

Practical Approach of Smart Wells Reservoir Simulation

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Abstract

One of the main goal of a reservoir engineering or simulation study is to do an almost accurately prediction of future oil and gas production. In the last years smart or intelligent wells are commonly used to maximize the well production and consequently to increase the oil or gas production of field. The intelligent completions is usual expensive and must to have an economical justification comparing with classical completion of wells. Therefore, the smart completion has to be included into dynamical simulation model and to run the simulation model with different configuration of completions in order to find out the optimum..

This paper presents some practical aspects of smart well completion integration into reservoir simulation, especially when simulation study uses two widespread commercial simulators like Eclipse (Schlumberger) and Nexus (Halliburton).

Key words: *simulation, smart completion, interval control valves, commingled production*

Introduction

In the last years the smart or intelligent completion of wells are widely used to maximize the fluid production and consequently to improve the oil and gas production of field.

A smart (intelligent) well [1,2] is a well completion which allows, without physical intervention, to achieve two major goals:

- selective production control of different reservoir zones (levels);
- ability to collect, transmit, analyze production and reservoir data and to allow the deliberately or automatic feed-back actions.

The short definition of smart wells reveals the two major improvements done by uses of smart well completion: improve well management (well production optimization) and improve reservoir management. Improve the well management was the initial goal of smart wells and consequently they primarily were equipped with down-hole gauges for pressure, temperature, fluid flow measurements and systems for real-time monitoring and control. This important improvement is not the topic of this paper and will not be detailed discussed here. The second important improvement is related to the increasing the well productivity by perforation of multiple reservoir units. Some countries legislation not allows simultaneously production on

same tubing string of different reservoir units having different pressure regime (commingled wells). Hence, the well has to include complex completion involving multiple tubing strings and production packers or the classic bottom-up strategy of completion, whether the smart well technology is not used. The smart well enable the commingled well production from different reservoir units or levels avoiding the cross-flow caused by different reservoir pressures using the flow controls that enable to decreasing production from regions with high gas-oil ratio or/and water cut.

The "smart" inflow control of different reservoir units is realized by two kinds of down-hole flow control as: Interval Control Valves (ICVs) or Inflow Control Devices (ICDs)[3]. Also, reference [3] presents a detailed description and comparison between ICVs and ICDs. The inflow control of ICVs is realized by down-hole valves (chokes) controlled remotely (from surface). Down-hole flow control valves may be binary (on-off), chocking with limited discrete settings or infinitely variable chocking.

For infinitely variable chocking or multiple discrete chocking the control trim profile can be standardized (equal percentage or linear)[6].

The ICDs are not active devices, they can not be operated remotely and consist usually on a restriction of different design including nozzles, orifices, tubes and helical or labyrinth channels [7]. The size of the restriction is set prior of the time of completion and other adjustments or changes can be done only after work-over intervention.

The inflow control devices (ICVs or ICDs) introduces extra pressure loses[5], causing the total pressure drawdown for a given rate, but the explanation for a small increasing of well productivity is due to the formation damage cleaning effect that allow to remove debris from drilling mud and completion fluids for damaged area.

Numerical Model of Smart Well Completions

Integration of smart well completion into numerical simulators is based on the multi-segment well concept[8]. The multi-segment well model initially designed for horizontal and multi-lateral branch well can provide a comprehensive description of fluid flow into wellbore by including sophisticated multiphase flow models for each well segment. The wellbore is divided into an arbitrary number of segments[8], each segment can be connected with one or more grid blocks and additional segments have to be used for branch junction and/or for length not perforated.

