



(11) **EP 2 004 953 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
07.10.2009 Bulletin 2009/41

(51) Int Cl.:
E21B 43/00 ^(2006.01) **E21B 49/08** ^(2006.01)
E21B 41/00 ^(2006.01) **G01F 1/74** ^(2006.01)
G01F 15/08 ^(2006.01)

(21) Application number: **07727816.6**

(86) International application number:
PCT/EP2007/053348

(22) Date of filing: **05.04.2007**

(87) International publication number:
WO 2007/116008 (18.10.2007 Gazette 2007/42)

(54) **METHOD FOR OPTIMISING THE PRODUCTION OF A CLUSTER OF WELLS**

VERFAHREN ZUR OPTIMIERUNG DER ERZEUGUNG EINER BOHRLOCHGRUPPE

PROCÉDÉS POUR OPTIMISER LA PRODUCTION D'UN GROUPE DE PUITS

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE
SI SK TR**

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(30) Priority: **07.04.2006 EP 06112401**
10.04.2006 EP 06112440

(56) References cited:
WO-A-02/29195 **US-B1- 6 434 435**

(43) Date of publication of application:
24.12.2008 Bulletin 2008/52

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Description**BACKGROUND OF THE INVENTION**

[0001] The invention relates to a method for optimising the production of a hydrocarbon production system comprising a cluster of hydrocarbon production wells and an associated fluid separation assembly.

[0002] Typically, fluid streams produced by individual wells of a well cluster are commingled into multiphase streams in one or more production manifold (header) conduits and routed via a fluid separation assembly (comprising one or more bulk separators and/or production separators) into fluid outlet conduits for transportation and sales of at least nominally separated streams of liquids, gas and/or other fluids.

[0003] A problem associated with management of fluid flow at the outlets of the bulk or production separator is that this fluid flow stems from the commingled flux from all the wells of the cluster and does not provide information about the composition and flux of fluids produced by the individual wells. Consequently, the individual flux of fluids produced by the individual wells cannot customarily be tracked accurately in real time or instantaneously. The inability to track the individual well productions, together with the variability of well production and properties over time, leads immediately to the inability to fully characterize the wells for the purposes of predicting flows if various well adjustments are made. Further, the production from the wells often interact due to limited capacity in the manifold and the separator to handle the full potential productions from the wells. As an example, over-production of gas in one well may reduce the total oil production in the cluster of wells.

[0004] A further problem with monitoring and controlling the production of a hydrocarbon production well is that such a well may produce a mixture of crude oil, gas, water and condensates and that the production may contain irregular slugs of crude oil, water, solids and/or condensates. Multiphase flowmeters are often too expensive, have too restricted an operating envelope and are too complex to install on individual well flowlines to allow individual oil, water and gas components of the well production to be measured continuously in real time, particularly as the well multiphase flow characteristic changes significantly over the life of the well. These multiphase flowmeters also require calibration at start up and/or from time to time thereafter. Consequently, in the vast plurality of cases, the production of fluids by the individual wells is not customarily measured directly accurately continuously, or in real time.

[0005] International patent application WO03/046485 discloses a production metering and well testing system, wherein the accumulated production of wells of an entire field is measured downstream of a bulk separator in which the produced fractions of crude oil, water, natural gas, solids and/or condensates are separated and the flux and composition of the produced crude oil and/or other fractions can be accurately monitored. This accurate measurement of the accumulated production of wells of an entire field is made simultaneously, and compared, with less accurate measurements upstream multiphase flow measurements that are taken simultaneously at each individual well.

[0006] Applicant's International patent application PCT/EP2005/055680, filed on 1 November 2005, "Method and system for determining the contributions of individual wells to the production of a cluster of wells" discloses a method and system named and hereafter referred to as "Production Universe Real Time Monitoring" (PU RTM). The PU RTM method allows accurate real time estimation of the contributions of individual wells to the total commingled production of a cluster of crude oil, gas and/or other fluid production wells, based on well models derived from well test data and updated regularly using commingled production dynamic data. The PU RTM method also does not require the deployment of multiphase meters at each monitored well. SPE 83978 discloses the concept of real-time optimization in general terms.

[0007] An object of the present invention is to provide a method and system to optimise production of a cluster of wells on the basis of an estimation of the contributions of individual wells to the production of the cluster of wells, tailored to the particular constraints and requirements of the oil and gas production environment. The wells in the cluster may differ in terms of nature and flux of its effluents, and/or mode of operation, stimulation and/or manipulation. The wells may also produce from multiple subsurface zones or branches. The wellheads of the wells in the cluster may be located on land or offshore, above the surface of the sea or on the seabed. The method according to the invention may be used to generate one or more optimisation models, taking into account only significantly relevant well and production system characteristics and effects.

SUMMARY OF THE INVENTION

[0008] In accordance with the invention there is provided a method for optimising production of a cluster of wells of which well effluent streams are commingled and separated in a fluid separation assembly into at least partly separated streams of crude oil, gas and/or other fluids, the method comprising:

- a) performing a well test on each of the wells during which production from the tested well is varied and one or more individual well production variables are monitored;
- b) deriving from data obtained by the well tests an estimation model for each well relating to the variation of the flow

pattern of effluents produced by the tested well and of the monitored well production variables;

c) putting the wells in normal commingled oil and/or gas production;

d) monitoring during step c) a dynamic fluid flow pattern of the at least partly separated streams of crude oil, gas and/or other fluids by means of flow meters arranged in the at least partly separated streams of crude oil, gas and/or other fluids downstream of the fluid separation assembly;

e) monitoring during step c) one or more well production variables relating to characteristics of the multiphase flow streams produced by the individual wells;

f) repeatedly estimating a dynamic commingled fluid flow pattern of the cluster of wells on the basis of the estimation models according to step b) and production variables monitored in accordance with step e);

g) performing a dynamic reconciliation process, wherein during a selected reconciliation period:

- it is assumed that the estimated dynamic commingled fluid flow pattern according to step f) is an accumulation of said individual well production estimation models that are multiplied by unknown weight coefficients;
- the unknown weight coefficients are estimated by iteratively varying each weight coefficient until the estimated dynamic commingled fluid flow pattern substantially matches with the monitored dynamic fluid flow pattern; and
- best estimates of production flow are provided for the selected reconciliation period, and using the individual well reconciliation factors with the estimation models to estimate production from each well for a next reconciliation period;

h) defining an operational optimisation target consisting of a target to be optimised regarding production of one or more wells and/or the cluster of wells;

i) adjusting production of well effluents of the well cluster such that the optimisation target is approached; and

j) steps g and i are repeated from time to time. Optionally, the method according to the invention may further comprise the steps of:

- identifying for at least one of the wells in the cluster one or more numerical manipulated variables that can be manipulated directly to vary the production of the well, and thereafter deriving from data, obtained by the well tests and/or during normal commingled production, and/or the estimation model, a prediction model relating the well manipulated variables to the variation of the flux or the flow pattern and/or other characteristics of the produced well effluents. Wells without identified manipulated variables will have prediction models that are constant numbers equal to the nominal estimated productions of wells;
- summing the prediction models of all wells of the well cluster to provide an overall commingled production prediction model;
- adjusting production of well effluents by means of the well manipulated variables as guided by the individual well prediction models and the overall commingled production prediction model to achieve the said optimisation target. Optionally, the method according to the invention may yet further comprise the steps of:
 - measuring an interaction pressure(s), such as a pressure(s) within one or more production manifolds in the flowlines that are connected to the wellheads of the wells of the cluster of wells, in which manifolds which the flux from a plurality of well flowlines is commingled, the variation of which, as total well productions vary, indicates and links interactions between effluent streams from various wells;
 - obtaining dynamic data relating the variations of interaction pressure(s) to the measured variables of the wells, from normal commingled production and / or during periods of production upsets and / or by performing a series of well interaction tests during which the interaction pressure is varied;
 - obtaining from dynamic data relating the variations of interaction pressure(s) to the measured variables of the wells well prediction models relating the variations of well manipulated variable(s) and interaction pressure(s) to the production of the wells;
 - obtaining dynamic data relating the variations of interaction pressure(s) to the total commingled production, from periods of normal commingled production and / or during periods of production upsets and / or by performing a series of tests during which the interaction pressure is varied, and thereafter one or more manifold interaction models relating the variation of the interaction pressure(s) with the total commingled production flows flowing through the manifolds;
 - combining the well prediction models to the interaction pressure models to obtain an overall commingled production prediction model.

[0009] Optionally the method according to the invention may further comprise the step of periodically repeating the optimisation method by aligning the prediction models with the current flows so that the aligned prediction models reflect the current flows as estimated by the dynamic reconciliation process.

[0010] The optimisation target may be a revenue function relating accumulated or averaged combined and / or individual well production to actual net or gross or incremental monetary revenue, optionally including associated production costs.

[0011] The optimisation target may be required to be achieved while obeying production constraints, consisting of bounds on the manipulated variables and / or the individual well productions, and / or well production quantities, including measurements, and / or that of groups of wells and / or on the interaction pressure(s), and / or on the commingled total productions.

[0012] The method according to the invention may further comprise the step of performing an optimisation using any of a plurality of numerical optimization algorithms over the manipulated variables based on the operational optimisation target, optionally with constraints, and well and/or overall commingled production prediction models to yield a set of optimised manipulated variables that achieve the operational optimisation target.

[0013] Optionally, the production of well effluents of the wells may be varied by adjusting the opening of a production choke valve at the wellhead of the wells or in flowlines connected to the wells, or of a flow control valve in a lift gas injection system of the wells, or by other means of stimulating or restricting the production of the wells.

[0014] Optionally, the production of well effluents of the wells may be varied by adjusting the interaction pressure(s) of the production system by means of rerouting well production through parallel production manifold conduits that are connected between upstream and downstream manifolds, or by adjusting the pressure of the fluid separation assembly or assemblies.

[0015] Required adjustments predicted by the method according to the invention to achieve the optimisation targets may be automatically transmitted to the wells and the production system, or alternatively, after validation by a human operator.

[0016] One or more of the estimation and/or prediction models may optionally be generated in part or in full from theoretical and/or empirical physical and/or mechanical and/or chemical characterization of the wells and/or the production system.

[0017] The optimization target can be adjusted in reaction to and/or in anticipation of changes to the production requirements and/or costs and/or revenues and/or production infrastructure and/or state of the wells and/or the state of the production facilities; and optionally followed up by the conduct of the optimization process, the results of which are implemented and/or used for analysis and planning and/or recorded for future action.

