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PARAMETERS OPTIMIZATION OF STIMULATED RESERVOIR VOLUME OF FRACTURED HORIZONTAL WELLS IN TIGHT GAS RESERVOIRS

[1]Xinfang Ma* **[1]Xiaoying Li**
[1] *College of Petroleum Engineering, China University of Petroleum (Beijing), Beijing, China*
**corresponding author,Email:maxinfang@cup.edu.cn*

Abstract-* Horizontal wells and hydraulic fracturing are the most effective technologies in the exploitation and development of tight gas reservoirs. Hydraulic fracturing with large volumes of proppant and water will not only create high conductivity primary fractures but also stimulate adjacent natural fractures. Fracture network forming around every hydraulic fracture yields a stimulated reservoir volume (SRV). A conceptual model which was based on a tight gas sand reservoir in Northeast China was established to analyze the effect of related parameters on the production of multi-fractured horizontal wells. In order to analyze the impacts of related parameters on production, a series of simulation scenarios and corresponding production performance were designed. Simulation results showed that the number of primary fractures, half length, SRV half-width and drop-down have great effects on the post-fracturing production. Formation anisotropies also control the production performance while the conductivity of the primary fractures and SRV permeability do not have much impact on production performance. Fracture number mainly affects the early time production performance. The increase of SRV width cannot broaden the drainage area of the multi-fractured horizontal wells, but it can really improve the recovery in its own drainage region. Permeability anisotropies have much effect on production rate, especially the late time production rate.

Keywords - Tight gas reservoir; Fractured horizontal well; Stimulated reservoir volume; Parameters Optimization

I. INTRODUCTION

Tight gas sand reservoirs are widely distributed in China[1]. Formations in tight sand are characterized by low effective porosity, low permeability and even complicated natural fractures[2,3,4]. Traditional stimulation and fracturing technology can not realize effective development and production. In American technology of stimulated reservoir volume (SRV) was developed to exploit the unconventional gas reservoirs, such as tight gas and shale gas[4].In conventional fracturing, there is one or several separate fractures. However, SRV greatly expands the volume of stimulated formation, which has great sense to improve production in low permeability reservoir.

Various technologies to realize SRV have been developed in recent several years .Cipolla[5] presented a comparison of the SRV created with a slicwater fracturing and a cross-linked gel fracturing in Barnett shale. The data showed that more than twice SRV was realized with slicwater fracturing than cross-linked gel fracturing. This increase of SRV was approximately validated by gas production rates from the slickwater fractured well at over twice that of the cross-link gel fractured well[6,7]. Studied simultaneous or sequential fracturing, which used real-time stress changes created by fractures in an adjacent well to form fracture network. M.Y. Soliman et al. figured that when the third interval for fracturing is performed between the forward two previously fractured intervals to take advantage of the altered stress in the rock and connect to stress-relief fractures from the previous fractures, there will be greater opportunity to create branch fracturing and effective conductivity deep into the reservoir[8]. Chen et al. pointed that horizontal wells with multiple fracturing stages are also the key method to realize SRV[9].

Parameters like primary fracture number, primary fracture conductivity, SRV width and SRV permeability have various effects on well production performance .In order to make full use of SRV, it is necessary to have good understanding of the effect of these parameters on production. As a result, sensitivity analyses and optimal design of stimulation zone parameters are needed to direct optimal fracturing design. In this paper, a simplified stimulated zone with higher permeability was used to simulate the hydraulic fracture and the induced complex natural fracture system. With this model, the impacts of several key parameters on production were analyzed. Simulation results also provide further insight of optimal parameters to direct fracturing design.

Numerical simulation model

The key to simulate SRV is to accurately represent the hydraulic fractures and the induced complex natural fracture system. However, current numerical simulation methods, dual porosity modeling[10]and discrete modeling [11], have the following limitations: 1) time-consuming to set up hydraulic and natural fracture system; 2) large computation time required.

In this paper, simplified stimulated zones with higher permeability were used to model the hydraulic fracture and

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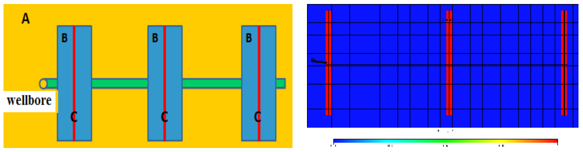
the induced complex natural fracture system. In other words, each primary fracture has an enhanced zone, named SRV zone. This method saves much developing fine-grid time and computing time. Compared with the simulation results of fine-grid reference model, it has shown that this simplified model greatly decreases simulation time and provides accurate results[12]. These comparisons have been shown by Jianwei Wang and Yang Liu [13].

