Optimization Deployment for Well Patterns of three-Dimensional Injection-production in the Buried-Hill Reservoirs

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Abstract

The optimum deployment of stereoscopically injecting and producing well pattern is a key to the buried hill reservoir's development. In the given reservoir, the spacing allocation factor of injecting and producing well type, vertical correspondent relationship, flat orientation relationship, injecting and producing well spacing for the stereoscopically injecting and producing the well pattern between the vertical well-horizontal well, horizontal well-horizontal well is optimized. With numerical simulation and by optimizing the multi injecting and producing schemes, the optimized scheme of stereoscopically injection-production well pattern for the buried hill reservoir is confirmed.

Keywords: Buried hill reservoir, Horizontal well, injection-production well pattern, optimization, fracture

The fractured buried hill reservoir is a characteristic of fracture growth, high penetration, and good connectivity [1], horizontal well and vertical well with water-injection development are usually one of rational development way, which can postpone flood water breakthrough time and enhance oil recovery [3,4], also, the pattern already obtain successful experience in overseas buried hill reservoir [5][6]. But it is necessary to further optimize three-dimensional injection-production initial disposition relation of the pattern is very complex.

1. Establishment of model of numerical simulation

The dual-permeability heavy oil model is used to numerical simulation of three-dimensional injection-production pattern optimization, the model is based in a buried hill reservoir grows partially in China. The model grid is the orthogonal grid, X direction is the west - east, which is divided to 20 grids, and the grid
spacing is 40m. The Y direction is North-south which is perpendicular to X direction, and divided to 20 grids, the grid spacing is 30 m. The grid spacing of Z direction is thickness of the oil layer which is the corresponding stratum, each well is situated in the center of a grid, and the total node is 2400.

Constraint condition of simulation plans includes: (1) analog computation assume constant production, and daily production of the horizontal well is 50m³/d, daily production of the vertical well is 20m³/d; (2) maintain a equilibrium of injection-production; (3) shutting well when water-cut of oil well is above 98%; (4) forecasting period of well production is ten years.

2. Deployment of combined injection-production of vertical well and horizontal well

The deployment of the combined injection-production of a vertical well and horizontal well can be vertical well injecting and horizontal well producing or horizontal well injecting and vertical well producing. Every combined deployment includes a positive injection and diagonal injection in the same layer, and a positive Injection and diagonal injection in the super and sub-layer. The distance between the vertical and horizontal wells is assumed to be same, and it is 300 meters, see Table 1 specifically.

Table 1. The forecast index of deployment of the combined injection-production of vertical and horizontal well

| Simulated Scheme | Injection-production patterns | Configuration of the combined injection and production | Accumulative Production (10⁴t) | Daily Production (t/d) | Water-bearing percentage (%) | Formation Pressure (MPa) |
|------------------|------------------------------|------------------------------------------------------|-------------------------------|------------------------|-------------------------------|-------------------------|
| ZPZH-1           | Vertical well injecting and the horizontal well producing | positive (the vertical well and the horizontal well in a straight line) | 5.40                          | 8.3                    | 83.5                          | 16.04                   |
| ZPZH-2           | Vertical well injecting and the horizontal well producing | diagonal (the Vertical well and tiptoe of the horizontal well have 45°angle) | 5.64                          | 8.6                    | 82.9                          | 16.02                   |
| ZPZH-3           | Vertical well injecting and the horizontal well producing | upper part and lower part is positive (the vertical well is positive on lower part of the horizontal well) | 6.64                          | 9.5                    | 81.0                          | 15.51                   |
| ZPZH-4           | Vertical well injecting and the horizontal well producing | upper part and lower part is diagonal (the horizontal well vertical well have certain diagonal angle on the horizontal plane) | 7.26                          | 10.1                   | 79.7                          | 15.25                   |
| ZPZH-5           | Vertical well injecting and the horizontal well producing | positive (the vertical well and the horizontal well in a straight line) | 3.16                          | 5.2                    | 74.1                          | 16.59                   |
| ZPZH-6           | Vertical well injecting and the horizontal well producing | diagonal (the Vertical shaft and tiptoe of the horizontal well have a 45°) | 3.25                          | 5.3                    | 73.6                          | 16.64                   |
| ZPZH-7           | Vertical well injecting and the horizontal well producing | the upper part and lower part are positive (the vertical well is positive on the lower part of the horizontal well) | 4.62                          | 8.4                    | 58.0                          | 16.06                   |
| ZPZH-8           | Vertical well injecting and the horizontal well producing | The upper part and lower part is diagonal (the horizontal well the vertical well have certain diagonal angle on the horizontal plane) | 4.50                          | 7.7                    | 61.5                          | 16.24                   |

With numerical simulation of deployment of the combined injection-production of vertical and horizontal well, the forecast index is obtained, see Table 1, and several conclusion is summarized.
(1) The forecast index of vertical well injecting and horizontal well producing is obviously prior to the horizontal well injecting and vertical well producing, and the effect of water drive development of the former is by far the latter.