[0018] The method and system outlined herein is further applicable to the case where the optimisation target is achieved by optional means of temporary close in of production in one or more wells of the well cluster, or the initiation of production of wells of the well cluster that were initially not in production.

[0019] One or more of the estimation and/or prediction models may optionally be compared and/or evaluated against theoretical and/or empirical physical and/or mechanical and/or chemical characterization of the wells and/or the production system; for the purposes of troubleshooting and/or diagnosis and/or for improving the models and/or for analysis leading to longer time horizon production management and optimization activities.

[0020] The methods of this invention apply also when one or more of the wells from the cluster of wells are periodically, or intermittently, operated, or are operated from time to time, and the production or associated quantities to be optimised, and optionally, constrained, are evaluated, for example averaged, over fixed periods of time larger than that characteristic of the periodicity or intermittent operation.

[0021] The methods of this invention apply also when one or more of the wells from the cluster of wells are periodically, or intermittently, operated, or are operated from time to time, and the duration of its operation, as a proportion of a fixed period of time, is taken a manipulated variable for the well.

[0022] The methods of this invention apply additionally to an optimization target defined on wells in the well cluster with two or more subsurface zones. In this case, "zone production estimation models" and "zone production prediction models" are generated in addition to the "well production estimation models" and "well production prediction models".

[0023] The method according to the invention allows the characterization of the behaviour of wells individually and within the context of the overall production facility as a function of variables that can be freely manipulated at the wells and also for the overall facility. The characterization of the wells and their interactions with the facility allows directly the accurate real time prediction and optimisation of well production within the context of the production facility. The method according to the invention may include consideration of constraints on the production, arising from both the interactions between wells due to the limitations on the facilities, as well as externally imposed constraints. The method according to the invention is also referred to as "Production Universe Real Time Optimisation" (PU RTO).

[0024] The "PU RTO" method according to the invention has several advantages over prior art methods, for example, as outlined in PU RTM described in International patent application PCT/EP2005/055680. In particular, the "PU RTO" method according to the invention may be used to derive various well and production system characteristics from simple well and production testing at the well and production facility alone, enabling easier model maintenance and dispensing with measurements and quantities not continuously measured, but nevertheless unpredictably variable over periods of time in a production environment, such as piping surface roughness, reservoir pressure-volume-temperature fluid characteristics and composition, equipment and well performance curves, and similar. In other words, "PU RTO" is "data

driven". Specifically, the "overall well and production system model" of the commingled well production system may be constructed without preconceptions as to its underlying physical nature other than the use basic fundamental topological and physical relations, and purely from measured data.

[0025] The method according to the present invention may be used to provide characterization of the combined well and production system that will be of benefit additionally for offline analysis and planning activities. In other words it is another benefit of the present invention that it may provide a method and system to link real time current well production characteristics to the offline analysis and modelling to support wider, weekly, monthly planning and optimisation of the potential of an integrated production system comprising of multiple cluster of wells and associated production facilities.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The invention will be described by way of example in more detail with reference to the accompanying drawings in which:

FIG. 1 schematically shows a production system according to the invention in which a multiphase fluid mixture comprising crude oil, water, natural gas and/or other fluids is produced by a cluster of multiple wells of which two are represented and transported via multiphase fluid transport pipelines to a bulk separator;

FIG. 2 schematically shows how the "Aligned Well Production Prediction Models" and "Aligned Well and Overall Production Prediction Model" is generated from a set of well and production system testing data; and

FIG. 3 schematically shows how the "Well Operational Production Optimisation" problem and the "Overall Facility Operational Production Optimisation" problem are formulated to solve for the "Optimised Setpoints" for the wells selected for individual well optimisation, and the "Optimised Setpoints" for the other wells and the overall production facility.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0027] Reference is made to FIG. 1. FIG. 1 depicts a simple embodiment of a production system comprising a cluster of wells of which effluents are commingled at a production manifold and routed to a production separator. Well 1 is shown in detail, and may be taken as representative of the other wells in the cluster. The other wells in the cluster may however differ in terms of nature and flux of its effluents, and / or mode of operation / stimulation / manipulation.

[0028] Well 1 comprises a well casing 3 secured in a borehole in the underground formation 4 and production tubing 5 extending from surface to the underground formation. The well 1 further includes a wellhead 10 provided with monitoring equipment for making well measurements, typically for measuring Tubing Head Pressure (THP) 13 and Flowline Pressure (FLP) 14. Optionally, there may be downhole monitoring equipment for making subsurface measurements, for example Downhole Tubing Pressure (DHP) 18, and/or subsurface and/or surface tubing and/or flowline differential pressure meters, for example wet gas meters (not shown). The wells may also produce from multiple subsurface zones or branches. The wellheads of the wells in the cluster may be located on land or offshore, above the surface of the sea or on the seabed.

[0029] The well 1, like well 2, and some but not necessarily all of the other wells in the cluster, will also have some means of adjusting production, such as: a production control choke 11 or a fixed bean choke (not shown) and/or a lift-gas injection control system 12 or downhole interval control valves (not shown), which control the production from one or more inflow regions of the well. Numerical "manipulated variables" are associated with each of these means of adjusting production.

[0030] The production system further includes a plurality of well production flow lines 20, extending from the wellheads 10 to a production manifold 21, a production pipeline 23 and a means of separating the commingled multiphase flow, in this case a production separator 25. Production manifold pressure measurement 22 and production separator pressure measurement 26 will often be available on the production manifold and the production separator as shown. There will be some means of regulating the level of the production separator, and optionally its pressure or the pressure difference between the separator its the single-phase outlets. For simplicity a pressure control loop 27 is shown in FIG. 1. Typically, the production manifold pressure measurement 22 (alternatively the production separator pressure measurement 26) will be used as "interaction pressure", the variation of which as the well production rates are varied, is an indicator of the degree of interaction between the wells.

[0031] The production separator 25 is provided with outlets for water, oil and gas 35, 36 and 37 respectively. Each outlet 35, 36 or 37 is provided with flow metering devices, 45, 46 and 47 respectively. Optionally, the water and oil outlets can be combined. The production separator pressure may optionally be controlled by regulating the gas flow from 37, thereby affecting the manifold pressure 26 and the flowline pressure 14 and thus the production of the individual wells.

[0032] The well measurements comprising at least data from 13 and optionally from 14, 18, liftgas injection rate from 12, position of production choke 11, and other measurements as available, are continuously transmitted to the "Production Data Acquisition and Control System" 50. Similarly, the commingled production measurements 45, 46, 47 are continu-

ously transmitted to the "Production Data Acquisition and Control System" 50. The typical data transmission paths are illustrated as 14a and 45a. The data in 50 is stored and is then subsequently available for non-real time data retrieval for data analysis and model construction as outlined in this patent. The data in the "Production Data Acquisition and Control System" is also accessed by "PU RTM" in real time for use in conjunction with "well production estimation models" for the continuous real time estimation of individual well productions. Some well production rate controls will also be adjustable from "Production Data Acquisition and Control System" 50 for remotely adjusting and optimising the well production, for example, the production choke opening or the liftgas injection rate, and the signal line for liftgas injection rate control is shown as 12a.

[0033] An associated well testing facility may optionally and is preferably to be available for the individual testing and characterization of the wells. In the absence of a well testing facility, testing for well model construction may be conducted utilizing measurements 45, 46, 47 from the production separator.

[0034] Reference is now made to FIG. 2, which provides one preferred embodiment of the "data driven" modelling process for this invention. The intent is to generate sustainably useful models fit for the purpose of the invention, taking into account only significantly relevant well and production system characteristics and effects. The procedure leading to the generation of "Aligned Well Production Prediction Models" and "Aligned Well and Overall Production Prediction Model" for a cluster of n wells indexed $i = 1, 2, \dots, n$, for which one "manipulated variable" for each well has been identified, and for which a dedicated well test facility are available, is described as follows:

- a series of well tests are conducted during which production from each well is varied for well characterization by changing the "manipulated variable" of the well. The well test data 60 is used to generate a "well production estimation model" 61 in the form $y_i = f_i(u_i, v_i)$, valid for a range of u_i, v_i within a set $U_i \times V_i$, wherein the vector y_i is the oil, water and gas production of well i , u_i is the vector of measurements at well i , and v_i is the manipulated variable at well i . The procedure for constructing "well production estimation model" using dedicated well test facilities is as previously outlined in "PU RTM". In "PU RTM" distinction is not made between the measured variables u_i and the manipulated variable v_i , (which is also measured) but the distinction is required for this invention;
- a series of "well and production facilities interaction tests" are then conducted to obtain "well and production facilities interaction test data" 62, or alternatively, data can also be derived from "production data" 63 which contains a record of dynamic events during normal production, such as when major gas producing wells are closed in.
- a "well production manipulation and interaction model" 65 is then constructed relating the variations of "manipulated variable" of the well and the "interaction pressure" to the measurements at the well flowline. The relation between the "manipulated variable" and the measurements at the well flowline may be derived from well test data 60, for example "DDWTs", or from "production data" 63 by adjusting the manipulated variable during normal well production, and recording the reactions of the measurements at the well flowline. Similarly, the relation between "interaction pressure" and the measurements at the well flowline is established from "well and production facilities interaction tests" data 62 or from "production data" 63 recording dynamic events during normal production.

[0035] The "well production manipulation and interaction model" 65 will have the form $u_i = g_i(v_i, w)$, for each of the wells $i = 1, 2, \dots, n$ where $w \in W$ is the common "interaction pressure" ranging over set W , u_i is the vector of measurements at well i , and v_i is the manipulated variable at well i , as before.

[0036] A "well production prediction model" 66 for each well $i = 1, 2, \dots, n$ is then generated from the "well production estimation model" 61 and the "well production manipulation and interaction model" 65 as follows:

$$y_i = f_i(u_i, v_i) = f_i(g_i(v_i, w), v_i) = h_i(v_i, w),$$

so that the function $h_i(v_i, w)$ relates the vector y_i , the oil, water and gas production of well i , to the w , the common "interaction pressure", and v_i , the manipulated variable at well i .

