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Qualitative Discuss on Well Test Curve Uncertainty Analysis in Remaining oil Evaluation of Thick Bottom Reservoir

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Abstract: In directional wells of thick bottom water reservoir, partial perforation is usually applied to prevent rapid coning of bottom water. Because of the existence of interlayers, water driving conditions and remaining oil distribution become complex. In partially perforated wells in the survey area oil saturation of lower unperforated section can't be tested directly due to the influence of completion structure. The "spherical flow" characteristics cannot be seen from the pressure derivative curve during the pressure building. The uncertainty analysis of well-test curve is used in the analysis of interpretation model, Kz/Kr value and boundary feature. The results show that the unperforated section at the lower part, slightly affected by the water flooding, contributes less to oil production. Through the study on reservoir numerical simulation mechanism, it's concluded that in oil wells driven by bottom, water cut features rapid rise in early stage and slow rise in later stage. The water cut rise curve mainly belongs to a convex type. In contrast, in oil well driven by edge water, water cut rises slowly in early stage but rapidly later. The water cut curve is mainly a concave type. The research well shows a concave type in the water cut curve. Test data shows the well is driven by edge water under the influence of interlayer. The unperforated section at the lower part of reservoir where the remaining oil concentrates can become the target of further tapping.

Keywords: Thick Bottom Water Reservoir, Well Test Curve, Uncertainty Analysis, Rising Law of Water Content, Remaining Oil

1. Introduction

Previous studies have shown that the different perforation schemes have great influence on the development effect at the bottom water reservoir. High perforation ratio will lead to rapid water breakthrough, or reduce the well productivity. Having a reasonable perforation scheme, the oilfield can get a long time for oil recovery without water prodcution, water cut rise slowly after water production and obtain better development effect [1]. In gravel packing completion string, the complex tools cause the well logging difficult at production stage [2].

The depositional facies of Wenchang Z group is fan delta plain- front edge distributary channel. It features thick reservoir, wide distribution, good physical properties. The thickness of the sandstone reservoir ranges from 109.53m to 147.1m, and that of the oil reservoir is from 59.38m to 101.1m. It's a fine sandstone reservoir controlled by fault nose structure with bottom water as main driving body. The reservoir has huge water body energy and the oil is drilled through directional wells. At present, the comprehensive oil production capacity is 212m^3/d, and the comprehensive water content 87.5%. The recovery percentage 46.4%, which falls on the category of high water-cut stage and is difficult to tap at the later stage. The filling and sand control technology was used in well completion, which result into that production logging operation can't be achieved in the low part of the reservoir, and the residue oil saturation can't be obtained either.

2. Outline of the Oil Wells

The natural water energy of wenchuan group Z in Wenchang oilfield mainly derives from the west side of the structure, and the main direction of water flooding flows from west to East and advances along the main channel of the river. Well B5 is an adjustment well in northern part of the structure (Figure 1). The well, which was put into operation in October 2009, is located in the river edge. At the beginning of operation the effect of water flooding is small. The water-free oil production period is 447 days, during which the water free oil production is $10.81 \times 10^4 m^3$ oil. At the beginning of operation, oil production peaks at $300 m^3/d$. Up until the end of March 2017, the cumulative oil production is $31.39 \times 10^4 m^3$, liquid yield $144 m^3/d$, moisture content 63.2% (Figure 2).

When B5 well is drilled into the oil water interface, the reservoir, which is 52.68m in thickness, belongs to medium permeability reservoir with the average porosity 19.4%, average permeability 296mD. In the wells, interlayer is developed vertically with strong heterogeneity (Figure 3, Figure 4). In consideration of delaying water coning, partial perforation is adopted at the upper section of the well. The length of perforation interval is 23.62m at the upper part, unperforated interval 29.06m, unperforated percentage 55.2%.

