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Utilizing well-reservoir pseudo-connections for multi-stage hydraulic fracturing modeling in tight gas saturated formations

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Abstract

Purpose. Research is aimed at integrating multi-stage hydraulic fracturing in horizontal wells with hydrodynamic simulation as a mandatory part of planning the mining of any shale oil or gas reservoir.

Methods. Geological and hydrodynamic reservoir modeling is part of the research. The properties and geometries of the hydraulic fracture network and its representation in the dynamic reservoir model were assessed. The comparative characterization was carried out based on the two methods of fracture modeling: cell dimension reduction for explicit fracture modeling (LGR – local grid refinement) and implicit fracture modeling method, presented in this paper, with additional pseudo-connections between well and reservoir.

Findings. A hydrodynamic model for low-permeable reservoir, produced by horizontal well, hydraulically fractured with 5 stages, has been generated. This model is calibrated to the production history and flowing bottom hole pressure by applying two methods of fracture modeling. Modeling results show that it is possible to replicate historical well production by using both methods. However, the proposed method with pseudo connections has several advantages compared to the generally accepted, local grid refinement (LGR) method.

Originality. For the first time, a system of pseudo connections between well and reservoir was constructed to model a multi-stage hydraulic fracturing for a hydrodynamic model of tight reservoir. Hydrodynamic simulation results were refined and calibrated to the history of hydrocarbon production and flowing bottom hole pressure data using the pseudo-connections and LGR methods. The similarity of the results by applying LGR and pseudo-connections methods was revealed.

Practical implications. The use of pseudo connections for hydraulic fracturing modeling can reduce simulation run time for cases where multi-stage hydraulic fracturing has already been carried out or is planned in the future. Additionally, the use of this method allows testing a larger number of realizations and scenarios, including hydraulic fracturing design (number of stages, size and conductivity of resulted fracture systems, fracture orientation, etc.), well placement and fracture growth relative to well trajectory. Also, there is no need to rebuild a model every time for each realization, as is the case with the LGR method.

Keywords: *modeling, multi-stage fracturing, reservoir, gas, filtration*

1. Introduction

The development of horizontal drilling and multi-stage hydraulic fracturing has had a significant impact on the expediency of developing tight oil and gas fields in a cost-effective manner. In addition, the possibility of performing fracture diagnostic to predict their geometry, properties and integration into commercial reservoir simulators that can consider non-Darcy flow and Langmuir's isotherm, along with their further development, have provided a comprehensive basis for field management optimization.

The advent of various diagnostic tools for fracture system assessment, such as microseismic [1], [2] has proved that it is possible to determine the geometry of the resulting complex fracture systems formed after multi-stage fracturing. Additional experimental studies have shown that the shape of each specific fracture can also be complex, non-uniform, with different apertures [3], [4]. Since the presence of fractures has a significant impact on filtration of reservoir fluids in porous media, it is important to correctly assess and model their impact on well productivity. However, the issue of realistic modeling of complex geometry fractures still exists [5]. The main challenge arises during integration of defined fracture properties (height, half length, asymmetry, conductivity) with hydrodynamic simulator to assess the productivity of the wells and their predicted cumulative production values. According to [6], the classic method of integration is to use the dimensional reduction of the grid cells in the hydrodynamic model for explicit fracture representation (LGR – local grid refinement). This method requires regridding for the hydrodynamic model at each multi-stage fracturing realization. The authors tried to semi-automize gridding process using build-in logic commands, but the dimensions of the static model cannot be changed over time, since this is a static property of the model. Therefore, when wells are put into production in sequence and with associated hydraulic fracturing, grid dimensions are set from the begin-

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ning of simulation run till the end and cannot be changed. This greatly increases the simulation run time and complicates it. Another limitation of the LGR method was encountered by the author [7] during the simulation of transient well tests, which were carried out in different time periods. This limitation is associated with constant fracture parameters that cannot be changed over time. This is especially critical for acid hydraulic fracturing in carbonate reservoirs when fracture closure can occur during first months after stimulation. So, it is currently impossible to change the fracture configurations over time or to carry out repeated hydraulic fracturing operations for one well within the same dynamic model. A similar situation is associated with more complex methods of explicit fracture models, such as unstructured gridding [8]. Unstructured geological models consist of non-orthogonal cells, whose geometry and properties also have static values and cannot be changed over time. In addition, most commercial dynamic simulators do not support this type of grids and their usage for large fields is not rational.

To simulate dual porosity and permeability models, rough approximation is used, which does not allow fully consider the conductivity of complex geometry fracture systems. This is primarily due to the interaction between matrix and fractures. Therefore, the discrete-fracture model (DFM) is used, which is based on the finite-difference method. The essence of this method is to duplicate each cell of the geological model to separately represent matrix and fracture properties. Since there is a doubling of the total number of the cells and the exchange of masses between the matrix and fractures is slow, the simulation run time increases significantly [9]. This type of hydraulic fracturing modeling is relevant for dynamic models of the single well, while it is much more difficult to implement it for a large reservoir with many wells [10].

The main purpose of this paper is to test proposed alternative method for hydraulic fracturing modeling by considering fracture properties and integrate them into dynamic reservoir model on the real well example introducing pseudo connections. Developed method aims to minimize the limitations of the classical LGR method and verify results obtained by both methods, reduce simulation run time and possibility of using the time function for fracture attenuation effect.

