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The Study and Application of Optimizing Staged Perforation in Horizontal Wells

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Abstract

Horizontal well is regarded as a mature development technique and has been widely used in all kinds reservoir developing. Many factors cause the uneven development of horizontal sections such as the differences of physical property, friction loss of horizontal section, changes of deviation angle and so forth. Therefore, wellbore flow coupled model is introduced for horizontal well reservoir to clear the influences on horizontal well's even liquid producing profile by all kinds factors. The perforating model of horizontal section is optimized, segmented perforating to achieve even liquid producing profile of horizontal section is used. Optimization software for segmented perforating technique of horizontal well is built up based on research results, and it has achieved good result through primary application.

Key words: Horizontal well; Reservoir-wellbore flow coupled model; Segmented perforating; Even liquid producing; Software

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INTRODUCTION

Horizontal well is referred as an important reservoir developing technique, compared to vertical well, it has many advances such as slow water climb, high production of single well and high cumulative production[1-2]. It has been used and promoted over 20 years at SLOF since the Eighth Five-Year plan period, and also has been extended from heavy oil reservoir to all the reservoir types. Annual production is 241 horizontal wells and annual oil-producing is 1.64 million ton during the 11th Five-Year plan period, and it is one of the most important techniques for stable production and increased production of SLOF. The liquid producing profile of horizontal section would be uneven because of the anisotropy of reservoir, inclination variation of horizontal section, friction loss in horizontal section and so forth[3-4]. Therefore, it is necessary to optimize research for segmented perforating of horizontal section, and apply unevenly perforating to match reservoir and develop anisotropy. Finally, it achieves the goal of balance development.

1. HORIZONTAL RESERVOIR-RESEARCH OF WELLBORE FLOW COUPLED MODEL

The fluid flowed in horizontal wellbore is metamorphic flow, pressure drop exist in the direction of wellbore flow at production section, and pressure distribute unevenly at production section. High production pressure difference and high radial flow exist at the toe part of wellbore down-steam[5]. Low production pressure difference and low radial flow exist at the heel part of wellbore up-steam. The reservoir flow into production range in radial direction along the wellbore direction of production range distribute unevenly. Uneven distribution of radial flow which in turn effect the pressure distribution of wellbore flow direction in production section[6]. Therefore, it is a coupled relationship between the reservoir influent and wellbore flow in production section. The process of fluid flow from reservoir to ground can be subdivided into reservoir influent.

1.1 Reservoir Influent Flow Pattern of Horizontal Well

When the thickness of reservoir is small, and the distance between drainage boundaries and wellbore is much bigger than the reservoir thickness. Horizontal well is like a crack of reservoir to yield oil. The main part of flow line present horizontality flow, only bend around wellbore and perpendicular to the direction of hole axis that gathered at well bore which present circular radial flow. Thus, the pressure drop produced when liquid flow to wellbore is made up of two parts, which is the pressure drop caused by horizontal flat influent resistance far away horizontal well and the pressure drop caused by radial influent resistance near horizontal well.

Divide reservoir research into three classes, which is unbounded water bottom closed reservoir, fringe water reservoir and bottom water reservoir. Build up a formula for pressure drop from drainage boundaries to wellbore separately[7-8].

(a) In the production under q_L output of one horizontal well of unbounded water bottom closed reservoir, the pressure drop from drainage boundaries to wellbore is:

$$\Delta p_r = \frac{\mu B q_L}{2\pi k h}\left\{\ln\left[\frac{a+\sqrt{a^2-(L/2)^2}}{L/2}\right]+\frac{\beta h}{L}\ln\left(\frac{(\beta h/2)^2-\beta^2\delta^2}{\beta\pi h r_w/2}\right)\right\}. \quad (1)$$

(b) In the production under q_L output of one horizontal well of fringe water reservoir, the pressure drop from drainage boundaries to wellbore is:

$$\Delta p_r = \frac{q_L \mu B}{8.377kL}\left[\ln\frac{\beta h}{2\pi r_w}+\frac{1.333\pi b}{\beta h}-\ln\sin\frac{\pi z_w}{h}\right]. \quad (2)$$

