

Oil extraction optimization case: horizontal permeability heterogeneity evaluation and application

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Abstract. Permeability is a parameter influenced by a direction and measurement scale that defines permeability as an anisotropic property. This parameter is very important, as it influences a fluid flow direction and velocities in the subsurface, which in turn causes problems with an uneven and unwanted water front, high early water production, losses of production and many other problems, if not addressed properly. Unfortunately, anisotropy becomes evident only when those unwanted symptoms occur. The knowledge of a magnitude and direction of anisotropy can be very important in production planning and management. Well pattern orientation, spacing, perforation program can all be optimized in the very early stages of development.

1. Introduction

Permeability is a parameter influenced by a direction and measurement scale that defines permeability as an anisotropic property. J.H. Baas et al. [1] made an observation that compares permeability measured in several different samples and in different directions. The authors concluded that permeability measured in a direction being parallel to a paleoflow in the bedding plane has the biggest value, while that measured perpendicularly to the bedding plane has the lowest one. These two extremes can be observed in the majority of cases, while the values of permeability measured in other directions fall between them [2].

The goal of this paper was to analyze data gathered and form general recommendations for an optimal production practice in an anisotropic reservoir to be proposed and, possibly, to create a potential strategy for further development.

2. Theory

Many geological methods were developed in the past to determine the direction and quantification of anisotropy and permeability alone. Conventional methods used for this purpose were: microscopic petrographic description, mineralogical analysis with infrared spectroscopy, as well as permeability and porosity correlation, conductivity and acoustic velocity measurements, etc. The authors also mention some novel techniques: permeability scans on rock surfaces, petrographic image analysis from a thin section, and density profiles obtained with a computerized tomographic (CT) scanner [3].

Wade et al. [4] wrote about particle methods that were used to determine anisotropy at the Eldfisk field in preparation for water flooding. The authors connect permeability anisotropy with horizontal stress anisotropy and use methods like: elastic strain relaxation, borehole image logs and oriented acoustic logs to determine the orientation of naturally occurring fractures in a depleted reservoir.



In the laboratory analysis of anisotropic sandstones, Auzeias et al. [3] showed that electrical and sonic anisotropies were found to be small in otherwise very anisotropic rock because in this case permeability was governed by texture and not by mineralogy.

J.H. Schon et al. used several log responses (induction, neutron and NMR) for the derivation and comparison of log-obtained permeability anisotropy with that obtained from core analysis and well tests. Very poor correlation was obtained for all the samples, which was expected, because all these responses represent scalar values, while the resulting parameter derived from them should be a vector [5].

3. K oilfield description

Field K is located in the West Siberian Plate in Tomsk Oblast. It was discovered in 1985 and the first oil was produced in 1998. The reservoir includes Jurassic sands of shallow marine and deltaic facies. Four possibly oil bearing layers were detected and are not all present in the cross section in different areal sections of the reservoir.

4. Core analysis

For the purpose of anisotropy investigation, quantification and orientation determination, several sets of data were available:

- Petrographic image analysis for the oriented core thin section of reference well 187
- Permeability analysis to liquid in principle directions

Petrographic grain orientation analysis of core samples

Being a clastic reservoir, the permeability anisotropy of field K formation was not expected to be the consequence of natural or other fracture occurrence, but the aftermath of depositional environment processes and matrix. That is why grain fabric analysis was performed on the core sample of reference well 187. Particle methods use thin section of core and microscope to determine mean grain orientation [1, 9]. Firstly, core samples were oriented to the geographical north by magnetic measurements, then they were observed under the microscope and one by one, a representative number of grains was processed. The core sample was rotated and the grains of satisfactory properties were inspected and counted. The result of this analysis is a rose (polar) diagram (figure 1). The number of grains with similar orientation is plotted onto the diagram with a predetermined step-angle, in our data it was 15°. Six rose diagrams were obtained as input data (Table 1.); they were all produced from well 187, samples from 2,762 to 2,787 m MD.