2. Materials and methods

2.1. Methods

Hydraulic fracturing is the dominant technology in the development of tight oil and gas reservoirs. The developed tools for fracture propagation modeling made it possible to simulate complex fracture systems in classical hydrodynamic simulators. Hydraulic fracturing technology enables cost-effective development of low-permeable reservoirs. However, interaction between fractures and matrix is a very complex process, the modeling of which requires taking into account a large number of variables, which in most of cases are uncertain. Many different technologies have been developed to model fluid filtration between a fracture and matrix, but most of them are based on finite-difference simulators and are limited by the dimensionality of geological models, computing hardware, and simulation run time. The basis of such solution is an analytical dependence that approximates the fracture as a separate rectangular reservoir, which contains only one phase and is homogeneous. In this case, the fracture is bounded by a given geometrical approximation (the cell of the simulation model). The properties of a given fracture are controlled by the value of the permeability multiplier for a given cell. The limitation of this method is that a cell can have only one average permeability and porosity which are constant values throughout the simulation period.

An alternative solution is to use effective well bore radius to model fracture implicitly. The increase in effective wellbore radius after hydraulic fracturing can be used in dynamic simulators to simulate well stimulation. Figure 1 shows schematically how the interaction between matrix and fracture is simplified using the concept of effective well bore radius increase.

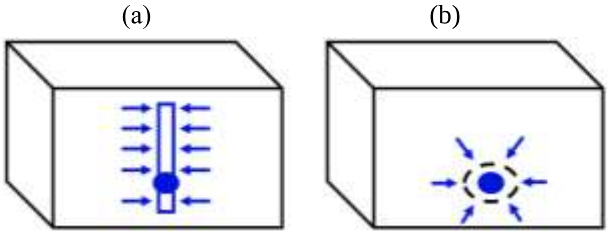


Figure 1. Industry reference methods for fracture modeling: (a) interaction between matrix and fractures; (b) effective well bore radius increase

Most of analytical solutions [11], [12] were in one or another way based on the concept of increased effective well bore radius. The equation for the dependence of the skin factor on the fracture conductivity can be represented as follows:

$$S_f = \frac{1.65 - 0.328 \cdot u + 0.116 \cdot u^2}{1 + 0.018 \cdot u + 0.064 \cdot u^2 + 0.005 \cdot u^2} - \ln\left(\frac{xf}{rw}\right), \tag{1}$$

where:

S_f – skin factor of the formed fractures;

xf – fracture half-length, m;

rw – effective well bore radius, m,

$u = \ln(F_{cd})$;

F_{cd} – dimensionless conductivity of the fractures, which is determined as follows:

$$F_{cd} = \frac{k_{wf}}{k_{xf}} = \frac{k_f \cdot w_p}{k_{xf}}, \tag{2}$$

where:

k_{wf} – fracture conductivity;

k_f – fracture permeability, mD;

w_p – average fracture aperture, m;

k – reservoir permeability, mD.

While using Equations (1) and (2), effective well bore radius can be calculated as follows:

$$r_{we} = r_w \cdot e^{-sf}. \tag{3}$$

Most commercial dynamic simulators calculate the well bore productivity index (PI) using the effective well bore radius. Therefore, in this case, the impact of fracture is calculated only in the form of a multiplier to well productivity, ignoring the physical and explicit modeling of the fracture-matrix interaction process. The influence of reservoir heterogeneity and the geometry of the fracture itself are also not considered, when using this methodology.

This paper proposes an alternative method for fracture modeling using a standard commercial hydrodynamic simulator, which considers reservoir heterogeneity in lateral and vertical direction, the influence of fracture geometry on the resulting well productivity. The main difference from classical modeling, using Local Grid Refinement (LGR), is the creation of additional pseudo well – reservoir connections in the cells through which the fracture plane passes after hydraulic fracturing, taking into account its parameters. The following are the basic principles and differences between the two methods.

2.1.1. Local grid refinement (LGR) method for geological model

This method allows changing the dimension of the simulation grid around the well or in a certain part of the model for a more detailed description of filtration processes. Change in the grid dimension can be done both vertically and horizontally. However, LGR will cause additional difficulties in the calculation and increase the simulation run time. This is due to the determination of transmissibility and filtration between cells, which are very different in pore volume. This calculation is performed automatically by a dynamic simulator. Process is characterized by the throughput ratio of the cell during the filtration of fluid through it. Only one pore volume of fluid can pass through the cell per timestep. Because of this, the simulator is forced to reduce the simulation run time.

Usually, filtration-capacitance parameters of the refined cells are automatically assigned from the global cells (cells of the initial size). Figure 2 shows an example of a local grid refinement in the grid cells dimension for a horizontal well to reproduce the fracture geometry after 5-stage hydraulic fracturing.

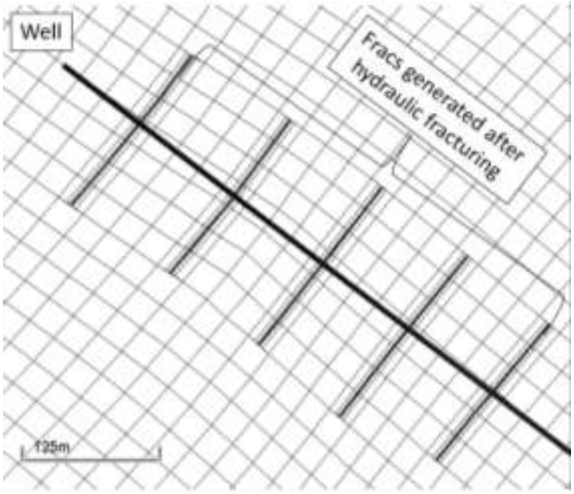


Figure 2. Local grid refinement to reproduce fracture geometry

Transmissibility between refined and global cells is automatically calculated by the dynamic simulator. The calculation is performed separately for projections by *X*-, *Y*- and *Z*- axes along the intersection between 2 grid cells. The distance from the center of each cell to the intersection is also calculated for both cells to take into account the correction factor due to the angle of cell inclination.

