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*Research Article*

# A Productivity Prediction Model for Multistage Fractured Horizontal Wells in Shale Gas Reservoirs

**Yongchao Xue, Hua Tian, Fengyuan Zhang, Longjun Wang, and Qingshuang Jin**

*State Key Laboratory of Petroleum Resources and Prospecting in China University of Petroleum, Beijing, China*

Correspondence should be addressed to Yongchao Xue; xyc75@cup.edu.cn

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The tiny sizes of pores and throats in shale gas reservoir increase the complexities of the flow mechanisms, which challenge the accuracy of current productivity models during optimization design and prediction for multistage fractured horizontal wells (MFHWs). This paper established a productivity prediction model for MFHWs with cased hole completion and open hole completion. The model couples the gas flow in the matrix, fractures, and wellbore using potential superposition principle and considers multiple mechanisms of gas flows in a shale gas reservoir, such as stress-sensitive effect, wellbore friction, as well as interference between fractures. Based on the developed model, a productivity prediction method for MFHWs in shale gas reservoirs has been established, and sensitivity of the impact factors on productivity was analyzed. The analysis revealed that MFHWs are suitable for shale gas reservoirs with certain thickness. The number of fractures has significant impact on the production of shale gas reservoir. And the fractures at the both sides have higher production rate than the intermediate ones for multistage fractured horizontal wells. The fracture half-length has insignificant effect on the productivity of MFHWs. The production of shale gas reservoir also increases with pressure drop. The wellbore friction has insignificant effect on the production of MFHWs. The findings of this study can provide a basis for scientific evaluation of the production of MFHWs in shale gas reservoirs.

## 1. Introduction

With the profound changes in the global energy pattern, unconventional oil and gas resources are playing an important role [1, 2]. Among the resources, shale gas has become a research hotspot due to its abundant reserve around the world. The exploration and exploitation of shale gas reservoirs are very successful in the United States and Canada. Other countries, such as Australia, China, and Russia, also started to put emphasis on shale gas resources [3]. Shale gas in China has become an important part of newly proved natural gas geological reserves in China due to its huge resource potential and considerable reserves [4, 5]. Due to the small pore size and narrow throats of the formation rock, shale gas reservoirs usually have extremely low permeability and productivity for a single well [6]. Accordingly, well stimulation are required for the economic development [7–11].

Among well stimulation techniques, horizontal well together with staged hydraulic fracturing is the most economical and effective way to enhance productivity. The multistage fractured horizontal well (MFHW) could effectively increase the drainage area of gas reservoirs and obtain better economic benefits [12, 13]. Therefore, the multistage fractured horizontal well has gradually become an important mean to effectively develop shale gas reservoirs.

The prediction of well productivity after fracturing is not only a main objective but also a difficult task in the optimization of horizontal well staged fracturing. At present, there are mainly two methods to predict the productivity of fractured horizontal wells, one is analytical method to establish analytical model, and the other is numerical simulation method [14]. The analytical method mainly uses mathematical models based on a physical model to describe fluid flow states under different conditions through various mathematical methods. The focus of the study is single-phase flow, and the construction of the physical model is the critical part of this study and will affect the accuracy of the productivity prediction. Analytical models are generally solved by a series

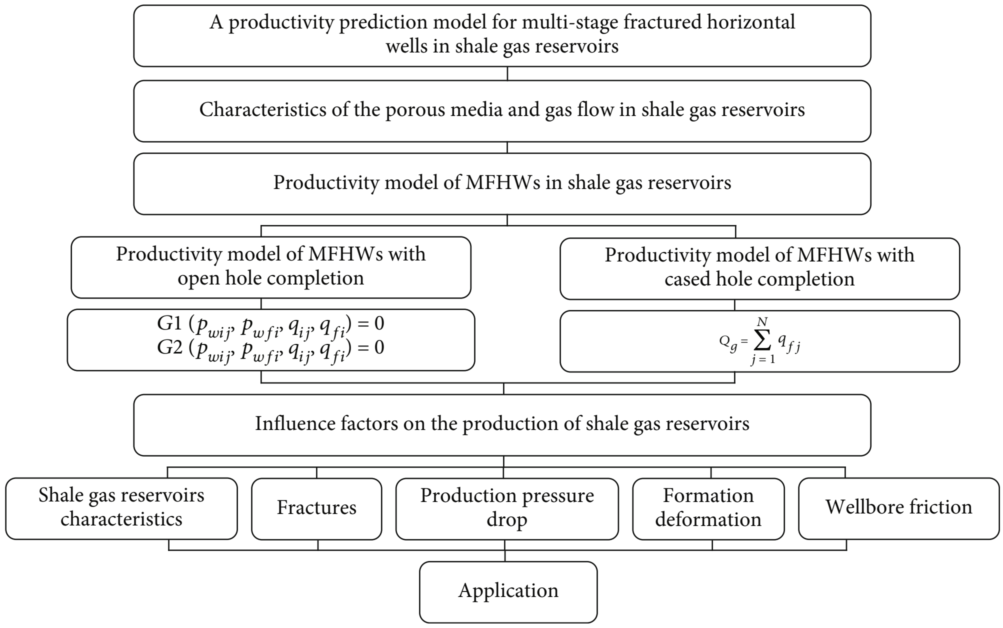



Figure 1: The work flow for this study.