[0037] Given the characterization of the well 66, it is now required to derive the dependence of w , the "interaction pressure" at the production manifold in this embodiment, to the total commingled production flows routed via the production manifold, and optionally, of variables, v_w , that are manipulated at a overall facilities level which also affect the "interaction pressure", for example, the production separator pressure setpoint 27. This is achieved by using the "well and production facilities interaction test" data 62 to build an "interaction pressure model" 67, $w = k(\hat{y}, v_w)$, where $\hat{y}$ is defined to be the vector of the sum of the production of the wells routed to the production manifold, in this case

$$\hat{y} = \sum_{i=1}^n y_i$$

[0038] There will be instances wherein data from well testing or production is not available or reliable for a particular well or parts of the overall system, for example when a well is not yet been brought into production. In such cases, models based on theoretical and/or empirical physical and/or mechanical and/or chemical characterization of the wells and/or the production system can be used in place of 65 or 67.

[0039] Once the "well production manipulation and interaction models" 66 and the "interaction pressure model" 67 are developed, the optimisation process is implemented as per the online part of the workflow in Fig.2 and then as in Fig.3. The desired production optimisation formulations are also set out as follows:

- Well Optimisation 78, for selected wells, defined by an index set I which is a proper subset of $1,2,\dots,n$, in the form

$$\max_{v_i} R_i(y_i, v_i)$$

subject to constraints $c_{i,j}(y_i, v_i, u_i) \geq 0, j=1,2,\dots,J_i$.

where $R_i(y_i, v_i)$ is the objective or revenue function 76 for the well i to be maximized by varying v_i , the manipulated variable at well i , subject to J_i constraints on y_i, v_i, u_i , the well production, the well manipulated variables and the measured variables, respectively, defined by the constraint inequalities $c_{i,j}(y_i, v_i, u_i) \geq 0$, 77.

- Overall Production Optimisation, 83, for wells $i \notin I$ (which are wells not already optimised as part of 78), in the form

$$\max_{v_i, i \in I, v_w} R(\hat{y}, v_i, u_i, w, v_w),$$

subject to constraints $c_j(\hat{y}, v_i, v_i, u_i, w, v_w) \geq 0, j=1,2,\dots,J_w$;

where $R(\hat{y}, v_i, v_i, u_i, w, v_w)$ is the objective or revenue function, 81, to be maximized by varying v_i , the manipulated variable at wells $i \notin I$, subject to J_w constraints, 82, $c_j(\hat{y}, v_i, v_i, u_i, w, v_w) \geq 0$ the on $\hat{y}, w, v_w$, the overall commingled production, the interaction pressure, and the optional vector of variables that can be manipulated at a overall facilities level, respectively, and $y_i, v_i, u_i, i=1,2,3,\dots,n$, the individual well productions, well manipulated variables, and well measured variables for the wells $i=1,2,3,\dots,n$.

[0040] With the wells in normal commingled production, "PU RTM" is run online to produce continuous real time estimates of production at each individual well 70. The "current" "PU RTM" estimates of individual well production $\tilde{y}_i$, and the "current" measurements and manipulated variable values $\tilde{v}_i, \tilde{w}$ are used to align the "well production manipulation and interaction models" $y_i = h_i(v_i, w)$ by defining a constant offset $d_i = \tilde{y}_i - h_i(\tilde{v}_i, \tilde{w})$ at $\tilde{y}_i, \tilde{v}_i, \tilde{w}$. The "Aligned Well Production Prediction Models" 75 then have the form $y_i = h_i(v_i, w) + d_i$. The alignment process allows the optimisation focus to be on incremental changes in the production at the well and overall production, so that if $\Delta v_i = v_i - \tilde{v}_i$, $\Delta w = w - \tilde{w}$ and $\Delta y_i = y_i - \tilde{y}_i$, then $\Delta y_i = 0$ if $\Delta v_i = 0$ and $\Delta w = 0$. For illustrative purposes, the "Aligned Well Production Prediction Model", 75, for each well i , can be cast in the "separated difference" form $\Delta y_i = A_i \Delta v_i + B_i \Delta w$. The symbols A_i, B_i can be envisaged as either matrices or functionals operating on Δv_i and Δw . Optionally, cross terms and second and higher order terms on Δv_i and Δw can be inserted without loss of generality.

[0041] For each well $i \in I$, which are wells for which a well optimization is desired, given its "Aligned well Production Prediction Model", 75, and the objective or revenue function 76, and associated optimisation constraints 77, the well optimisation, 78, may then be conducted to solve for the optimal value of v_i , 79, the manipulated variable at well i . Note that the well optimisation necessarily assumes the common well interaction variable w , which is a variable affected by the collective production of the wells and variables at the overall production system level, is unchanged by the well optimisation, or has negligible effect on the optimisation result.

[0042] The "interaction pressure model" 67 $w = k(\hat{y}, v_w)$ be aligned by defining constant $d_w = \tilde{w} - k(\tilde{y}, \tilde{v}_w)$, where the "current nominal value" of the commingled production measurements $\hat{y}$ is denoted by $\tilde{y}$. The "aligned interaction pressure model" is then of the form $w = k(\hat{y}, v_w) + d_w$. Further, we assume the estimates $\tilde{y}_i$ have been fully reconciled by "PU RTM" with the latest nominal overall commingled production measurements so that

$$\tilde{y} = \sum_{i=1}^n \tilde{y}_i$$

Again, for illustrative purposes, the "aligned interaction pressure model" can also have the "separated difference" form $\Delta w = K \Delta \hat{y} + L \Delta v_w$, where

$$\Delta \hat{y} = \hat{y} - \tilde{y} = \hat{y} - \sum_{i=1}^n \tilde{y}_i$$

and $\Delta v_w = v_w - \tilde{v}_w$.

[0043] Now $\sum_{i=1}^n y_i$ is the estimate of total commingled production from the "Aligned Well Production Prediction Models" 75. Hence the "Aligned Well + Overall Production Prediction Model" 80 in "Difference" form is then constructed by combining "Aligned Well Production Prediction Models" 75 with the "aligned interaction pressure model". From

$$\Delta \hat{y} = \left(\sum_{i=1}^n y_i \right) - \tilde{y} = \sum_{i=1}^n \Delta y_i = \sum_{i=1}^n A_i \Delta v_i + B_i \Delta w = \sum_{i=1}^n A_i \Delta v_i + \left(\sum_{i=1}^n B_i \right) (K \Delta \hat{y} + L \Delta v_w)$$

we get

$$\Delta \hat{y} = \sum_{i=1}^n A_i \Delta v_i + \left(\sum_{i=1}^n B_i \right) (K \Delta \hat{y} + L \Delta v_w)$$

which is an implicit form of the "Aligned Well + Overall Production Prediction Model" 80 relating the variables $\Delta \hat{y}, \Delta v_i, \Delta v_w$, respectively, the total commingled production, the manipulated variables at the wells, and the manipulated variables at the overall production system level. For given values of $\Delta v_i, \Delta v_w$, depending on the form of the functionals

$$\sum_{i=1}^n A_i, \sum_{i=1}^n B_i, K, L,$$

the implicit form of 80 can be solved $\Delta \hat{y}$ by a plurality of methods. In the case where the interaction components

$$\sum_{i=1}^n B_i, K, L$$

are matrices of real numbers, for example, we have

$$\left[I - \left(\sum_{i=1}^n B_i \right) K \right] \Delta \hat{y} = \sum_{i=1}^n A_i \Delta v_i + \left(\sum_{i=1}^n B_i \right) L \Delta v_w,$$

which is solvable for $\Delta \hat{y}$ given values of v_i, v_w , unless, for example, the operator

$$\left[I - \left(\sum_{i=1}^n B_i \right) K \right]$$

is not invertible.

[0044] An estimate of the manipulated variables v_j, v_w required to optimise the production of the overall facility is then obtained by combining "Aligned Well + Overall Production Prediction Model" 80 with the objective or revenue function 81, and associated optimisation constraints 82 to form the "Overall Facility Operational Production Optimisation" 83. The optimisation is then conducted to solve that for optimal values of the "optimised manipulated variables" v_j, v_w , 84.

[0045] Depending on the form of 83, the optimised variables 84 may be directly computed or an automated numerical iterative optimisation procedure applied. There is a plurality of automated numerical iterative optimisation approaches that are applicable depending on the form of 83. Refer for example to the textbook "Nonlinear Programming - Theory and Algorithms", 2nd Edition, 1993, by M Bazarra, H.D. Sherali and C.M. Shetty, or more generally for various rigorous or heuristic "Global Optimisation" methods, see for example, Computers and Chemical Engineering 28 (2004) 1169-1218, "Part I Retrospective on optimization", and "Part II. Future Perspective on Optimization", by L.T. Biegler, I.E. Grossmann, and references therein. For a preferred embodiment where the manipulated variables are continuous variables, and 83 is defined by continuous smooth nonlinear model and revenue functions and inequality constraints, a sequential quadratic programme (SQP) with multiple starting points is used for the automated numerical iterative optimisation to yield the "optimised manipulated variables".

[0046] The set of "optimised manipulated variables" is then available for further action. Optionally, the "optimised manipulated variables" are reported to the production facility operators for implementation at the wells and the facility, or alternatively, directly transmitted to the "Production Data Acquisition & Control System" 50 for automated implementation.

[0047] The computation and application of the optimised manipulated variables is conducted from time to time, and is controlled by a "Optimization Initiation System" 90. Preferably, "Well Operational Production Optimisation" and the "Overall Facility Operational Production Optimisation" are initiated on a periodic basis, for example once every day, and/or on demand, in anticipation of changes to the state of the philosophy of management of the wells or of the production system or of the constraints or of the optimisation target. In one embodiment, changes in gaslift availability will automatically initiate an optimisation.

[0048] In a preferred embodiment of the "PU RTO" method according to the invention:

- All models are validated and updated as necessary using current latest and historical test data.
- The "PU RTM Well Production Estimation Model" is verified and updated periodically by checking against normal well testing.
- The well manipulated variables are cycled periodically during normal well production to allow verification and updates of the "Well Manipulation & Interaction Models".
- Production data is captured during normal operations to validate and update as necessary the "Well Manipulation & Interaction Models", and the "Interaction Pressure Model".
- The "optimised manipulated variables" are transmitted after inspection by a human operator.
- The computational optimisation step determines the wells that will either be opened up to resume the individual well production, or closed in to stop the individual well production, or switched between different production separators, addition to the "optimised manipulated variables" for the well while in production.

In this case, the manipulated variables v_j, v_w will include binary values 0 or 1, and various rigorous and heuristic methods are available for its solution, depending on the structure of the models and optimisation formulations used.

- The prediction models of the wells and the overall production system, which reflect the reality of the well and production system, should periodically be compared and evaluated against theoretical physical and mechanical models of the wells and/or the production system, if these are available. The evaluation and comparison of the models derived from the actual well performances as per this invention against theoretical models will yield information to aid in longer time horizon production management and optimization activities.