Transmissibility on the *X*-axis is calculated using the following Equation:

$$Tr_i = \frac{Cd \cdot TMX_i}{\frac{1}{T_i} + \frac{1}{T_j}}, \qquad (4)$$

where:

T_r – transmissibility between cell *i* and *j* on the *X* plane.

Cd – Darcy constant (у системі СІ – 0.008527).

TMX_i – transmissibility multiplier (by default is 1).

$$T_i = PermX_i \cdot NTG_i \cdot \frac{A \cdot D_i}{D_i \cdot D_i}, \qquad (5)$$

where:

A – cross-sectional area of the corresponding cells *i* and *j*, m^2;

$PermX_i$ – permeability tensor in the *X* direction, mD;

D – distance between cell center for cells *i* and *j*, m.

NTG – net to gross ratio, fraction;

If we decompose $A \cdot D_i$ in the equation into the projection and distance from the center to the cell boundary, we obtain:

$$\left(A \cdot D_i\right) = A_x \cdot D_{ix} + A_y \cdot D_{iy} + A_z \cdot D_{iz}; \qquad (6)$$

$$\left(D_i \cdot D_i\right) = D_{ix}^2 + D_{iy}^2 + D_{iz}^2. \qquad (7)$$

A_x, A_y and A_z are projections of *X*-, *Y*- and *Z*- of neighboring cells *i* and *j*, respectively. D_{ix}, D_{iy} and D_{iz} are distances between the cell centers. The equations for the *Y* and *Z* axes are identical. The main calculation element is illustrated in Figure 3, where the X-axis permeability (PEMX) is given as K_x.

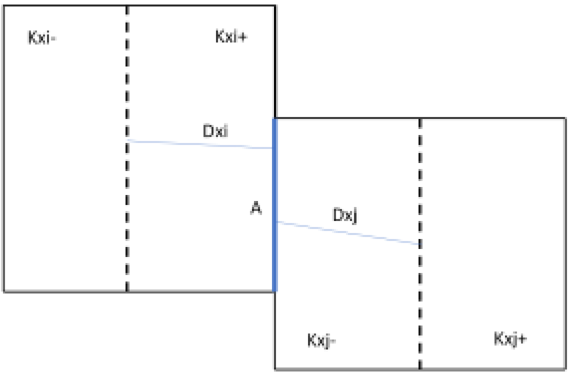


Figure 3. Schematic illustration of transmissibility calculation between two cells

In this case, the fractures are modeled explicitly using cells with very low dimensions and high permeability and conductivity. Since a full-field dynamic model is used, including lateral and vertical heterogeneity, interaction between layers, fluid, and rock properties as a function of pressure, this approximation is believed to be the most realistic. However, it requires much longer simulation run time. Local grid refinement cannot be implemented for a specific period (exploitation starting day or date when the hydraulic fracturing was performed), so refinement is simulated for the entire simulation period, which is a significant limitation for full field dynamic models of a large reservoirs.

2.1.2. Pseudo well – reservoir connections method

This method is based on the fracture plane construction, generated in software and transformed into additional connections in a dynamic model, between well and reservoir along cells through which fracture planes pass. Transmissibility for these additional connections is calculated based on the fracture properties (half length, aperture, conductivity). The main advantages of this method are significant reduction in simulation run time, possibility to enter connections at any time interval of the simulation, as well as control fracture attenuation and modify fracture properties over time.

Since the reservoir dynamic models consist of cells, their dimension is not always sufficient for a detailed description of the reservoir and well location. There are situations where well trajectory penetrates a grid cell at the cell edge, as shown in Figure 4.

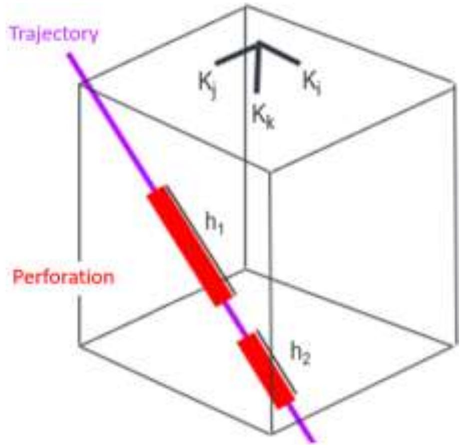


Figure 4. Schematic representation of the well trajectory and grid cell

Dynamic simulators use the cell center as a reference point to simplify the solution of partial differential equations. In this case, each cell has single value of porosity, permeability, saturation (oil, gas, water), pressure referenced and averaged in the cell center. Similarly, the well trajectory is shifted towards the cell center. Connection factor (CF) is used to compensate and evaluate intersection plane between well and grid cell. This factor is also an indicator of the quality of the well-reservoir connection and depends on filtration-capacitance characterization of the rock.

Equation of well inflow in a dynamic simulator is presented below. Eclipse 100 was used as a reference commercial dynamic simulator. Software selection was based on available licensing, compliance with industry reference standards, which have been verified through testing on SPE1 to SPE10 models. It should be noted that pseudo-connections method can be used in other dynamic simulators. The following equation is a function of the flow rate of each phase under the surface conditions:

$$q_{p,j} = T_{w,j} \cdot M_{p,j} \cdot \left(P_j - P_w - H_{w,j} \right), \tag{8}$$

where:

$q_{p,j}$ – volumetric flow rate of phase p in connection j under surface conditions. Flow is considered as positive from reservoir (cell) to the well and negative during injection, m^3/day;

$T_{w,j}$ – transmissibility factor;

$M_{p,j}$ – phase mobility at the phase level, fraction;

P_j – pressure in the cell, bar;

P_w – bottom hole pressure, bar;

$H_{w,j}$ – pressure difference between bottom hole pressure and pressure in the cell, bar.