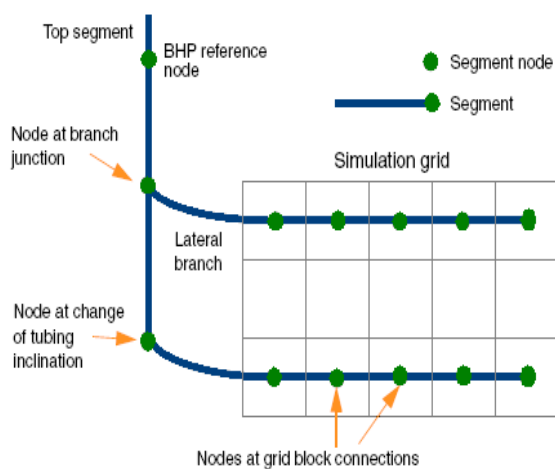


Fig. 1. Segments structure scheme for a multilateral well [8].

Each segment has a node and a flow-path, each node is positioned at the far end of segment at a specific depth has a pressure computed by well model. Each flow-path has a specified length, diameter, roughness, area and volume used for wellbore storage calculation and for pressure loss and fluid rates calculations [9].

From practical point of view the well segment nodes can be placed at:

- branch junction where two or more segments may be connected;
- grid block connections -any number of grid blocks can be connected to a segment node, the greatest accuracy

is obtained when is allocated one node per grid but with computational cost;

- intermediate points along wellbore path -tubing/casing properties or inclination changing;
- intermediate points to model different well bottom- hole devices: chokes, inflow control devices, down hole separators, down-hole pumps.

The multi-segment wells model require significantly more iterations to converge than classical well model therefore the optimum number of nodes(segments) must be obtained as a compromise between convergence speed and accuracy.

Even seems a perfect choice for some commercial simulators it is not advantageous to model all wellbore in segment till wellhead. In this case the pressure in the top of segments registered as bottom- hole pressure is in fact tubing head pressure. Therefore, for majority of simulators is recommended that the topmost segment to be placed close to the formation above all completed intervals to correspond to well bottom hole reference depth and the topmost segment pressure corresponds to bottom-hole pressure [8].

The pressure drop across each segment calculation for multi-segment wells can be performed by following available methods (for detailed information about pressure drop calculation see Holmes et al. [8]):

- homogeneous flow model assuming no slip between fluid phases(all phases flow with the same velocity), the hydrostatic terms is simply a phase weighted average of phase densities of fluid mixture within the segment;
- simple "drift flux" model allowing gas-liquid slip;
- interpolating the pressure drop pre- calculated tables expressing the pressure loss data as a function of outlet pressure, water fraction, gas fraction and flow rate. The tables are similar with Vertical Flow Performance Tables used for calculating tubing head pressure for classical well model;
- specific flow control devices models - subcritical flow through a valve with a specific cross- section area, labyrinth flow control devices or spiral constriction of inflow control devices;
- specific built-in pressure drop complex algorithms- multiphase flow algorithms such as Hagedorn-Brown, Beggs- Brill already coded inside the simulators.

Interpolating the pre- calculated tables method (VFP table) is the most flexible, faster and

accurate method for pressure loss calculation because can include practically any other multiphase flow model (Hagedorn-Brown, Beggs- Brill, Hasan- Kabir, Govier- Aziz, etc.) and also can model any type of flow control device once the device characteristics can be expressed in form of hydraulics table.

The smart well completion can be included in a multi-segment well model by setting the well segments corresponding to well architecture and to inflow devices.

The surface adjustable interval control valves which assure the isolation of each reservoir are modeled by specific well segments. The fluid enters from

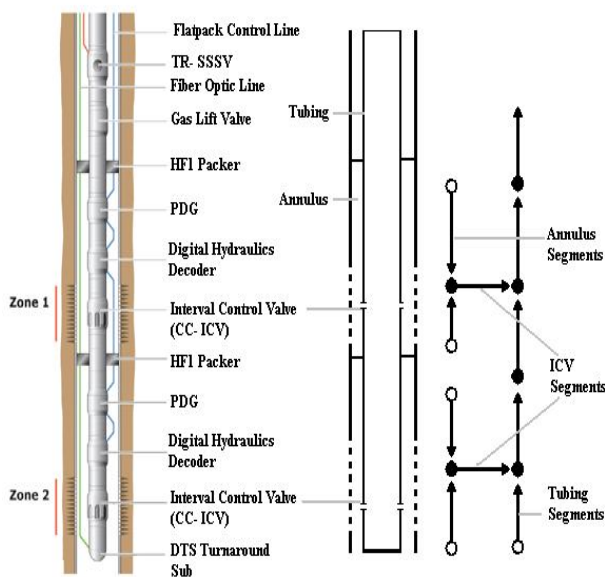


Fig.2. Smart well completion schematic representation with interval control valves.