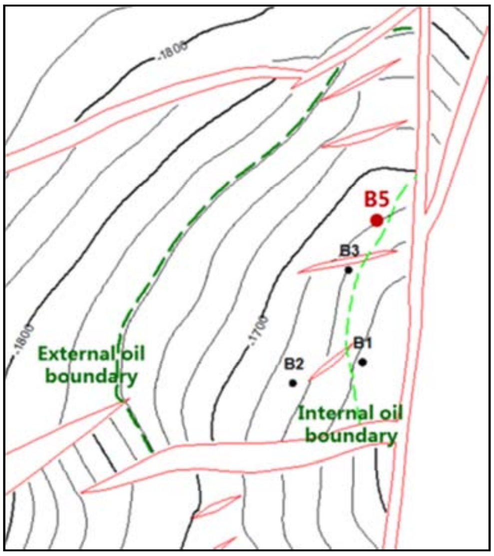

Figure 1. *Well map of Z oil formation in Wenchang Oilfield.*

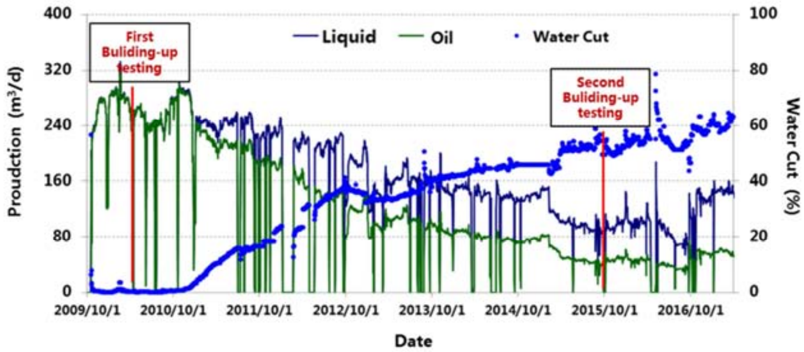

Figure 2. *Production curve of B5.*

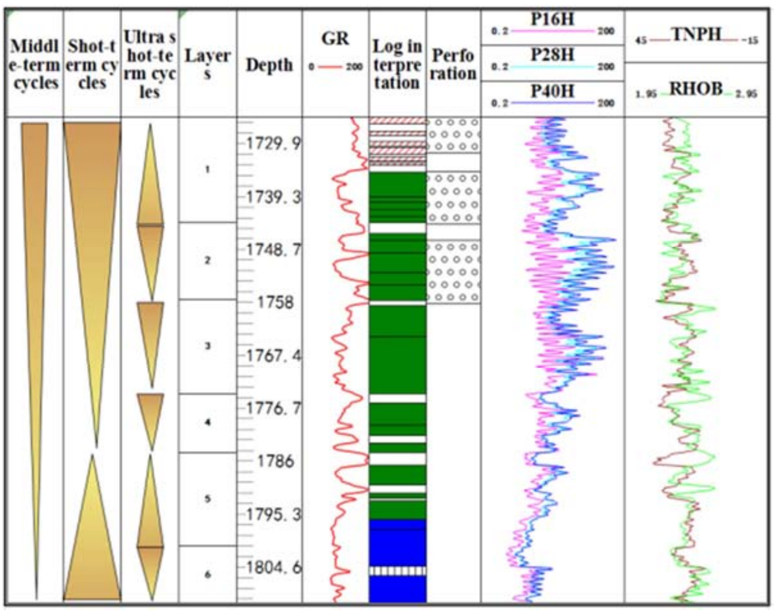

Figure 3. *Log interpretation histogram of B5.*

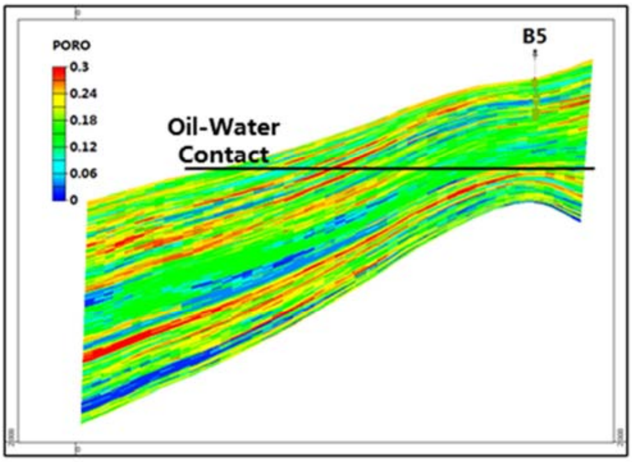

Figure 4. *Through-well porosity profile of B5.*

3. Well-Testing Characteristics of Partially Perforated Oil Wells

Bottom pressure change during the spherical flow stage:

$$\Delta p(t) = p_i - p_{wf}(t) = \frac{0.933q\mu B}{Kr} - \frac{8.833q\mu B}{K}\sqrt{\frac{\phi\mu C_t}{Kt}} \quad (1)$$