Transmissibility factor is a function of cell geometry and its permeability. This value can be set up manually or calculated by default in simulator. In the second option, simulator calculates it automatically, using the following Equation:

$$T_{w,j} = \frac{c \cdot \theta \cdot Kh}{\ln\left(r_0 / r_w \right) + S}, \tag{9}$$

where:

c – conversion factor (0.001127 for field units, 0.008527 – metric units and 3.6 – lab units);

θ – connection angel in radians (it is used since well connection is referenced to the grid cell center, especially if well crosses the cell at its corners);

Kh – effective permeability multiplied by effective thickness, mD·m;

r_0 – effective well radius, m;

r_w – well radius, m;

S – skin factor.

To model multistage hydraulic fracturing, using pseudo-connections methods, a term responsible for the fracture conductivity is added to the well inflow equation. This additional term changes resulted Kh and transmissibility between well and reservoir, based on the fracture properties. Pseudo-connections method has several advantages, compared to classic LGR method – reduced simulation run time, ability to add hydraulic fracturing at specific date and for specific time along with variable fracture properties over time, minimized convergence issues due to throughput ratio.

To test and verify the validity of pseudo-connections method, a geological and dynamic model was constructed. Several dynamic simulations were performed using both LGR and pseudo-connections methods for well W1, on which 5-stage hydraulic fracturing was carried out. The modeling steps and available inputs are described below.

2.2. Geological model

During the study, one block was identified from the full field geological model with faults framework and used for dynamic simulation sensitivities. Block is produced by horizontal well W1. Geological model and well W1 trajectory are shown in Figure 5. Grid dimensions were selected based on the optimal simulation run time without compromising on results accuracy. Table 1 shows main geometrical parameters of the static model.

Table 1. Static model dimensions

Cells (*nI* x *nJ* x *nK*)	163 × 199 × 235
Total number of active cells	176000
Cell size in X direction, m	85
Cell size in Y direction, m	100
Vertical resolution, m	2.5

2.3. Petrophysical rock properties

Reservoir A is a typical low-permeable (permeability – 0.0001-0.5 mD), low porosity (porosity – 1-8%) gas condensate (CGR – 0.0003 m^3/m^3) reservoir. Top reservoir depth is around 3050 m. Table2 and histograms on Figure 6 summarizes ranges and distribution of such properties as porosity, permeability, and saturation.

Table 2. Petrophysical reservoir properties

Property	Minimum	Maximum
Porosity, %	1.2	8
Horizontal permeability, mD	0.0001	0.5
Vertical permeability, mD	0.00001	0.05
Connate water saturation	0.13	0.42

Petrophysical parameters were determined based on available well logs and core data from well W1 and surrounding appraisal wells. Facies log (reservoir/non-reservoir flag) and porosity log were generated as result of petrophysical interpretation.