reservoir into well annulus space and then flows through interval control valves into well production tubing. Fig.2 shows schematically a smart well completion for simultaneous production of two reservoir zones and the multi- segment network model associated with well completion.

The inflow control devices are used primarily for production equalizer and they were positioned along the horizontal well to balance and control the production inflow along the entire well-bore. The ICD is constructed in sections of 36 feet, in each section the inflow from reservoir to tubing is forced to enter to a labyrinth with a small channel diameter[7], [8]. To increase the flow resistance the channel length in each labyrinth can be extended in stages.

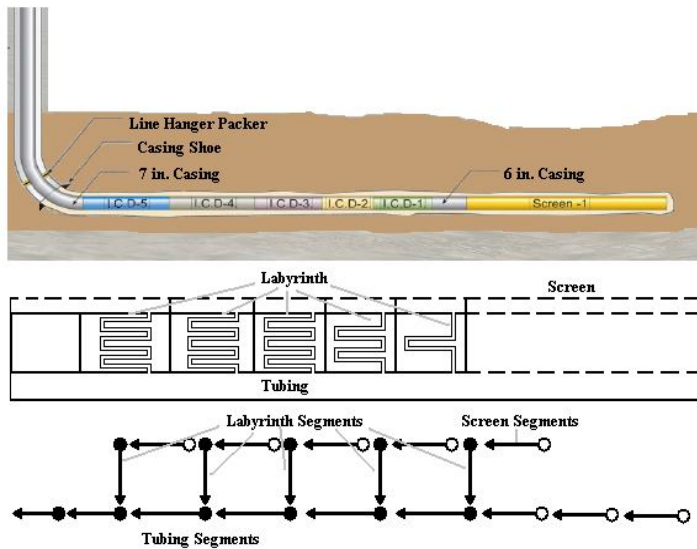


Fig. 3 Smart well completion schematic representation with Inflow Control Devices.

The ICD can be integrated in reservoir simulation well mode adding specific segments to wellbore path, segments that may characterize accurately the flow inside the labyrinth path. **Eroare! Fără sursă de referință.** shows a smart well completion (Well M-22 in Troll Field from Lorenz et al. [7]), the simplified completion scheme showing the fluid flow path and the associated well segments network for simulation.

The schematic diagram assumes a horizontal well where the inflow control devices are labyrinth type and there are 8 nodes connected to the grid block.

Integration of Smart Well Description into Commercial Simulators

The majority of the reservoir simulators available on the market have options for advanced well modeling: well segments and smart wells completion. This paper presents only the comparative implementation in ECLIPSE (Schlumberger) and NEXUS-VIP (Halliburton).

In ECLIPSE reservoir simulator the well segments are introduced in RUNSPEC section by keyword WSEGDIMS that specify the number of multi segment wells, the maximum number of segments per well and the maximum number of branches including main stem. The multi-segment well is declared in SCHEDULE section as a classical well by WELSPECS and COMPDAT keywords. The well is defined as multi- segment well using the keywords WELSEGS (WELSEGL for local grid refinement) and COMPSEGS (COMPSEGL for local grid refinement) keywords. WELSEGS can be used only for a well at a time, so, if the reservoir has more than one multi- segment well it must be specified separately for each multi- segment well. The first record of the WELSEGS keyword defines the top segment (where the BHP is equal to the segment pressure) the other records define the properties for other segments numbered in free order from 2 to maximum number of segments entered in WSEGDIMS. It is not mandatory that neighbor segments to have successive numbers. The COMPSEGS keyword defines the association between grid block completions and well segments. Eclipse automatically allocates each grid block connection to the segment whose node lies nearest to the center of connection. The flow is modeled as entering the well segment at its node. It is possible

