Role of Well Testing and Information in the Petroleum Industry- Testing in Multilayers Reservoirs

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Abstract:
The actual demand for oil and gas so as their products shows a clear increasing trend, despite some fluctuation mostly because of the global economic negative situation as well as some other geostrategic impacts. The new drilling activities and progressing toward deeper formations require stronger and abundant financial support, and looks that the safest way remains the increase of the oil recovery factor in the existing oil and gas fields. Well testing and their numerical modelling, gives responses that support their exploitation optimization. In many cases the oil and gas fields, represents as very complex systems composed by a large number of thin layers. Generally, they represent very complex hydrodynamic systems. The classification systems of these reservoirs, the calculation of the most important parameters, the factors that impacts and determine their exploitation performance as well as some economic indicators, are subject of this paper.

Key words: Well test, reservoir, petroleum engineering, production forecasts, skin effect

1 INTRODUCTION
The oil well test represents one of the basic disciplines of the reservoir engineering. The information collected regarding the fluid flow and the drawdown testing in the formation plays a key role for the determination of the productive capacities of the oil and gas fields. The drawdown test gives an important support regarding the determination of the average pressure of the formations. This information’s allows the study and identification of the formations behavior and particularly their yield forecast, for different regimes. The pressure data’s are without any doubt, among the most important, regarding the reservoir engineering. They play a key role to all the reservoirs exploitation stages [7, 10]. Oil and gas wells testing, main objectives are:

1. Well status evaluation and the reservoir characterization;

2. Calculation of the formation parameters for the purpose of the identification of its productive segment;

3. The identification of the well productive segment;

4. Skin effect and factor calculation, and based in its value could be decided regarding the implementation of the EOR methods.

2 WELL TESTING AND ITS ROLE IN THE PETROLEUM INDUSTRY
The oil and gas wells testing represent one of the strongest tools, mostly regarding their reservoir engineering prospect, as well the reservoir exploitation optimization. In a more descriptive way the information collected by the well testing is presented in the Figure 1 [7].

Is important to highlight that along the lifetime of the oil and gas wells, starting from it’s drilling an up to its “abandonment”, should be collected information’s regarding its technical status and daily activity. Here differs the pressure data’s, to each single well or at least for the “key wells”, whose represent not less than 25% of the total wells, in a periodical basis. Is very important to make careful programming regarding the information’s that should be collected through the well testing and its frequency. A very simplified logical sketch on the well testing is presented in the Figure 2 [7]. It’s obvious that, the well testing could be used for the selection of the well that should be subject of the Enhancement Oil Recovery (EOR) methods. The core of the process stands in the identification of all factors, which pushed toward the well productivity decline [3]. For this, could be very helpful the pressure build-up or pressure drawdown tests, the drill stem, the samples analysis or any...
additional information. After "the identification", should be selected the optimal stimulation process and its implementation design. Summarized, the selection of all the calculation procedures regarding the determination of the exploitation parameters of each single well and the reservoir, of the formation properties evaluation, regarding the efficiency and results of the EOR for the purpose of the OR (Oil Recovery) increase with aim to maximize the financial profit, is given in Figure 3. A well testing process can be efficient regarding collecting the information’s, and later on with their analysis, but only if is done a detailed and accurate planning, design, evaluation and coordination of all processes [1, 3].

Drilling samples analysis ensures valuable information’s regarding the preliminary identification of the rocks. The well testing process somehow support toward its improvement. Also, the well testing support, regarding the identification of all areas with low permeability whose can create difficulties during the normal process of the reservoir exploitation, or even for the identification of all areas with well-developed fractures, and by summarizing it helps for the preparation of the permeability map of the formation. The main goal of the reservoir engineering is the OR optimization, and this can be achieved only after having the correct classification. Figure 4 shows all activities that help starting from the formation classification, and the Figure 5 which shows the reservoir pressure data’s analysis for the purpose of the accurate evaluation of the reservoir properties.

Figure 2: Well testing programming

Figure 3: Well selection for the purpose of the EOR optimization
The multilayers reservoirs well testing, including the natural fracturing reservoirs, the solution of the flow differential equations with constant flow or pressure, and the economic aspects of the exploitation of these kinds of reservoirs, have been always challenging for their industrial exploitation. Figure 6 represents the multilayers reservoirs classifications systems [7].

3 NUMERICAL MODELLING AND ITS USE

The numerical modelling includes the large scale use of the computers for the solution of the flow differential equations, and in this way, to make possible the modelling of the fluids flow. These methods give very satisfactory results, and consist in the creation of a model (spatial net) whose approach the porous medium (by combining of all its properties). The reservoir is divided in a number of elementary blocks, and to each one of them is applied simultaneously the mass and energetic material balance. The techniques used for this purpose are different, and they are presented in a summarized way in the Figure 7 [3, 7, and 13].

3.1 Scope and aim of the reservoir modelling

The simulation programmers can be used for the purpose of the reservoirs testing, even if they are exploited by a single well, by some wells or even by systems of wells, whose interact with each-other. Summarized this is presented in the Figure 8 [7].

