Analysis of Seepage Law of Precipitation in Horizontal Wells with Low Permeability Formation

Jibin He1*, Guowei Li2 and Li Yu2

1 China Geological Survey Hydrogeological Environment Geological Survey Center, Baoding, Hebei, China
2 Hebei University, College of Civil Engineering and Architecture, Baoding, Hebei
Email: yulihejibin@126.com

Abstract. Based on the euler model of multiphase flow in FLUENT and standard k-epsilon model, considering the influence of negative pressure inlet position (pump position) and initial water head height (water head thickness), a 3d Pipe flow-seepage coupling pumping model for horizontal wells is built and calculated iteratively. On this basis, a detailed study is carried out on how to improve the fluid collection efficiency of horizontal wells. The results show that: (1) the fluid velocity at the negative pressure inlet increases as the pressure inlet location decreases from the top of the horizontal well to the heel, in the process of the depth change from heel to toe in the horizontal section, the fluid velocity at the negative pressure inlet increases first and then decreases; (2) the pressure increases in a certain proportion with the increase of the initial water head (that is, the thickness of water layer) , and then the efficiency of horizontal well is improved; (3) Combined with numerical simulation analysis, in the model experiment, fluid flow causes uneven distribution of sand around the horizontal well, leading to a certain degree of pore annihilation, which causes pressure fluctuation along the horizontal well and reduces the production efficiency.

Keywords: Horizontal well, Fluent, Numerical simulation

1. Introduction
China has a considerable scale of low-permeability reservoirs, low-permeability reservoirs with complex reservoirs, low permeability, not easy to develop the characteristics. Compared with vertical wells, horizontal wells can increase the contact area with underground fluid, and can also produce small pressure difference, and increase permeability, reduce cost and increase production through fracturing and inserting borehole into high permeability well sections, therefore, it is widely used in the development of oil and gas reservoirs. In order to improve the production efficiency of horizontal wells, a lot of research has been done by scholars at home and abroad. The following is a brief summary of the research on horizontal wells.

Zhang Dongli [1] established a numerical model considering the start-up pressure gradient and studied its effect on the gas production efficiency of pinnate horizontal wells.

Based on the actual working data of horizontal Wells, Kuang Tie [2] studied the influence of wellbore loss on horizontal Wells and the coupling law of wellbore flow with gas reservoir.

In order to study the working rules of horizontal Wells with the technology of turning horizontal Wells within the government, Ma Dongjun [3] established a working model of horizontal Wells with the technology of numerical simulation based on fluid mechanics.
Fan Dongyan [4] considered gas viscosity, adsorption and desorption as well as numerical simulation of Knudsen's diffusion of horizontal Wells, and obtained different degrees of influence of artificial fractures on different mining periods.

Wang Haijing [5] established the coupling model of pipe flow and seepage, and studied the influence of simple well pressure on various performance indexes of horizontal Wells by using numerical simulation. The simulation results showed that pressure drop led to the advance of water appearance time at the simple end of the well and the decrease of water-free collection rate.

In order to solve the gas production difficulty in Qinshui Basin, a special region, Wang Wenchao [6] used numerical simulation method to study the mining efficiency of horizontal Wells under different factors.

In order to understand the complicated percolation mechanism and productivity dynamics of multi-fracture horizontal Wells in mudstone gas reservoirs, QiguoLiu [7] established a rectangular closed reservoir triple pore physical model, and obtained the gas production rate of production Wells under constant wellbore pressure.

In order to study the working dynamics of horizontal Wells under composite reservoirs, Zhang Wei [8] established corresponding mathematical models taking into account the influences of desorption, diffusion and viscous flow. The point source function method, Laplace transform and Stehfest algorithm were used to solve the horizontal well dynamic performance analysis model.

In order to study the transient pressure response of multistage fractured horizontal Wells in tight reservoirs, QihongFeng [9] established a fluid flow model for four adjacent areas in a tight formation based on green's function and the principle of pressure continuity and mass conservation, and believed that the reduction of fracture conductivity has a great impact on the dynamic performance of oil and gas Wells.