to define the pressure and fluid saturations in each segment using the WSEGINIT keyword. Also it is possible to change the flow model specified by WELSEGS keyword using the WSEGFMOD keyword and/or the model definition default parameters by WSEGDFMD keyword or individual parameters with WSEGDFPA keyword. The interfacial tensions required by drift flux flow model are entered using the STOG, STOW, STWG keywords or can be calculated from built-in correlations. Using the keyword WSEG TABL can be specified the Vertical Flow Performance (VFP) table for pressure drops calculations. Down hole general valve can be entered by WSEGVALV and flow trim valves can be entered by WSEGFLIM. Also the inflow control devices like labyrinth or spiral are built-in correlations for pressure drop calculation if are used keywords WSEGLABY respectively WSEGSICD. More detailed information about the ECLIPSE keywords used for well segments simulation can be found in [9], [10].

Nexus treats the well as part of surface network and represents the wells with nodes and connection between nodes and perforations which connect nodes to grid- block [11]. For classical wells the surface network representation is automatically generated from the WELLSPEC and well connection data defined by WELLS keywords in RECURRENT_FILES section. Usually, each entry in WELLSPEC table represents a perforation or a connection from the specified grid cell to a network node. The user can define nodes in wellbore using the WELLNODE keyword to connect the nodes appropriately for desired wellbore path. This is the only way for specifying the intelligent well completion consisting in controllable connections (where constraints can be specified) or flow devices like valves, chokes, inflow control devices.

By defaults the well connections defined in WELLS table connects the bottom hole node to a sink/injection source not requiring to be connected to surface network. More complex runs require to connect the well to surface network or connection between nodes and is necessary to use the NODECON and optionally NODES tables. NODECON tables are used together WELLNODE for specifying the intelligent well completion (valves and chokes). More information about keywords in Nexus can be found in [11,12].

The next section will give suggestive examples of using the Eclipse and Nexus keywords for intelligent completion well simulation.

Case Study

The first case study is a simple case study showing the effective use of keywords for smart well completions. The well is an oil producer located in a simple flat reservoir consisting in two production levels with different pressure regime and different properties.

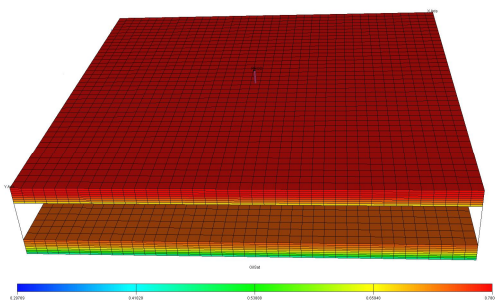


Fig. 4 Initial oil saturation for case study

There are many approaches for defining the segments structure of well. There are two limit cases, first use one segment for each grid block where the well is perforated and the second is to use one segment for each perforated interval (see Fig. 5). Fig. 5 also presents the segments architecture of the two approaches. The most detailed is the first case while the second case assures the minimum of running time per time step.

Specification of well segments and smart well completion for case study in ECLIPSE (Schlumberger) numerical simulator is done taking into account of schema presented in Fig. 5. The smart well segments are defined in SCHEDULE section of input data file using keywords

WELSEGS, COMPSEGS, WSEGVALV as is shown in Fig. 6 for the one segment for each grid cell where the well is perforated approach.

