Subsection Optimization Method Research of Slotted Screen Liner Parameters for Horizontal Wells

LIU Naizhen¹, GAO Qing-chun¹

1 CNPC Greatwall Drilling Company
E-mail: qc_gwdc@163.com

Abstract: The slotted screen liner parameters are the same along the whole horizontal wellbore for most slotted Screen Liner completion of horizontal well, it will lead to water prematurely appears and the high water cut in high permeability area, so the research of subsection optimization for slotted screen liner parameters of horizontal well is important, which can adjust the inflow profile along the whole horizontal wellbore to enhance oil recovery, stabilize oil production and control water cut. Based on the skin factor model of slotted screen liner and the inflow control principle of horizontal wellbore, a subsection optimization model for slotted parameters of horizontal wells in heterogeneous reservoirs is established, and the subsection optimization design of horizontal well slotting parameters in heterogeneous reservoirs is realized by genetic optimization algorithm.

1. Introduction
Since the domestic slotted screen liner completion technology is used for open-hole horizontal well, casing side-tracking wells and horizontal well in Drilling and Production Research Institute of Dagang Oilfield Group Company, slotted screen liner completion technology has been widely used in horizontal well completion[1][2]. So far the slotted screen liner parameters are the same along the whole horizontal wellbore for most slotted screen liner completion of horizontal well, due to the formation plane heterogeneity, the permeability varies along the horizontal wellbore, it will lead to fast inflow speed in high permeability area and slow inflow speed in low permeability area, which can lead to water prematurely appears and the high water cut in high permeability area, seriously affecting the horizontal well development effect. Scholars at home and abroad have done a lot of researches on the influence of the slotting technology, strength design, slotting width and slotting parameters to the oil well productivity[3-13], but there is less research about the slotted screen liner parameter subsection optimization to control the inflow profile of horizontal well. In 2000 Kaiser[12]studied the influence of slotting parameters on horizontal well oil productivity, pointed out that the flow pressure drop loss near the slotted screen is mainly caused by collecting effect, the slotting circumferential density is the main factor affecting the completion skin factor, at the same time, a subsection optimization model for slotting parameters of horizontal wells in homogeneous reservoirs is given, it is pointed out that the inflow profile can be adjusted by optimizing the circumferential density of the slotted screen liner along the horizontal wellbore. Based on the slotted screen completion skin model and the horizontal wellbore inflow control principle, a subsection optimization model for slotting parameters of horizontal wells in heterogeneous reservoirs is established, and the subsection optimization design of horizontal well slotting parameters in heterogeneous reservoirs is realized by genetic optimization algorithm.
2. Mathematical model

2.1 Skin factor model of slotting screen liner completion

There are many skin factor models for horizontal well slotting screen completion[6] [7] [12] [13]. In this paper, the comprehensive skin factor model of slotted screen completion for horizontal well is given by Furui[13], the specific expressions are as follows:

\[
S_{SL} = S_{f0} + S_{SL,l} + S_{SL,r} / k_{Dt}
\]

\[
S_{f0} = (k_{Dt}^{-1} - 1) \ln \left[ \frac{1}{l_{ani} + 1} \left[ r_{Dsl} + \sqrt{r_{Dsl}^2 + l_{ani}^2} - 1 \right] \right]
\]

\[
S_{SL,l}^0 = \frac{2\pi}{n \cdot m \cdot w_{Ds} \cdot \kappa_{k}}
\]

\[
l_{Ds} / \lambda \ln \left( \frac{1 - \lambda + 2l_{Ds} / w_{Ds}}{1 - \lambda + n_{l_{Ds}} / w_{Ds}} \right) + \frac{2}{m} \ln \left( \frac{1}{\lambda} \ln \left( 1 - \lambda + l_{Ds} / w_{Ds} \right) + 2\lambda \nu \right) - \ln \left( 1 + \nu \right)
\]

If \((\gamma < \nu)\):

\[
S_{SL,r}^0 = \frac{2}{n \cdot m \cdot \lambda^{1/2}} \ln \left( \frac{1 - \lambda + 2l_{Ds} / w_{Ds}}{1 - \lambda + n_{l_{Ds}} / w_{Ds}} \right) + \frac{2}{m} \ln \left( \frac{1}{\lambda} \ln \left( 1 - \lambda + l_{Ds} / w_{Ds} \right) + 2\lambda \nu \right) - \ln \left( 1 + \nu \right)
\]