Claims

1. A method for optimising production of a cluster of wells of which well effluent streams are commingled and separated in a fluid separation assembly into at least partly separated streams of crude oil, gas and/or other fluids, the method comprising:

- a) performing a well test on each of the wells during which production from the tested well is varied and one or more individual well production variables are monitored;
- b) deriving from data (60) obtained by the well tests an estimation model (61) for each well relating to the variation of the flow pattern of effluents produced by the tested well and of the monitored well production variables;
- c) putting the well cluster in normal commingled oil and/or gas production;
- d) monitoring during step c) a dynamic fluid flow pattern of the at least partly separated streams of crude oil, gas and/or other fluids by means of flow meters arranged in the at least partly separated streams of crude oil, gas and/or other fluids downstream of the fluid separation assembly;
- e) monitoring during step c) one or more well production variables relating to characteristics of the multiphase flow streams produced by the individual wells;
- f) repeatedly estimating a dynamic commingled fluid flow pattern of the cluster of wells on the basis of the estimation models (61) according to step b) and production variables monitored in accordance with step e);
- g) performing a dynamic reconciliation process, wherein during a selected reconciliation period:

- it is assumed that the estimated dynamic commingled fluid flow pattern according to step f) is an accumulation of said individual well production estimation models that are multiplied by unknown weight coefficients;
- the unknown weight coefficients are estimated by iteratively varying each weight coefficient until the estimated dynamic commingled fluid flow pattern substantially matches with the monitored dynamic fluid flow pattern; and
- best estimates of production flow are provided for the selected reconciliation period, and using the individual well reconciliation factors with the estimation models to estimate production from each well for a next reconciliation period;

- h) defining an operational optimisation target consisting of a target to be optimised regarding production of one or more wells and/or the cluster of wells;
- i) adjusting production of well effluents of the well cluster such that the optimisation target is approached; and
- j) steps g and i are repeated from time to time.

2. The method of claim 1, further comprising the steps of:

- identifying for at least one of the wells in the cluster one or more numerical manipulated well production variables that can be manipulated directly to vary the production of the well, and thereafter deriving from data, obtained by the well tests and/or during normal commingled production, and/or the estimation model, a prediction model relating the well manipulated variables to the variation of the flux or the flow pattern and/or other characteristics of the produced well effluents, wherein any wells without identified manipulated well production variables will have prediction models that are constant numbers equal to a nominal estimated production of the wells;
- summing the prediction models of all wells of the well cluster to provide an overall commingled production prediction model;
- adjusting production of well effluents by means of the well manipulated variables as guided by the individual well prediction models and the overall commingled production prediction model to achieve the said optimisation target.

3. The method of claim 2, further comprising the steps of:

- measuring one or more interaction pressures, such as a pressure within one or more production manifolds in well flowlines that are connected to the wellheads of the wells of the cluster of wells, in which manifolds the flux from a plurality of well flowlines is commingled, the variation of which interaction pressure, as total well productions vary, indicates and links interactions between effluent streams from various wells;
- obtaining dynamic data relating the variations of interaction pressure(s) to the measured variables of the wells, from normal commingled production and/or during periods of production upsets and/or by performing a series of well interaction tests during which the interaction pressure is varied;
- obtaining from dynamic data relating the variations of interaction pressure(s) to the measured variables of the wells well prediction models relating the variations of well manipulated variable(s) and interaction pressure(s) to the production of the wells;
- obtaining dynamic data relating to the variations of one or more interaction pressures to the total commingled production, from periods of normal commingled production and/or during periods of production upsets and/or

by performing a series of tests during which the interaction pressure is varied, and thereafter one or more manifold interaction models relating the variation of one or more interaction pressures with the total commingled production flows flowing through the manifolds;

- combining the well prediction models to the interaction pressure models to obtain an overall commingled production prediction model.

4. The method of claims 2 and 3, wherein the method further comprises periodically repeating the optimisation method by aligning the prediction models with the current flows so that the aligned prediction models reflect the current flows as estimated by the dynamic reconciliation process.

5. The method of any one of claims 1-4, wherein the optimisation target is a revenue function relating accumulated or averaged combined and/or individual well production to actual net or gross or incremental monetary revenue, optionally including associated production costs.

6. The method of claim 5, wherein the optimisation target is to be achieved while obeying production constraints, consisting of bounds on the manipulated variables, and/or the individual well productions, and/or well production quantities, including measurements, and/or that of groups of wells and/or on one or more interaction pressures, and/or on the commingled total production of the well cluster.

7. The method of claims 5 or 6, further comprising the step of performing an optimisation using any of a plurality of numerical optimisation algorithms over the manipulated variables based on the operational optimisation target, optionally with constraints, and the well and/or overall commingled production prediction models to yield a set of optimised manipulated variables that achieve the operational optimisation target.

8. The method of any of the claims 1-7, wherein the production of well effluents of the wells is varied by adjusting the opening of a production choke valve at the wellhead of the wells or in flowlines connected to the wells, or of a flow control valve in a lift gas injection system of the wells, or by other means of stimulating or restricting the production of the wells, such as any means of reversible and controlled closing in and opening up of a well, a setpoint of a control loop at the well with the production choke valve as an actuator, a setpoint of a control loop on the well gas-lift injection rate or pressure, well gas-lift injection off duration, well gas-lift injection on duration, well gas-lift injection rate, a setpoint of a control loop on the well jet pump hydraulic fluid injection line, well electrical submersible pump (ESP) speed, well rod pump motor speed, well rod pump off duration, and/or well downhole interval control valve opening.

9. The method of any of the claims 1-8, wherein the production of well effluents of the wells is varied by adjusting one or more interaction pressures of the production system by means of rerouting well production through parallel production manifold conduits that are connected between upstream and downstream manifolds, and/or by adjusting the pressure of the fluid separation assembly and/or by adjusting the valves for the routing of well effluents to one or more manifolds that commingle production or that route the commingled production to one or more production separators, and/or by adjusting speed of a compressor in an outlet conduit of the fluid separation assembly.

10. The method of any of the claims 1-9, wherein required adjustments predicted to achieve the optimisation targets are automatically transmitted to the wells and the production system, optionally, after validation by a human operator.

11. The method of any of the claims 1-10, wherein one or more of the estimation and/or prediction models may optionally be generated in part or in full from theoretical and/or empirical physical and/or mechanical and/or chemical characterization of the wells and/or the production system.

12. The method of any of the claims 1-11, wherein the optimisation target is adjusted in reaction to and/or in anticipation of changes to the production requirements and/or costs and/or revenues and/or production infrastructure and/or state of the wells and/or the state of the production facilities; and optionally followed up by the conduct of the optimisation process, the results of which are implemented and/or used for analysis and planning and/or recorded for future action.

13. The method of any of the claims 1-12, wherein the optimisation target is achieved by optional means of temporary close in of production in one or more wells of the well cluster, or the initiation of production of wells of the well cluster that were initially not in production.

14. The methods of claims 2 and 3, whereby one or more of the estimation and/or prediction models may optionally be compared and/or evaluated against theoretical and/or empirical physical and/or mechanical and/or chemical characterization of the wells and/or the production system; for the purposes of troubleshooting and/or diagnosis and/or for improving the models and/or for analysis leading to longer time horizon production management and optimisation activities.

15. The methods of the claims 1-13, wherein one or more of the wells from the cluster of wells are periodically, or intermittently, operated, or are operated from time to time, and the production or associated quantities to be optimised and optionally constrained are evaluated, for example averaged, over fixed periods of time larger than that characteristic of the periodicity or intermittent operation.

16. The method of claim 15, wherein one or more of the wells from the cluster of wells are periodically, or intermittently, operated, or are operated from time to time, and the duration of its operation, as a proportion of a fixed period of time, is taken a manipulated variable for the well.

17. The method of any one of claims 1-13, wherein of the method is applied additionally to an optimisation target defined on wells in the well cluster with two or more subsurface inflow zones, in which case, "zone production estimation models" and "zone production prediction models" are generated in addition to the "well production estimation models" and "well production prediction models".

18. The method of Claim 1, whereby the well production variables, such as pressure and/or other fluid flow characteristics of the individual well effluent streams include one or more of the following variables: well tubing head pressure, well flowline pressure, well tubing head temperature, well flowline temperature, differential pressures across well production choke valve, differential pressures across any differential pressure producer, including a wet gas venturi, on the well flowline, flow meters, nominally suitable only for single phase flow, which are suitable to be used to provide an input to the well estimation models even if the well has multiphase flow, well production choke valve opening state or position, opening state or position of any means of reversible and controlled closing in and opening up of the well, well lift-gas injection rate, well jet pump hydraulic fluid injection rate, well production casing pressure, well electrical submersible pump (ESP) speed, well ESP pump intake pressure, well ESP down hole pump discharge pressure, well ESP down hole venturi differential pressure, well ESP power consumption, well ESP motor phase current, well rod pump motor power input, well rod pump motor speed, well rod pump stroke displacement, well rod pump load cell, beam pump gear box shaft position, well rod pump differential speed / motor/gear box slip, well downhole tubing pressure, well downhole annulus pressure, well downhole tubing or annulus temperature, or various derivations thereof monitored by distributed temperature sensors, well downhole interval control valve opening, amplitude of a selection of sound frequencies from one or more sound sensors mounted on well flowline, propagation delay of correlated sound patterns at a selection of frequencies from two or more sound sensors mounted in an upstream-downstream direction on a well flowline.