Fig.1 (a) shows the stimulated volume of a horizontal well with three fracturing stages while Fig.1(b) is the corresponding reservoir model. As shown in Fig.1(a), the horizontal well in the center of a gas reservoir had three fracturing stages. Each stage formed a primary fracture and a SRV zone. Then the gas reservoir consists of three parts: part A—unenhanced zone, part B—SRV zone, part C—primary fracture.



（a）Stimulated Volume （b）Reservoir model

Fig.1 Simulation model of SRV

II. PARAMETERS EFFECTS ON PRODUCTION

This simplified model was applied to a tight gas sand reservoir in China. A conceptual simulation model was constructed to simulate a horizontal well and predict its production in 3 years.

1. Model description

The size of the reservoir model is 2000m×1225m×50m.The base model is networked with 80×49×5 grids. The depth of the reservoir is 3500m.Presure in the formation is 36MPa.The length of the horizontal well is 1000m. Properties for fluid and rock of this model are mentioned in Table 1.

TABLE 1 Fluid and rock properties

Permeability($10^{-3}\mu m^2$)	0.01
Porosity (%)	2
Water density（kg/m^3）	1000
Gas density（kg/m^3）	0.5883
Initial saturation(fraction)	0.5
FVF(sm^3/rm^3)	1.02
Water compressibity(1/bar)	1.40E-05
Rock compressibity(1/bar)	4.0E-05
Viscosity(mPa·s)	0.75

All those parameters shown in Table 2 were studied in the simulation. In each scenario, following parameters were assigned value according to this table except the object variable.

Table 2 Basic values of parameters

Parameter	nf	Xf (m)	FRCD (μm^2•cm)	SRV width (m)	KSRV (md)	Ky/Kx (fraction)	ΔP (MPa)
Value	8	200	20	25	0.1	1	16

2. Number of primary fractures

Number of primary fractures is the first one to be designed. As shown in Fig.2 and Fig.3, well performance after hydraulic fracturing is very sensitive to the number of primary fractures. Fracture number mainly affects the early time production performance. Production rate in early time increases the number of fractures. However, when fracture number is large than eight, the increment of three-year cumulative production is small. Then the best fracture number is seven or eight.

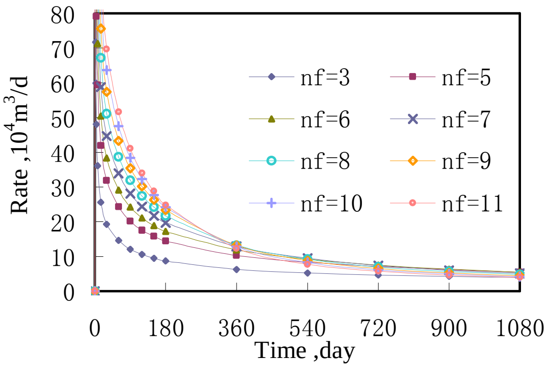


Fig.2 Production rates versus fracture numbers

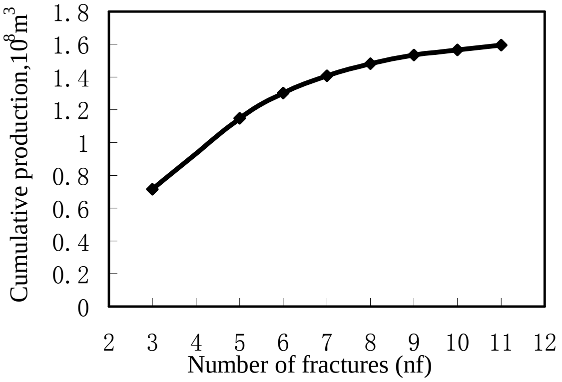


Fig.3 Cumulative productions for three years versus fracture numbers

3. Primary fracture half-length

The length of fracture which affects the area of reservoir controlled by one horizontal well and the recoverable reserve in a long run .As shown in Fig.4, production rate dropped down very quickly in early time. The sensitivity of fracture half-length to production performance is tense, which can be indicted by early-time rate and cumulative production. With the increasing of half length, cumulative production shows linear enhancement. However, risks and capability in construction must be taken into consideration when fracturing program is being designed. In addition, the optimal half-length in a well pattern is affected by well interference in the exploration of a gas reservoir. Then excessive long fractures were not suggested to get favorable production.