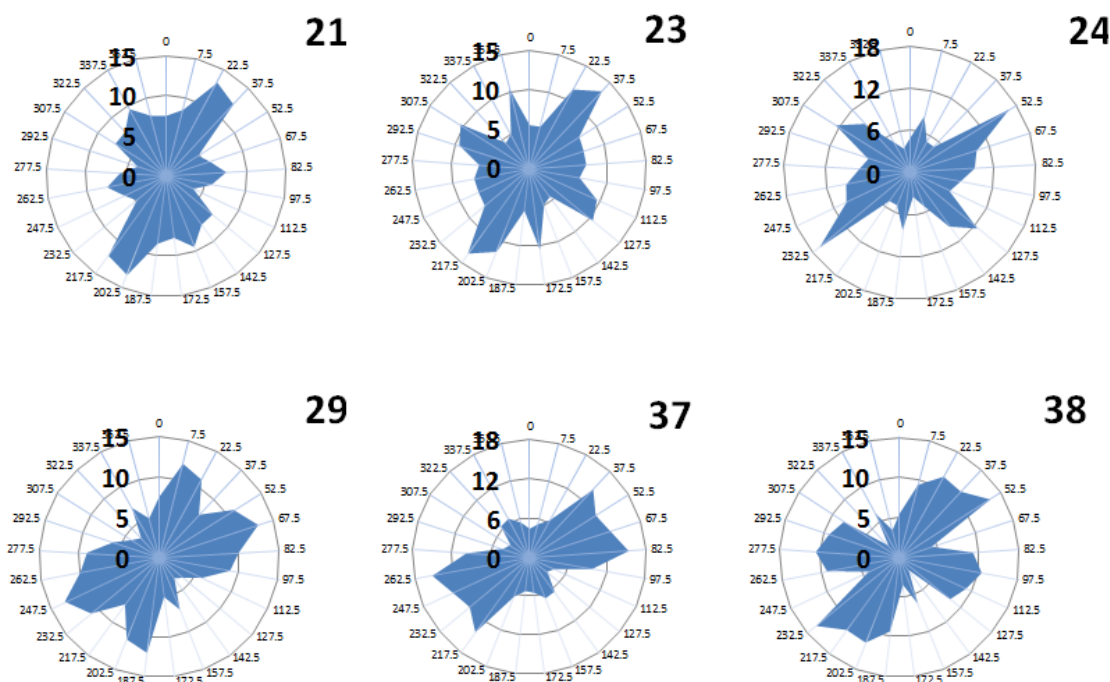


Figure 1. Rose diagrams of long particle quartz grain directions

Table 1. Permeability measured for six oriented core samples in two directions

Sample No.	Interval, m	Porosity, %	Permeability, mD	Direction	k_{Hmax}/k_{Hmin}
21	2,762-2,769	18.6	212.8	NE	2.00
			106.4	NW	
23	2,762-2,769	6.5	0.67	NE	1.14
			0.59	NW	
24	2,762-2,769	9.8	5.4	NE	1.86
			2.9	NW	
29	2,769-2,776	12.2	1.5	NE	1.15
			1.3	NW	
37	2,776-2,783	12.1	0.5	NE	2.00
			0.25	NW	
38	2,776-2,783	10.8	1.6	NE	1.30
			1.23	NW	

It is evident that the majority of grains have the SE – NW direction, it is even more obvious on the cumulative rose diagram for all samples. A value of orientation, 48° from N, was obtained graphically and adopted as a general anisotropy orientation for the entire field (figure 2).

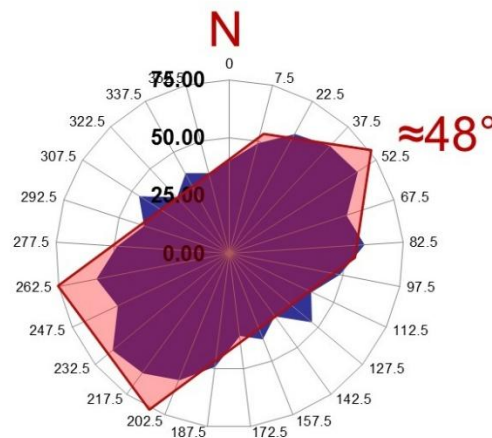


Figure 2. Cumulative rose diagram

Having the orientation of grain alignment (the main permeability anisotropy cause in field K), a measurement of maximum and minimum permeability was performed in direction parallel (NE) to grain orientation and perpendicular to it (NW). The results are presented in Table 1 where it can be seen that the uppermost part of the reservoir has high values of permeability (212 mD) that only grow smaller with depth to only few mD in the bottom part. The magnitude of anisotropy can also be noticed in the same table, which varies from 0.5 to 0.88. In proportion to the sample length and the layer that they represent, the values of k_{Hmax}/k_{Hmin} ratio were calculated for three layers that can be easily separated in the J_1^3 formation: 2 for the upper part, 1.5 for the middle and 1.3 for the lower layer. Those values were used later on in geological model simulation.

