Selection of the optimal completion of horizontal wells with multi-stage hydraulic fracturing of the low-permeable formation, field C

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Abstract. At the moment, many fields of Western Siberia are in the later stages of development. In this regard, the multilayer fields are actually involved in the development of hard to recover reserves by conducting well interventions. However, most of these assets may not to be economical profitable without application of horizontal drilling and multi-stage hydraulic fracturing treatment. Moreover, location of frac ports in relative to each other, number of stages, volume of proppant per one stage are the main issues due to the fact that the interference effect could lead to the loss of oil production. The optimal arrangement of horizontal wells with multi-stage hydraulic fracture was defined in this paper. Several analytical approaches have been used to predict the started oil flow rate and chose the most appropriate for field C reservoir J1. However, none of the analytical equations could not take into account the interference effect and determine the optimum number of fractures. Therefore, the simulation modelling was used. Finally, the universal equation is derived for this field C, the reservoir J1. This tool could be used to predict the flow rate of the horizontal well with hydraulic fracturing treatment on the qualitative level without simulation model.

1. Introduction
Most oil companies are beginning to develop field with hard to recover reserves due to growing demand. However, development of these types of deposits cannot be achieved an uneconomical production rate by conventional method (i.e. vertical wells with hydraulic fracturing treatment). The new technology (horizontal wells with multi-stage hydraulic fracturing treatment) replaces the previous one due to high production rate.

Further, many scientists have analyzed this issue since 1984 years, for example, such scientist as Giger et al. suggested the first analytical solution for evaluation of horizontal wells intersecting fractures; however, this equation could not manage with flow in the fracture and in the reservoir properly. Moreover, Hujun Li (1996) and Economides and Martin (2010) presented the more practical application of mathematical models. In addition, the next mathematical model was introduced by Boyun Gou and Xiance Yu (2008). The proposed equation includes several flows (the reservoir radial and linear flow, fracture linear and radial flow respectively).T.M. Herge (1994) presented accurate methods of determining a productivity of multifractured horizontal wells as well as Hong Yuan (2010) showed the new approach for calculation of horizontal wells productivity with and without fractures [1-8].

In addition, these models are intended for horizontal wells with transverse fractures. The horizontal well with transverse fractures will be used for field C. Geological and petrophysical properties of the field C reservoir J1 are presented in the Table below.

Table. Petrophysical properties of the field C reservoir J_1.

Parameter	Unit	Value
Average depth (TVDSS)	m	3006
Average total thickness	m	3.3
Average net pay thickness	m	1.6
Porosity	fr.	0.15
Oil saturation factor	fr.	0.43
Permeability	mD	2.5
Net to Gross ratio	fr.	0.85

Unfortunately, none of these methods give good result due to the following reasons:
- Fracture radial flow is not taken into account
- Low permeable reservoir
- Interference effect

However, Economides method demonstrates best convergence in comparison with other methods. Moreover, the wells that have been exposed by the interference effect can be detected on the following chart (only 16 wells) (Figure 1). The coefficient of correlation showed a good result. It equals 71.4 % without wells with interference effect.
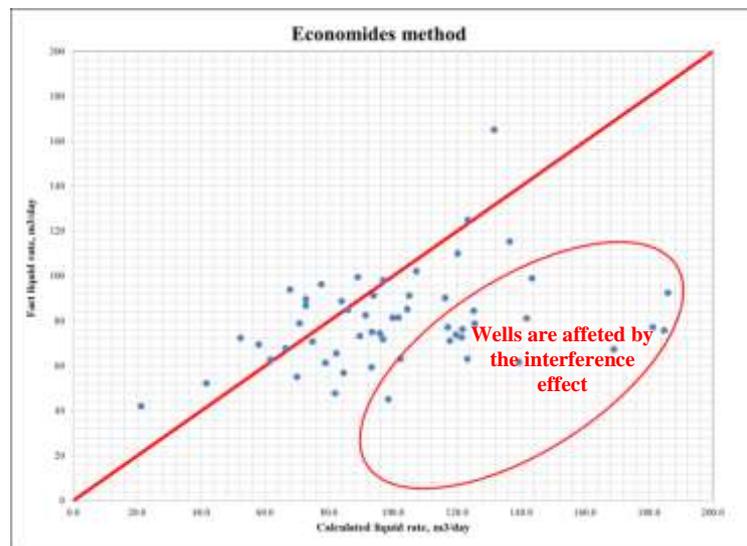
Figure 1. Economides method with interference wells.