3.1.1 Reservoir modelling process development

After that all information are collected they are at first individually processed by creating some models. Via the geostatistical methods is possible to intertwine all in one single model. Summarized this process in presented in the Figure 9 [7].

3.1.2 Numerical modelling simulators selection and their use

Most of the numerical simulators can be very efficiently used for the determination of the fluids properties, water cones creation process, the geological profiles creation etc., and also can be used as modelling methods for the reservoir engineering. To the reservoir engineers remains the difficult task for the selection of the optimal method for the purpose of the modelling of the formation. Its selection could be done only after analysing all the parameters and gathered information’s. This is a very complex and high costly process. Summarized this is presented in the Figure 10 [7].

Figure 6: Multilayer reservoirs classification systems

Figure 7: Reservoir modelling

Figure 8: Computer simulation aims

Figure 9: Reservoir modelling development

Figure 10: Numerical modelling optimization process

The most important parameters for this selective process are [1]:

- The reservoir type;
- The geometry and formation extension;
- Database validity;
- Secondary and tertiary EOR methods applied in the reservoir;
- Expert’s needs;
- Logistic;
- The financial efficiency of the numerical modelling.
4 PRESSURE CHANGE ANALYSIS IN THE MULTILAYERS RESERVOIRS

Generally the multilayers reservoirs can be classified in tow groups: Multilayer reservoir with interlayer’s communication, whereas the thin layers do have hydrodynamic communication, mainly in the contact areas, and the reservoir without such a communication [4, 8].

4.1 Multilayers reservoirs with communication layers

Figure 11 represents a simplified sketch of a reservoir composed by four thin layers, whose communicate in between. The transitory well testing shows that the pressure in these systems changes in the same way as in the homogenous reservoirs. In this type of reservoirs can be implemented the following equations - For the calculation of the product permeability-layers thickness [4, 6 and 11]:

\[(kh)_j = \sum_{j=1}^{n}(kh)_j\]  
\[(1)\]

For the calculation of the product porosity-compression [4, 6, and 11]:

\[(\phi c_i h)_j = \sum_{j=1}^{n}(\phi c_i h)_j\]  
\[(2)\]

The total number of the layers is n. The permeability of each one of the layers can be calculated through the following equation [4, 6 and 11]:

\[k_j = \frac{q}{a} \left[\frac{(kh)_j}{h_j}\right], j = 1, 2, \ldots, \ldots, n\]  
\[(3)\]

Figure 11: Four layers reservoir with communication layers

4.2 Multilayers reservoirs without communication layers

Figure 12 represents a simplified sketch of a reservoir composed by four layers that doesn’t have inter-layers communication. The only communication way in this case remains the well. In the initial phase of the well exploitation the pressure drawdown curve is linear, as it is showed in the Figure 12. Once the reservoir boundaries effects appear the curve is bending [2, 5 and 8].

The pseudo-steady regime begins approximately at the time:

\[(t_{DF})_{p,v} \approx 23.5\left(\frac{k_1}{k_2}\right), k_1 > k_2\]  
\[(4)\]

The beginning time of this regime depend also on the:

- The fluctuation of the values of the porosity, width and compression of the layers, by each-other;
- The geometric shape of the reservoir;
- Layers number;
- Well location.

Figure 13 represents the curve of the dimensionless pressure by the dimensionless time, for a reservoir composed by two layers with permeability ratio k_1/k_2=100, 10, 2, 1. For all four curves the ratio r_w/r_o=2000. The dimensionless parameters are calculated as follows:

\[t_D = \frac{0.000264\epsilon t}{\phi \mu g \phi c_f^2}\]  
\[(5)\]

\[t_{DF} = \frac{\phi \mu g \phi c_f^2}{0.000264\epsilon t}\]  
\[(6)\]

\[p_D = \frac{\epsilon h (p_f-p_p)}{141.2\phi \mu \phi c_f^2}\]  
\[(7)\]

where:

\[
\bar{k} = \frac{k_1 h_1 + k_2 h_2}{h_1 + h_2}
\]
\[(8)\]

\[
\bar{h} = \frac{h_1 + h_2}{h_1 + h_2}
\]
\[(9)\]

\[
\bar{\phi} = \frac{\phi_1 h_1 + \phi_2 h_2}{h_1 + h_2}
\]
\[(10)\]
4.3 The composed reservoirs

The kinds of reservoirs, as mentioned above are named composed reservoirs. The thin layers do communicate with each other, only by the well, as it showed in the Figure 14. Practically the fluid flows by the thin layer and raise to the surface only via the well [4, 6, 11].

![Figure 14: Composed reservoir with communication layers](image)

4.4 The reservoirs with inter-layers communication

Figure 15 represents a composed reservoir with inter-layer communication. The flow and pressure changes profile, for a gas well, can be based in the homogenous reservoir theory. Whilst, with regard to the oil wells, that behaves as homogenous, with product permeability-thickness, kh, equal with the value of the entire system. The presence of the inter-layers communication can be verified only by analysing the wells flow and pressure profiles [4, 6, and 11].