of mathematical methods such as point source function [15, 16], conformal transformation [17, 18], superposition principle [19, 20], Laplace transform [21], Green function [22], and equivalent well diameter method [23]. In contrast, the numerical simulation method simulates reservoir geometry with the help of grid discretization, grid division, and property interpolation [24–26]. Due to the huge difference of permeability between matrix and fracture, grid refinement is required to solve the governing equations so that we can make sure the iteration converge. The transmissibility between grids is obtained to characterize the fluid flow between grid blocks. The commonly used numerical methods to solve the governing equation include finite difference method [27, 28], finite element method [29, 30], and boundary element method [31, 32]. Compared to the numerical simulation, the analytical model is much simpler, and the solution is more straightforward, and the calculation speed is often faster. However, the analytical method could not consider complex reservoir geometries and fracture network and usually ignore complex fluid storage and transport mechanisms.

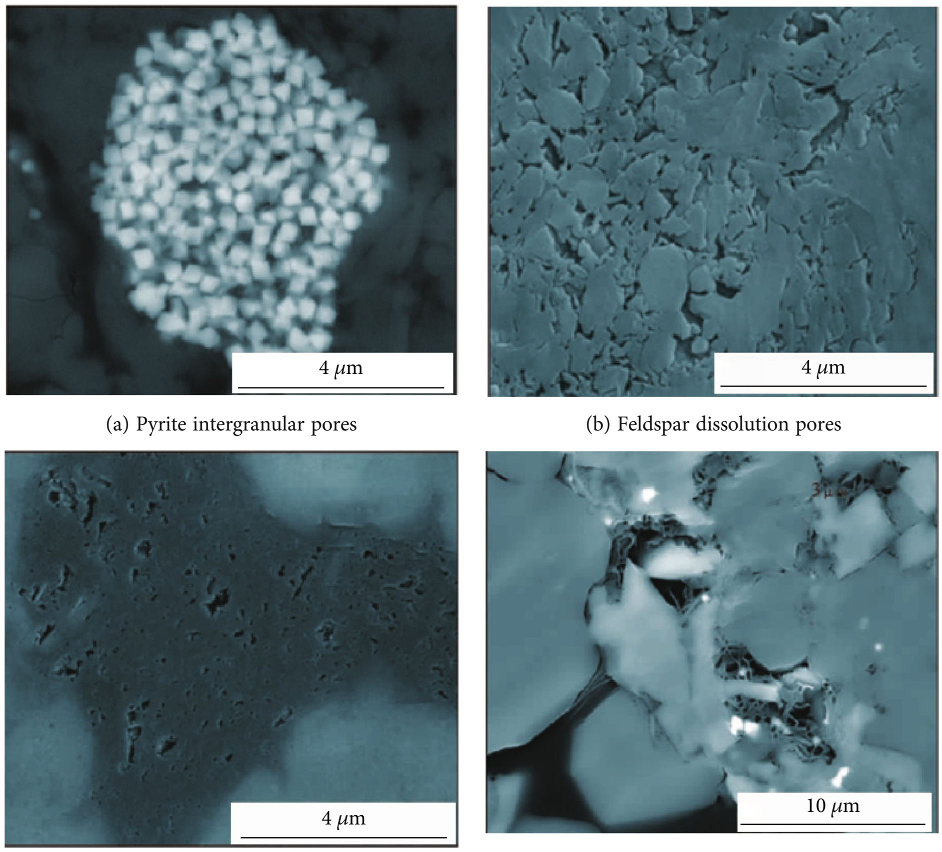
For shale gas reservoirs, multiple mechanisms such as stress-sensitive effect and interfracture interference need to be considered. Nevertheless, very few methods incorporated these mechanisms into productivity models for MFHWs in shale gas reservoirs, which inevitably have many drawbacks [33–35]. Therefore, it is urgent to conduct the productivity analysis and systematic study for MFHWs in shale gas reservoirs.

First, the characteristics of the porous media and gas flow in shale gas reservoirs are described. Based on the formation characteristics and gas flow mechanisms in shale gas reservoir, this study proposed a productivity prediction model for MFHWs in shale gas reservoir using the potential superposition principle. The model considers wellbore friction, interference between fractures, and formation rock deformation when gas flows in wellbore, fracture, and gas reservoir. Then, the main influencing factors on productivity were analyzed for MFHWs. Finally, the field example analysis from a shale gas reservoir illustrates the application effect of the model. Therefore, it provides a basis for scientific evaluation of the productivity estimation for MFHWs in shale gas reservoirs. The whole workflow is shown in Figure 1.

## 2. Characteristics of the Porous Media and Gas Flow in Shale Gas Reservoirs

*2.1. Characteristics of Porous Media in Shale Gas Reservoirs.* Pyrite in shale gas reservoirs forms intergranular pores (Figure 2(a)). The existence of feldspar results in the formation of dissolution pores (Figure 2(b)). There are abundant nanopores in shale reservoir. The nanopores are mainly irregular organic matter nanopores (Figure 2(c)). In addition, illite nanopores exist in shale gas reservoirs (Figure 2(d)). In contrast to conventional gas reservoirs, shale gas reservoir has the remarkable characteristics of ultracompact, ultralow porosity, and ultralow permeability.