Patentansprüche

1. Verfahren zum Optimieren der Förderung aus einem Cluster von Schächten, deren Schachtaustragströme vermischt sind und in einer Fluidtrennanordnung in zumindest teilweise getrennte Ströme aus Rohöl, Gas und/oder anderen Fluiden getrennt werden, wobei das Verfahren umfaßt:

- a) Ausführen eines Schachttests an jedem der Schächte, während die Förderung aus dem getesteten Schacht variiert wird und eine oder mehrere einzelne Schachtfördervariablen überwacht werden;
- b) Erzeugen eines Schätzmodells (61) für jeden Schacht aus den durch die Schachttests gewonnenen Daten (60), das sich auf die Variation der Strömungsmuster der Austragströme, die von dem getesteten Schacht gefördert werden, und der überwachten Schachtfördervariablen bezieht;
- c) Einführen des Schachtclusters in normal vermischte Öl- und/oder Gasförderung;
- d) Überwachen während des Schrittes c) eines dynamischen Fluidströmungsmusters der zumindest teilweise getrennten Ströme aus Rohöl, Gas und/oder anderen Fluiden mittels Durchflußmessern, die in den zumindest teilweise getrennten Strömen aus Rohöl, Gas und/oder anderen Fluiden stromabwärts der Fluidtrennanordnung angeordnet sind;
- e) Überwachen während des Schrittes c) einer oder mehrerer Schachtfördervariablen, die sich auf die Merkmale der Mehrphasenströme beziehen, die von den einzelnen Schächten gefördert werden;
- f) wiederholtes Schätzen eines dynamisch vermischten Fluidströmungsmusters des Clusters von Schächten

auf der Basis des Schätzmodells (61) gemäß Schritt b) und der Fördervariablen, die gemäß dem Schritt e) überwacht werden;

g) Durchführen eines dynamischen Verträglichkeitsverfahrens während einer ausgewählten Verträglichkeitsperiode:

- es wird angenommen, daß das geschätzte dynamische vermischte Fluidströmungsmuster gemäß Schritt f) eine Ansammlung von einzelnen Schachtförder-Schätzmodellen ist, die durch unbekannte Gewichtskoeffizienten multipliziert werden;
- die unbekannten Gewichtskoeffizienten werden durch iteratives Variieren jedes Gewichtskoeffizienten geschätzt, bis das geschätzte dynamische vermischte Fluidströmungsmuster im wesentlichen dem überwachten dynamischen Fluidströmungsmuster entspricht; und
- die besten Schätzungen des Förderstromes werden für die ausgewählte Verträglichkeitsperiode bereitgestellt, wobei die einzelnen Schachtverträglichkeitsfaktoren mit den Schätzmodellen verwendet werden, um die Förderung aus jedem Schacht für eine nächste Verträglichkeitsperiode zu schätzen;

h) ein betriebliches Optimierungsziel wird definiert, das aus einem zu optimierenden Ziel hinsichtlich der Förderung aus einem oder mehreren Schächten und/oder des Clusters von Schächten definiert wird;

i) Einstellen der Förderung der Schachtausträge des Schachtclusters derart, daß das Optimierungsziel angenähert wird; und

j) die Schritte g) und i) werden von Zeit zu Zeit wiederholt.

2. Verfahren nach Anspruch 1, das ferner die Schritte aufweist:

- Identifizieren für zumindest einen der Schächte in dem Cluster einer oder mehrerer numerischer manipulierter Schachtfördervariablen, die direkt manipuliert werden können, um die Förderung des Schachtes zu variieren, und danach Ableiten aus den Daten, die aus den Schachttests und/oder während der normalen vermischten Förderung erhalten wurden, und/oder dem Schätzmodell, ein Vorhersagemodell, das sich auf die manipulierten Schachtvariablen zur Variation des Flusses und/oder Strömungsmusters und/oder anderer Merkmale der geförderten Schachtausträge bezieht, wobei irgendwelche Schächte ohne identifizierte manipulierte Schachtfördervariablen Vorhersagemodelle aufweisen, die konstante Zahlen gleich einer geschätzten Nennförderung der Schächte sind;
- Summieren der Vorhersagemodelle aller Schächte des Schachtclusters zur Schaffung eines Gesamtvermischtförderungs-Vorhersagemodells;
- Einstellen der Förderung der Schachtausträge mittels der manipulierten Schachtvariablen, geführt von den einzelnen Schachtvorhersagemodellen und des Gesamtvermischtförderungs-Vorhersagemodells zur Erzielung des Optimierungszieles.

3. Verfahren nach Anspruch 2, das ferner die Schritte aufweist:

- Messen eines oder mehrerer Interaktionsdrücke, wie eines Druckes innerhalb eines oder mehrerer Förderverteiler in den Schachtströmungsleitungen, die mit den Schachtköpfen der Schächte des Clusters von Schächten verbunden sind, wobei in diesen Verteilern der Fluß aus einer Vielzahl von Schachtströmungsleitungen vermischt wird, wobei die Variation des Interaktionsdruckes, wenn die Gesamtschachtförderungen variieren, angezeigt und die Interaktionen zwischen den Austragströmen von verschiedenen Schächten verlinkt werden;
- Erzeugen aus dynamischen Daten, welche die Variationen der Interaktionsdrücke auf die gemessenen Variablen der Schächte beziehen, aus der normalen Vermischtförderung und/oder während Perioden der Förderungsstörung und/oder des Durchführens einer Reihe von Schachtinteraktionstests, während welchen der Interaktionsdruck variiert wird;
- Erzeugen aus den dynamischen Daten, die sich auf die Variationen des Interaktionsdruckes bzw. der Interaktionsdrücke zu den gemessenen Variablen der Schächte beziehen, von Schachtvorhersagemodellen, die sich auf die Variationen der manipulierten Schachtvariable(n) und des Interaktionsdruckes bzw. der Interaktionsdrücke zur Förderung der Schächte beziehen;
- Erzeugen dynamischer Daten, die sich auf die Variationen eines oder mehrerer Interaktionsdrücke zur Gesamtvermischtförderung beziehen, aus Zeitspannen normaler Vermischtförderung und/oder während Zeitspannen der Förderungsstörung und/oder des Durchführens einer Reihe von Tests, während denen der Interaktionsdruck variiert wird, und danach eines oder mehrerer Verteilerinteraktionsmodelle, die sich auf die Variation eines oder mehrerer Interaktionsdrücke zu den Gesamtvermischtförderströmen beziehen, die durch die Verteilerströmen;

- Kombinieren der Schachtvorhersagemodelle mit den Interaktionsdruckmodellen zur Erzielung eines Gesamtvermischtförderungs-Vorhersagemodells.

- 5 4. Verfahren nach den Ansprüchen 2 und 3, wobei das Verfahren ferner umfaßt periodisches Wiederholen der Optimierungsmethode durch Ausrichten der Vorhersagemodelle mit den vorhandenen Strömungen derart, daß die ausgerichteten Vorhersagemodelle die vorhandenen Strömungen als durch das dynamische Verträglichkeitsverfahren geschätzt reflektieren.
- 10 5. Verfahren nach einem der Ansprüche 1-4, bei welchem das Optimierungsziel eine Gewinnfunktion ist, welche einen Bezug der angesammelten oder durchschnittlich kombinierten und/oder einzelnen Schachtförderung zu dem tatsächlichen Netto- oder Gesamt- oder Teilgeldgewinn herstellt, gegebenenfalls einschließlich assoziierter Förderkosten.
- 15 6. Verfahren nach Anspruch 5, bei welchem das Optimierungsziel erreicht werden soll, während Förderungszwänge beachtet werden, die aus den Grenzen der manipulierten Variablen und/oder der einzelnen Schachtförderungen und/oder Schachtfördermengen, einschließlich Messungen, und/oder der Gruppen von Schächten und/oder einem oder mehreren Interaktionsdrücken und/oder der vermischten Gesamtförderung des Schachtclusters bestehen.
- 20 7. Verfahren nach Anspruch 5 oder 6, das ferner den Schritt des Durchführens einer Optimierung unter Verwendung jedes einer Vielzahl von numerischen Optimierungsalgorithmen gegenüber den manipulierten Variablen umfaßt, basierend auf dem Betriebsoptimierungsziel, gegebenenfalls mit Zwängen, und den Schacht- und/oder Gesamtvermischtförderungs-Vorhersagemodellen, um einen Satz von optimierten manipulierten Variablen zu erzeugen, welche das Betriebsoptimierungsziel erreichen.
- 25 8. Verfahren nach einem der Ansprüche 1-7, bei welchem die Förderung der Schachtausträge der Schächte durch Einstellen der Öffnung des Förderdrosselventils am Schachtkopf der Schächte oder in Strömungsleitungen, die mit den Schächten verbunden sind, oder eines Durchflußsteuerungsventils in einem Liftgaseinspritzsystem der Schächte, oder durch andere Mittel der Stimulierung oder Beschränkung der Förderung der Schächte variiert wird, wie

30 irgendwelche Mittel des reversiblen und gesteuerten Schließens und Öffnens eines Schachtes, eines Einstellpunktes einer Steuerschleife des Schachtes mit dem Förderdrosselventil als Betätiger, eines Einstellpunktes einer Steuerschleife an dem Schachtgaslift-Einspritzdurchsatz oder -druck, der Dauer des Abschaltens des Gaslifteinspritzens, der Dauer des Anschaltens der Gaslifteinspritzung, des Schachtgaslift-Einspritzungsdurchsatzes, eines Setzpunktes einer Steuerschleife an der Schachtdüsenpumpen-Einspritzleitung für hydraulisches Fluid, der Geschwindigkeit einer elektrischen Schachttauchpumpe (ESP), der Schachtstangenpumpen-Motorgeschwindigkeit, der Dauer des Abschaltens der Schachtstabschleife und/oder der Öffnung des Bohrlochintervall-Steuerventils.
- 35 9. Verfahren nach einem der Ansprüche 1-8, bei welchem die Förderung von Schachtausträgen der Schächte variiert wird, indem ein oder mehrere Interaktionsdrücke des Fördersystems **dadurch** eingestellt werden, daß die Schachtförderung durch parallele Förderverteilungen umgeleitet wird, die zwischen dem stromaufwärtigen und dem stromabwärtigen Verteiler eingeschaltet sind, und/oder durch Einstellen des Druckes der Fluidtrennanordnung und/oder durch Einstellen der Ventile zum Umleiten der Schachtausträge zu einem oder mehreren Verteilern, welche die Förderung vermischen oder die vermischte Förderung zu einem oder mehrerer Fördertrenneinrichtungen leiten, und/oder durch Einstellen der Geschwindigkeit eines Kompressors in einer Auslaßleitung der Fluidtrennanordnung.
- 40 10. Verfahren nach einem der Ansprüche 1-9, bei welchem die erforderlichen Einstellungen, die vorhergesagt sind, um Optimierungsziele zu erreichen, automatisch an die Schächte und das Fördersystem, gegebenenfalls nach der Validierung durch einen menschlichen Betreiber, übertragen werden.
- 45 11. Verfahren nach einem der Ansprüche 1-10, bei welchem eine oder mehrere der Schätzungs- und/oder Vorhersagemodelle gegebenenfalls teilweise oder zur Gänze aus theoretischen und/oder empirisch physikalischen und/oder mechanischen und/oder chemischen Merkmalen der Schächte und/oder des Fördersystems erzeugt werden können.
- 50 12. Verfahren nach einem der Ansprüche 1-11, bei welchem das Optimierungsziel in Reaktion auf und/oder in Erwartung der Änderungen der Förderanforderungen und/oder Kosten und/oder Erträge und/oder Produktionsinfrastruktur und/oder des Status der Schächte und/oder des Status der Förderanlagen eingestellt wird; und gegebenenfalls gefolgt von der Durchführung des Optimierungsverfahrens, dessen Ergebnisse implementiert und/oder zur Analyse und zur Planung und/oder Aufzeichnung weiterer Aktionen verwendet werden.