If \((\gamma > \nu)\):

\[
S_{SL,r}^0 = \frac{1}{l_{Ds} - 2(1 - \lambda)} \ln \left( \frac{\lambda + l_{Ds} / 2}{1 + \nu} \right) \left( 1 + 2\nu(1 - \lambda) \frac{l_{Ds}}{l_{Ds}} \right) - \ln (1 + l_{Ds} / 2\lambda)
\]

\(s_k\) is the pollution zone permeability, \(mD\); \(s_r\) is the major axis radius of pollution zone, \(m\); \(k_l\) is the penetration permeability in seams, \(mD\); \(t_l\) is the plugging depth in seams, \(m\); \(n_s\) is the seam number of each slotting unit, seam numbers/slotting unit; \(m_s\) is the circumferential slotting unit number of slotted screen liner, slotting unit number/circle; \(l_s\) is the slotting length, \(m\); \(u_s\) is the slotting spacing, \(m\); \(w_s\) is the slotting width, \(m\); \(w_u\) is the slotting unit width, \(m\); \(l_{ani}\) is the anisotropy coefficient(\(\sqrt{k_h / k_v}\)), dimensionless; \(r_{Dsl}\) is the dimensionless pollution zone radius (\(s_{sl} / r_w\)), dimensionless; \(k_{Ds}\) is the dimensionless pollution zone permeability \((k_l / k)\), dimensionless; \(k_{lx}\) is the dimensionless permeability in seams \((k_l / k)\), dimensionless; \(t_{Ds}\) is the dimensionless plugging depth in seams, dimensionless; \(w_{Ds}\) is the dimensionless slotting width(\(w_s / r_w\)), dimensionless; \(l_{Ds}\) is the dimensionless slotting length(\(2l_s / (r_w \sqrt{k_h / k_v} + r_w)\)), dimensionless; \(w_{Ds}\) is the dimensionless slotting unit width(\(w_u / r_w\)), dimensionless; \(\nu\) is the radial confluence radius of slotted screen(\(\sin(\pi / m_s)\)), dimensionless; \(\gamma\) is the axial confluence radius of slotted screen(\(l_s / 2r_w\)) dimensionless; \(\lambda\) is the slotting penetration ratio(\(l_s / (l_s + u_s)\)) dimensionless.
2.2 Subsection optimization model of slotted screen liner parameter

This paper is based on the coupling model of heterogeneous reservoir seepage model and wellbore pipe flow model\cite{14}, the average permeability of reservoir can be obtained by the arithmetic mean \( k \) of the permeability \( k_a(x) \) along the horizontal wellbore. Firstly, the horizontal wellbore inflow profile \( q_{x,th} (x) \) is obtained under the infinite conductivity condition in homogeneous reservoirs. Then, the ideal skin value \( s_{th} (x) \) along horizontal wellbore under the ideal condition of finite reservoir diversion in homogeneous reservoir is obtained. Finally, combined with the slotted screen completion skin model and heterogeneous permeability pseudo-skin model along horizontal wellbore. The subsection optimization model of slotted screen slotting parameters is:

Objective function: \( \min \left| s_{th} (x) - S_a (x) - S_{stl} (U) \right| \)

2.3 Subsection optimization constraint condition of slotted screen liner parameter

The total length of each slotted screen, the length of each slotted screen section and slotting width are generally fixed, so the subsection optimization parameters of slotted screen completion of horizontal well inflow surface are: slotted length, slotting axial distribution density and slotting circumferential distribution density, as shown in figure 1.

![Fig 1. Slotted screen diagram](image)

According to the technical requirements and engineering experience, the subsection optimization constraint conditions of slotted screen liner completion parameter for horizontal well inflow surface are:

1. The total length of each slotted screen, the length of each slotted screen section, slotting width and slotted screen diameter should meet engineering requirements.
2. The maximum and minimum allowable values of slotted length.
3. The maximum and minimum allowable values of slotting axial distribution density.
4. The maximum and minimum allowable values of slotting circumferential distribution density.
5. The optimization results of slotted screen number, slotting axial distribution density and slotting circumferential distribution density should take integers.

The optimization problem of the objective function belongs to the problem of multi parameter discontinuous function optimization. There are many numerical algorithms to solve this problem. In this paper, the genetic algorithm is selected to optimize it.