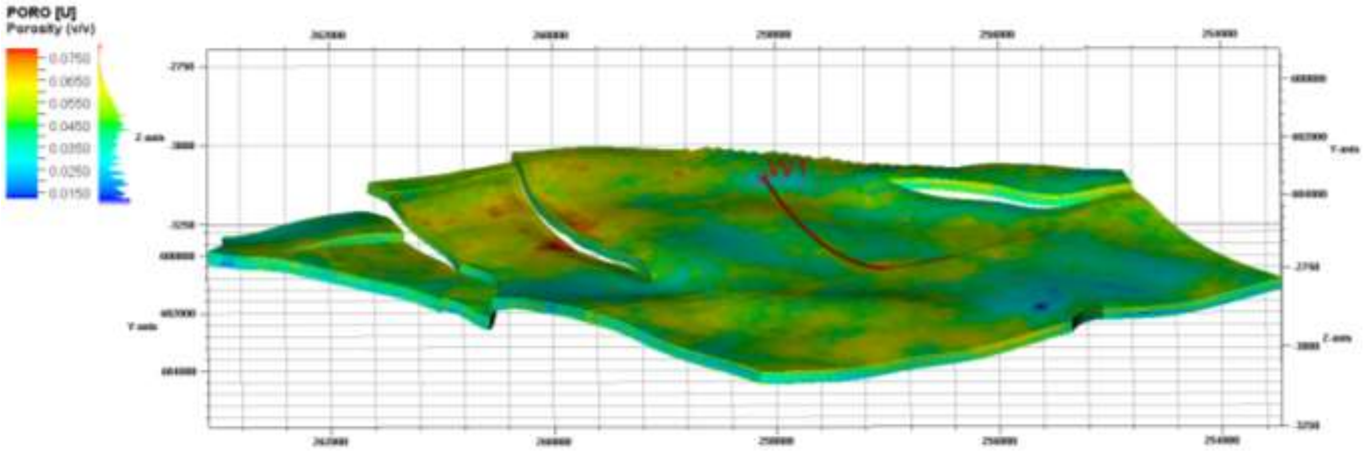


Figure 5. Geological model and W1 trajectory

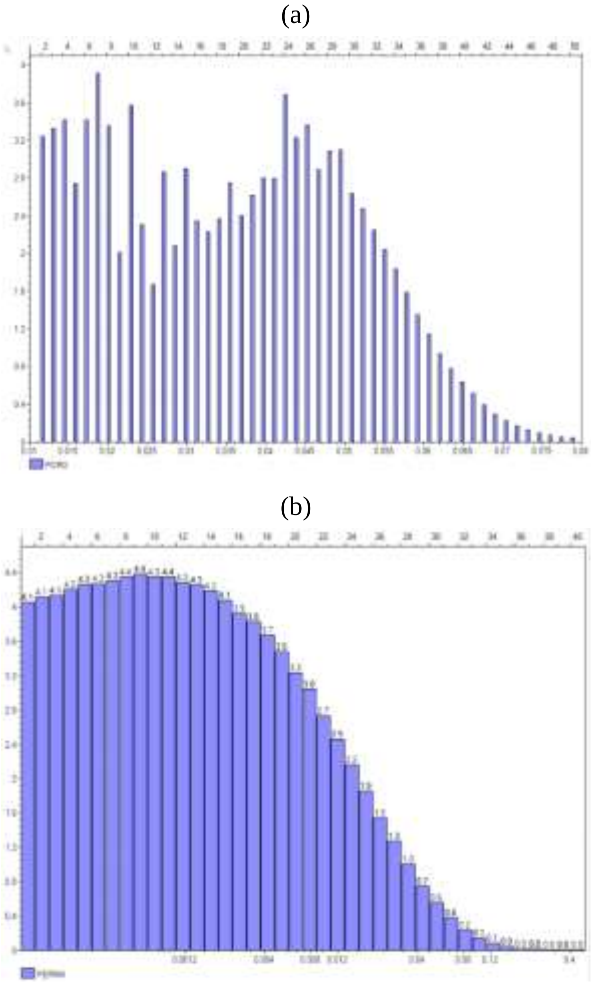


Figure 6. Distribution histograms for static model: (a) porosity; (b) permeability

Porosity distribution was done using stochastic distribution, based on well data statistics. Permeability is calculated for each cell based on the porosity-permeability transformation derived from the core data. Investigated reservoir is characterized by relatively low porosity and permeability values, but has a thickness of around 70 m and a large lateral extend, which can be correlated by signature in logs from drilled wells. Mainly, such type of reservoirs is not consi-dered as perspective in Ukraine, due to their low properties (below cut off). However, they may still contain a large hydrocarbon reserves.

2.4. Reservoir fluid

Initial reservoir conditions (pressure and temperature) are very close to the saturation pressure (dew point), based on PVT lab report done for bottom hole sample acquired from well W1. Reservoir is saturated with hydrocarbon – 75% of methane (CH_4), 8% of ethane (C_2H_6) and 5% propane (C_3H_8), heavy fractions C_{7+} around 6%. CO_2 and N_2 content are 3 and 0.12%, respectively.

Phase diagram and reservoir temperature (134°C) are presented in Figure 7. Tuned Equation of state was exported as black oil tables (viscosity, formation volume factor and condensate gas ratio as a function of pressure). Black oil model was used for simulation. Initial reservoir pressure is around 340 bar.

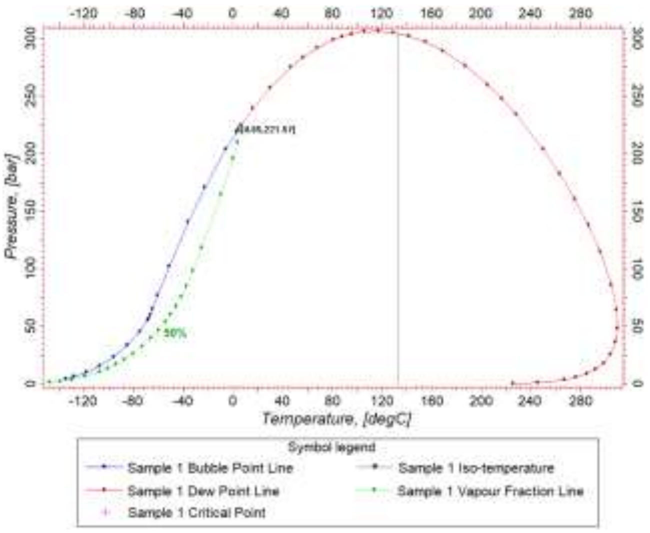


Figure 7. Reservoir fluid phase diagram

Black line in Figure 7 represents isothermal reservoir pressure depletion. Under initial reservoir pressure of 340 bars, reservoir fluid is single-phase (100% gas). When the reservoir pressure drops to 300 bars, condensate drops out from gas phase.

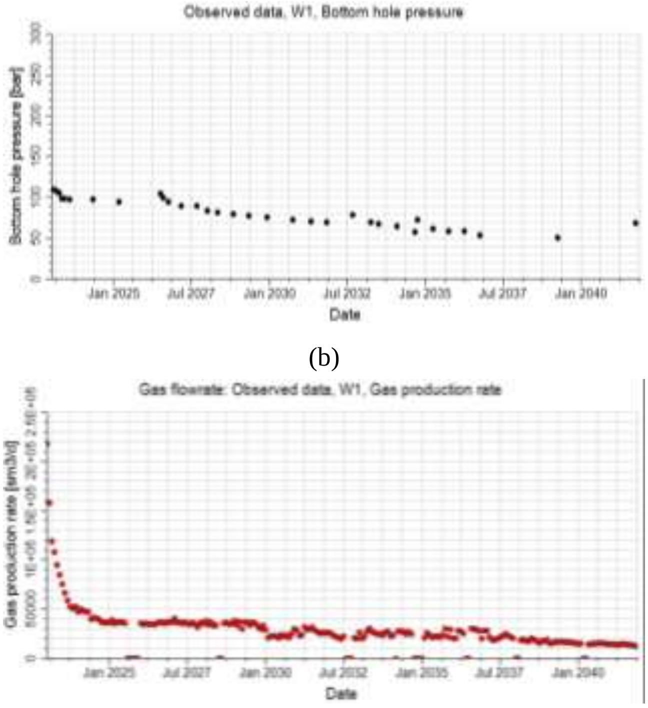
This leads to partial blockage in the pore volume and gas relative permeability decrease due to liquid phase presence. The gas oil ratio (GOR) is 5500 sm^3/sm^3, so the impact of condensate drop out on well productivity is minimal after multi-stage fracturing.

2.5. Well model

Well W1 has a measurement depth (MD) of 6400 m, of which only 1500 m is a horizontal section. Well has 6.6-inch casing and 5 perforated intervals, which are on the equal distance between each other. Well completion is presented in Figure8. Historical gas production and measured flowing bottom hole pressure after 5-stage hydraulic fracturing are shown in Figure 9.

