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Horizontal Well Modeling in Complex Reservoir with Uncertainties Assessment

E.F. Tsyganova* (Tyumen Petroleum Research Center)

SUMMARY

Horizontal wells application in heterogeneous reservoirs is challenging as implies high expenditures in conditions of difficulties with such wells modeling. In case of complex reservoir the model matched to history data and accepted to be rather accurate can give the erroneous estimation of horizontal wells performance. This paper is aimed to study the issue with using of integrated approach.

As a possible reason of the mistaken forecast the uncertainties related to reservoir complexity are investigated. At first, by means of analytical solutions the uncertain parameters influencing horizontal well performance are identified. Then the qualitative analysis of their impact on the oil rate as a decision criterion is performed on the model. After that basing on the field data, the ranges of uncertainty are determined and incorporated into simulation process. Finally, by Monte Carlo technique with automatic history matching applied to the model its non-uniqueness is demonstrated proving the necessity of performing multivariant forecast that is especially critical for horizontal wells.

As a result the modelling procedure is proposed and the complex of research is recommended in order to increase model reliability. This will allow uncertainties management and proper decision making in terms of projects profitability.

Introduction

Reservoir heterogeneity coupled with the complexity of modeling process in the absence of an integrated approach can lead to the mistaken prediction of horizontal wells performance and the difficulty with decision making. Therefore it is necessary to determine the set of controlling parameters that can be accounted and corrected in practice to overcome this problem.

According to the analytical models of Borisov (1964), Renard and Dupuy (1990), Joshi (1991) et al. horizontal wells performance is expected to be affected by the number of factors concerning reservoir characteristics. In turn, reservoir properties are often obtained from insufficient data creating the range of uncertainties. As a geological model is the basis of a simulation model they can represent the sources of inaccuracy in prediction of reservoir response to production. It is possible to evaluate the number of responses with using of simulators, but often no attention is paid to this.

The attempts of uncertainties quantification were described in some papers (Salomão et al. 2001, Corre et al. 2001, Charles et al. 2001), but their impact was not particularly studied for horizontal wells. Present work demonstrates the risk in uncertainties ignoring in case of heterogeneous anisotropic reservoir and illustrates the importance of reservoir testing.

Case study: challenge of horizontal wells modeling

The reservoir considered represents a great complexity in terms of its heterogeneity and anisotropy. As a result of active depositional environment geological cross-section is characterized by irregular alternation of shalestone, siltstone and sandstone, turning into chaotically allocated, differently oriented and severely discontinuous lenticular sand bodies. Such rocks have fine-grained structure, poor sorting, high shaliness and poor reservoir properties. Complex geological conditions cause insufficient performance of production and injection wells within the field. It has led to the necessity of development optimization. Horizontal drilling was preferred to hydraulic fracturing by reason of the risk of water breakthrough from underlying flooded-out formation.

Within the considered field sector the primary attention was paid to the reservoir pressure maintenance. It was necessary to evaluate the potential performance of horizontal injection wells by means of modeling. Because of high reservoir compartmentalization the model cell size in vertical direction was chosen on the level of logging resolution. The model was matched to the history data of the existing vertical wells with verification of all required parameters such as liquid, oil and water production rates that was to have been its accuracy indicator. However subsequent comparison of wells injectivity predicted by the model with real data showed the significant difference that created a problem with further development planning and necessitated the issue investigation.

Analytical models: affecting parameters identification

First of all analytical models were reviewed in order to detect the key parameters controlling fluid flow in heterogeneous anisotropic reservoir penetrated by horizontal well. The most common is Joshi and Economides equation (1991). From among the affecting factors we are interested in those dependent on reservoir heterogeneity and anisotropy including: effective thickness, horizontal permeability, permeability anisotropy – related to the reservoir and the effective length of wellbore, skin factor – related to the horizontal well. It should be noticed that the dependence of horizontal well skin factor on permeability anisotropy in vertical direction is explained by the elliptical cross-section of reservoir damage and illustrated by the analytical solution derived by Renard and Dupuy (1991).

Qualitative analysis: sensitivity study

Due to the reservoir complexity and insufficiency of research data all the listed parameters have the certain level of uncertainty that influences the results of modeling. In order to evaluate their impact

qualitatively and identify the specific of horizontal wells the groups of horizontal and vertical wells were modelled in heterogeneous anisotropic reservoir of the sector. Obtained tornado plots (Figure 1) illustrate that Net to Gross Ratio has the most impact on production rates. Radial flow to vertical wells provides equal influence of permeabilities in x , y directions while k_z has almost no impact. Horizontal wells performance is much more sensitive to vertical permeability and k_x has the maximum effect. In our case it can be explained by horizontal wellbores predominant orientation in y direction.

The sensitivity of horizontal well production rate to the effective length of wellbore varies due to high reservoir heterogeneity: the loss of the portion opened to high-permeable layers is more significant in terms of production. Damage impact increases at higher reservoir anisotropy (Figure 1) and in critical case ($k_v/k_h=0.001$) can reduce horizontal well (HW) productivity down to the one of fractured vertical well (VW). Thus, undetermined permeability anisotropy not only creates the uncertainty in horizontal wells performance, but also can result in the advantage of the alternative development variant.