5. Results

Simulation model history matching comparison

The newly obtained data about overall horizontal anisotropy were, at this point, included into the existing geological model, simulation was performed and results were analyzed in comparison with the isotropic model.

The simulation of the isotropic model was performed and history matching was compared. The main parameter that was observed and compared was the water cut. Most of the wells showed improvement in prediction of that parameter compared to the isotropic simulation. A reference well simulation result comparison can be seen in figure 3, while changes in the relative difference (d) between the observed and predicted water cut for all wells in the investigated area can be noticed in figure 4.

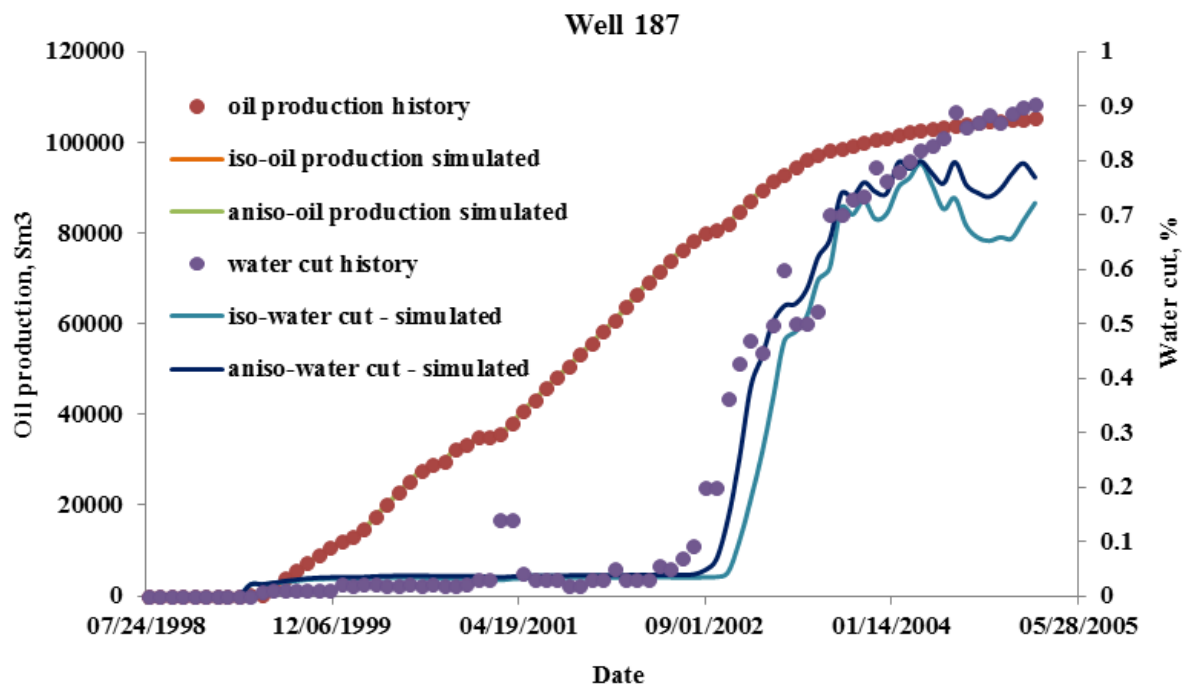


Figure 3. Comparison of isotropic and anisotropic model match

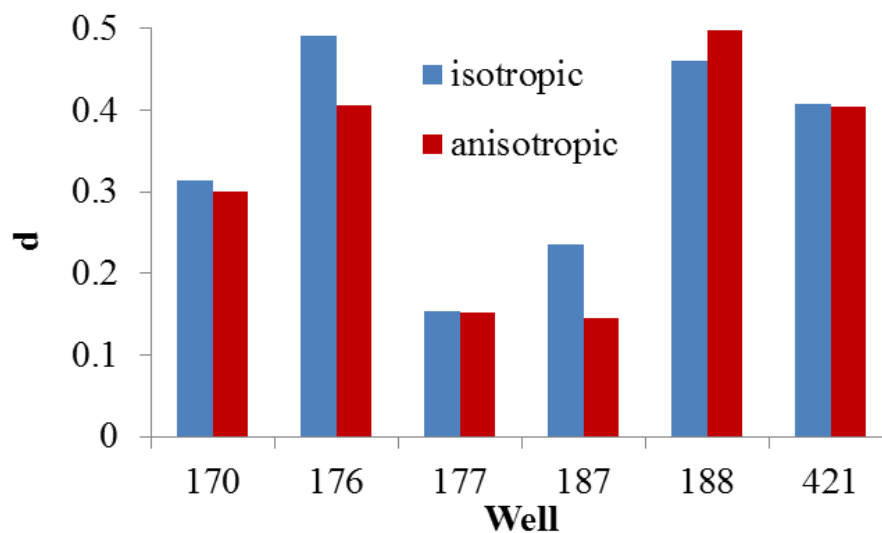


Figure 4. Parameter of match success (d) in both isotropic and anisotropic model

For comparison of the history matching success, one more parameter was created. This parameter is abbreviated with d and represents the square root of the sum of squared difference between the simulated and historical water cut normalized by the square of the historical water cut

($d = \sqrt{\frac{\sum (WC_S - WC_H)^2}{\sum WC_H^2}}$). It is evident that all the wells except well 188 show improvement in

matching if anisotropy is incorporated in the model. In the case of 188, the previous artificial matching could have caused specific irregularities.

It is possible to make a conclusion that taking anisotropy into account can help and improve reservoir and well history matching. As it can be seen, this is also true in the case of field K. It could be said that the introduction of reservoir anisotropy in the beginning of the model adaptation, before individual well history matching by artificially increasing permeability values in some grid blocks, can lead to a more efficient, less time consuming and more accurate model.

Optimization and proposition of further production strategy

The information on anisotropic reservoir behaviour obtained by simulating different scenarios of a conceptual model play a role in the further optimization of water injection and secondary oil recovery. Available production data only come to 2005, so it becomes the starting year for further optimization. The base case would be production until 2010 without any changes. An optimum scenario was sought after only with the transformation of production wells into injectors for the period of 2005 to 2010. In this way, otherwise an unfavourable water front can be distorted to meet the needs. It was performed and simulated in several different variations, resulting in the optimum case where production was enhanced by obeying the general rules described and discovered in the previous sections and by converting production wells into injectors. In the optimum simulation, beginning from 2005, wells 1001, 1002, 407 and 177 had their function altered.

The results show (figure 5 and figure 6) that the simple targeted transformation of a producer into an injector can enhance production in field K up to 70,222 cm³ (around 2% of the overall oil production). The above- mentioned figure also shows enlargement in cumulative oil production for two wells, 391 and 425. The first one has undergone the cumulative oil production increase of 13.2%, while well 425 showed a growth by 8.5%. The magnitude of oil production enhancement differs from well to well in a range from unchanged to as high as 18.2% (well 379).