Figure 8. W1 trajectory and completion

(a)



(b)

Figure 9. Historical conditions of well operation: (a) flowing bottom hole pressure data, bar; (b) production gas rate, sm^3

Well has relatively high initial gas production rate of 250 Msm3/d, followed by a sharp decline and subsequent stabilization, which may indicate slow fluid flow beyond the stimulated reservoir volume (SRV). To test the feasibility of using pseudo-connections method, two similar dynamic models were constructed and calibrated to the historical conditions of well operation (production rates and pressures). For the first model, LGR was used to model hydraulic fractures, while for the second one – pseudo connections.

3. Results and discussion

For the constructed dynamic reservoir models, a 5-stages hydraulic fracture was simulated for well W1. Distance between stages is uniform – 250 m. All fractures are characterized by similar half-length of 250 m and same aperture and conductivity. Visualization of resulted fracture planes for both methods is presented in Figures 10 and 11.

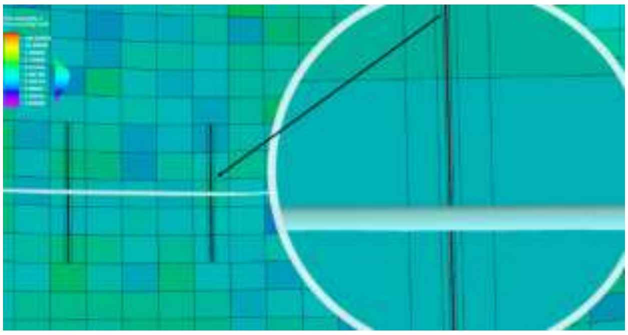


Figure 10. Resulted fractures created by Local grid refinement

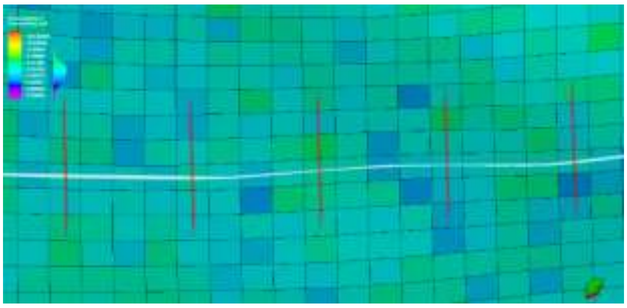


Figure 11. Fracture planes created by pseudo-connections

Thus, Figure 10 zooms on the fracture, represented by a cell of few cm and characterized by a high permeability value (calculated from the estimated fracture properties and geometry). This type of fracture modeling is static, and the fracture properties cannot be changed over time, since the cell permeability is a static property of geological grid. Local grid refinement can be applied only once and will be valid for the entire simulation run. Figure 11 shows the fracture planes from hydraulic fracturing that intersects grid cells perpendicularly to the well trajectory. Each cell penetrated by a fracture plane will be connected to the well bore by a pseudo-connection. Connection factor (CF) for such connections is based on the fracture properties.

Two alternative simulations were performed and calibrated to production history and flowing bottom hole pressure trend using both fracture modeling methods. Resulted plots are almost identical and presented in Figures 12 and 13. It should be noted that difference in bottom hole pressure trends is related to the convergence issues. As in LGR case, since fracture cells are much less, comparing to the neighboring cells, simulator requires higher number of non-linear iterations to solve flow equations and satisfy material balance error convergence criteria. If pseudo connections are used, flow equations are solved for more uniform cells. This minimizes necessity to shorten simulation timestep due to the higher throughput ratio. Resulted CPU time for LGR is 4715 sec, while for the case with pseudo connections is only 1953 sec. Also, LGR method generates non neighboring connections (NNC) between the cells that have big differences in pore volume. This connections type is not physical as flow is calculated even for the cells that are not geometrically connected. LGR method cannot be used for other geological realization without re-gridding and changing grid dimension for a new model. At the same time pseudo connections can be used for any geological realization without additional manual gridding.