*2.2. Characteristics of Gas Flow in Shale Gas Reservoirs.* Although slippage effect is observed in gas flow in porous media, it can be ignored in shale gas reservoirs if the reservoir pressure exceeds 4 MPa [36]. The effect of start-up pressure gradient on productivity could still be ignored if there is only single gas flow in a shale gas reservoir [37]. Stress-sensitive effect in shale gas reservoirs is more serious, and it has great influence on gas productivity [38, 39]. Therefore, a productivity prediction model of a shale gas reservoir should consider stress-sensitive effect. On the basis of the stress-sensitive effect experiments of shale gas reservoirs, we used the following equation to characterize the




(a) Pyrite intergranular pores

(b) Feldspar dissolution pores

(c) Organic-matter nanopores

(d) Illite nanopores

Figure 2: Characteristics of porous medium in shale gas reservoirs.

relationship between permeability and effective stress in a shale gas reservoir:

$$\frac{K}{K_0} = \left(\frac{\sigma}{\sigma_0}\right)^{-S_p}. \quad (1)$$

## 3. Productivity Model of MFHWs in Shale Gas Reservoirs

The horizontal well is located in the middle of the formation with the length $L$. The lateral section of the well is equally fractured with a distance of $d$, and the fracture number is $N$. By considering wellbore friction, interference of fluid flow between fractures, and formation deformation, the productivity prediction models of MFHWs with open hole completion and cased hole completion can be established separately.

*3.1. Productivity Model of MFHWs with Open Hole Completion.* In a horizontal well with open hole completion, gas can either flow from the reservoir to fractures and then from fractures to wellbore, or flow from reservoir to wellbore directly. If the wellbore friction is neglected, the potential distribution of the reservoir when gas flows within the fractures and horizontal wellbore simultaneously can be obtained:

$$\Phi(x,y,z) = \Phi_e + \left(\frac{p_{sc}T}{2\pi Z_{sc}T_{sc}}\sum_{i=1}^{N} q_{fi}\Omega(md,x,y,z) + \frac{p_{sc}T}{4\pi Z_{sc}T_{sc}}\sum_{i=1}^{N}\sum_{j=1}^{M} q_{ij}\left(-\psi_{ij}\right)\right) - \left(\sum_{i=1}^{N}\Phi_{fie} + \sum_{i=1}^{N}\sum_{j=1}^{M}\Phi_{ije}\right), \quad (2)$$

$$\Omega(x_0,x,y) = \operatorname{arcch}\frac{1}{\sqrt{2}}\left\{\left[1 + \frac{y^2}{L_f^2} + \left(\frac{x_0 - x}{L_f}\right)^2\right] + \sqrt{\left[1 + \frac{y^2}{L_f^2} + \left(\frac{x_0 - x}{L_f}\right)^2\right]^2 - 4\frac{y^2}{L_f^2}}\right\}^{1/2}, \quad (3)$$

$$\psi_{ij}(x,y,z) = \frac{1}{L_{ij}}\left\{\xi_{ij}(z_w,x,y,z) + \xi_{ij}(-z_w,x,y,z) + \sum_{n=1}^{\infty}\cdot\left[\xi_{ij}(2nh + z_w,x,y,z) + \xi_{ij}(2nh - z_w,x,y,z) + \xi_{ij}(-2nh + z_w,x,y,z) + \xi_{ij}(-2nh - z_w,x,y,z) - \frac{2L_{ij}}{(nh)}\right]\right\},$$

$$\xi_{ij}(\eta,x,y,z) = \ln\frac{r + L_{ij}}{r - L_{ij}},$$

$$r = \sqrt{\left(x_{1j} - x\right)^2 + y^2 + (\eta - z)^2} + \sqrt{\left(x_{2j} - x\right)^2 + y^2 + (\eta - z)^2}. \quad (4)$$

If we use the pseudopressure, equation (2) can be written as:

$$\tilde{p}(x,y,z)=\tilde{p}_e+\left(\frac{p_{sc}T}{2\pi K_i Z_{sc}T_{sc}}\sum_{i=1}^{N}q_{fi}\Omega(id,x,y)+\frac{p_{sc}T}{4\pi K_i Z_{sc}T_{sc}}\sum_{i=1}^{N}\sum_{j=1}^{M}q_{ij}\left(-\psi_{ij}\right)\right)-\frac{1}{K_i}\left(\sum_{i=1}^{N}\Phi_{fie}+\sum_{i=1}^{N}\sum_{j=1}^{M}\Phi_{ije}\right). \tag{5}$$

The pseudopressure can be given as:

$$\tilde{p}_{wij}=\tilde{p}_e+\frac{1}{K_i}\left(\sum_{s=1}^{N}\Phi_{fs}-\sum_{s=1}^{N}\sum_{t=1}^{M}\Phi_{st}\right)-\frac{1}{K_i}\left(\sum_{s=1}^{N}\Phi_{fse}+\sum_{s=1}^{N}\sum_{t=1}^{M}\Phi_{ste}\right), \tag{6}$$

where $p_{wij}$ is the pressure at midpoint of the $j$th line sink of the $i$th segment; $\Phi_{fs}$ is the potential generated at midpoint of the $j$th line sink of the $i$th segment by the $s$th fracture; $\Phi_{st}$ is the potential generated at midpoint of the $j$th line sink of the $i$th segment by the $t$th line sink of the $s$th segment.