Chen Huijuan [10] conducted numerical simulation of well simplification and reservoir coupling in order to study the working rules of horizontal Wells under multi-point water injection technology, and obtained the changing rules of pressure, temperature and steam dryness in horizontal section of horizontal Wells under this technology.

In summary, previous studies have focused on the properties of fluid objects and technology in specific environments. Aiming at horizontal well structure and combining with numerical simulation, the influence of horizontal well structure on production efficiency is systematically explored. In view of this, based on the euler model of multiphase flow in FLUENT and the standard k-epsilon model, the author establishes the 3D Pipe flow-seepage coupling pumping model of horizontal well, calculates it iteratively, and carries on the 3D numerical simulation of gas-liquid coupling pumping in horizontal well, the influence of pump location and initial water head (Aquifer thickness) on horizontal well production is studied by comparing the simulation results with physical model experiments.

2. Introduction of Model Experiment

The self-designed three-dimensional seepage model test system of horizontal well is adopted. The system consists of sand tank, horizontal well pipe, Pore pressure monitoring system, water supply and pumping device and data acquisition system.

The size of the prototype to length x width x height of 45 m x 23 m by 30 m, in order to reduce the influence of boundary effect on the test results, the indoor model 10 times, the model test of 4.5 m * 2.3 m * H m (H is the thickness of the aquifer, 60, 79, 94, 113, 123 cm), pump located in: deflecting section and horizontal section and horizontal section entrance inside.

Test principle is: according to different aquifer thickness (sand groove configuration simulation of strata filling thickness), through the tank water recharge area (stable supply head), put water tube at different positions of the horizontal well (pumping pipe diameter (phi) 12 is less than the horizontal tube diameter (phi) 50, simulating pump by adjusting its position in the horizontal position), the outlet of the horizontal well head unchanged, recharge and discharge of the form stable head, measuring the changes of pore water pressure and flow rate. The simulation system of indoor horizontal well seepage test is shown in figure 1.
Figure 1. Simulation system of indoor horizontal well seepage test.

Figure 2. Pore pressure curve at different positions of 123cm pump (Laboratory experiment).

Figure 2 is the pore pressure curve of different pump positions at the initial water head height of 123cm. It can be seen that the pore pressure curve of different pump positions varies almost the same size along the horizontal section of horizontal well, it shows that the change of pump position has little effect on seepage flow in the scope of indoor model test.

Figure 3. Pressure curves of horizontal wells in different thickness aquifers (Laboratory experiment).

Figure 3 shows the variation of axial pressure curves of horizontal wells in different thickness aquifers obtained from laboratory experiments. These curves have similar wave shape. As the thickness of the Aquifer increases, the fluctuation of the pore pressure curve becomes more and more similar, which shows that the thickness of the Aquifer has a great influence on the pore pressure and seepage characteristics.

3. Model Building
As shown in figure 4, the sand groove is 450 cm long, 230 cm wide and 150 cm high, the diameter of the outer pipe is 6 cm and 140 o in the direction of the axis, the center angle of the pipe is 50 o at the turning point, the diameter of the inner pumping pipe is 50 mm, and the horizontal section of the horizontal well is 250 cm long, the flow is formed by alternating circular arrays of 1mm in width, 25mm in radius and 24mm in diameter. The circular outer contact tank of 25mm in radius is not in contact with the round of 24mm in radius, and the end of the horizontal section is not in contact with the tank.

Figure 5 is the boundary condition definition diagram, the top is the pressure outlet, and the red mark is the position of the pressure inlet under different conditions.
4. Analysis of Calculation Results

4.1. Influence of Negative Pressure Inlet (Pump Inlet) Position

When the initial water head is 123cm, the velocity nephogram at the negative pressure inlet is shown in figure 6 when the internal pumping pipe is in different positions.

Figure 6 a1, a2, a3 show the velocity cloud charts of negative pressure inlet (pump mouth) along the top of the vertical section, the slanting section and near the end of the horizontal section. The central red part is the high-speed core area, followed by yellow and cyan, which is the low-speed edge area. Obviously, when the inlet of the pumping pipe is located on the upper part of the slanting fault, the nuclear area is small. As shown in figure 6 a1, a2, and a3, the range of the nuclear zone gradually increases, and the maximum velocity is 0.526m/s, 1.152m/s, and 1.413m/s, respectively. This is because the pressure difference increases with the decrease of negative pressure inlet position, so the fluid flow velocity increases.