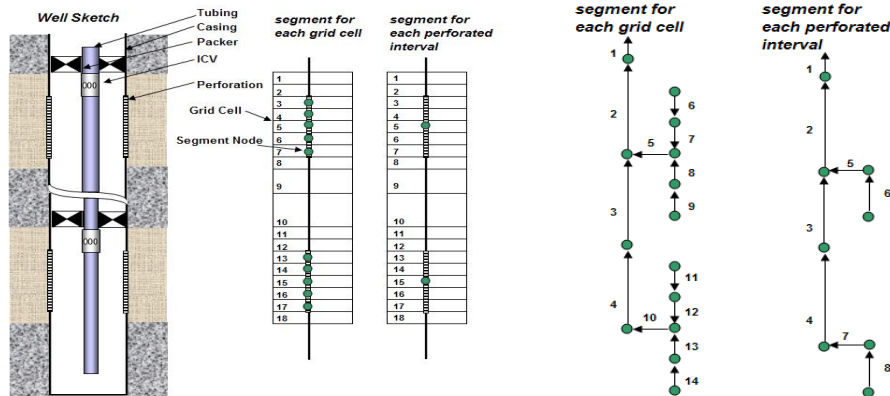


Fig. 5 Smart well completion schematic representation for case study.

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WELSEGS
-- Name Dep Tlen Vol
'PROD' 7000 0 0.87 'INC' 1* 1* 1000 1000 /
-- First Last Branch Outlet Length Depth Diam Ruff Area Vol
-- Seg Seg Num Seg Chang
-- tubing segments
2 4 1 340.0 340.0 0.33 1.E-3 1* 1* /
-- Casing first completion
5 5 2 2 0.3 0.0 0.33 1.E-3 1* 1* /
6 9 2 5 40.0 0.33 1.E-3 1* 1* /
-- Casing second completion
10 10 3 4 0.3 0.0 0.33 1.E-3 1* 1* /
11 14 3 10 40.0 0.33 1.E-3 1* 1* /
/

COMPSEGS
-- Name
'PROD' /
-- I J K Brn Start End Dirn End
-- No Length Penet Range
-- Casing first completion
20 20 3 2 20 1* 'Z' 6 /
-- Casing second completion
20 20 13 3 300 1* 'Z' 16 /
/

WSEGVALV
PROD 5 0.326 0.0001 1* 1* 1* /
PROD 10 0.326 0.0005 1* 1* 1* 1* /
/

! Define the flow section characteristics
WELLBORE
WELL FLOWSECT TYPE METHOD DIAM INNERDIAM ROUGHNESS
PROD 1 PIPE MIXED 8.0 4.0 0.0005 ! casing
PROD 2 PIPE MIXED 8.0 4.0 0.0005 ! casing
PROD 3 PIPE MIXED 3.5 0.0 0.0005 ! tubing
ENDWELLBORE

! Define the additional nodes on wellpath
WELLNODE
WELL NODE MD FLOWSECT CONNECT
PROD PROD-T1 7020 3 YES
PROD PROD-V1 7020 1 NO
PROD PROD-T2 7300 3 YES
PROD PROD-V2 7300 2 NO
ENDWELLNODE

! Define the connection between casing and tubing
NODECON
NAME NODEIN NODEOUT TYPE METHOD
ICV1 PROD-V1 PROD-T1 VALVE 1
ICV2 PROD-V2 PROD-T2 VALVE 1
ENDNODECON

! Define the settings of valves
CONSTRAINTS
ICV1 SETTING 2
ICV2 SETTING 5
ENDCONSTRAINTS
    