$$\tilde{p}_{wfi}=\tilde{p}_e+\frac{1}{K_i}\left(\sum_{s=1}^{N}\Phi_{fs}-\sum_{s=1}^{N}\sum_{t=1}^{M}\Phi_{st}\right)-\frac{\mu_g q_{fi}}{2\pi K_f(t)w}\frac{p_{sc}}{Z_{sc}T_{sc}}\frac{ZT}{p}\ln\frac{L_f}{r_w}-\frac{1}{K_i}\left(\sum_{s=1}^{N}\Phi_{fse}-\sum_{s=1}^{N}\sum_{t=1}^{M}\Phi_{ste}\right), \tag{7}$$

where $p_{wfi}$ is the pressure at midpoint of horizontal wellbore.

Considering frictional pressure drop in wellbore, acceleration pressure drop can be calculated as follows:

$$\Delta p_{fi}=p_{f1i}-p_{f2i}=m_{2i}v_{2i}-m_{1i}v_{2i}=4\rho_{gsc}\frac{p_{sc}}{Z_{sc}T_{sc}}\frac{ZT}{p}\left[\frac{\left(Q_{i(M/2-1)}+q_{fi}\right)^2}{\pi D^2}-\frac{Q_{i(M/2-1)}^2}{\pi D^2}\right],$$

$$\Delta p_{wij}=\left(\frac{8f\rho_{gsc}Q_{ij}^2}{\pi^2D^5}\Delta x+\frac{4f\rho_{gsc}Q_{ij}q_{ij}}{\pi^2D^5}\Delta x+\frac{8f\rho_{gsc}q_{ij}^2}{3\pi^2D^5}\Delta x+\frac{32\rho_{gsc}Q_{ij}q_{ij}}{\pi^2D^4}+\frac{16\rho_{gsc}q_{ij}^2}{\pi^2D^4}\right)\frac{p_{sc}}{Z_{sc}T_{sc}}\frac{ZT}{p}. \tag{8}$$

Combining Equations (6) and (7), we can establish $N+N\times M$ equations:

$$G1\left(p_{wij},p_{wfi},q_{ij},q_{fi}\right)=0. \tag{9}$$

Then, relationship between the two-line sink pressures should be

$$p_{wiM/2}-p_{wi(M/2+1)}=\Delta p_{fi}. \tag{10}$$

Therefore, the pressure at midpoint of the $j$th line sink of the $i$th segment is given by

$$p_{wij}=p_{wf}\,;\Delta p_{wij}=0(i=N\,;j=M), \tag{11}$$

$$p_{wij}=p_{w(i+1)1}+0.5\left(\Delta p_{w(i+1)1}+\Delta p_{wij}\right)(i<N\,;j=M), \tag{12}$$

$$p_{wij}=p_{wi(j+1)}+0.5\left(\Delta p_{wij}+\Delta p_{wi(j+1)}\right)+\Delta p_{wfi}\left(i=1,2,\cdots N\,;j=\frac{M}{2}\right), \tag{13}$$

$$p_{wij}=p_{wi(j+1)}+0.5\left(\Delta p_{wij}+\Delta p_{wi(j+1)}\right)\left(i=1,2,\cdots N\,;j\neq\frac{M}{2},M\right), \tag{14}$$

$$p_{wfi}=p_{wi(M/2+1)}+0.5\left(\Delta p_{wfi}+\Delta p_{wi(M/2+1)}\right)(i=1,2,\cdots N). \tag{15}$$

With Equations (11)–(15), $N+N\times M$ equations are obtained:

$$G2\left(p_{wij},p_{wfi},q_{ij},q_{fi}\right)=0. \tag{16}$$

The productivity model considers the interference of gas flow between fractures and couples the reservoir flow to fractures, reservoir flow to wellbore, fracture flow to wellbore, and pipe flow within wellbore.

*3.2. Productivity Model of MFHWs with Cased Hole Completion.* In a horizontal well with cased hole completion, gas flows from the reservoir to fractures and then from fractures to wellbore. Accordingly, gas production from MFHWs is the sum of gas contributions from the $N$ fractures.

For shale gas reservoirs with the stress-sensitive effect, the pseudopressure is defined as $\tilde{p}=\int_{p_0}^{p}p/\mu Z((p_c-p)/(p_c-p_i))^{-S_p}dp$. We introduced a new potential function:

$$\Phi=K_i\tilde{p}=K_i\int_{p_0}^{p}\frac{p}{\mu Z}\left(\frac{p_c-p}{p_c-p_i}\right)^{-S_p}dp. \tag{17}$$