13. Verfahren nach einem der Ansprüche 1-12, bei welchem das Optimierungsziel durch allfällige Mittel zum temporären Stillsetzen der Förderung in einem oder mehreren Schächten des Schachtclusters oder durch Initiierung der Förderung von Schächten des Schachtclusters, die ursprünglich nicht in Förderung waren, erreicht wird.

14. Verfahren nach den Ansprüchen 2 und 3, bei welchen eines oder mehrere der Schätz- und/oder Vorhersagemodelle gegebenenfalls mit theoretischen und/oder empirischen physikalischen und/oder mechanischen und/oder chemischen Merkmalen der Schächte und/oder des Fördersystems verglichen und/oder ausgewertet werden; zum Zwecke der Überprüfung und/oder Diagnose und/oder Verbesserung der Modelle und/oder zur Analyse, die zu längerem Zeithorizontfördermanagement und Optimierungsaktivitäten führen.

15. Verfahren nach den Ansprüchen 1-13, bei welchen einer oder mehrere der Schächte aus dem Cluster von Schächten periodisch oder intermittierend betrieben wird, oder von Zeit zu Zeit betrieben wird, und die Förderung oder assoziierte Mengen, die optimiert werden sollen und gegebenenfalls beschränkt sind, ausgewertet werden, beispielsweise als Durchschnitt ausgewertet werden, über feststehende Zeitspannen, die größer als dieses Merkmal des periodischen oder intermittierenden Betriebes sind.

16. Verfahren nach Anspruch 15, bei welchem einer oder mehrere der Schächte aus dem Cluster von Schächten periodisch oder intermittierend betrieben wird, oder von Zeit zu Zeit betrieben wird, und die Betriebsdauer als Teil einer feststehenden Zeitspanne als manipulierte Variable für den Schacht genommen wird.

17. Verfahren nach einem der Ansprüche 1-13, bei welchem das Verfahren zusätzlich zu einem Optimierungsziel angewendet wird, das an den Schächten des Schachtclusters mit zwei oder mehr unterirdischen Einstromzonen definiert ist, in welchem Fall die "Zonenförderung-Schätzmodelle" und die Zonenförderungs-Vorhersagemodelle" zusätzlich zu den "Schachtförderungs-Schätzmodellen" und "Schachtförderungs-Vorhersagemodellen" erzeugt werden.

18. Verfahren nach Anspruch 1, bei welchem die Schachtfördervariablen, wie Druck und/oder Fluiddurchflußmerkmale der einzelnen Schachtaustragströme, eine oder mehrere der folgenden Variablen umfassen: den Schachtrohrkopfdruck, den Schachtströmungsleitungsdruck, die Schachtrohrkopftemperatur, die Schachtströmungsleitungstemperatur, Differentialdrücke über das Schachtförderungs-Drosselventil, Differentialdrücke über Differenzialerzeuger, einschließlich eines Nassgas-Venturi, an der Schachtströmungsleitung, Durchflußmesser, die für eine Einphasenströmung nominal geeignet sind, aber die geeignet sind, um einen Input für die Schachtschätzmodelle zu liefern, selbst wenn der Schacht ein Mehrphasen-Strömungsschacht ist, die Öffnungs- oder Schließposition des Schachtdrosselventils, den Öffnungsstatus oder die Position irgendwelcher Mittel zum reversiblen und kontrollierten Schließen und Öffnen des Schachtes, die Schachtliftgas-Einspritzrate, die Schachtdüsenpumpen-Hydraulikfluid-Einspritzrate, den Schachtförderauskleidungsdruck, die elektrische Schachttauchpumpengeschwindigkeit, den Schachttauchpumpen-Eingangsdruk, den Schachtbohrloch-Ausgangsdruck, den Schachttauchpumpen-Bohrloch-Venturi-Differentialdruck, den Schachtbohrlochpumpen-Energieverbrauch, den Schachttauchpumpenmotor-Phasenstrom, den Schachtpumpenmotor-Energieeintrag, die Schachtpumpenmotorgeschwindigkeit, den Schachtpumpenmotorhub, die Schachtpumpenmotor-Ladezelle, die Position des Pumpengetriebeschafes, die Schachtpumpenstangen-Differentialgeschwindigkeit / den Motor/Getriebekastenschlupf, den Schachtbohrlochdruck, den Schachtbohrloch-Ringdruck, die Schachtbohrloch- oder Ringdrucktemperatur, oder verschiedene Ableitungen derselben, die von verteilten Temperatursensoren gemessen werden, das Schachtbohrloch-Steuerventil-Öffnungsintervall, die Amplitude einer Auswahl von Tonfrequenzen aus einem oder mehreren Tonsensoren, die in der Schachtströmungsleitung montiert sind, die Fortpflanzungsverzögerung der zugehörigen Tonmuster bei einer Auswahl von Frequenzen aus zwei oder mehr Sensoren, die in stromaufwärtiger oder stromabwärtiger Richtung an einer Schachtströmungsleitung montiert sind.

Revendications

1. Procédé d'optimisation de la production d'un ensemble de puits, dont des courants effluents sont mêlés et séparés dans un ensemble de séparation de fluides en courants au moins partiellement séparés de pétrole brut, de gaz et/ou d'autres fluides, le procédé comprenant les étapes consistant à :

- a) effectuer un test sur chacun des puits, au cours duquel la production du puits testé est modifiée et une ou plusieurs variables de production de puits individuels est ou sont contrôlées ;
- b) tirer de données (60) obtenues par les tests sur les puits un modèle d'évaluation (61) pour chaque puits se

référant à la variation du motif d'écoulement d'effluents produits par le puits testé et des variables de production de puits contrôlées ;

c) amener l'ensemble de puits en production mixte normale d'huile et/ou de gaz ;

d) contrôler au cours de l'étape c) un motif d'écoulement de fluides dynamiques des courants au moins partiellement séparés de pétrole brut, de gaz et/ou d'autres fluides au moyen de débitmètres aménagés dans les courants au moins partiellement séparés de pétrole brut, de gaz et/ou d'autres fluides en aval de l'ensemble de séparation de fluides ;

e) contrôler au cours de l'étape c) une ou plusieurs variables de production de puits se rapportant à des caractéristiques des courants d'écoulement multiphase produits par les puits individuels ;

f) évaluer de manière répétée un motif d'écoulement de fluides dynamiques mixtes de l'ensemble de puits sur la base des modèles d'évaluation (61) selon l'étape b) et des variables de production contrôlées selon l'étape e) ;

g) effectuer un processus de réconciliation dynamique, dans lequel, au cours d'une période de réconciliation choisie :

- on suppose que le motif d'écoulement de fluides dynamiques mixtes évalué selon l'étape f) est une accumulation desdits modèles d'évaluation de production des puits individuels qui sont multipliés par des coefficients pondéraux inconnus ;

- les coefficients pondéraux inconnus sont évalués en faisant varier de manière itérative chaque coefficient pondéral jusqu'à ce que le motif d'écoulement de fluides dynamiques mixtes évalué corresponde sensiblement au motif d'écoulement de fluides dynamiques contrôlé ; et

- de meilleures évaluations de l'écoulement de production sont fournies pour la période de réconciliation choisie et l'usage de facteurs de réconciliation de puits individuels avec les modèles d'évaluation pour évaluer la production de chaque puits pendant une période de réconciliation suivante ;

h) définir une cible d'optimisation opérationnelle constituée d'une cible à optimiser concernant la production d'un ou plusieurs puits et/ou de l'ensemble des puits ;

i) ajuster la production d'effluents de l'ensemble de puits de sorte que la cible d'optimisation soit approchée ; et

j) les étapes g et i sont répétées de temps à autre.

2. Procédé selon la revendication 1, comprenant par ailleurs les étapes consistant à :

- identifier pour au moins un des puits de l'ensemble une ou plusieurs variables numériques de production de puits manipulées qui peuvent être manipulées directement pour faire varier la production du puits et, ensuite, tirer de données obtenues par les tests des puits et/au cours d'une production mixte normale, et/ou du modèle d'évaluation, un modèle de prédiction rapportant les variables manipulées des puits à la variation de l'écoulement ou du motif d'écoulement et/ou d'autres caractéristiques des effluents produits dans les puits, dans lequel les puits éventuels sans variables de production de puits manipulées identifiées auront des modèles de prédiction qui sont des nombres constants égaux à une production théorique évaluée des puits ;

- sommer les modèles de prédiction de tous les puits de l'ensemble de puits pour fournir un modèle de prédiction de production mixte global ;

- ajuster la production des effluents de puits au moyen des variables manipulées des puits, telles qu'elles sont guidées par les modèles de prédiction de puits individuels et le modèle de prédiction de production mixte globale pour obtenir ladite cible d'optimisation.

3. Procédé selon la revendication 2, comprenant par ailleurs les étapes consistant à :

- mesurer une ou plusieurs pressions d'interaction, telles qu'une pression dans un ou plusieurs collecteurs de production dans des conduites d'écoulement de puits qui sont raccordées aux têtes des puits de l'ensemble de puits, dans lesquels collecteurs l'écoulement provenant d'une pluralité de conduites d'écoulement de puits est mélangé, la variation de la pression d'interaction, lorsque les productions totales des puits varient, indiquant et liant les interactions entre courants d'effluents des divers puits ;

- obtenir des données dynamiques rapportant les variations de la ou des pressions d'interaction aux variables mesurées des puits, à partir d'une production mixte normale et/ou au cours de périodes de dérèglement de la production et/ou en effectuant une série de tests d'interaction de puits, au cours desquels la pression d'interaction est modifiée ;

- obtenir à partir de données dynamiques rapportant les variations de la ou des pressions d'interaction aux variables mesurées, des modèles de prédiction de puits rapportant les variations de variable(s) manipulée(s) des puits et la ou les pressions d'interaction à la production des puits ;

- obtenir des données dynamiques rapportant les variations d'une ou plusieurs pressions d'interaction à la production mixte totale, à partir de périodes de production mixte normale et/ou au cours de périodes de dérèglement de production et/ou en effectuant une série de tests au cours desquels la pression d'interaction est modifiée, et ensuite, un ou plusieurs modèles d'interaction de collecteurs rapportant la variation d'une ou plusieurs pressions d'interaction aux écoulements de production totale mixte s'écoulant à travers les collecteurs ;
- combiner les modèles de prédiction des puits avec les modèles de pression d'interaction pour obtenir un modèle de prédiction de production mixte global.