So:

$$\Delta' p(t) = \frac{d\Delta p}{dlnt} = \frac{d\Delta p}{dt} * t = \frac{4.4164q\mu B\sqrt{\phi\mu C_t}}{K^{\frac{3}{2}}} * t^{-\frac{1}{2}} \quad (2)$$

$$\lg(\Delta' p(t)) = -\frac{1}{2}lgt + lg\frac{4.4164q\mu B\sqrt{\phi\mu C_t}}{K^{\frac{3}{2}}} \quad (3)$$

Based on formula (1) ~ (3), seepage characteristic of spherical infiltration (Figure 5) flow in the Cartesian coordinate diagram is displayed as follows: there is a linear relationship between the P and t-1/2. In hemispherical flow (Figure 6) cases, the slope of half semi logarithmic curve is half that of spherical flow; in a double logarithmic plot, pressure derivative curve is a straight line with the slope of -1/2 [3-6] (Figure 7).

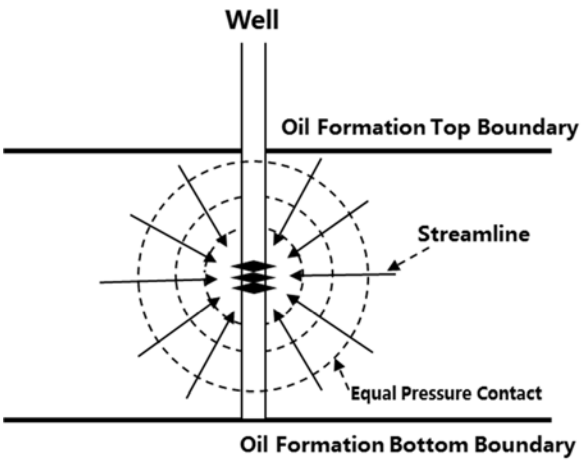

Figure 5. *Schematic diagram of spherical flow streamline.*

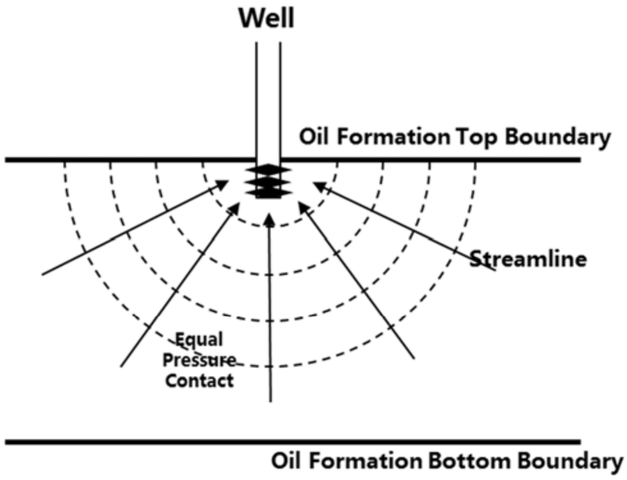

Figure 6. *Schematic diagram of hemispherical flow streamline.*

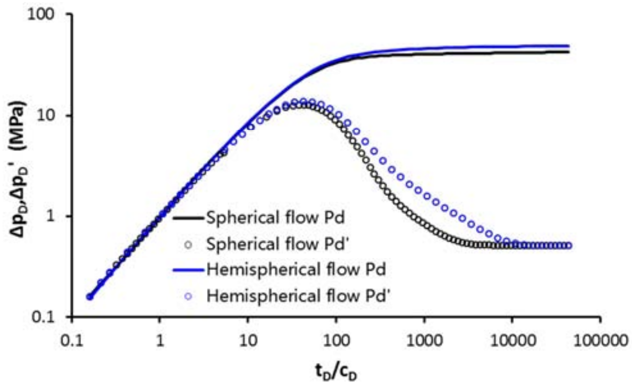

Figure 7. *Pressure derivative characteristic curve of partial perforation well.*

4. Characteristic of Well Testing Curve

The well test interpretation has multiple solutions. More reliable interpretation models and results can be obtained with the help of uncertainty analysis combining with the geological conditions and well production dynamics.