Based on the productivity of each fracture (the $j$th fracture), the bottomhole pressure drop for the MFHW with cased hole completion using potential superposition principle was obtained as follows:

$$\tilde{p}_e - \tilde{p}_{wfj} = \frac{p_{sc}T}{2\pi h K_i T_{sc} Z_{sc}} \sum_{i=1}^{N} q_{fi} \ln \frac{\left(\left(R_e/L_f\right) - \left(id/L_f\right)\right) + \sqrt{1 + \left(\left(R_e/L_f\right) - \left(id/L_f\right)\right)^2}}{\left|\left(\left(jd/L_f\right) - \left(id/L_f\right)\right)\right| + \sqrt{1 + \left(\left(jd/L_f\right) - \left(id/L_f\right)\right)^2}} + \frac{q_{fj} p_{sc} T \bar{\mu} \bar{Z}}{\pi K_f \omega T_{sc} Z_{sc}} \ln \frac{L_f}{r_w}. \quad (18)$$

The pressure drop consists of frictional pressure drop and acceleration pressure drop [40–42]. Therefore, the pressure drop along the horizontal wellbore between two fractures can be deduced according to the momentum theorem:

$$p_{1j} - p_{1(j+1)} = f_j \cdot \frac{1}{4r_w (\pi r_w^2)^2} \frac{\rho_{gsc} p_{sc} Z T}{p_{wfj} Z_{sc} T_{sc}} Q_{jsc}^2 \Delta L_j + \frac{1}{(\pi r_w^2)^2} \frac{\rho_{gsc} p_{sc} Z T}{p_{wfj} Z_{sc} T_{sc}} \left(Q_{2jsc}^2 - Q_{1jsc}^2\right) (j = 1, 2, \cdots\cdots, N\text{-}1). \quad (19)$$

When $N$ is even, $\Delta L_j = 2d(j \neq N)$; $\Delta L_j = d(j = N)$.

When $N$ is odd, $\Delta L_j = d(j \neq N)$; $\Delta L_j = d/2(j = N)$.

Friction factor of the $j$th wellbore segment, $f_j$, can be can obtained as follows:

$$f_j = \frac{64}{N_{ej}} N_{ej} \leq 2000, \qquad \frac{1}{\sqrt{f_j}} = 1.14 - 2 \ln \left[\frac{e}{2r_w} + \frac{21.25}{N_{ej}^{0.9}}\right] N_{ej} \geq 4000. \quad (20)$$

Reynolds number, $N_e$, can be can obtained as follows:

$$N_e = \frac{2\rho v r_w}{\mu}, \qquad N_{ej} = 2\rho_g \frac{r_w}{\mu_g} \cdot \frac{Q}{A} = 2\rho_g \cdot \frac{Q}{\mu_g \pi r_w} = 2\rho_{gsc} \cdot \frac{Q_{sc}}{\mu_g \pi r_w}. \quad (21)$$

Gas flow rate of the $j$th wellbore segment $Q_{jsc}$ is calculated by the following equations:

$$Q_{jsc} = Q_{(j-1)sc} + q_{fj}(j \neq 1), \quad (22)$$

$$Q_{jsc} = q_{fj}(j = 1). \quad (23)$$

If $p_{wf} = p_{wfj}$, wellbore pressure $p_{wfj}$ is approximated by $p_{wfj} = (p_{1j} + p_{2j})/2$.

Finally, an equation system has been established by using Equations (19) and (22). According to the equations, the total production of the horizontal well, $Q_g$, can be calculated:

$$Q_g = \sum_{j=1}^{N} q_{fj}. \quad (24)$$

## 4. Influence Factors on the Production of Shale Gas Reservoirs

*4.1. Effect of Shale Gas Reservoir Characteristics.* Figure 3 shows the influence of gas layer thickness on the production of MFHWs. The figure indicates that the production of MFHWs increases with the formation thickness, so layer thickness is one of the important factors affecting the productivity of gas wells. Nevertheless, when the thickness reaches a certain value, the thickness has no significant effect on shale gas production. This demonstrates that MFHWs apply to stratified shale gas reservoirs with certain thickness.

Figure 4 shows the influence of reservoir permeability on the well production. As can be seen from the picture, the well production increases with the permeability, but when the permeability of the reservoir increases to a certain value, the permeability has no significant effect on shale gas production. When $0.001 \times 10^{-3}\ \mu\text{m}^2 < K < 0.1 \times 10^{-3}\ \mu\text{m}^2$, the gas production rate can be dramatically enhanced with fractured horizontal wells, which indicates that MFHWs are appropriate for shale gas reservoirs.

*4.2. Effect of Fractures.* The number of fractures is an important parameter in the design of MFHWs. Figure 4 shows the influence of fracture number on the output of staged fractured horizontal wells. As shown in the picture, the gas production increases with an increase in the number of fractures, but when the number of fractures reaches a certain value, the trend stops (As shown in Figure 5, when the number of fractures increases from 2 to 4, the gas well production increases significantly. When the number of fractures is above four, the increase of production is not obvious.). But increasing the number of fractures also increases the cost of fracturing. Therefore, the optimal number of fractures can be determined by considering economic factors.

Figure 6 shows the effect of fracture half-length on the gas production of MHFWs. As shown in the picture, the fracture half-length has insignificant effect on the productivity of MFHWs. Therefore, increasing fracture number and lateral section length of horizontal wells should be taken as priorities when hydraulic reconstruction is made in tight sandstone gas reservoirs.