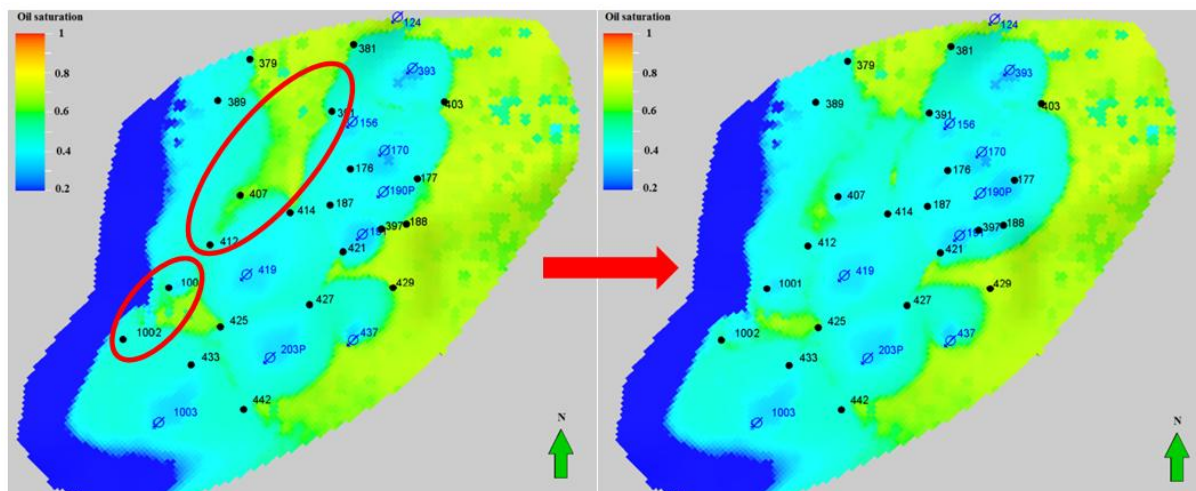


Figure 5. Oil saturation areal view for base and optimal case

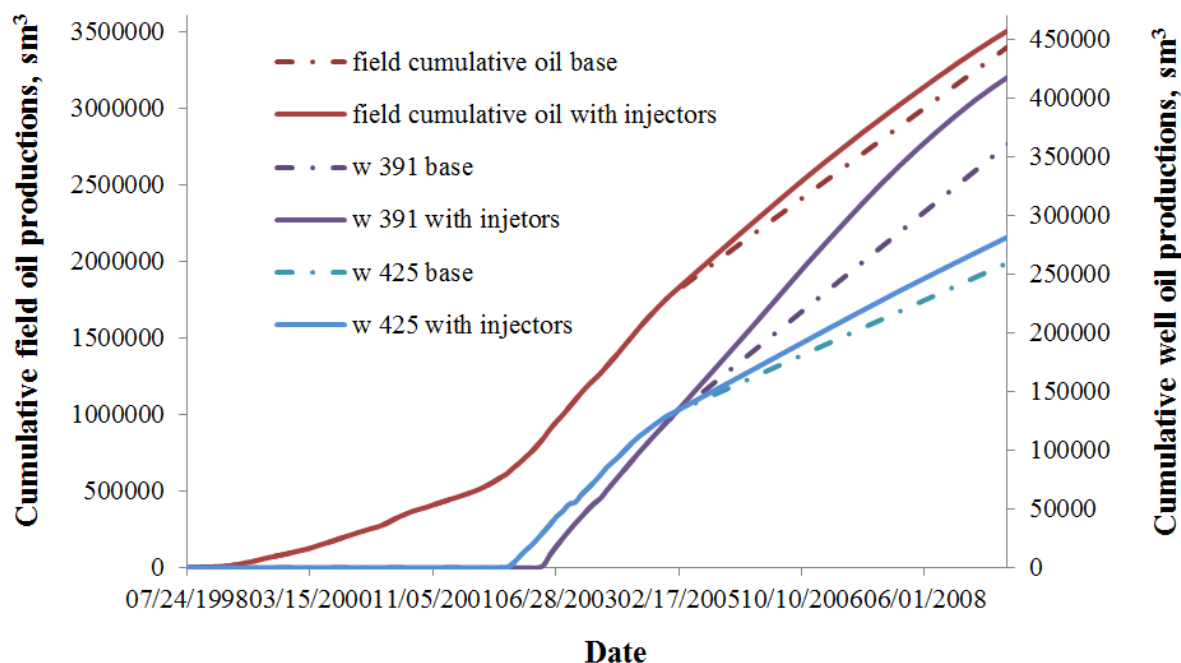


Figure 6. Diagram of cumulative field and well oil production for two cases

At this point, there were no changes in the perforation program; it can be one of the sources of extensive water injection and production enhancement. In that light, the optimization of the perforation program is proposed for further work as well as more detailed optimization of injector flow-rates.

6. Conclusion

These relatively inexpensive and quick methods can be applied during field exploration in order to gather information regarding formation properties and anisotropy. It can lead to the early understanding and prediction of possible future production problems that can arise from them. With every new well that is drilled and set of data being analyzed, a more complete picture is formed, potentially saving considerable funds in the future.

Summing up the results obtained in this study the following conclusions can be made:

- The orientation of grain alignment and the axis of the maximum permeability were determined to be 48° from N. This azimuth was also adopted as the direction of spatial absolute permeability spread that revealed parts of the reservoir with good properties and was confirmed with permeability map construction.
- The petrographic grain fabric analysis revealed microscopic anisotropy within a range from 0.5 to 1. This was the result of the depositional environment and, as expected, in further analysis it was proved to be present in the entire field.

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