```

Fig. 6 Smart well segments definition in ECLIPSE and Nexus Data File.

Smart well segments specification in NEXUS (Halliburton) reservoir simulator software for case study is done in included surface network data file. It uses the WELLBORE WELLNODE, NODECON, CONSTRAINTS as in shown in Fig. 6.

The segment specification is based on the well grid block connection definition in included well data file through the WELLSPEC keyword.

The model built for case study smart well completion was simulated and the results were compared with similar cases that not use the smart well completion like when the well is completed in classical bottom to top strategy (first the deeper level and then the shallower level) and when the well is completed commingled (all the levels simultaneous in production).

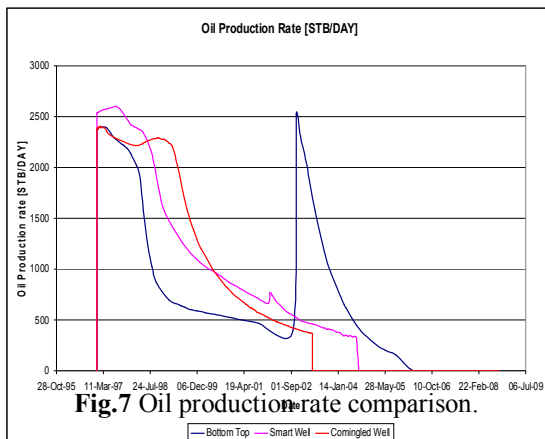


Fig. 7 Oil production rate comparison.

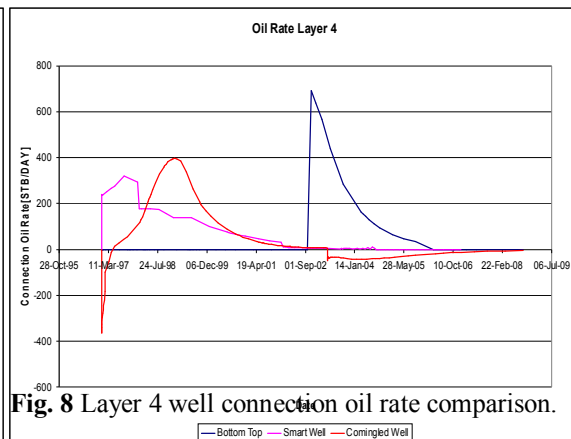


Fig. 8 Layer 4 well connection oil rate comparison.

Even without any optimization of valves constriction area settings can be observed in Figure 7 that smart well completion can have better results than classical completions. Figure 8 displays the comparison between oil rate production of well connection with layer 4 grid cell.

It can be observed in Fig. 8 that for comingled completion because of different pressure regime is happen a cross-flow in well in the first 4 months of production when a part of fluid produced by deeper connection entered in shallower connection. This effect is avoided by the smart well completion where all the production goes through surface network to gathering center.

Figure 9 shows the water-cut comparison between considered completion scenarios where the smart well completion has less water cut than classical comingled completion. The control of water production is another advantage of using smart well completion.

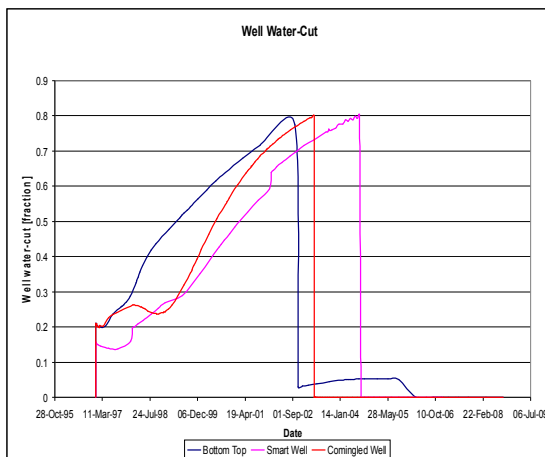


Fig. 9. Water cut comparison

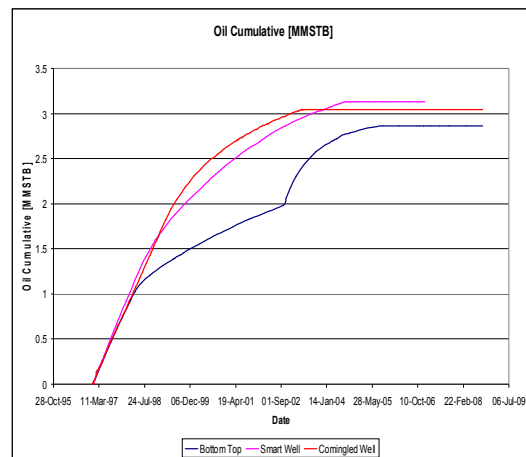


Fig. 10. Oil cumulative

Figure 10 presents the oil cumulative for the different well completions considered. Even without optimization of valves settings it can be observed that the smart well completion provide the better results than the other classical completions.

However, the most important step when smart well simulation is used is to optimize the valve constriction area settings in order to maximize the cumulative of produced oil and to minimize the produced water.

Conclusions

Smart well completion, even if it is more expensive than classical completions, beginning to be very wide used because of it's major advantages. A smart well can contains sensors for flowing bottom hole pressure temperature and rates measurements, flow controls and other down- hole devices like separators, pumps.

The simulation of smart well completion can be realized in commercial simulators available on market using multi-segments well facility which offers the ability to separately define and handle tubing string, case string and different inflow control devices and connections of well with the field model grid.