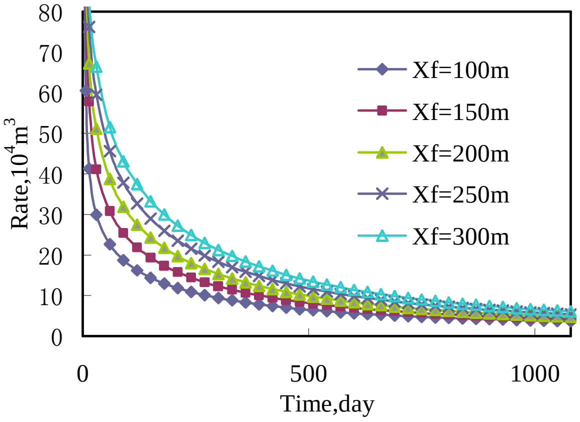


Fig.4 Production rates versus fracture half-length

4. Conductivity of primary fractures (FRCD)

The simulation results showed that conductivity of primary fractures has small impact on well performance(Fig.5). As the matrix permeability is $0.01\times10^{-3}\mu m^2$, the increase of FRCD yields only a few production increments. When FRCD is larger than $20\mu m^2\cdot cm$, the increase of cumulative production is too small. As a result, the optimal FRCD is about $20\mu m^2\cdot cm$.

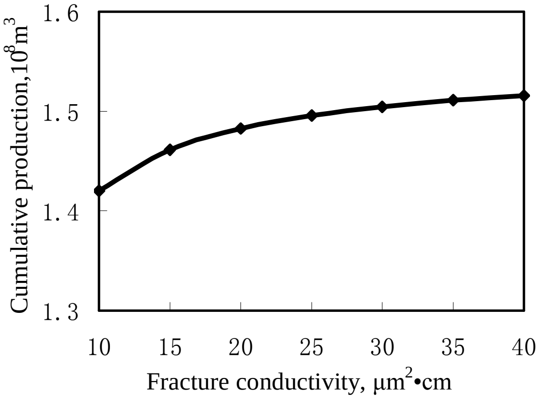


Fig.5 Cumulative productions for three years versus fracture FRCD

5. SRV half- width

Actually, the enhanced zone is usually irregular and SRV can be measured with microseismic event[14].In the simulation, a regular cuboid was used to represent the stimulated zone. As a result, SRV is the volume of the cuboid. The height is assumed invariant. SRV half-length is equal to primary fracture half-length, and its impact has been discussed above. Here SRV width reflects the impact of SRV on production performance. Simulation results reflect that SRV width has large impact on production performance. Fig.6 shows the recovery of variable SRV width. With the SRV width increases, the recovery increases proportionally. However, when SRV width is larger than 100m, recovery increment is small. As a result, the optimal SRV width is about 100m.

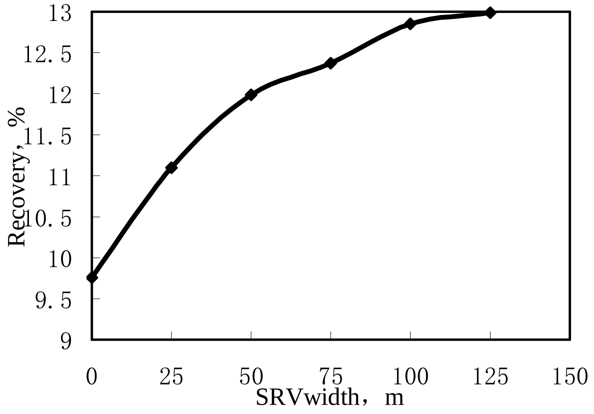


Fig.6 Recovery for three years versus SRV width

The mechanism of impact that SRV width had on well production. Fig.7shows the pressure distribution after 3 years with different SRV width .