3. Example calculation and analysis

3.1 Parameter Value

In order to study the effect of reservoir permeability for the horizontal well slotting parameters subsection optimization, the basic parameters of reservoir, fluid and horizontal well are shown in Table 1.
Table 1. Basic parameters of reservoir, fluid and horizontal well

| Variable name                                      | Variable value | Variable name                                  | variable value |
|---------------------------------------------------|----------------|-----------------------------------------------|----------------|
| Supply radius                                     | 500.0m         | Oil viscosity                                 | 5.0mPas        |
| Oil layer thickness                               | 10.0m          | Volume factor                                 | 1.15           |
| Distance between wellbore and bottom of the oil layer | 5.0m           | Pollution degree                              | 0.4            |
| Outside diameter of slotted screen liner          | 0.1397m        | Pollution depth                               | 0.12m          |
| Slotted screen liner thickness                    | 0.00917m       | Fluid density                                 | 95kg/m3        |
| Relative roughness factor of slotted screen liner surface | 0.1          | Oil well liquid production                    | 200m3/d        |
| Wellbore length                                   | 400.0m         | Slotted screen liner length                   | 11.0m          |
| Slotted width                                     | 0.0005m        | Slotting width                                | 0.10m          |
| Slotting circumferential distribution density     | 10seam/circle~ 36seam/circle | Slotting spacing | 0.02m |

Table 2. Permeability along horizontal wellbore

| Distance from well heel end(m) | 0  | 10 | 30 | 50 | 70 | 90  | 110 | 130 | 150  | 170 | 190 |
|--------------------------------|----|----|----|----|----|-----|-----|-----|------|-----|-----|
| Permeability 1(mD)             | 450| 452| 278| 94 | 243| 99  | 387 | 340 | 144  | 31  | 317 |
| Permeability 2(mD)             | 13 | 205| 194| 398| 500| 185 | 53  | 338 | 156  | 117 | 150 |
| Permeability 3(mD)             | 300| 300| 257| 215| 347| 175 | 206 | 242 | 247  | 228 | 316 |
|                                | 372| 252| 381| 235| 131| 359 | 104 | 231 | 119  | 252 | 100 |
|                                | 230| 240| 209| 216| 247| 282 | 264 | 247 | 240  | 210 | 241 |
|                                | 212| 292| 295| 243| 241| 261 | 296 | 281 | 200  | 258 | 203 |

The permeability values at different positions along the horizontal wellbore are shown in Table 2. 3 sets of static value were obtained, with an average permeability of 250mD, the mutation coefficient $T_i = \frac{k_{max}}{k}$ is about 2.0 and the permeability contrast $J_i = \frac{k_{max}}{k_{min}}$ is about 38.0 when permeability value is 1; the mutation coefficient is about 1.5 and the permeability contrast is about 4.0 when permeability value is 2; The mutation coefficient is about 1.2 and the permeability contrast is about 1.5 when permeability value is 3. Figure 2 gives 3 sets of permeability values distribution curve along the horizontal wellbore, and it takes the equivalent radius 3 times of the well diameter in the heterogeneous area.
3.2 Result analysis

In order to study the heterogeneity of permeability along horizontal wellbore effect of slotting parameters subsection optimization results, the optimization results of 3 kinds of permeability are compared, for slotting circumferential distribution density, the slotting circumferential density optimization results of slotted screen along the horizontal wellbore from toe to heel end are shown in Table 3 and figure 5, it shows that the slotting parameters vary from toe to heel along horizontal wellbore, in high permeability areas, the slotting density is small, and the slotting density is large in low permeability areas, moreover, as the permeability heterogeneity along horizontal wellbore increases, the range of slotting density increases and vice versa.