The case study presented shows that well layers cross- flow can be easy controlled and avoided by smart well completion in order to maximize the well oil production.

References

1. Gao, C., Rajeswaran, T., Nakagawa, E.- *A Literature Review on Smart- Well Technology*, Paper SPE No. 106011-MS, SPE Production and Operation Symposium, Oklahoma, April 2007.
2. Da Silva, J.P.Q.G., Schiozer, D.J.- *Comparison between Smart and Conventional Well Considering Uncertainties*, SPE 121279, SPE/EAGE Europe ACE Amsterdam 8-11 June 2009.
3. Al-Khelaiwi, F.T., Birchenko, V.M, Konopczynski, M.R., Davies, D.R.- *Advanced Wells: A Comprehensive Approach to the Selection between Passive and Active Inflow Control Completions*, IPTC 12145-MS, 2008.
4. Coats, B.K., Fleming, G.C., Watts, J.W., Rame, M., Shiralkar, G.S. - *A Generalized Wellbore and Surface Facility Model, Fully Coupled to a Reservoir Simulator*, Paper SPE No. 79704-MS, 2003.
5. Ho-Jeen Su, Dogru, A. H.- *Modeling of Equalizer Production System and Smart-Well Applications in Full-Field Studies*, Paper SPE No 111288-PA 2009.
6. Konopczynski, M., Ajayi, A.- *Design of Intelligent Well Downhole Valves for Adjustable Flow Control*, Paper SPE No. 90664-MS 2004.
7. Lorenz, M., Ratterman G., Augustine, J.- *Uniform InFlow Completion System Extends Economic Field Life: A Field case study and technology Overview*, Paper SPE 101895, 2006 SPE Annual Conference, San Antonio Texas, USA, 24-27 September 2006.
8. Holmes, J.A., Barkve, T., ASA; Lund, O.- *Application of a Multisegment Well Model to Simulate Flow in Advanced Wells*, Paper SPE 50646-MS 1998.
9. ****Eclipse Technical Description 2007.2*, Schlumberger, pg 535-575.
10. ****Eclipse Reference Manual 2007.2*, Schlumberger, pg 2168-2174.
11. ****Nexus Technical Reference Guide -2008* Landmark Graphics Corporation pg. 141-225.
12. ****Nexus Keyword Document- 2008* Landmark Graphics Corporation pg. 301-368.

Aspecte practice privind simularea sondelor inteligente

Rezumat

Unul dintre obiectivele principale ale studiilor de simulare a zăcămintelor de hidrocarburi este de a face o cât mai exactă prevedere a producției viitoare de țiței și gaze. În ultimii ani sondele inteligente sunt de regulă utilizate în scopul maximizării producției sondei și prin urmare la creșterea producției de țiței sau gaze pe zăcămintă. Completarea inteligentă este de obicei mai scumpă și trebuie să aibe o justificare economică în comparație cu completarea clasică a sondelor. De aceea, completarea inteligentă trebuie să fie inclusă într-un model dinamic de simulare și să se ruleze modelul de simulare cu diferite configurații de completare pentru a găsi configurația optimă.

Acest articol prezintă unele aspecte practice privind integrarea în simulator a sondelor cu completare inteligentă în special când studiile de simulare folosesc unul din simulatoarele comerciale cum ar fi Eclipse (Schlumberger) sau Nexus (Halliburton).