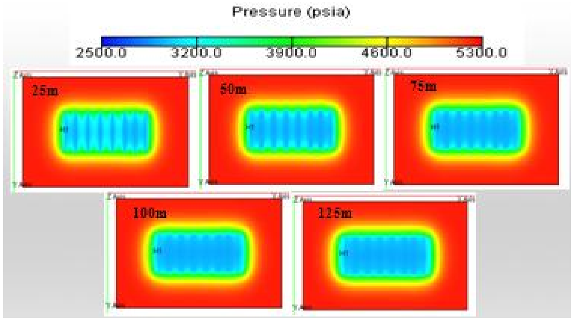


Fig.7 Pressure distributions after 3 years of different SRV width

As the horizontal well length and the SRV length were identical, the drainage volume is similar for different SRV width. However, with the SRV width rise up, the drop of pressure in the drainage region increase apparently.

According to the Darcy's law, large pressure drop yields more production when other parameters remain stationary. All above have shown that the increase of SRV width cannot broaden the drainage area of the multi-fractured horizontal wells, but it really improved the recovery in its own drainage region.

6. SRV permeability

The realization of high permeability in SRV is the key point and difficulty of fracturing stimulation. In general, large SRV permeability was preferred to get more production. However, simulation results showed small impact of SRV permeability on well production(Fig.8). When the matrix permeability is $0.01\times10^{-3}\mu m^2$, the increase of SRV permeability yields only a few production increments. When SRV permeability is larger than 1md, the increase of cumulative production is very small, so the optimal SRV permeability is about 1md(Fig.9). As a result, there is no need to consume too much cost and energy to pursue very high SRV permeability in fracturing design.

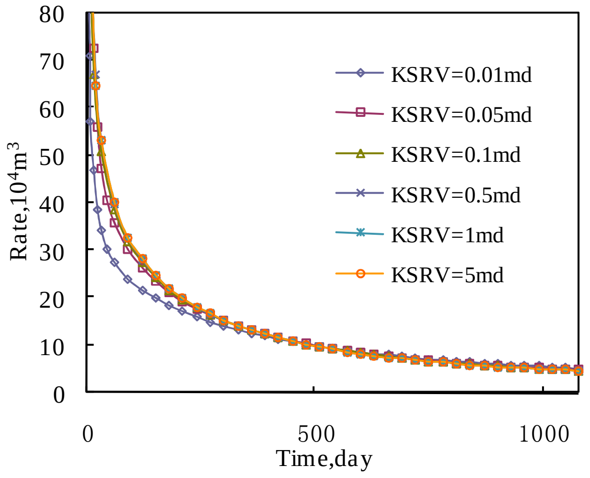


Fig.8 Production rate versus SRV permeability

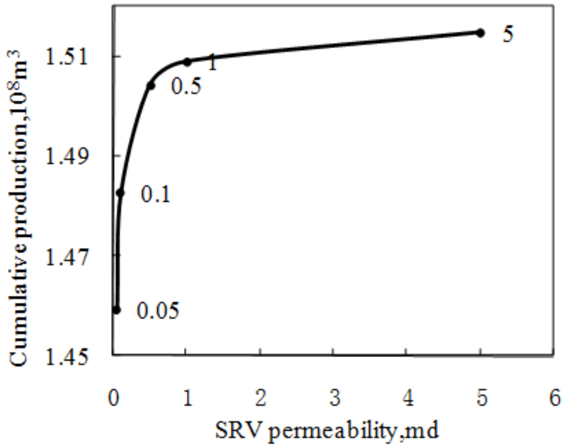


Fig.9 Cumulative production for three years Versus SRV permeability

7. Formation anisotropies

The anisotropy of matrix permeability is a typical parameter to reflect the formation heterogeneity [15].The index of formation anisotropies is represented by Ky/Kx. The flow in X direction is perpendicular to primary fractures. According to production rate and cumulative production, permeability anisotropy has relative high impact on production performance. Fig.10 shows the production rate versus permeability anisotropies. As we can see, permeability anisotropies have much effect on production rate, especially the late time production rate. With the permeability anisotropy varies from 1, 0.5 and 0.1 to 0.01, there is apparent decrease in cumulative production. Table 3 summaries the data.