(c) In the production under q_L output of one horizontal well of bottom water reservoir, the pressure drop from drainage boundaries to wellbore is:

$$\Delta p_r = \frac{q_L \mu B}{2\pi k L}\left(\ln\frac{4\beta h}{\pi r_w}+\ln\mathrm{tg}\frac{\pi z_w}{2h}\right). \quad (3)$$

(d) Skin Effect

The pressure drop formula of reservoir influent given earlier is build up under the condition of open hole or completely penetrating well, as to horizontal well of cemented completion well, the permeability around wellbore and reservoir permeability is unequal which must cause the pressure drop of reservoir influent is different from the pressure calculated as open well. Establish the skin factors of drilling damage, open grade and the total perforating skin factor.

1.2 Turbulence Model of Eyehole

To horizontal well which is perforated completion can be regarded as wellbore radial flow that ended at the tail of eyehole. Due to the zone of wellbore outside the eyehole is closed, liquid gathered at eyehole. Hence, we can approximate refer the gathered flow near eyehole as radial flow, as shown in figure 1.Radial flow zone of each eyelet including damaged zone of formation and perforation compacted zone. The external diameter of radial flow can take half of the spacing between two adjacent eyelets. For each shaft unit, eyelets can be considered as even distribution.

1.3 Flow Model of Horizontal Shaft

The pressure loss is different for fluid which exist in horizontal section that flows in perforated section and non-perforated section, it only effected by pressure drop of friction and weight in non-perforated section; besides those two factors, acceleration pressure drop and mixing pressure drop also influence the pressure loss at perforated section.

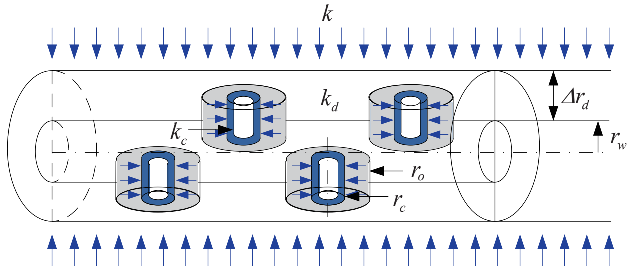

Figure 1
Radial Flow of Eyelet Inside Damage Zone

1.4 Reservoir-Coupled Governing Equation of Shaft

Divided perforated section of horizontal well into n_1 perforating units which length is Δx, and the non-perforated section is divided into n_2 units according to its number. Make the total number of units be n, from toe part to heel part, and numbered them in turn from 1 to n. The division result is shown in Figure 2.

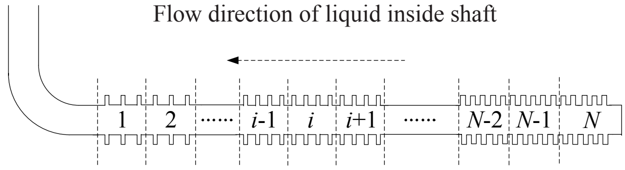

Figure 2
Division Sketch Map of Perforating Units for Horizontal Well

Shaft pressure drop for two adjacent perforating units:

$$\Delta p_{w,i} = p_{w,i} - p_{w,i-1} = (\Delta p_{r,i-1} - \Delta p_{r,i}) + (\Delta p_{s,i-1} - \Delta p_{s,i}) \ (i=1, 2,... N). \quad (4)$$

Equation (4) is the reservoir-governing equation of shaft coupled model.

2. PERFORATION PARAMETERS EFFECT THE FACTOR ANALYSIS

2.1 The Influence of Inclination on Perforation Parameters

The differences of horizontal well's angle, influence of weight and friction have important influence on perforation optimization. When the horizontal well's inclination is bigger than 90°, weight pressure drop in wellbore is negative by gravity, flow pressure of heel part is higher than toe part, production pressure is low, hole density is high at heel part (Program 1); when the horizontal well's inclination is equal to 90°, production pressure of toe part is lower than heel part by shaft friction, hole density is little low at heel part (Program 2); when the horizontal well's inclination is smaller than 90°, flow pressure of heel part is lower than toe part by gravity, large production pressure differences and small hole density at hell part (as shown in Figures 3 and 4).