(2) The forecast index of producing in the upper part and injecting. The lower part is prior to the producing and injecting in the same layer.

(3) The diagonal deployment is prior to a positive deployment of the vertical well injecting and horizontal well.

From Table 1, water injection efficiency of injecting on the lower part of a vertical well and producing on the upper part of the horizontal well is the best. Then, the best position and the well spacing of the vertical well injecting around the horizontal well are further researched, see Fig. 1 and Table 2, Table 3.

From Fig. 1 and Table 2, Table 3, several conclusions are summarized.

(1) injecting nearby tip toe of the horizontal well, well spacing of the horizontal well must be more effective than the position for water injection efficiency, but effect of the water drive is little different from different injection-production patterns.

(2) The maximum water flooding swept volume and best water injection efficiency and peak accumulative production are obtained when a vertical well and tip toe from the horizontal well have a 45° angle, see No. ZPZH-4.

(3) The water injection efficiency is worst when the vertical well and the horizontal well are in a straight line, next is injecting from vertical well perpendicular to the middle part of the horizontal well section (ZPZH-14). And the water injection efficiency of a vertical well and tip toe from the horizontal well have 45°~90° angle is prior to a vertical well and tip toe for the horizontal well have 0°~45° angle.

![Fig. 1. Injecting from a vertical well and producing a horizontal well](image)

### 3. Deployment of injection-production of horizontal well

The deployment of injection-production of a horizontal well refers to horizontal well injecting and horizontal well producing, its spatial disposition relations can be parallel, bottom and diagonal injection and production, see table 4.

With numerical simulation to above three spatial disposition relations, the forecast target are obtained, see Table 4, and some conclusion indicated from these forecast result analysis research as follows: a horizontal well is up and the other is bottom, and crisscross each other on the horizontal plane, which are the best deployment of injection and production, the maximum water flooding swept volume and best water injection efficiency are obtained. Next are the bottom injection which is one-up and one-bottom,
and the vertical coincide. When horizontal wells are on the horizontal plane and parallel injecting, water injection efficiency is the worst, watered-out is too fast and water flooding swept volume is small. The diagonal deployment of the horizontal well which water injection efficiency is the best is further researched, the best position and the well spacing of the horizontal well are optimized, see Table 5 and Table 6.

From Table 5 and Table 6, several conclusions are summarized. Maximum water flooding swept volume and best water injection efficiency are obtained when the horizontal will have 60° angles with the horizontal plane.

Table 2. The forecast index of injecting from a vertical well and producing the different positions of the horizontal well different

| Different Position on Horizontal Plane | Simulated Scheme | Accumulative production (10⁴t) | End of Forecast Period | Accumulative Production Added (10⁴t) |
|---------------------------------------|------------------|-------------------------------|------------------------|------------------------------------|
| Angle of vertical well and tiptoe of the horizontal well is 0° | ZPZH-3 | 6.64 | 9.5 | 81.0 | 15.51 | - |
| Angle of vertical well and tiptoe of the horizontal well is 15° | ZPZH-9 | 6.87 | 9.7 | 80.6 | 15.42 | 0.23 |
| Angle of vertical well and tiptoe of the horizontal well is 30° | ZPZH-10 | 6.96 | 9.9 | 80.3 | 15.37 | 0.09 |
| Angle of vertical well and tiptoe of the horizontal well is 45° | ZPZH-4 | 7.26 | 10.1 | 79.7 | 15.25 | 0.30 |
| Angle of vertical well and tiptoe of the horizontal well is 60° | ZPZH-11 | 7.14 | 10.0 | 79.9 | 15.31 | -0.12 |
| Angle of vertical well and tiptoe of the horizontal well is 75° | ZPZH-12 | 7.09 | 10.0 | 80.1 | 15.32 | -0.05 |
| Angle of vertical well and tiptoe of the horizontal well is 90° | ZPZH-13 | 6.98 | 9.8 | 80.3 | 15.36 | -0.11 |
| Angle of vertical well and the middle part of the horizontal well section is 90° | ZPZH-14 | 6.74 | 9.5 | 80.9 | 15.46 | -0.24 |