4. Procédé selon les revendications 2 et 3, dans lequel le procédé comprend par ailleurs la répétition périodique du procédé d'optimisation en alignant les modèles de prédiction avec les écoulements courants de sorte que les modèles de prédiction alignés reflètent les écoulements courants tels qu'ils sont évalués par le procédé de réconciliation dynamique.

5. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel la cible d'optimisation est une fonction de revenu rapportant la production de puits accumulée ou moyenne combinée et/ou individuelle au revenu monétaire réel net ou brut ou incrémental, incluant éventuellement des coûts de production associés.

6. Procédé selon la revendication 5, dans lequel la cible d'optimisation doit être réalisée tout en répondant à des contraintes de production, qui sont constituées de limites sur les variables manipulées, et/ou à des productions de puits individuels et/ou à des quantités de production de puits, notamment des mesures, et/ou à celles de groupes de puits et/ou sur une ou plusieurs pressions d'interaction et/ou sur la production totale mixte de l'ensemble de puits.

7. Procédé selon la revendication 5 ou 6, comprenant par ailleurs l'étape de réalisation d'une optimisation en utilisant l'un quelconque d'une pluralité d'algorithmes d'optimisation numériques sur les variables manipulées sur la base de la cible d'optimisation opérationnelle, éventuellement avec des contraintes, et des modèles de prédiction de production mixte et/ou globale des puits pour donner un ensemble de variables optimisées manipulées qui assure la cible d'optimisation opérationnelle.

8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel la production d'effluents des puits est modifiée en ajustant l'ouverture d'une soupape d'étranglement de production sur la tête des puits ou dans les conduites d'écoulement raccordées aux puits, ou d'une soupape de commande d'écoulement dans un système d'injection de gaz sustentateur des puits ou par d'autres moyens de stimulation ou de restriction de la production des puits, notamment tout moyen réversible et contrôlée de fermeture et d'ouverture d'un puits, un point de consigne d'une boucle de commande dans le puits avec la soupape d'étranglement de production comme moyen d'actionnement, un point de consigne d'une boucle de commande sur le taux d'injection ou la pression de gaz sustentateur, une durée d'arrêt d'injection de gaz sustentateur des puits, une injection de gaz sustentateur des puits sur la durée, un taux d'injection de gaz sustentateur de puits, un point de consigne d'une boucle de commande sur la conduite d'injection de fluide hydraulique dans les pompes d'injection de puits, une vitesse de la pompe submersible électrique des puits (ESP), une vitesse de moteur de pompes à tiges de puits, une durée d'arrêt de pompes à tiges de puits et/ou une ouverture de la soupape de commande d'intervalle de forages de puits.

9. Procédé selon l'une quelconque des revendications 1 à 8, dans lequel la production des effluents des puits est modifiée en ajustant une ou plusieurs pressions d'interaction du système de production au moyen d'un ré-acheminement de la production de puits via des conduites de collecteurs de production parallèles qui sont raccordées entre collecteurs amont et aval et/ou en ajustant la pression de l'ensemble de séparation de fluides et/ou en ajustant les soupapes pour l'acheminement des effluents de puits à un ou plusieurs collecteurs qui mélangent la production ou qui acheminent la production mixte à un ou plusieurs séparateurs de production, et/ou en ajustant la vitesse d'un compresseur dans une conduite de sortie de l'ensemble de séparation de fluides.

10. Procédé selon les revendications 1 à 9, dans lequel les ajustements requis prédits pour obtenir les cibles d'optimisation sont automatiquement transmis aux puits et au système de production, éventuellement, après validation par un opérateur humain.

11. Procédé selon l'une quelconque des revendications 1 à 10, dans lequel un ou plusieurs des modèles d'évaluation et/ou de prédiction peut ou peuvent éventuellement être générés en partie ou en totalité à partir d'une caractérisation physique et/ou mécanique et/ou chimique théorique et/ou empirique des puits et/ou du système de production.

12. Procédé selon l'une quelconque des revendications 1 à 11, dans lequel la cible d'optimisation est ajustée en réaction

et/ou en anticipation de variations des exigences de production et/ou des coûts et/ou des revenus et/ou de l'infrastructure de production et/ou de l'état des puits et/ou de l'état des installations de production ; le tout étant éventuellement suivi par la réalisation du processus d'optimisation, dont les résultats sont mis en oeuvre et/ou utilisés pour l'analyse et la planification et/ou enregistrés pour une action future.

5 13. Procédé selon l'une quelconque des revendications 1 à 12, dans lequel la cible d'optimisation est obtenue par des moyens facultatifs de fermeture temporaire de la production dans un ou plusieurs puits de l'ensemble de puits, ou par l'initiation de la production de puits de l'ensemble de puits qui n'étaient initialement pas en production.

10 14. Procédé selon les revendications 2 et 3, dans lequel un ou plusieurs des modèles d'évaluation et/ou de prédiction peut ou peuvent éventuellement être comparés et/ou évalués vis-à-vis de la caractérisation physique et/ou mécanique et/ou chimique théorique et/ou empirique des puits et/ou du système de production ; aux fins de dépanner et/ou de diagnostiquer et/ou d'améliorer les modèles et/ou pour l'analyse menant à des activités de gestion de production et d'optimisation à plus long terme.

15 15. Procédé selon les revendications 1 à 13, dans lequel un ou plusieurs des puits de l'ensemble de puits est ou sont exploités de manière périodique ou intermittente ou sont exploités de temps à autre, et la production de quantités associées à optimiser et éventuellement contraintes est évaluée, par exemple mises en moyenne, sur des périodes de temps fixes plus grandes que la caractéristique de l'exploitation périodique ou intermittente.

20 16. Procédé selon la revendication 15, dans lequel un ou plusieurs des puits de l'ensemble de puits est ou sont exploités périodiquement ou de manière intermittente ou sont exploités de temps à autre et la durée de leur exploitation, en proportion d'une période de temps fixe, est prise comme variable manipulée pour le puits.

25 17. Procédé selon l'une quelconque des revendication 1 à 13, dans lequel le procédé est appliqué en outre à une cible d'optimisation définie sur les puits de l'ensemble de puits avec deux zones d'influx de sous-surfaces ou plus, auquel cas des « modèles d'évaluation de production de zones » et des « modèles de prédiction de production de zones » sont générés en plus des « modèles d'évaluation de production de puits » et des « modèles de prédiction de production de puits ».

30 18. Procédé selon la revendication 1, dans lequel les variables de production de puits, telles que la pression et/ou d'autres caractéristiques d'écoulement de fluides des courants d'effluents de puits individuels comprennent une ou plusieurs des variables suivantes : pression de tête des canalisations de puits, pression de canalisation de puits, température de tête des canalisations de puits, température de canalisations de puits, pressions différentielles aux bornes de la soupape d'étranglement de production de puits, pressions différentielles aux bornes du producteur de pression différentielle éventuel, notamment un venturi à gaz humide, sur la conduite d'écoulement de puits, des débitmètres, convenant théoriquement uniquement à un écoulement en phase unique, qui conviennent pour être utilisés afin de fournir une entrée aux modèles d'évaluation de puits, même si le puits a un écoulement multiphase, un état ou une position d'ouverture de la soupape d'étranglement de production, un état ou une position d'ouverture d'un moyen quelconque de fermeture et d'ouverture réversible et contrôlée de puits, taux d'injection de gaz sustentateur de puits, taux d'injection de fluide hydraulique de pompe à jet de puits, pression de cuvelage de production de puits, vitesse de pompe submersible électrique (ESP) de puits, pression d'admission de pompe ESP de puits, pression de décharge de pompe de forage ESP de puits, pression différentielle venturi de forages ESP de puits, consommation d'énergie ESP de puits, courant de phase motrice ESP de puits, entrée d'énergie de moteur de pompe à tige de puits, vitesse de moteur de pompe de tige de puits, déplacement de course de pompe à tige de puits, cellule de charge de pompe à tige de puits, position de l'arbre de la boîte de vitesse du mâât de charge, vitesse différentielle de pompe à tige de puits/moteur/glisement de la boîte de vitesse, pression de cuvelage de forages de puits, pression d'anneau de forages de puits, température de cuvelage ou d'anneau de forages de puits ou leurs diverses dérivations contrôlées par des capteurs de température distribués, ouverture de soupape de commande à intervalles de forages de puits, amplitude d'une sélection de fréquences sonores provenant d'un ou plusieurs capteurs sonores montés sur une canalisation de puits, retard de propagation de motifs sonores corrélés pour une sélection de fréquence provenant de deux ou plusieurs capteurs de son montés dans la direction amont-aval sur une canalisation de puits.