There is flow interference between fractures in MFHWs, and productivities of hydraulic fractures in different positions have large difference. Fractures at ends have higher productivity, while those in the middle have relatively lower because of the more interference from other fractures. Figure 7 shows the production distribution of each fracture under different fracture numbers. As can be seen from the

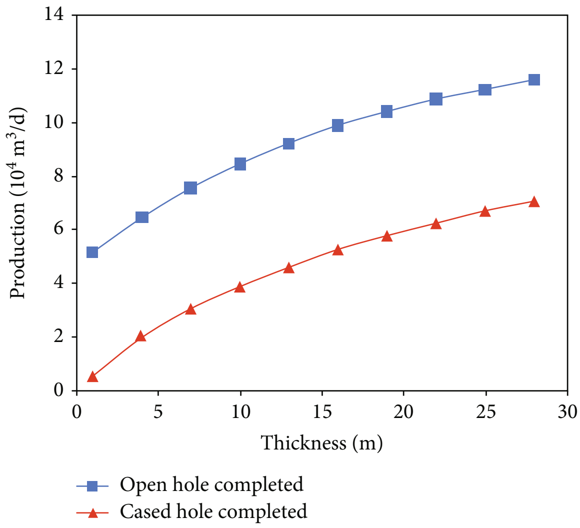



Figure 3: The effect of the thickness.

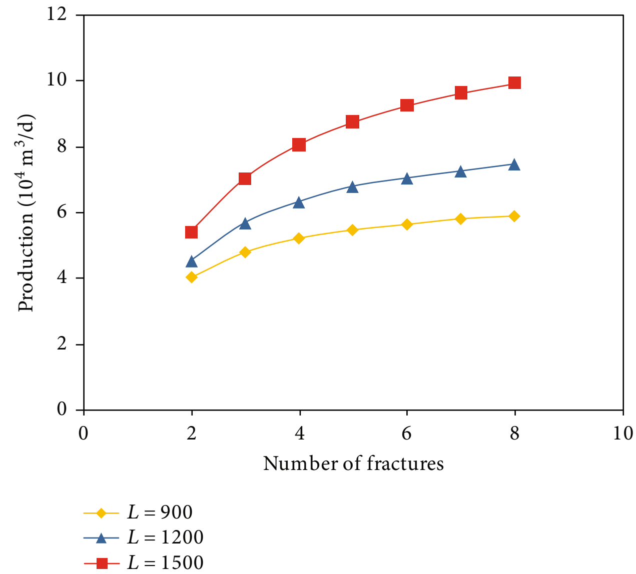



Figure 5: The effect of the number of fractures.

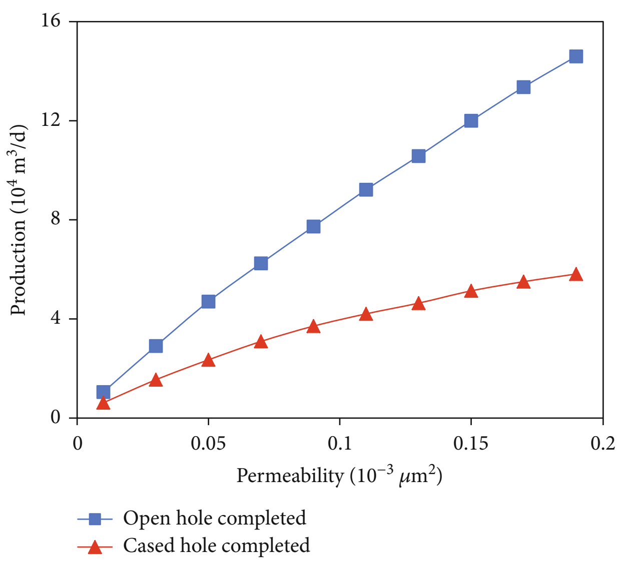



Figure 4: The effect of the permeability.

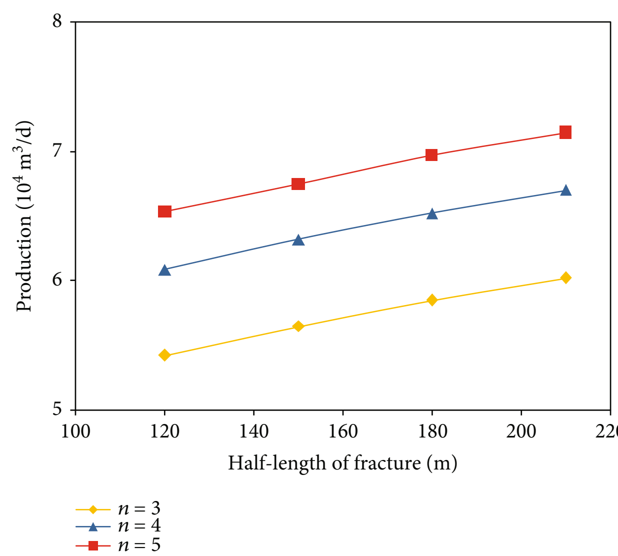



Figure 6: The effect of the fracture half-length on the production of shale gas.

picture, with the increase in fracture number, there is a reduction in the productivities of fractures at the middle and ends, but the decreasing rate becomes slower.

*4.3. Effect of Production Pressure Drop.* Figure 8 shows the influence of production pressure drop on the output of MFHWs. As can be seen from the picture, the production also increases with pressure drop.