Figure 6 b1, b2, b3 show the velocity cloud map near the tail end, middle end and toe end when the negative pressure inlet goes deep along the horizontal section successively. From the values, it can be seen that the maximum velocity is 1.496m/s and 1.523m/s 1.493m/s respectively, with a very small range of variation. Because the negative pressure inlet moves in the same horizontal plane, the pressure difference does not change.
a3) Near the horizontal heel  
b3) Near the horizontal toe

**Figure 6.** Velocity nephogram at negative pressure inlet at different positions (numerical simulation).

**Figure 7.** Pore pressure curve at different positions (numerical simulation).

Figure 7 for numerical simulation of initial water head height 123 cm, respectively along the horizontal section of the pump is located at the bending section, horizontal section of the entrance, the horizontal segment of internal pore pressure curve, the maximum of 8.686 KPa, 8.598 KPa, 8.506 KPa, we can find that, due to the data extraction began in the horizontal section near the entrance, so when the negative pressure inlet pump (mouth) is located in the horizontal section of the entrance, pore pressure curve presents the linear growth first, and then tends to level. The three maximum value is close, this is due to the pump where the height is close, so the pressure is close.

### 4.2. Head Impact

The velocity nephogram at the negative pressure inlet at different water heads is shown in figure 8. Figure 8 e1, e2, e3, e4 and e5 are velocity nephograms of negative pressure inlet at initial head of 123 cm, 112 cm, 94 cm, 79 cm and 60 cm, respectively. The shape of the low-speed boundary region is irregular circle, and the Red high-speed flow core region presents regular circle, and the scope size is similar. The red high-speed flow core region decreases with the decrease of the initial water head (aquifer thickness) , 1.507m/s, 1.379m/s, 1.225m/s, 0.894m/s and 0.204m/s, respectively. There is a linear relationship between them.

**Figure 7** for numerical simulation of initial water head height 123 cm, respectively along the horizontal section of the pump is located at the bending section, horizontal section of the entrance, the horizontal segment of internal pore pressure curve, the maximum of 8.686 KPa, 8.598 KPa, 8.506 KPa, we can find that, due to the data extraction began in the horizontal section near the entrance, so when the negative pressure inlet pump (mouth) is located in the horizontal section of the entrance, pore pressure curve presents the linear growth first, and then tends to level. The three maximum value is close, this is due to the pump where the height is close, so the pressure is close.

**Figure 8** e1, e2, e3, e4 and e5 are velocity nephograms of negative pressure inlet at initial head of 123 cm, 112 cm, 94 cm, 79 cm and 60 cm, respectively. The shape of the low-speed boundary region is irregular circle, and the Red high-speed flow core region presents regular circle, and the scope size is similar. The red high-speed flow core region decreases with the decrease of the initial water head (aquifer thickness) , 1.507m/s, 1.379m/s, 1.225m/s, 0.894m/s and 0.204m/s, respectively. There is a linear relationship between them.
Figure 8. Velocity nephogram of negative pressure inlet under different initial head (numerical simulation).

e3) 94mm

e4) 79mm

e5) 60mm

Figure 9. Pressure curves of horizontal wells in different thickness aquifers (numerical simulation).

Figure 9 is a graph showing the variation of pressure along the axis of a horizontal well when the initial water head is different. It is divided into inclined ascending section and basic horizontal section, which has obvious regularity.

In figure 9, the pump port is located at the heel end of the horizontal section. Therefore, from the heel end of the horizontal section, the pressure increases from zero to the maximum pressure along the horizontal axis, then decreases slightly and enters the basic horizontal section, they are 2.282 KPA, 4.503 KPA, 5.986 KPA, 7.779 KPA and 8.886 KPA respectively. Based on the simulated data, the maximum pressure is basically equal to the product of the liquid density, the gravitational acceleration and the water level difference.