For wells B5, two pressure recovery tests are carried out respectively, at the initial stage (April 2010) and in the middle of the development (September 2015). It is shown from the pressure double logarithmic graph (Figure 8) that, the two curve is generally consistent, reflecting good inheritance in reservoir property, pollution and late boundary reaction. In the initial stage of production, due to the instability of wellbore fluid, the pressure recovery curve of the reservoir in early stage is abnormal, which conceals the flow characteristics in the near wellbore formation. During the second test, the wellbore fluid is stable, the pressure build-up is stable, and the pressure derivative curve is in complete shape. The early test interpretation analysis is carried out using the test result curve.

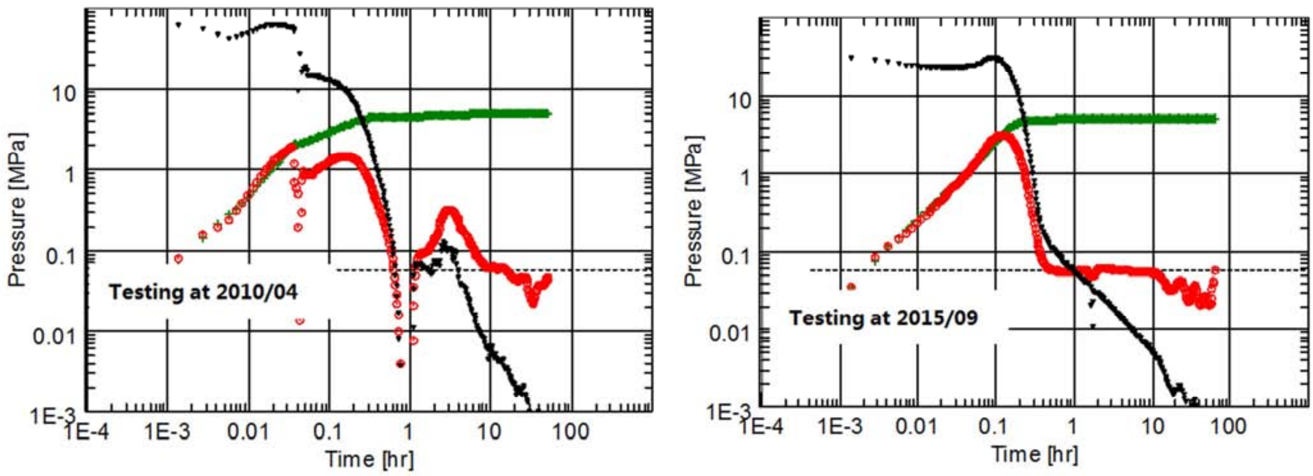

Figure 8. *Pressure derivative curve of Well B5 taken at two different time.*

4.1. Uncertainty Analysis of Kz/Kr Value

Because of the influence of the interlayer, the pressure derivative characteristic curve of unperforated wells in the reservoir with bottom water has no "spherical flow" response characteristics. It is concluded that the lower part of the reservoir can hardly be tapped because of the existence of interlayers.

It is also known according to the characteristics of the double logarithmic pressure curve that under different Kz/Kr values: the lower the Kz/Kr value is, the more obvious spherical flow characters can be seen from the pressure derivative (-1/2 slope segment) curve, the longer the duration is; and vice versa, and this character will be easily overshadowed by the well storage effect (Figure 9). From the second measured pressure derivative curve of well B5, wellbore storage section is short, and there is no spherical flow characteristics, may be due to the impact of Kz/Kr values and the difference in longitudinally thickness. Uncertainty analysis shows that the two fit well in the curve (Figure 10).