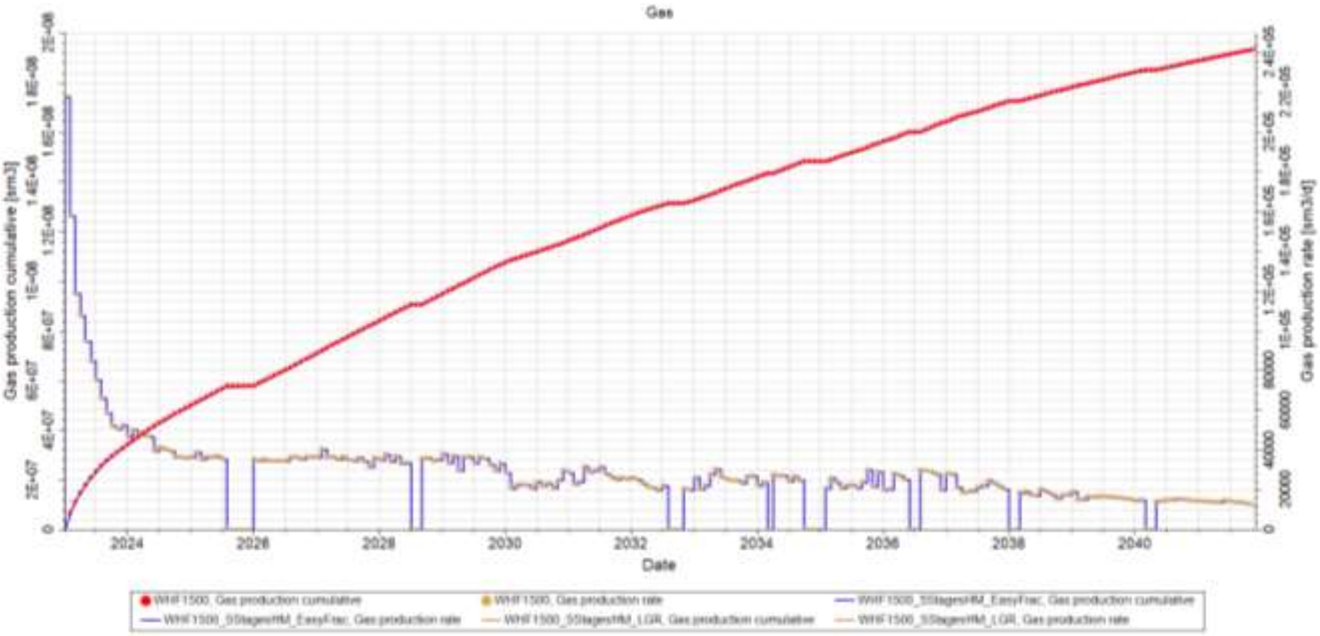


Figure 12. Gas production rate and cumulative calibration results for both models

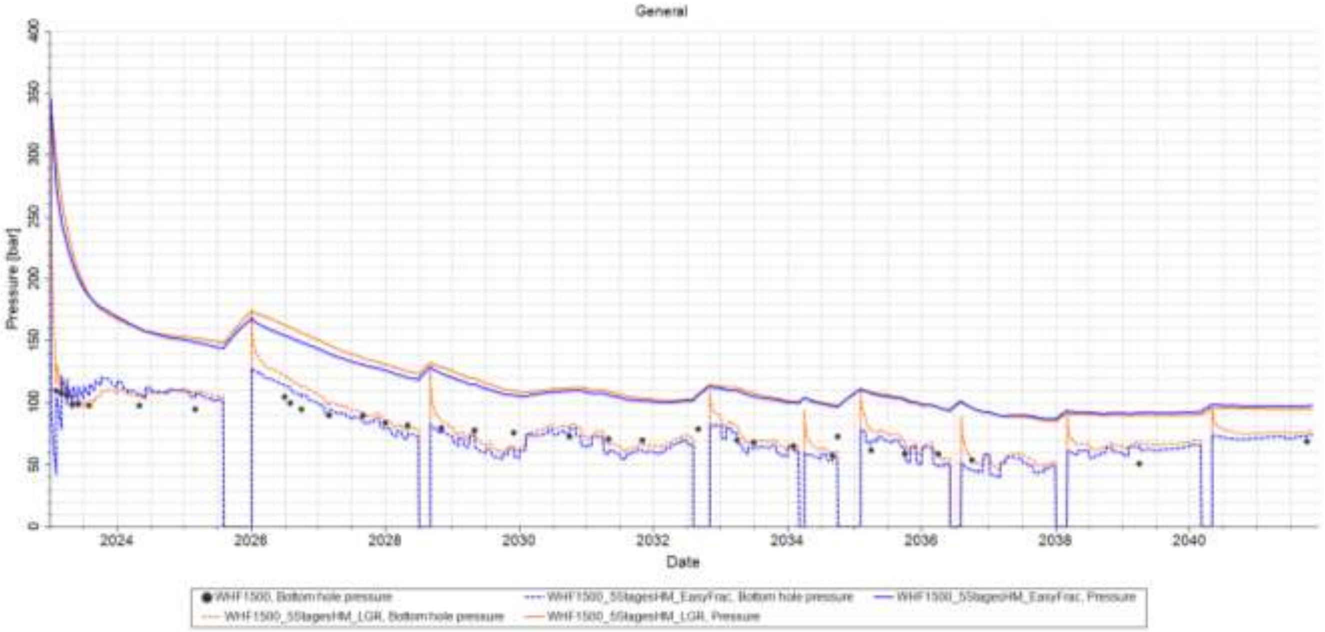


Figure 13. Bottom hole pressure calibration results for both models

Pressure distribution along fracture planes for both cases, at the last historical timestep, is presented in Figures 14 and 15. Used PVT model is characterized by a dry gas with low condensate gas ratio. As continuation of this publication, it is planned to focus on the condensate gas ratio variation and its influence on well productivity due to the condensate banking.

The authors of [13] investigated the possibilities to optimize and improve LGR methodology for hydraulic fracturing modeling. However, they concluded that improvement is possible only through a new user interface that will allow automatically or semi-automatically perform gridding to introduce refined cells in the static model. Similar conclusion was derived from [14], where the main bottleneck of LGR method is characterized as a lack of integration into uncertainty and optimization workflows. In this publication, a plug-in for a geological software platform has been developed that allows to re-build grid refinements for different static realizations.

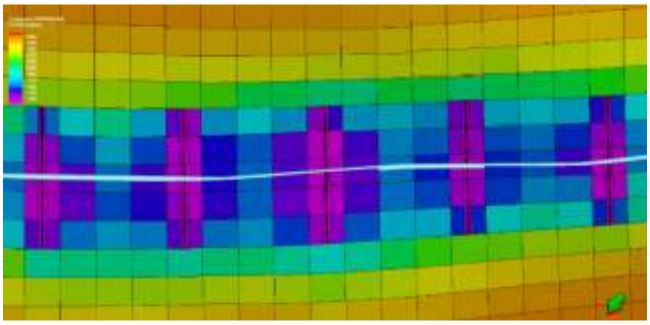


Figure 14. Pressure distribution at the end of the simulation run for LGR

From other side, pseudo connections can be easily integrated into any uncertainty workflow as it does not require changing dimensions of geological models and only calculates connection factors based on reservoir and fracture properties.