Furthermore, none of these analytical solutions which were listed above, take interference effect between adjacent fractures into account. Therefore, the simulation model seems to be an appropriate approach to solving this problem (optimum completion of the wellbore).

2. Simulation approach
The size of this sector model is 1400 meters in length (X-direction) and 800 meters in width (Y-direction), moreover the number of the cells in the X-direction, Y-direction and Z-direction is 28, 16 and 32 respectively. Also, the dimensions of the sector model were selected with respect to the well pattern.

After that, the horizontal well (length of horizontal section is around 600 meters) was added in the center of the sector model with fractures along the horizontal wellbore. Moreover, the fractures were set by the function WFRA (well fracture) in the Tempest software. In addition, there is no pressure support, so horizontal well is on depletion drive during three years (normal lifetime of the fractures after multi-stage hydraulic fracturing treatment)

The simulation model was provided for the next cases:

• 1-7 hydraulic fractures along the horizontal wellbore (the maximum 7 fractures, because the minimum distance between fractures should not be less 80 meters due to technological constraints).

• The mass of proppant varies from 30 ton to 167 ton per one stage (there is a risk of breakthrough in the overlying water-saturated reservoirs above 167 ton of proppant per one stage).

Location of frac ports relative to each other should be uniform because uniform distribution of frac ports along horizontal part of the well gives the effective involvement of the reserves by a well and exclusion of interference effect.

In general, forty seven models have been done with different fractures and mass of proppant. The cumulative oil production schedule is presented with 100 ton of proppant per one stage for different number of fractures.

Based on this graph, it is possible to conclude that interference effect can be observed with increasing number of fractures (reduction of rate of cumulative oil production). Moreover, this effect also could be detected at the start of the well production. The following chart demonstrates that the production rate does not increase linearly, the production rate remains the same with 7 fractures in comparison with 6 fractures (Figure 2). In addition, the flow rate from the simulation model with 5 fractures (Qliquid =76.86 m3/day) is approximately the same in comparison with the real data, for example the well H5 (L=593 m, Qliquid =78 m3/day).
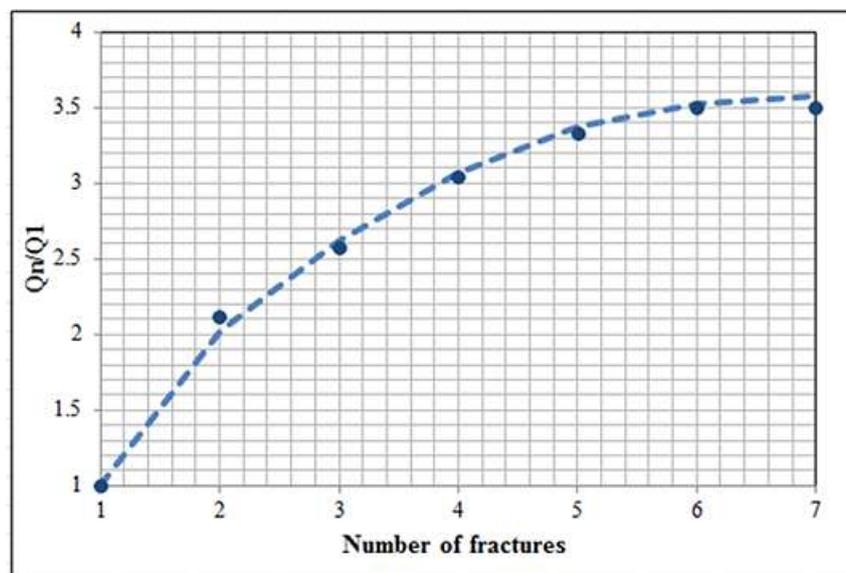
Figure 2. Influence of number fractures on the production rate of the horizontal well with 100 tons of proppant per one stage.