Due to difference in effective thickness, physical parameters and boundary distance, the epidermal coefficient is cosistent (Table.1). The results show that the average permeability is 180mD, the Kz/Kr value is 2, and the total skin is 37.5 when all layers are developed (bottom developed model). Through the uncertainty analysis of Kz/Kr values (Figure 9), only when the value is greater than 2, the shape of fitting curve is consistent with that of the test curve. It is known from the well logging interpretation results and plane interbeds distribution (Figure 3, Figure 4) that interlayer is developed vertically at the upper part of the wells, and the interlayer is continuously distributed at the bottom of the reservoir. The longitudinal flow of the fluid is greatly obstructed. It is very unlikely that Kz/Kr value is 2. The interpretation model recommends it as the bottom undeveloped model.

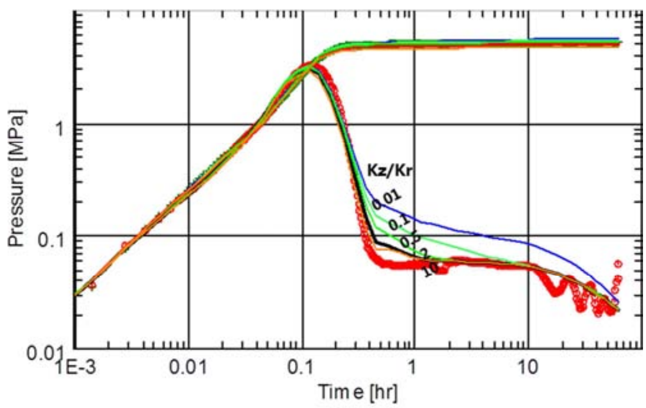

Figure 9. *Pressure derivative curve of different Kz/Kr values.*

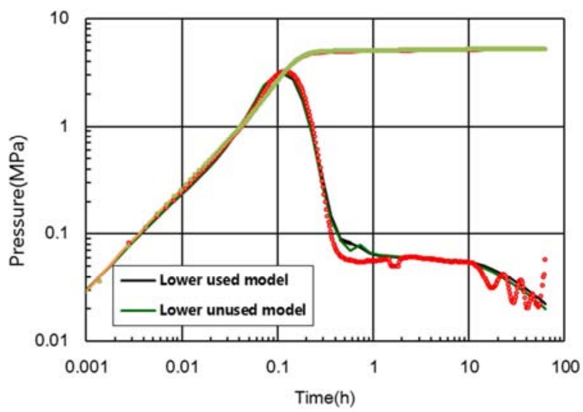

Figure 10. *Fitting results for different models.*

Table 1. Comparison of different model fitting results of B5.

Well	Testing Depth	Testing Time	Model	Effective Thickness (m)	wellbore storage coefficient (m^3/MPa)	Permeability (mD)	Kz/Kr	Mechanical Skin	Geometrical Skin	Total Skin	Constant Pressure Boundary m
B5	2802.6m-	2015/09	Lower Used	52.68	0.06	180	2.0	36.8	4.9	37.5	184
	2814.7m	2015/09	Lower Unused	23.62	0.06	400	—	37.9	0	37.9	256

4.2. Uncertainty Analysis of Well Testing Interpretation Boundary

The oil group has strong natural energy of edge and bottom water, B5 well is drilled into oil-water interface, and the vertical distance between well B5 perforation section and oil-water interface is 43m, and the plane distance is from 220 to 330m. The late stage of the well testing curve shows the characteristic of boundary recharge and the pressure derivative falloff (Figure 8). The closer the constant pressure supply boundary is to the oil well, the earlier the pressure derivative curve falls. According to the boundary uncertainty analysis of different models chosen from Table 1, when the bottom of the reservoir is used (Figure 11), as it is close to the bottom water, approximately 43m, pressure derivative curve decreases rapidly in the reservoir after the end of well storage, inconsistence with the supply boundary distance reflected from the actual curve (about 184m).

When the bottom of the reservoir is not developed (Figure 12), the recharge boundary is mainly displaced by the edge water above the plane. The location interpreted from the actual curve (256m) is consistent with that of oil-water interface (220 ~ 330m). The interpretation model recommended it as the bottom unused model. An analysis of the early test results is conducted based on the model. Two pressure derivative curves show (Figure 13) that property, skin factor and recharge boundary characteristics are basically the same in two tests. The boundary effect appeared later than in the late test, and the initial recharge boundary is interpreted as 350m, the value of recharge boundary changes in the development process as the edge water advances towards the bottom of wellbore.