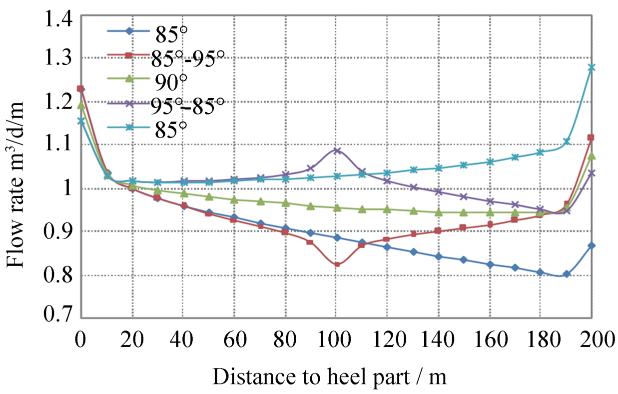

Figure 3
Relationship Curve Between Inclination and Flow

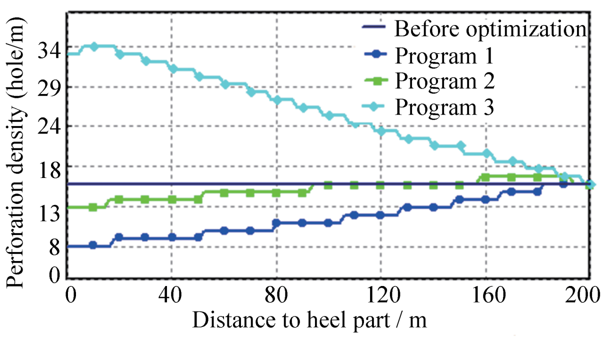

Figure 4
Optimization Curve of Inclination and Perforation Density

2.2 The Influence of Transverse Permeability's Variation on Perforation Parameters

Transverse permeability has serious influence on inflow, sections with high transverse permeability have large inflow, high flow rate and small perforating density; sections with evenly transverse permeability have small perforating density at heel part due to friction; sections with low transverse permeability have small flow rate and large perforating density. There are three designed programs. Program one: Transverse permeability increasing from heel part to toe part, range of permeability is 1,500~2,500 mD. Program two: The permeability of all homogeneous reservoir is 1,500 mD. Program three: Transverse permeability decreasing from heel part to toe part, range of permeability is 1,500~500 mD (as shown in Figures 5 and 6).

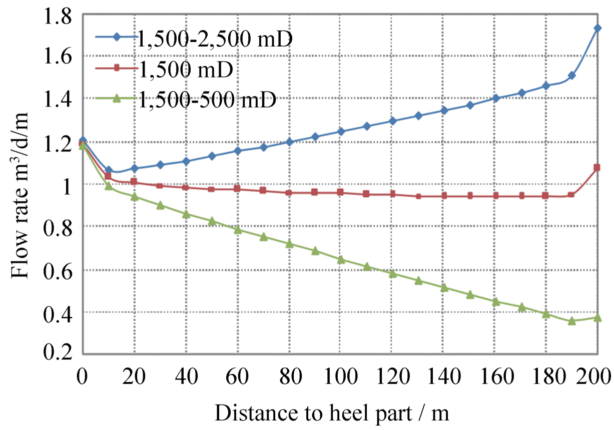

Figure 5
Relationship Curve Between Transverse Permeability and Flow Rate

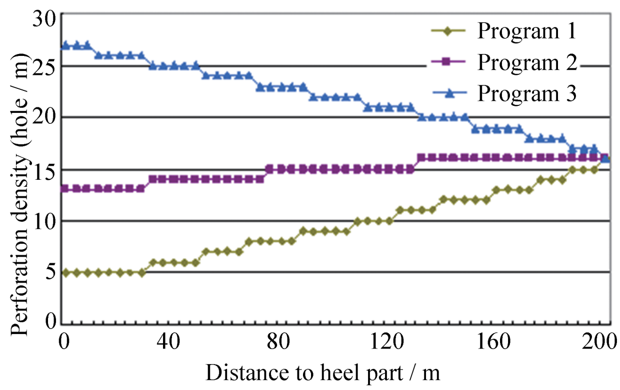

Figure 6
Optimization Curve of Transverse Permeability and Perforating Density

2.3 The Influence of Distance to Bottom Water on Perforation Parameters

The distance to bottom water affects each flow of horizontal sections. The closer distance to bottom water, the bigger differences between heel part and toe part. The closer distance to bottom water, higher flow rate of heel part and lower perforating density. Far from bottom water, less differences between each section, and less differences of perforating density. Designed three programs: (a) the distance between horizontal section and bottom water is 10 m; (b) the distance between horizontal section and bottom water is 15 m; (c) the distance between horizontal section and bottom water is 20 m (as shown in Figures 7 and 8).