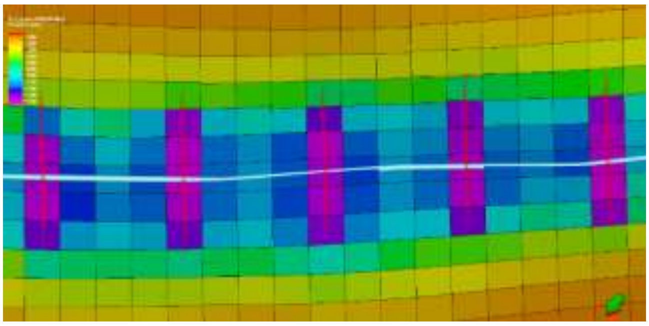


Figure 15. Pressure distribution at the end of the simulation run for pseudo connections

However, pseudo connections have also several issues. For example, hydraulic fracture approximation by a connection factor fully ignores matrix – fracture interaction. This effect is very important especially for naturally fractured reservoir. A study [15] conducted for naturally fractured reservoirs shows that sigma parameter (interaction level and volume transaction between matrix and fracture) has a major impact on cumulative production rates. Tornado analysis conducted for more than 200 realizations ranked the Sigma parameter as the third most influential. Pseudo connections method can be used for quick assessment of well productivity based on fracture properties without compromising the accuracy of results, compared to LGR method. However, it is just an approximation that requires a detailed analysis of fracture parameters for each specific scenario.

4. Conclusions

Alternative method for hydraulic fractures modeling in dynamic reservoir simulation is presented and validated. Two simulation models were constructed, run and calibrated to historical production and pressure profiles using local grid refinement and pseudo connections. Calibrated historical operating conditions for W1 well reproduced by both methods prove validity of pseudo connections. This method has several advantages comparing to LGRs: reduced simulation run time, uniformity of the results, user friendly application and repeatability for any other geological realization, possibility to introduce hydraulic fractures in a certain simulation timestep and apply attenuation effect as a function of time by adjusting connection factor values.

The pseudo connections method in dynamic reservoir simulation and connection factor modification is sufficient and accurate method for a quick analysis of incremental production after multi-stage hydraulic fracturing in tight reservoirs. This allows for faster results compared to the LGR method. This method can also be used to calibrate the simulation results to production history and pressure trends. However, when fracture level physics, such as condensate banking caused by high-condensate gas ratio, fractures interference, LGR provides a much more accurate estimate due to numerical dispersion in the refined cells of smaller size.

Classical LGR method requires access to additional software licenses, while pseudo connections can be used manually in a text editor, significantly reducing the total cost of the required software solutions. The proposed method is a valid alternative to LGRs for multi-stage fracturing modeling in dynamic reservoir simulation. This approach allows a larger number of scenarios to be considered for probabilistic forecasting while producing results similar to more time consuming LGR method. It becomes possible to focus on more influential parameters for resulted cumulative hydrocarbon production and reduce uncertainty by discarding parameters with a minimal impact.

Author contributions

Conceptualization: OL, OK; Investigation: OL; Methodology: OK; Resources: OL; Software: OL; Supervision: OK; Visualization: OL; Writing – original draft: OL; Writing – review & editing: OL, OK. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Апробація методу псевдо зв’язків свердловина – пласта для моделювання багатостадійного гідророзриву в ущільнених газонасичених колекторах

О. Лукін, О. Кондрат

Мета. Інтеграція багатостадійного гідророзриву пласта (ГРП) в горизонтальних свердловинах з поєднанням гідродинамічної симуляції, які є невід’ємною частиною розробки будь-якого ущільненого газо чи нафто насиченого колектора.

Методика. В роботі проводилося геологічне моделювання колекторів з побудовою гідродинамічної моделі. Оцінювались властивості та геометрії утвореної мережі гідродинамічних тріщин та репрезентація тріщин у гідродинамічній моделі. Порівняльна характеристика здійснювалася на основі порівняння двох методів репрезентації тріщин, а саме: загальноприйнятого методу зменшення розмірності сітки гідродинамічної моделі (LGR), та – запропонованого у даній роботі методу додаткових псевдо зв’язків свердловина – пласт.

Результати. Побудована гідродинамічна модель ущільненого покладу А, що розробляється горизонтальною свердловиною на якій було проведено 5-ти стадійне ГРП. Дану модель налаштовано на історію видобутку та відтворено динаміку робочих вибійних тисків, використовуючи два методи репрезентації тріщин. Результати моделювання показали, що можливим є відтворення історії основних показників роботи свердловини, використовуючи обидва методи. Проте, запропонований метод додаткових псевдо зв’язків має ряд переваг у порівнянні із класичним методом (LGR).

Наукова новизна. Вперше побудовано систему псевдо в’язків типу свердловина пласт для моделювання багатостадійного ГРП для гідродинамічної моделі покладу. Уточнено результати гідродинамічної симуляції та налаштовано гідродинамічну модель на історію видобутку вуглеводнів та динаміку робочих вибійних тисків із використанням методу псевдо зв’язків та LGR. Виявлено схожість результатів гідродинамічної симуляції під час моделювання 5-ти стадійного ГРП за методом LGR та псевдо зв’язків.

Практична значимість. Отримані результати дозволяють скоротити час розрахунку основних показників розробки ущільнених покладів, на яких було проведено або планується багатостадійне ГРП, із використанням гідродинамічного симулятора. Крім цього, використання методу псевдо з’єднань дозволяє спрогнозувати більшу кількість сценаріїв, а саме схем проведення ГРП (кількість стадій, розмір та провідність тріщин їх орієнтація), розміщення свердловини та розміщення тріщин відносно траєкторії (азимут та кут), через свою універсальність та відсутність потреби перебудови сітки геологічної моделі для кожної окремої реалізації, як це потрібно робити для методу LGR.

Ключові слова: *моделювання, багатостадійне ГРП, колектор, газ, фільтрація*

Publisher’s note