Figure 1: Sensitivity plots. Left) Tornado plots for horizontal and vertical wells (10% parameters variation). Right) Combined impact of skin factor and reservoir anisotropy.

Practical issues: uncertainty ranges

For the impact quantification the preliminary determination of uncertainty ranges for each influencing parameter is performed basing on the field data. These ranges will determine the total uncertainty in modeling outcome. Moreover, the parameters can be varied within these ranges to adjust the model.

Reservoir effective thickness. Because of high reservoir heterogeneity the intense alternation of permeable and impermeable layers can not be properly recognized by logging tool. As a result, for number of wells an inflow was obtained from the intervals that were non-productive according to the initial characterisation of the lithology. By this reason in process of reinterpretation cut-off criterion for reservoir identification (spontaneous polarization coefficient) was reduced from 0.3 to 0.25 and the effective thickness was increased at 50 %. Insufficient data coupled with the ambiguity in logs interpretation create the range of uncertainty in NTG equal to 0.5-1 from the current value.

Reservoir permeability. In complex heterogeneous reservoir well test data is considered to be more precise for permeability determination. However in the considered case core and logging data are more representative. Therefore the range of uncertainty in reservoir permeability is taken 4-12 mD that represent the estimations obtained from the sources mentioned.

Vertical and lateral permeability anisotropy. Directional core was taken only from wells of the adjacent field sector. The analysis indicates wide variation of vertical anisotropy coefficient (0.001-1). From stress measurements the ratio of horizontal permeabilities varies from 0.9 to 1.

Effective length of wellbore and skin factor. These parameters depend on the number of factors including reservoir characteristics, drilling and completion processes and their ranges of variation can hardly be limited on the stage of horizontal wells performance prediction.

Quantitative analysis: Monte-Carlo technique with automatic history matching

The concept of uncertainties incorporation into simulation model was applied by means of Monte-Carlo method taking into account the ranges determined. The following case was modelled. The group of vertical wells has the production history of three years (2007-2009). After that horizontal wells are planned to put into production, while vertical wells continue the operation. Wells performance forecast is made for a year. In process of history matching the control on vertical wells liquid production rate was set. With using of Monte-Carlo technique **300** model realizations were performed. On each step random value from uncertainty ranges was chosen for each parameter. At more than **100** combinations of parameters the model was automatically matched with real data at different bottomhole pressures (Figure 2). Then bottomhole pressure for each well was matched to 70 bar (average value from the field data) with 10 % tolerance. After that oil and water production rates were adjusted. As a result about **50** cases showed good matching and were included into vertical and horizontal wells performance prediction with bottomhole pressure control.

Figure 2: History matching. Left) Cumulative liquid production matched in 100 cases. Right) The example of bottomhole pressure matching.

The results (Figure 3) clarify the reason of the model inaccuracy detection when modeling horizontal wells: minimum and maximum initial oil rates differ from each other in two times, while possible mistake for vertical wells is 16 %. It is also reflected on cumulative oil production. From the sensitivity study such a difference is controlled by vertical permeability with a high level of uncertainty. Thus, in such a complex heterogeneous reservoir at this range of uncertainty the flow rate prediction should be performed not as a single variant, but the range of possible ones.

Figure 3: Uncertainty ranges. Left) Predicted cumulative oil production. Right) Predicted oil production rate.

Recommendations

In order to avoid inaccuracy in horizontal wells performance forecast geological uncertainties should be investigated individually for each reservoir and included into prediction by construction the range of profiles for multiple scenarios. For horizontal wells the following modeling process is proposed:

If the economic estimation justifies the additional research reducing the uncertainty then the attention should be paid to the sensitivity study and the uncertainties ranges indicating which quantity to focus on first. For horizontal wells the most efforts should be focused on vertical permeability determination. To obtain it directional core plugs can be taken from pilot wellbore or well test can be performed. To determine proper well direction the uncertainty in lateral permeability anisotropy can be reduced by stress measurements in pilot section. Net to Gross ratio is specified by the complex of logging including micro logs that are more sensitive to layering. After these investigations the decision about horizontal well drilling can be made with the much narrower range of uncertainty. To reduce the uncertainty connected with the effective length of wellbore and adjust simulation model production logging in horizontal wells can be held. Skin factor should be obtained from well test and applied to the required intervals. Uncertainties in these parameters can not be reduced on the stage of modeling. However the absence of such investigations can lead to model misinterpretation and problems with history matching.

Conclusions

Thus, the original integrated concept was applied to horizontal well modeling in heterogeneous anisotropic reservoir. In whole the results obtained clearly indicate non-unique nature of models in conditions of reservoir complexity and input data uncertainties. Matched model is just a model with a certain combination of geological parameters while numerous such combinations are possible. It proves the importance of converting uncertainties in input parameters of the model into uncertainties in output results to generate more realistic models to be used in wells performance prediction and economic analysis. As a result, risk analysis, uncertainties management and proper decision making in terms of projects profitability will be allowed.

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