*4.4. Effect of Formation Deformation.* Figure 9 shows the influence of formation deformation on the IPR curve of staged fractured horizontal Wells. As can be seen from the picture, the media deformation of a shale gas reservoir has significant impact on the production of shale gas. When bottom hole pressure of a gas well is low (pressure drop is larger than 15 MPa), the formation deforms seriously and the production decreases rapidly. This is because the media deformation speeds up the fracture closure, resulting in reduced gas production. When bottom hole pressure of a gas well exceeds more than 25 MPa (production pressure drop is smaller than 15 MPa), reservoir deforms little and has insignificant impact on the production of shale gas.

*4.5. Effect of Wellbore Friction.* Figure 10 shows the influence of wellbore friction on the production of MFHWs. As can be seen from the picture, wellbore friction has insignificant effect on the production of a MFHW and therefore can be neglected.

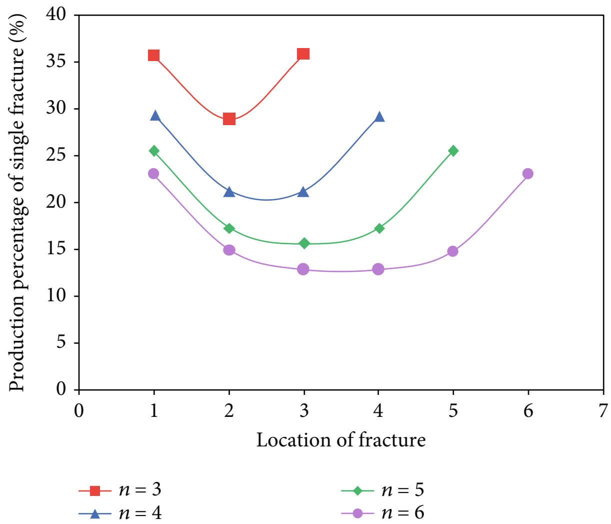



FIGURE 7: The effect of the location of the fractures.

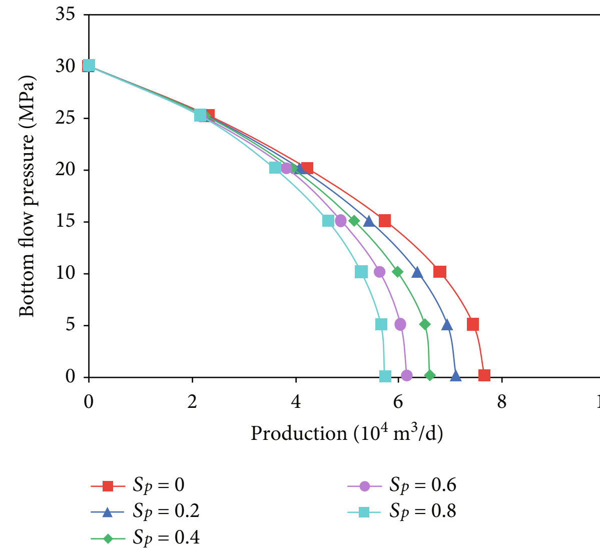



FIGURE 9: The effect of formation deformation.

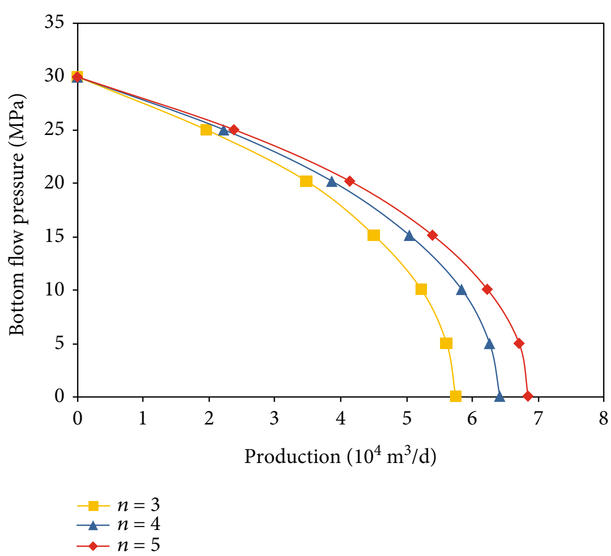



FIGURE 8: The effect of pressure drop.

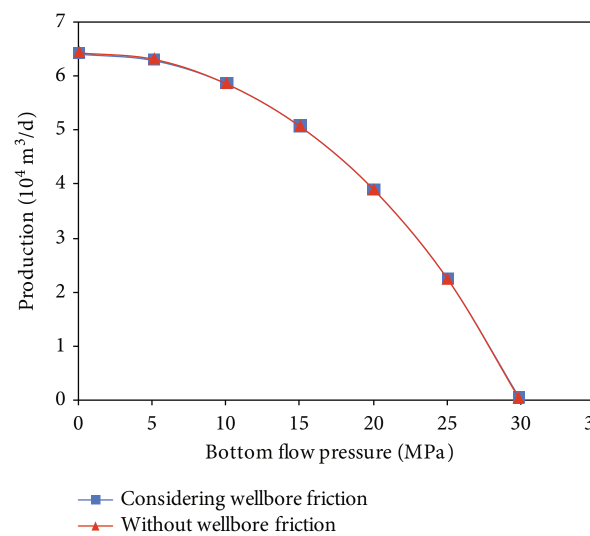



FIGURE 10: The effect of wellbore friction.