Table 3. The forecast index of injecting from a vertical well and producing the different well spacing of the horizontal well

| Well spacing of horizontal well (m) | Simulated scheme | Accumulative Production (10⁴t) | End of forecast period | Accumulative Production added (10⁴t) |
|-------------------------------------|------------------|-------------------------------|------------------------|------------------------------------|
| 200 | ZPZH-15 | 6.55 | 9.5 | 81.0 | 15.53 | - |
| 250 | ZPZH-16 | 6.91 | 9.8 | 80.4 | 15.39 | 0.36 |
| 300 | ZPZH-4 | 7.26 | 10.1 | 79.7 | 15.25 | 0.35 |
| 350 | ZPZH-17 | 7.57 | 10.4 | 79.2 | 15.13 | 0.31 |
| 400 | ZPZH-18 | 7.85 | 10.6 | 78.8 | 15.02 | 0.28 |
Table 4. The forecast index of different deployment of the horizontal well (well spacing is 300m)

| Deployment of Horizontal Well | Simulated Scheme | Accumulative Production (10^4t) | End of Forecast Period |
|------------------------------|------------------|---------------------------------|------------------------|
| horizontal well are abreast on the same horizontal plane (parallel) | PPZH -1 | 4.72 | 7.1 | 85.9 | 16.35 |
| one-up and one-bottom, and vertical coincide (bottom) | PPZH -2 | 6.95 | 9.9 | 80.3 | 13.59 |
| one-up and one-bottom, and crisscross each other on the horizontal plane (diagonal) | PPZH-3 | 8.12 | 11.8 | 76.5 | 11.92 |

With the well spacing increasing, the accumulative production of well group is increased, but the accumulative production added is decreased gradually, also the formation pressure is declining obviously. Therefore, the suitable well spacing of injection-production of horizontal well are about 300m.

Table 5. The forecast index of injecting and producing the different positions of horizontal well

| Different Position on Horizontal Plane | Simulated Scheme | Accumulative Production (10^4t) | End of Forecast Period |
|---------------------------------------|------------------|---------------------------------|------------------------|
| 0°(parallel)                          | PPZH -1          | 4.72 | 7.1 | 85.9 | 16.35 |
| 30°with the horizontal plane          | PPZH -4          | 6.97 | 9.3 | 81.4 | 15.34 |
| 60°with the horizontal plane          | PPZH -3          | 8.12 | 11.8 | 76.5 | 11.92 |
| 90°with the horizontal plane (bottom) | PPZH -2          | 6.95 | 9.9 | 80.3 | 13.59 |

Table 6. The forecast index of injection-production from the different well spacing of horizontal wells

| Well Spacing of Horizontal Well (m) | Simulated Scheme | Accumulative Production (10^4t) | End of Forecast Period |
|------------------------------------|------------------|---------------------------------|------------------------|
| 200                                | PPZH -5          | 7.48 | 10.5 | 79.0 | 12.84 | - |
| 250                                | PPZH -6          | 7.79 | 11.0 | 77.9 | 12.41 | 0.31 |
| 300                                | PPZH -3          | 8.12 | 11.8 | 76.5 | 11.92 | 0.33 |
| 350                                | PPZH -7          | 8.43 | 12.3 | 75.4 | 11.34 | 0.31 |
| 400                                | PPZH -8          | 8.60 | 12.6 | 74.8 | 11.09 | 0.17 |
| 450                                | PPZH -9          | 8.76 | 12.9 | 74.2 | 10.89 | 0.16 |
| 500                                | PPZH -10         | 8.86 | 13.2 | 73.6 | 10.81 | 0.10 |

4. Contrast combined injection-production of vertical well and horizontal well with injecting-production of horizontal wells

Contrasting the spatial disposition relations combined injecting and producing a vertical well and horizontal well with injecting and producing horizontal wells, a conclusion is drawn as follows. For combined injecting and producing of a vertical well and horizontal well, injection on the bottom part of a
vertical well, production on the up part of the horizontal well, vertical well and tiptoe of horizontal well with 45° angle is optimism. For injecting and producing horizontal wells, one-up and one-bottom and horizontal wells 60° angle with the horizontal plane is optimism. And 10 year accumulative production of one-up and one-bottom and horizontal wells 60° angle with the horizontal plane is more 10.6% than the combined injecting and producing of vertical well and horizontal well, see Fig. 2. Water flooding swept volume is bigger when horizontal well injecting; residual oil saturation of fracture and matrix is lower and well-distributed, see Fig. 3 and Fig. 4.

![Graph](image_url)

**Fig. 2** Contrast is combined injection-production of vertical and horizontal well with injection-production of horizontal wells

![Distribution](image_url)

**Fig. 3** Distribution of residual oil saturation of combined injecting and producing of vertical well and horizontal well
5. Conclusion

(1) For combined injecting and producing of a vertical well and horizontal well, injection on the bottom part of a vertical well, production on the up part of the horizontal well, vertical well and tiptoe of horizontal well with 45° angles is optimism. The suitable well spacing of the horizontal well of the combined injection-production of a vertical well and horizontal well is 300~400m.

(2) The maximum water flooding swept volume and the best water injection efficiency are obtained when the horizontal well have 60° angle with the horizontal plane. The suitable well spacing of injection-production of horizontal wells is about 300m.

(3) Generally, the water injection efficiency of combined injecting and producing horizontal wells is prior to the combined injecting and producing of vertical well and horizontal well. Residual oil saturation of fracture and matrix is lower and well-distributed.

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