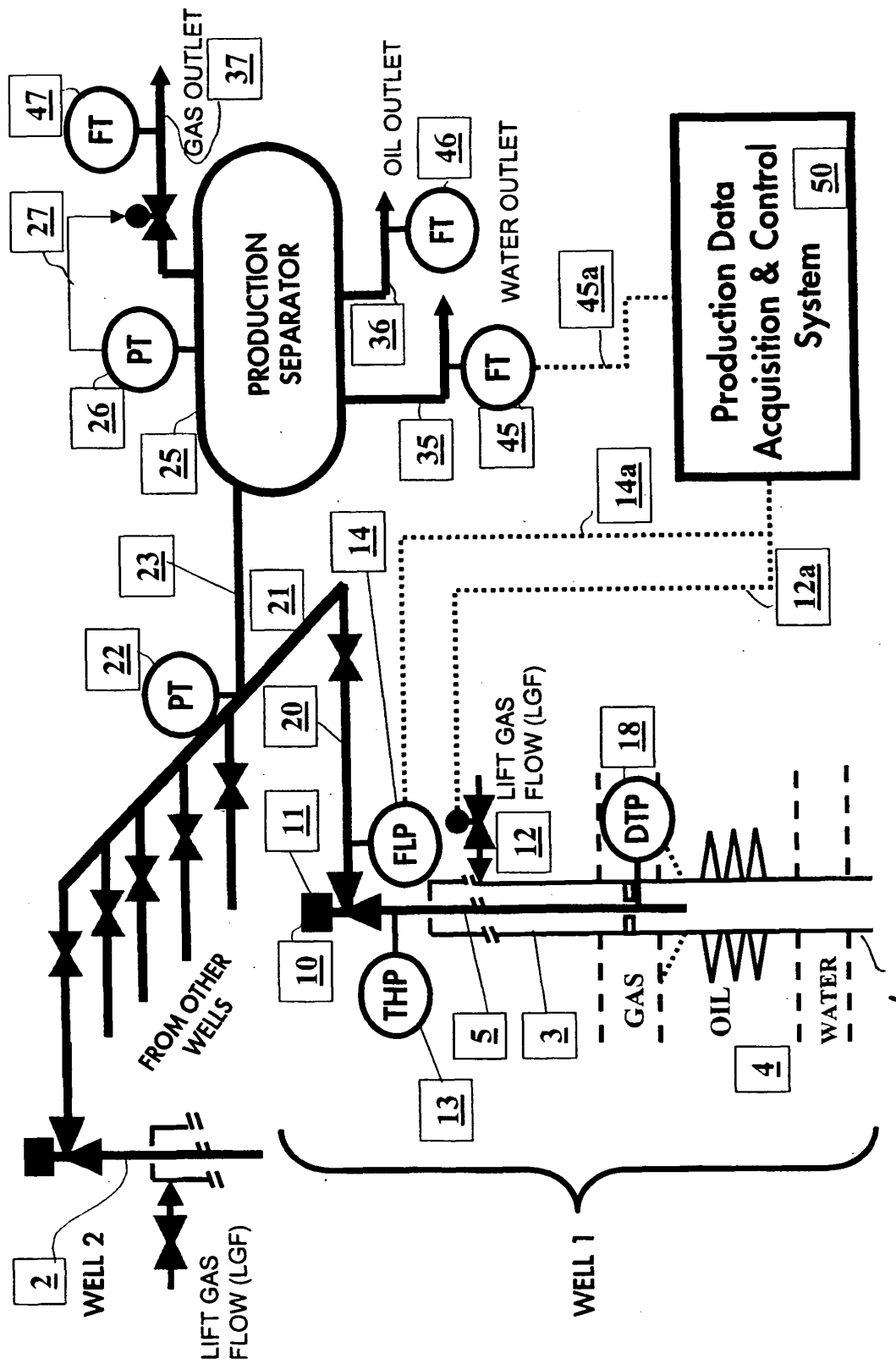


Fig 1: Production from a Cluster of Wells to a Production Separator

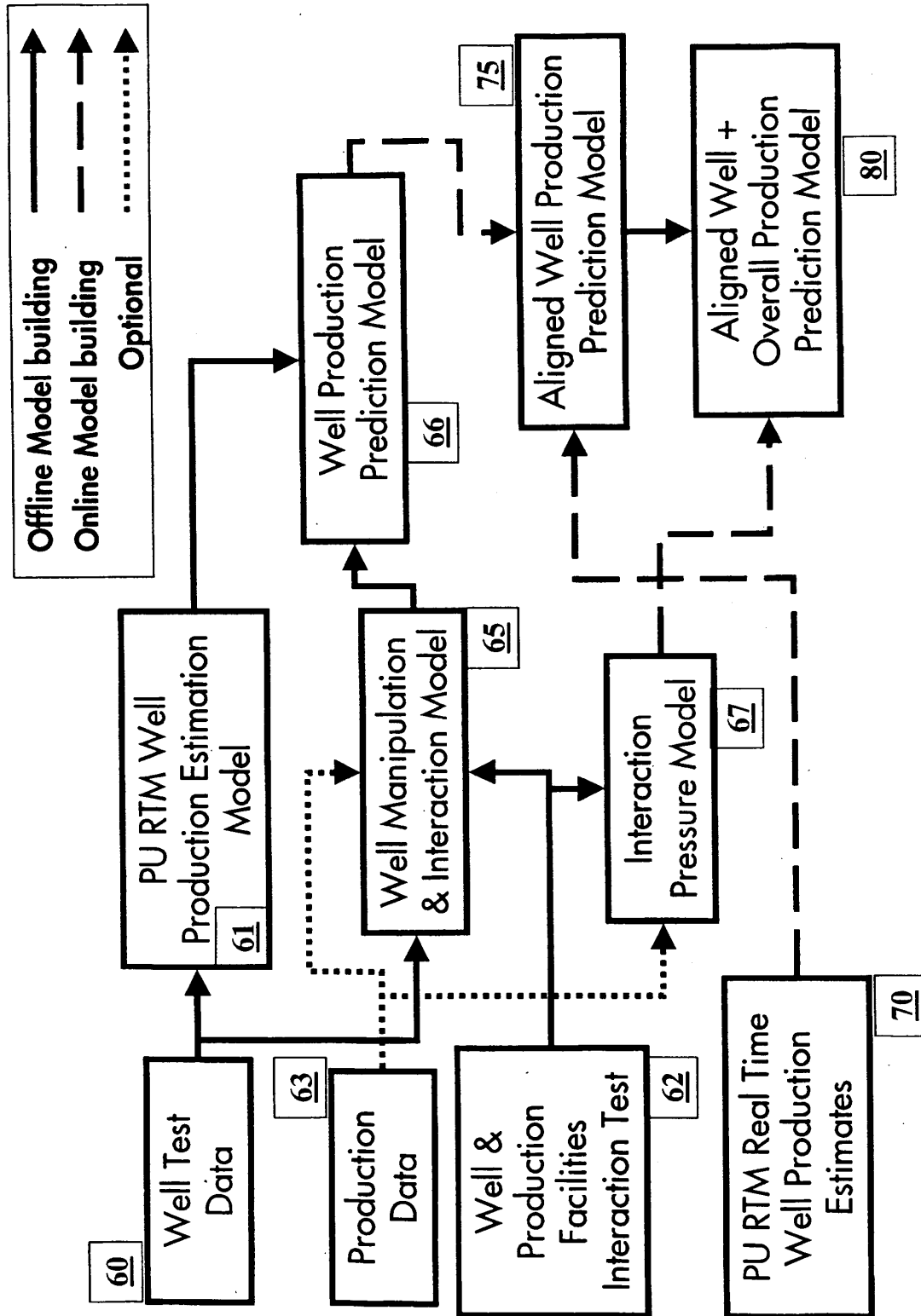


Fig 2: Setup of Well + Overall Production Prediction Models

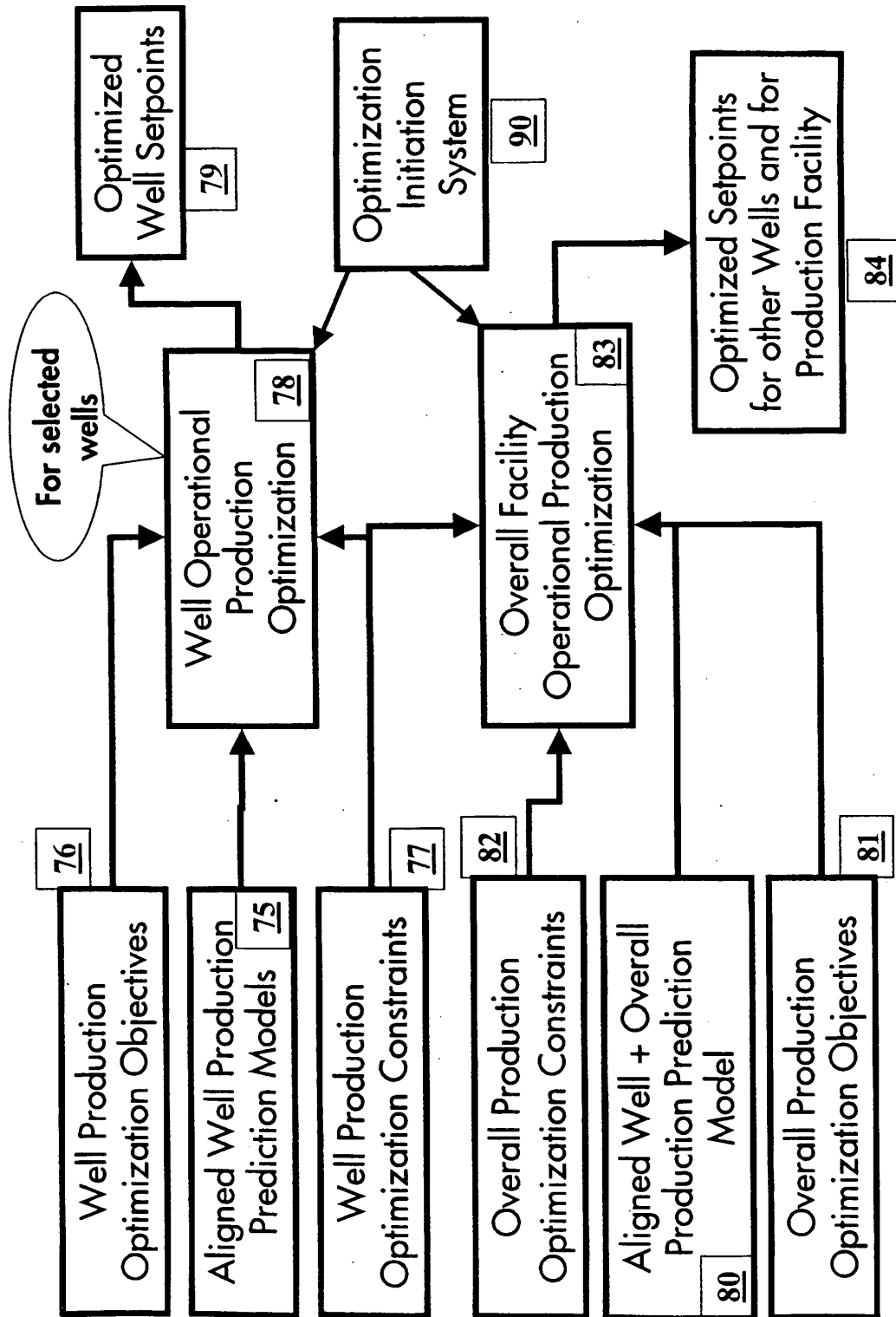


Fig 3: Procedure for Optimization

REFERENCES CITED IN THE DESCRIPTION

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