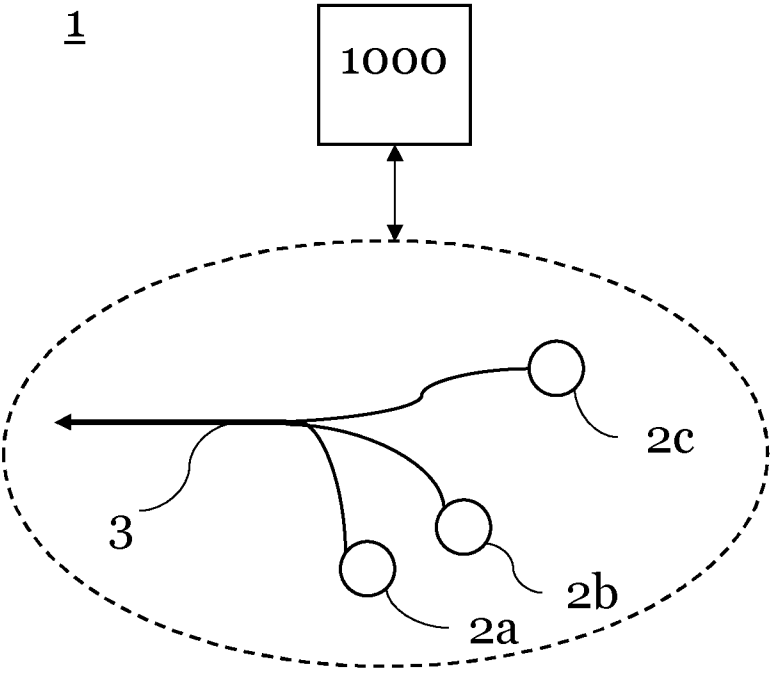


Fig. 3

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/IB 2022/051515

| A. CLASSIFICATION OF SUBJECT MATTER<br>IPC: <b>E21B 43/12</b> (2006.01); <b>E21B 43/17</b> (2006.01); <b>E21B 47/00</b> (2006.01); <b>E21B 21/08</b> (2006.01)          |                                                                                                                            |                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                       |                                                                                                                            |                                                                                                                                                                                                                                                  |
| B. FIELDS SEARCHED<br>Minimum documentation searched (classification system followed by classification symbols)<br><b>E21B</b>                                          |                                                                                                                            |                                                                                                                                                                                                                                                  |
| 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)<br><b>EPODOC, WPIap, TXTnn, Internet</b>   |                                                                                                                            |                                                                                                                                                                                                                                                  |
| C. DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                  |                                                                                                                            |                                                                                                                                                                                                                                                  |
| Category*                                                                                                                                                               | Citation of document, with indication, where appropriate, of the relevant passages                                         | Relevant to claim No.                                                                                                                                                                                                                            |
| X                                                                                                                                                                       | WO 2019165013 A1 (SAUDI ARABIAN OIL CO) 29 August 2019 (29.08.2019)<br>paragraphs [0004], [0027], [0064]; claim 1; figures | 2                                                                                                                                                                                                                                                |
| A                                                                                                                                                                       |                                                                                                                            | 1, 25-28                                                                                                                                                                                                                                         |
| X                                                                                                                                                                       | WO 2008104750 A1 (BP EXPLORATION OPERATING ET AL.) 04 September 2008 (04.09.2008)<br>paragraph [0060]; figures             | 2                                                                                                                                                                                                                                                |
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| A                                                                                                                                                                       | US 2005267718 A1 (GUYAGULER ET AL.) 01 December 2005 (01.12.2005)<br>claim 1                                               | 1, 2                                                                                                                                                                                                                                             |
| A                                                                                                                                                                       | US 2021349237 A1 (ZAHUR ET AL.) 11 November 2021 (11.11.2021)<br>figure 1                                                  | 1, 2                                                                                                                                                                                                                                             |
| Further documents are listed in the continuation of Box C.                                                                                                              |                                                                                                                            | <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                     |
| * Special categories of cited documents:                                                                                                                                |                                                                                                                            |                                                                                                                                                                                                                                                  |
| "A" document defining the general state of the art which is not considered to be of particular relevance                                                                |                                                                                                                            | "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                                              |
| "E" earlier application or patent but published on or after the international filing date                                                                               |                                                                                                                            | "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone                                                                     |
| "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) |                                                                                                                            | "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 |
| "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                                                                  |                                                                                                                            | "&" document member of the same patent family                                                                                                                                                                                                    |
| Date of the actual completion of the international search<br>19 October 2022 (19.10.2022)                                                                               |                                                                                                                            | Date of mailing of the international search report<br>28 October 2022 (28.10.2022)                                                                                                                                                               |
| Name and mailing address of the ISA/AT<br>Austrian Patent Office<br>Dresdner Straße 87, A-1200 Vienna<br>Telephone No. +43 (1) 53424 342                                |                                                                                                                            | Authorized officer<br><br>Stamminger Philipp<br>Telephone No. +43 1 534 24 447                                                                                                                                                                   |

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/IB 2022/051515

| Box No. II                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| <p>This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:</p> <p>1. <input type="checkbox"/> Claims Nos.:<br/>because they relate to subject matter not required to be searched by this Authority, namely:</p> <p>2. <input type="checkbox"/> Claims Nos.:<br/>because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:</p> <p>3. <input type="checkbox"/> Claims Nos.:<br/>because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                   |
| Box No. III                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Observations where unity of invention is lacking (Continuation of item 3 of first sheet)          |
| <p>This International Searching Authority found multiple inventions in this international application, as follows:</p> <p>This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1.</p> <p>Group I: claim 1 and all claims dependent on claim 1 are directed to a method for determining at least one hydrocarbon fluid flow rate, comprising the steps receiving comingled-flow measurement data, accessing historical well test data, determining based on Lagrange multipliers and adapting at least one operating parameter, wherein the last step of adapting one operating parameter is the only remaining special technical feature in view of the cited prior art.</p> <p>Group II: claim 2 is directed to a method for determining at least one hydrocarbon fluid flow rate, comprising the steps receiving comingled-flow measurement data, accessing historical well test data, determining based on Lagrange multipliers. The step of adapting operation parameter is missing, which means that unity is not achieved.</p> <p>The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features.</p> <p>1. <input type="checkbox"/> As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.</p> <p>2. <input checked="" type="checkbox"/> As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.</p> <p>3. <input type="checkbox"/> As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:</p> <p>4. <input type="checkbox"/> No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:</p> <p><b>Remark on Protest</b></p> <p><input type="checkbox"/> The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.</p> <p><input type="checkbox"/> The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.</p> <p><input type="checkbox"/> No protest accompanied the payment of additional search fees.</p> |                                                                                                   |

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
PCT/IB 2022/051515

| Patent document cited<br>in search report | Patent family<br>member(s) | Publication<br>date |
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