In figure 9, the curves are well hierarchically arranged. The pressure increases with the increase of the water head, thus increasing the flow velocity of the pump mouth, indicating that the water head has a significant impact on the efficiency of the horizontal well. By increasing the head within a certain range, the pressure can be increased and thus the efficiency of horizontal Wells can be improved.

After an inflection point, the inclined section descends into the basic horizontal section. The main reason for this inflexion is the pumping action and the flow of fluid in the wellbore. As shown in figures 10 and 11, the flow potential of a flow in a horizontal section.
Figure 10. Fluid potential Diagram (near pump port).

Figure 11. Fluid potential Diagram (away from the pump port).

The direction of the Arrow represents the direction of the water, blue for high-speed flow, blue for low-speed flow. The gaps between the squares are on the Wellbore, and the flow of water from the gaps into the wellbore can be clearly seen in figures 10 and 11.

The downward flow of water is based on the pressure provided by gravity, and the upward is based on the buoyancy to reduce the pressure. Figure 10 shows the fluid potential near the pump outlet. Due to the proximity to the negative pressure inlet, there is a strong suction effect. As the axis extends from heel to toe, the suction weakens and the pressure increases. As shown in figure 11.

Compared with the curve obtained from the simulation experiment, the numerical simulation results are more consistent with Darcy law. The reason is that the fluid flow leads to the non-uniform distribution of the soil particles, and the soil particles act on the outer wall of the well, which leads to the non-uniformity of the permeable pores. According to the flow potential diagram of numerical simulation, with the increase of water head, the weight of the fluid increases. When the water head is far away from the pump mouth and the pumping action is weak, the gravity of the fluid is far greater than the buoyancy provided by the rising fluid, which becomes the main influence factor, and the stability factor occupies the dominant factor, therefore, the simulation experiment image has similar trend and different value at a distance from the pump mouth.

5. Conclusion
(1) The pump nozzle position drops, the pressure difference increases, the fluid flow rate increases, is beneficial to improve the production efficiency. The change of pump position along the horizontal direction has little effect on the production efficiency.
(2) The pressure increases in a certain proportion with the increase of the initial water head (that is, the thickness of water layer), and then the efficiency of horizontal well is improved.
(3) Combined with numerical simulation analysis, in the model experiment, fluid flow causes uneven distribution of sand around the horizontal well, leading to a certain degree of pore annihilation, which causes pressure fluctuation along the horizontal well and reduces the production efficiency.

References
[1] Zhang D, Wang X, Song B 2006 Numerical simulation of coalbed methane pinnate horizontal well production considering threshold pressure gradient Journal of Petroleum Sciences 27: 89-92.
[2] Kuang T 2012 Numerical simulation of flow coupling between horizontal wellbore and gas reservoir Science, Technology and Engineering 12: 4515-4517.
[3] Ma D, Li G, Guo R 2013 Numerical simulation of rock-carrying law of radial horizontal well with in-pipe steering Journal of Petroleum Sciences 41: 6-10.
[4] Fan D, Yao J, Sun H 2015 Numerical simulation of fractured horizontal wells in shale gas reservoirs considering multiple migration mechanisms Journal of Mechanics 47: 906-915.
[5] Wang H, Xue S 2016 Effect of wellbore pressure drop on production performance of horizontal wells in bottom water reservoir Fault Block Oil and Gas Fields 23: 73-76.
[6] Wang C, Peng X, Jia C 2016 Numerical simulation of drainage gas recovery from roof horizontal well in coalbed methane reservoir Petroleum Geology and Oil Recovery 23: 112-116.

[7] Liu Q, Li K, Wang W H, Hu X H and Liu H 2016 Production behavior of fractured horizontal well in closed rectangular shale gas reservoirs Mathematical Problems in Engineering.

[8] Zhang W, Jiang R 2017 Production performance analysis for horizontal wells in composite coal bed methane reservoir Energy Exploration & Exploitation 35: 194–217.

[9] Feng Q, Xia T 2017 Pressure transient behavior of horizontal well with time-dependent fracture conductivity in tight oil reservoirs Geofluids.

[10] Chen H, Li M 2017 Numerical simulation of wellbore outflow in multi-point steam injection horizontal well Journal of Petroleum Sciences 38: 696-704.