![Figure 15: Two communication layers reservoir](image)

4.5 Fractures conductivity in the multi-layers reservoirs

This concept is introduced by Raghavan et al, and is calculated with the following equation:

\[ C_{\text{RSh}} = \frac{k_j h_j}{k h} \sqrt{\eta_j} \]  \hspace{1cm} (11)

where: \( \eta_j \) diffusion coefficient of the layer \( j \).

\[ \bar{\eta} = \frac{k}{\phi \mu \bar{g}} \hspace{1cm} C_{\text{RSh}} = \sum_{j=1}^{n} C_{\text{RShj}} \]

The equivalent length of the fractures and their equivalent conductivity are calculated as follows:

\[ \bar{K}_c = \sum_{j=1}^{n} C_{\text{RSh}} \eta_j \]  \hspace{1cm} (12)

\[ \bar{K}_c = \frac{\left( \sum_{j=1}^{n} k_j \eta_j \right)^{\frac{3}{2}}}{k \bar{h}} \]  \hspace{1cm} (13)

The dimensionless conductivity is calculated [4, 6, and 11]:

\[ C_{\text{D}} = \frac{k_i \eta_i}{k \bar{h}} \]  \hspace{1cm} (14)

As the solution of the diffusion problem for the multi-layers reservoirs as very complicated, by Camacho is showed how can be handled this problem by considering the reservoir as it represent a single layer system. The basic assumption is that the fractures don’t communicate in between. In the fracture would communicate than the value of the \( C_{\text{D}} \) would be somehow bigger and the value of the ratio \( h_i / \eta_i \) plays an important role regarding the well performance. In the layers have been subject of hydraulic fracking, than the maximal yield could be taken only in case that the flow front reach any fracture simultaneously. Regarding the gas reservoirs, the maximal yield of a two layers reservoir could be gotten when is fulfilled the following criteria [4, 6, and 11]:

\[ \frac{C_{\text{D}} \delta h_2}{C_{\text{D}} \delta h_1} = \frac{C_{\text{D}} \delta h_3}{C_{\text{D}} \delta h_1} \]  \hspace{1cm} (15)

where: \( C_{\text{D}} = k_i \eta_i / k \bar{h} \)

(16)

The dash line in the Figure 16 is drawn by the solution of the equation 15. Its solution is done based in the assumption that the boundaries effect is negligible. Is not possible to use the reservoir conductivity if the boundaries of the reservoirs effects plays any role.

![Figure 16: Productivity criteria’s for the maximal yield](image)

5 FACTORS THAT IMPACT THE MULTI-LAYERS RESERVOIRS PERFORMANCE

Generally, the factors that impact the multi-layers reservoirs exploitation are [12]:

- The dimensionless conductivity
- The thickness of the layers
- The permeability of the layers
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• **Relative permeability**: If all thin layers have the same value of the relative permeability, the average water saturation will be larger in the less permeable layers than in the more permeable ones. This is because their average pressure is higher in the layers will lower permeability;

• **Pores size**: If the pores size in the less permeable layers are smaller than those of the more permeable layers, than to the fluid flow in the reservoir would appear additional resistance. This effect can be calculated by the utilization of the capillary pressure curves;

• **The formation geometry**: The geometric shape and the inter-layer communication spatial distribution, have strong impacts with regard to the multilayers reservoir exploitation;

• **The permeability anisotropy**: In most of cases of the oil reservoirs, the vertical permeability is much smaller than the horizontal one;

• **N-Layers systems**: The exploitation performance analysis is strongly depending by the accuracy of the flow equations, especially in the case of the sum formulas.

6 THE ECONOMIC INDICATORS OF THE MULTILAYERS RESERVOIRS

The multilayers reservoirs type has direct impact with regard to the economic efficiency (feasibility) of their exploitation. Some of the inter-layer communication advantages are [7, 12]:

- Shorter exploitation time;
- Higher oil recovery coefficient;
- Lower cost for the well perforation and completion;
- Shorter time for the well test information interpretation.

In many cases the reservoirs with lack of inter-layers communication, could be converted in reservoirs with communication via the application of the hydraulic fracking. The artificially vertical fractures created, allows the fluid flow by all layers, whose are already communication in between and not only by the well, whose was representing the only communication way.

7 CONCLUSIONS

1. The well testing process allows the wellbore status evaluation and the reservoir characterization;
2. It allows the reservoir properties determination for the purpose of the accurate reservoir description;
3. It helps for the identification of the productive section of the well;
4. The wellbore status, reservoir permeability calculation combined with the statistical and graphical processing of the information’s allows the skin effect calculation. These processes facilitate the decision making regarding the EOR implementation;
5. The reservoir numerical modelling, as the most important scope toward the reservoir exploitation optimization is based in the identification of the type, spatial extension and its geometry, human and financial resources;
6. The multilayers reservoirs exploitation process is very complex, mostly due to their heterogeneity and anisotropy;
7. The well testing allows the evaluation of the conditions and characteristics of these kinds of reservoirs;
8. Though the well testing is possible the determination of the parameters for each layer for the purpose of the accurate description of the multilayers reservoir;
9. This process allows the prediction of the reservoirs performance along their exploitation period;
10. The economic indicators of these reservoirs exploitation tend to be more positive than of the simple ones.

8 REFERENCES


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