![Figure 2. Circumferential slotting distribution density along horizontal well diagram](image)

| Distance from the toe (m) | Slotting width (mm) | Slotting length (cm) | Slotting spacing (cm) | Permeability 1 | Permeability 2 | Permeability 3 | Average permeability |
|--------------------------|--------------------|---------------------|----------------------|----------------|----------------|----------------|---------------------|
|                          |                    |                     |                      | Slotting circumferential density (seam/circle) | Slotting circumferential density (seam/circle) | Slotting circumferential density (seam/circle) | Slotting circumferential density (seam/circle) |
| 0—11                    | 0.5                | 10                  | 2                    | 36             | 36             | 32             | 36                  |
| 11—22                   | 0.5                | 10                  | 2                    | 36             | 36             | 36             | 36                  |
| 22—33                   | 0.5                | 10                  | 2                    | 36             | 36             | 36             | 36                  |
| 33—44                   | 0.5                | 10                  | 2                    | 25             | 36             | 34             | 36                  |
| 44—55                   | 0.5                | 10                  | 2                    | 23             | 36             | 26             | 36                  |
| 55—66                   | 0.5                | 10                  | 2                    | 36             | 36             | 24             | 36                  |
| 66—77                   | 0.5                | 10                  | 2                    | 36             | 36             | 25             | 36                  |
| 77—88                   | 0.5                | 10                  | 2                    | 36             | 21             | 29             | 36                  |
| 88—99                   | 0.5                | 10                  | 2                    | 21             | 27             | 33             | 36                  |
| 99—110                  | 0.5                | 10                  | 2                    | 14             | 36             | 36             | 36                  |
| 110—121                 | 0.5                | 10                  | 2                    | 14             | 36             | 36             | 36                  |
| 121—132                 | 0.5                | 10                  | 2                    | 16             | 36             | 36             | 36                  |
| 132—143                 | 0.5                | 10                  | 2                    | 23             | 21             | 28             | 36                  |
| 143—154                 | 0.5                | 10                  | 2                    | 36             | 18             | 24             | 36                  |
| 154—165                 | 0.5                | 10                  | 2                    | 36             | 24             | 24             | 36                  |
4. Conclusions and suggestions
A subsection optimization model for slotting parameters of horizontal wells in heterogeneous reservoirs is established. The subsection optimization design of horizontal well slotting parameters in heterogeneous reservoirs is realized by genetic optimization algorithm. The slotting parameters subsection optimization can adjust the inflow profile to a certain extent, which provides a scientific basis for slotting parameter design of slotted screen liner completion.

Acknowledgement
This work was supported by the National Natural Science Foundation of China [grant number 51474070].

References
[1] Navarro J B. Slotted-liner completions used in the first horizontal wells in Mexico[R]. SPE37110,1996.
[2] Li Zaisheng, Xu Jieshan, Cui Jun. Application of slotted screen completion technology in Tarim Oilfield[J]. West-china Exploration Engineering, 2001, 69(2): 42-43.
[3] Zhang Jianqiao, Liu Yonghong. Lv Guangzhong. Design and application of sand control slotted liner with compound cavity[J]. CPM, 2005, 33(9): 30-33.
[4] Zhang Jianqiao, Liu Yonghong. Research on parameter optimization design of taperoidal slotted liner[J]. Journal of Oil and Gas Technology, 2005, 27(2): 417-418.
[5] Huang Renmei and Wang Dexin. Analysison pressure of slotted pipes and determination of reasonable kerfs parameters[J]. Shiyou Daxue Xuebao, 2002, 26(5): 46-47
[6] Yula T. Optimization of horizontal well completion[D]. Theuniversity of Tulsa, 2001.
[7] Spivak D, Roland N. Unsteady-state pressure response due to production with a slotted liner completion[R]. SPE10785,1982.
[8] Liu jianjun, Yan Jianzhao, Cheng Linsong. Decomposition of skin factor and quantity damaged...
evaluation of oil and gas formation[J]. Well Testing, 2005, 14(2):17–20.

[9] He shenghou, Zhang Qi. Sand control theory and application in oil and gas wells[M]. Beijing: China Petrochemical Press, 2003

[10] Gao Haihong, Wang Xinmin, Wang Zhiwei. Review of horizontal well productivity formulae study[J]. Xinjiang Petroleum Geology, 2005, 26(6): 723–726.

[11] Wan Renpu. Horizontal well production technology[M]. Beijing: Petroleum Industry Press, 2004.

[12] Kaiser T. Inflow analysis and optimization of slotted liners[J]. SPE65517, 2000.

[13] Furui K. A comprehensive skin factor model for well completions based on finite element simulations[D]. The University of Texas at Austin, 2001.

[14] WEI Jian-guang, WANG Zhi-ming, WANG Xiao-qi. Sectional optimization model of perforation parameters of horizontal well in heterogeneous reservoir[J]. Journal of China University of Petroleum, 2009, 33(2): 75–79