TABLE 3 Impact of permeability anisotropy on cumulative production

K_y/K_x fraction	cumulative production 10^8m^3	decrease of cumulative production 10^4m^3
1	1.559705	
0.5	1.4632925	964.125
0.1	1.3274832	1358.093
0.01	1.255671	718.122

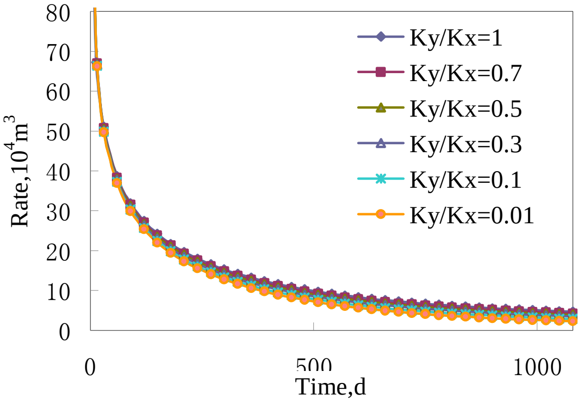


Fig.10 production rates versus formation anisotropies index (Ky/Kx)

8. Drawdown of producing pressure

The effect of producing pressure drawdown is analyzed by setting different bottom-hole pressure.

The matrix permeability case with $0.01\times10^{-3}\mu m^2$ for a horizontal well with eight primary fractures is shown in Fig.11 and Fig.12.The change in drawdown has significant impact on early time production rate and cumulative production. With the increase of drawdown, production displays nearly linear promotion. So it is important to set the appropriate drawdown in exploration with the consideration of whole reservoir pressure level and years of stable production

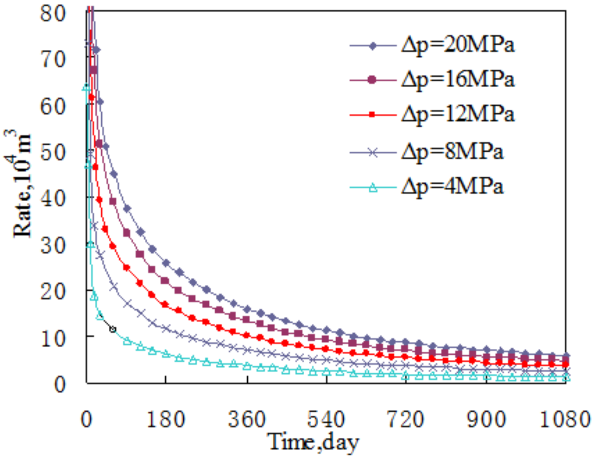


Fig.11 Production rates versus producing pressure drawdown

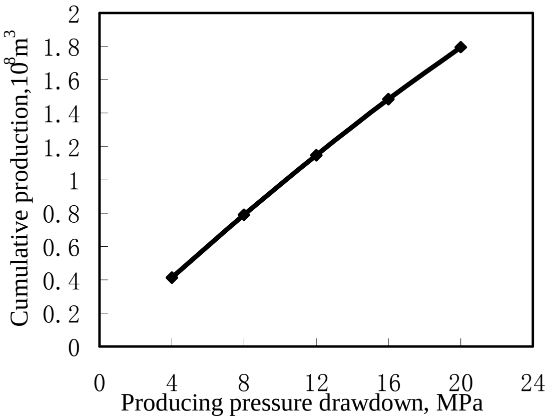


Fig.12 Cumulative productions for three years versus producing pressure drawdown

III. CONCLUSIONS

The simplified model with enhanced permeability to represent fracture network was successfully applied to simulate production performance of horizontal wells with complex fracture network. The simulation results reflect the impacts of several key parameters on production. It also provides further insight of optimal parameters to direct fracturing design.

Fracture number mainly affects the early time production performance. The increase of SRV width cannot broaden the drainage area of the multi-fractured horizontal wells, but it really improved the recovery in its own drainage region. Permeability anisotropies have much effect on production rate, especially the late time production rate.

In summary, the number of primary fractures, half length, SRV half-width and pressure drop-down have great effects on post-fracturing production. Formation anisotropies also control the production performance while the conductivity of the primary fractures and SRV permeability do not have much impact on production performance.

NOMENCLATURE

Nf= Number of primary fractures

Xf= Fracture half-length, m

FRCD=Conductivity of primary fracture, $\mu m^2 \cdot cm$

KSRV=SRV permeability, $10^{-3}\mu m^2$

Kx= permeability in X direction, $10^{-3}\mu m^2$

Ky= permeability in Y direction, $10^{-3}\mu m^2$

Δ p=Producing pressure drawdown, MPa

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