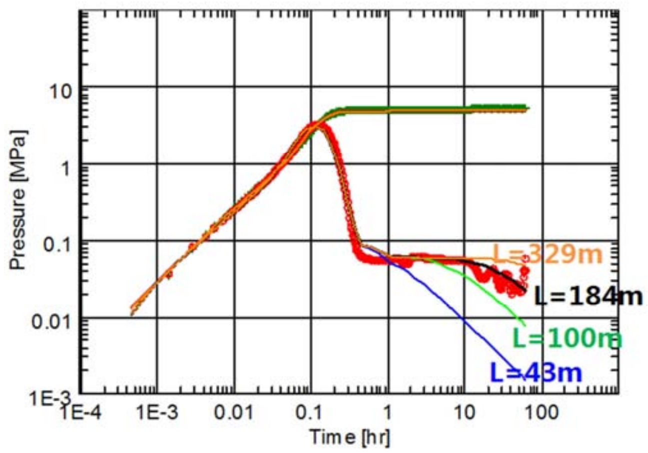

Figure 11. Boundary uncertainty analysis of lower producing model.

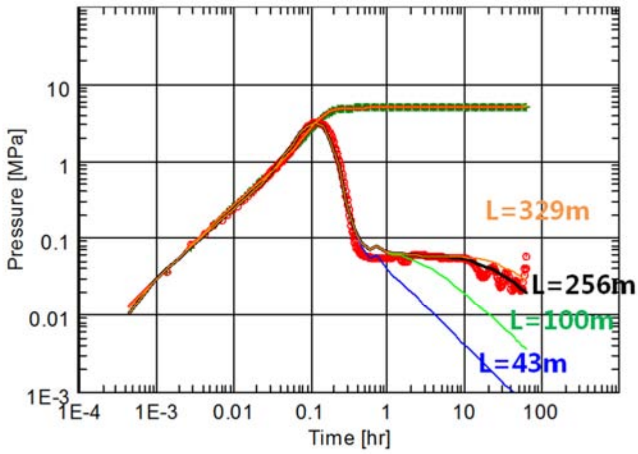

Figure 12. Boundary uncertainty analysis of lower non-producing model.

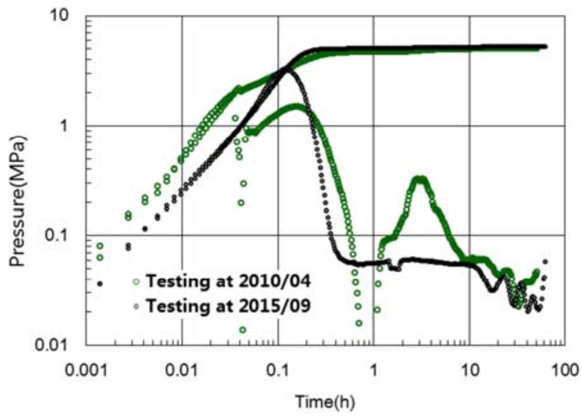

Figure 13. Comparison of pressure derivative curves of pressure building test of B5 taken at two different time.

5. Mechanism Analysis of Numerical Simulation

Through the comparison analysis of reservoir numerical simulation mechanism research and the oil well water cut rising rules, the reliability and the rationality of the well test result has been proven, providing solid basis for future adjustment and potential tapping.

According to the uncertainty analysis result of well-testing interpretation model, combined with the actual block, reservoir numerical simulation model is established. It is a homogeneous model built with physical property obtained from well-testing interpretation, considering different interlayer distribution, the relative permeability curve and production distribution consistent with the actual data of oil field, and the calibration recovery rate defined with water content of 98% as a standard.

The results of different model numerical models (Figure 14, Figure 15) show that when the lower part of Well B5 is developed, water coning is obvious, mainly driven by the bottom water, the water cut curve shows "convex" type in the rising trend, water-free oil production is low, water cut rises fast after the breakthrough, most amount of oil is drilled with high water cut. When the lower part is undeveloped, the well is mainly driven by edge water, showing "concave" type in the rising trend-----high water-free oil production, slow water cut rise after the breakthrough and rich residue oil in the unperforated area [7-12].