## 5. Application

This study takes a shale gas reservoir as an example and applied the established model of MFHWs to evaluate the production of the whole block. Combined with fracturing design, the parameters of a multistage fractured horizontal well in shale gas reservoirs are obtained, shown in Table 1. Figure 11 shows the diagram of the multistage fractured horizontal well. Figure 12 shows the comparison of the gas production calculated from the productivity model of MFHWs under cased hole completion in this paper with the field data. The production data calculated by the proposed model shows a good agreement with the field data. The result shows that the established model is suitable for giving an accurate prediction of the production of MFHWs in shale gas reservoirs.

TABLE 1: Fundamental parameters of a shale gas field.

| Parameters (unit) | Value |
|---|---|
| Permeability ($10^{-3}\mu m^2$) | 0.0653 |
| Thickness of formation (m) | 11.3 |
| Bottom hole flow pressure (MPa) | 21.63 |
| Initial formation pressure (MPa) | 31 |
| Reservoir temperature (°C) | 109 |
| Viscosity (MPa·s) | 0.020655 |
| Horizontal length (m) | 300 |
| Fracture numbers | 3 |
| Half-length of fracture (m) | 150 |
| Width of fracture (m) | 0.008 |

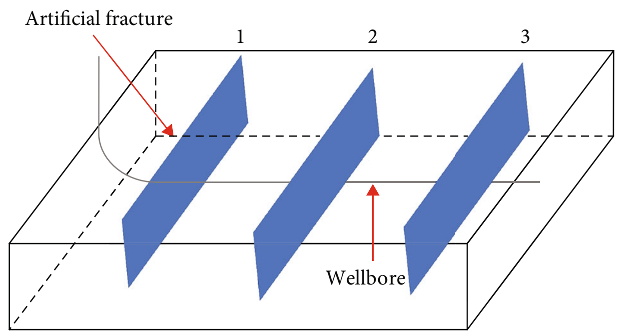



FIGURE 11: Diagram of the multistage fractured horizontal well.

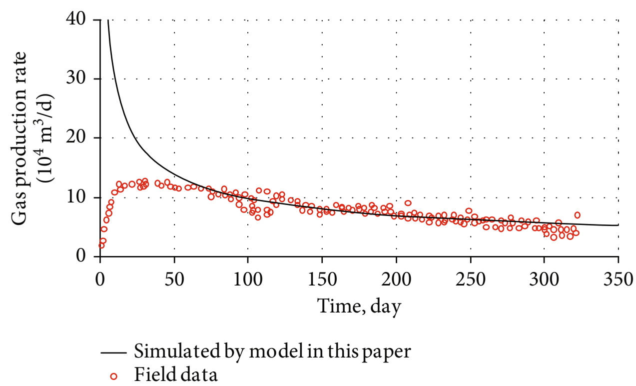



FIGURE 12: Comparison of the field data and the gas production calculated by the model.

## 6. Summary and Conclusions

We presented a productivity prediction model for the staged fractured horizontal well in shale gas reservoir. And the main influencing factors on productivity were analyzed. Based on the above studies, the key conclusions are made as follows:

(1) The size of pores and throats of the shale gas reservoir is very small. The tiny sizes of pores and throats increase the complexities of the flow mechanisms, which has a significant impact on the production of shale gas. Therefore, a productivity model of MFHWs is established with open hole completion and cased hole completion separately

(2) The production of MFHWs increases with the formation thickness in shale gas reservoirs. This demonstrates that MFHWs were applied to stratified shale gas reservoirs with certain thickness. The gas production increases with an increase in the number of fractures. And there is an optimal number of fractures by considering economic factors. The productivity of fractures at both ends is higher than intermediate ones due to the interference of fractures. The media deformation of a shale gas reservoir has significant impact on the production of shale gas

## Nomenclature

$\sigma_0$: Initial effective stress of shale gas reservoir, MPa
$\sigma$: Effective stress of shale gas reservoir, MPa
$K_0$: Reservoir permeability, $10^{-3}\ \mu m^2$
$K$: Reservoir permeability with stress sensibility, $10^{-3}\ \mu m^2$
$S_p$: Coefficient of stress sensibility
$h$: Reservoir thickness, cm
$L$: Lateral length of horizontal wellbore, m
$w$: Fracture width, m
$d$: Fracture spacing, m
$r_w$: Wellbore radius, m
$N$: The number of fractures
$L_f$: Hydraulic fracture half-length, m
$e$: Wall absolute roughness
$f_1$: Laminar friction coefficient
$f_2$: Turbulence friction coefficient.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Disclosure

We note that a shorter conference version of this paper has been presented in The Fourth International Symposium on Hydrogen Energy Renewable Energy and Materials (2018). This manuscript expands the original conference papers and is a perfect and supplement to the previous research. We thoroughly investigated the development process of productivity evaluation model of segmented fractured horizontal wells at home and abroad and applied the established productivity evaluation model to shale reservoir.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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