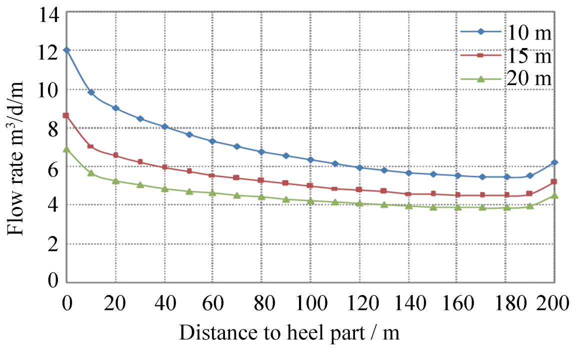

Figure 7
Relationship Curve Between Distance to Bottom Water and Flow Rate

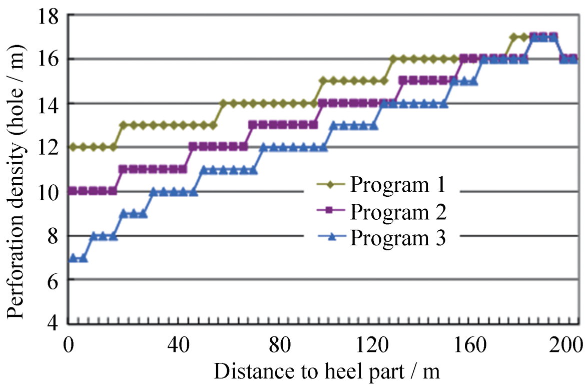

Figure 8
Optimization Curve of Distance to Bottom Water and Perforating Density

2.4 The Influence of Crude Oil's Viscosity on Perforation Parameters

The viscosity of crude oil has little influence on the trend of inflow profile. But with the increment of viscosity, apparent decrease in flow rate of horizontal section, flow capacity also decrease. As shown in Figure 9, designed three programs, the trend of inflow profile are basically same of these three programs.

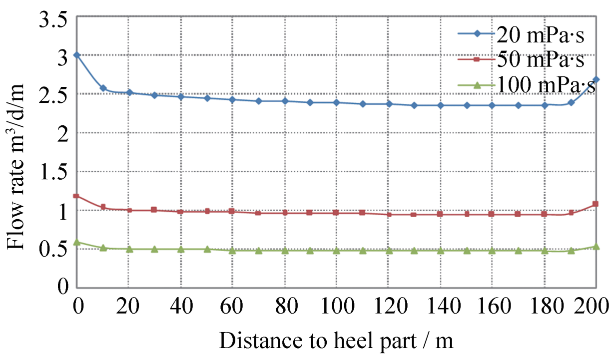

Figure 9
Relationship Curve Between Different Crude Oil's Viscosity and Flow

3. APPLICATION EFFECT

So far, segmented perforation optimizationhas been applied in 11 horizontal wells, daily fluidof single well is 32.9 m^3, daily oil is 29 t, cumulative increment of single well is 5,246 t. Compared to neighboring horizontal well, water climb is slow and has a better development effect after optimized.

CONCLUSION

(a) With the advancement of the horizontal well technology and the increasing number of horizontal wells, more and more emphasizing is put on the research about perforated wells completion in horizontal wells.

(b) Horizontal well reservoir-wellbore flow in coupled model is introduced, control the production pressure drop and achieve the evenly flow profile of horizontal section through segmented and combined optimization for the perforation parameters and screen parameters of horizontal well. By using the VB program, an engineering designing software is developed according to theoretical model.

(c) Theoretical foundation and optimization methods are supplied for horizontal well perforated completion, perforated level of horizontal well are advanced, and also, the research has very important instruction function to the horizontal well development effect's enhancement.

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