The actual water cut rising curve of B5 well shows a "concave" feature, which is consistent with that of the bottom undeveloped model (Figure 16). It shows that the bottom undeveloped model is more consistent with the actual production in oil well. The production level of the lower part of the unperforated section is low and the remaining oil accumulation potential is great. It can be used as a potential area for tapping the remaining oil at the next step.

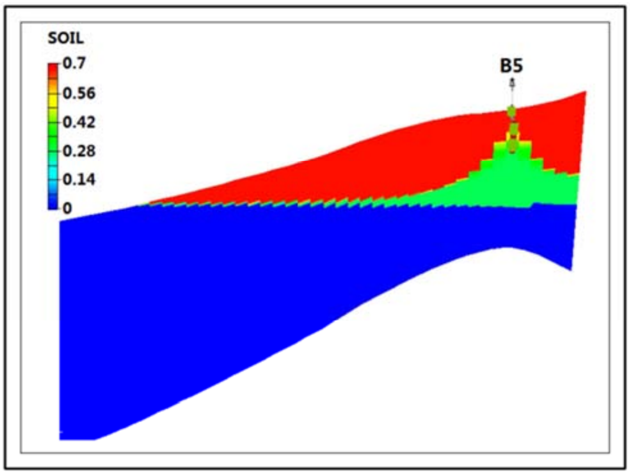

Figure 14. *Water saturation of lower producing model.*

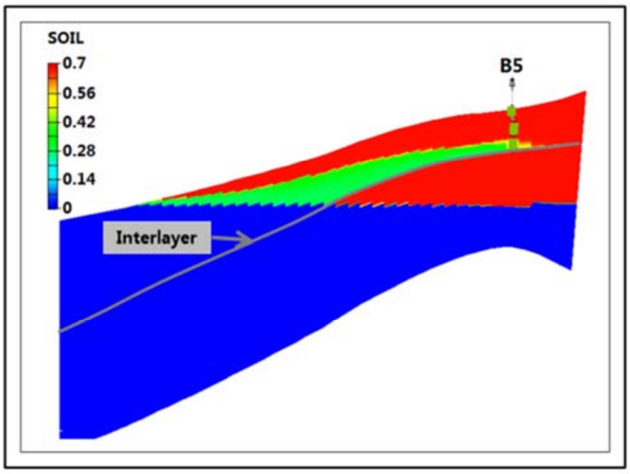

Figure 15. *Water saturation of lower non-producing model.*

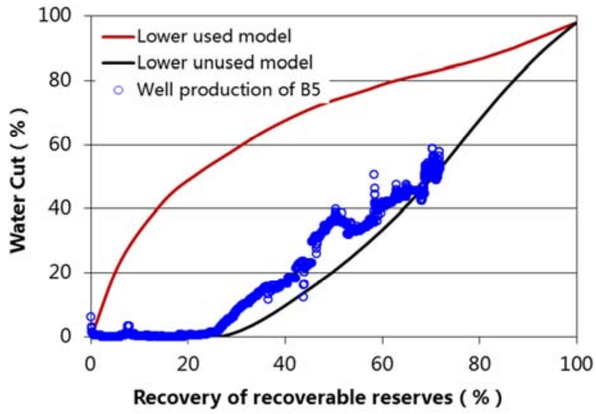

Figure 16. *Comparison of water cut rising law under different production models.*

6. Conclusion

(1) The well test interpretation results have multiple solutions. Uncertainty analysis combining the geological conditions and production dynamics is helpful to obtain more reliable interpretation models and results.

(2) Because of the influence of the interlayer, the pressure derivative characteristic curve of oil wells in the bottom water reservoir has no "spherical flow" response characteristics. It is concluded that the lower part of the reservoir is not used according to the uncertainty analysis.

(3) Through the comparison analysis of reservoir numerical simulation mechanism research and the oil well water rising law, the reliability and the rationality of the well test result has been proven, providing solid basis for the future adjustment tapping.

Nomenclature

$\Delta p(t)$ = differential pressure, MPa
P_i = initial reservoir pressure, MPa
P_{wf} = well bottom flow pressure, MPa
q = oil well production, m^3/d
μ= fluid viscosity, cP
B = oil formation volume factor, m^3/m^3
Φ = reservoir porosity, fraction
K = reservoir permeability, mD
C_t = total compressibility, MPa^{-1}
t = time, hours
r = radius, m

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