Selection of the optimal horizontal well arrangement is directly dependent on the economic results. As the rate of cumulative oil production reduces with fracture number increase, however, it is still the highest in comparison with others. However, the expenses also increase with the number of fractures [9-11]. The chart of NPV was constructed for different cases. The obtained results are demonstrated in Figure 3.
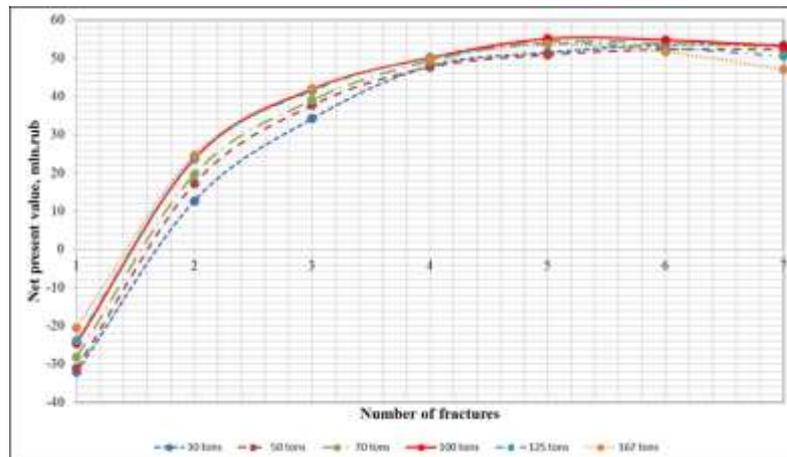
Figure 3. Net Present Value for different cases.

The optimum number of fractures of horizontal well is five with 100 ton of proppant per one stage based on the NPV results. Moreover, the fractures with higher mass of proppant per one than 100 ton show lower NPV. It could be explained by insufficient increase in fracture geometry (width and length) that can cover expenses.

Finally, the geometry of the fracture (100 ton of proppant) is listed below:
- Propped Half-Length 151 meters
- Total propped Height 56 meters
- Average Frac Width 3.65 mm

3. The universal equation

When the recommended distance between fractures is determined, the universal equation could be derived through the simulation modeling data. The principle of universal equation is the representation of fractures (horizontal well) as vertical wells with hydraulic fracturing [12]. This equation can be used to determine the starting flow rates for horizontal wells with multi-stage hydraulic fracturing treatment on a qualitative level. However, there are several conditions for the application of this equation:
- The presence of a vertical well in the proposed area of horizontal well drilling;
- Hydraulic fractured vertical wells;
- The properties and geometry of the fracture should be identical as for vertical well and for horizontal well with multi-stage hydraulic fracturing;
- Flow from fractures into the wellbore (or negligible flow from matrix into the horizontal section).

First of all, the geometry and properties of the fracture were chosen for 100 ton of proppant per one stage for which the universal equation will be derived. Therefore, the average fracture properties are almost similar to the real fractures after hydraulic fracturing treatment.
Secondly, the correspondence of the interference effect on the multiplicity of the starting flow rates (QL_{120} /$QLn<120$) were obtained from the simulation model (5 fractures), with a distance between the fractures being less than 120 meters (limiting distance).

Thirdly, the starting liquid flow rate depends on three variables:

$$, \tag{1}$$

where   – the starting liquid flow rate of vertical well with hydraulic fracturing, N- number of fractures of the horizontal well,   – reservoir pressure in the region where the planned horizontal well will be drilled.

In addition, this function does not depend on the reservoir properties (KH), because the depositional environment is shallow marine so the reservoir properties do not tend to vary significantly. The following chart demonstrates the multiplicity of the starting liquid rate with different

number of fractures in comparison with the starting flow rate with one fracture at different reservoir pressure (Figure 8). According to this chart, the equation was calculated based on the linear regression through the least-square deviation method that was derived in the special software Kompas.

$$\qquad\qquad \overline{\qquad\qquad} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (2)$$

Finally, the universal equation of determining the starting liquid flow rate for horizontal well with multi-stage hydraulic fracturing was derived by combining these two equations:

$$\rule{10cm}{0.4pt} \qquad (2)$$

If L≥120 than L=120

There are two main factors leading to a production decline at Field A, i.e. liquid loading and condensate banking.

To compare the obtained results (through the universal equation) with the starting liquid flow rate of horizontal well (with Hydraulic fracturing) 47 wells were chosen (Figure 4).
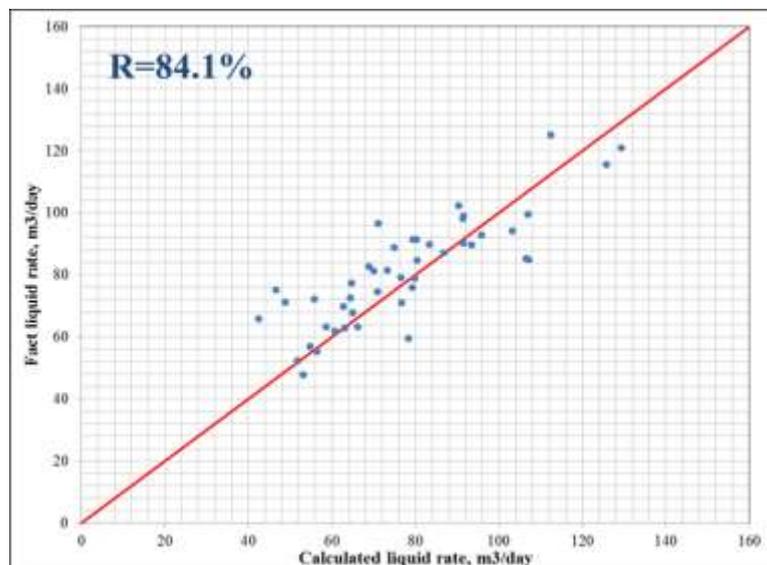
Figure 4. Comparison of the actual data with the calculation through the universal equation.

According to this chart, the linear relationship is observed and the correlation factor is approximately 84.1%. In conclusion, this tool could be used to predict the flow rate of the horizontal well with hydraulic fracturing treatment on the qualitative level without simulation model if the listed conditions have been already satisfied.

5. Conclutions

1. The horizontal wells with multi-stage hydraulic fracturing seem to be more preferable than vertical wells with hydraulic fracturing treatment in the Field C, reservoir J1.

2. The technology (Frack ports or Ball dropping process) of multi-stage hydraulic fracturing is applied in the Field C, reservoir J1

3. Analytical approaches do not take into account the interference effect. However, Economides method should be used with caution, despite the fact that the possible wells with interference effect are observed

4. The simulation model tends to be an appropriate approach to choosing the optimum completion of the wellbore

5. The optimum arrangement of the horizontal well is five fractures with 100 ton of proppant per one stage based on the NPV results. The geometry of the fracture (100 ton of proppant) is listed below:

- Propped Half-Length 151 meters
- Total propped Height 56 meters
- Average Frac Width 3.65 mm

6. The universal equation gives the appropriate correlation factor (R=84,1%) and could be used to predict the flow rate of the horizontal well with hydraulic fracturing treatment on the qualitative level without simulation model

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