Study on production decline law of fracturing wells in southeast Sulige tight gas field

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Abstract. The main exploitation strategies in southeast Sulige gas field of Ordors Basin are hydraulic fracturing and downhole throttling are mainly adopted. Fractured wells in southeast Sulige gas field have no real stable production process, and the production is constantly decreasing. Fitting effect of adopting one decreasing method to investigate production decline is poor, such as Arps decline, SEPD decline and Duong decline methods. Because of such problems and production characteristics of southeast Sulige, a three-stage decline law study is put forward. The early production decline of gas well belongs to exponential decline, the middle stage belongs to exhaustion decline, and the intermittent exploitation stage belongs to linear decline mode. Most of the production of gas well comes from early and middle production. The study of decline law could provide certain guidance for the evaluation of recoverable reserves and development strategy.

Keywords: Sulige gas field; tight sand gas; Fractured well; Production decline.

1. Introduction

Tight sandstone gas reservoir plays an important role in China's natural gas reserves and is one of the important resources for the rapid development of natural gas in China [1]. Sulige gas field is a tight sandstone gas field with the highest development, the largest scale and the most successful development in China. The main horizons of the gas field are Shanxi Formation and Shihezi Formation. The reservoir is dense and heterogeneous [2]. Due to the poor physical properties of the reservoir, the development strategy of hydraulic fracturing and downhole throttling is adopted for the gas wells in the southeast of Sulige, and the casing pressure and production value of the gas wells continue to decrease after well opening and production. The research on the production decline law of the gas wells in the block can effectively improve the understanding of the production capacity of the gas wells [3-4].

Production decline model is an important tool to evaluate the production and recoverable reserves of oil and gas wells and reservoirs [5]. For the production performance of conventional and unconventional tight gas and shale gas, scholars have put forward different classical decline curve analysis methods to evaluate them [6-9]. These methods, from experience to semi experience and theory, have specific assumptions, limitations and do not have universality. Using a single model to fit the decline law cannot accurately and reasonably understand the production law of gas wells [10-11]. In view of the above problems, based on the understanding of the production law of gas wells in southeast Sulige gas field, this paper divides the production stage of gas wells into three different periods for fitting, which can effectively understand the production change characteristics of gas wells in different production stages, and plays an important guiding role in the evaluation of recoverable reserves and the formulation of development strategies.

2. Common production decline models of tight gas

Production decline rate refers to the change rate of production per unit time or the percentage of production decline per unit time, which reflects the stable production situation of the oilfield. The smaller the decline rate, the better the stable production situation. At present, the chart fitting methods commonly used for the production decline law of unconventional natural gas wells such as tight gas and shale gas include three types: Arps decline, SEPD decline and Duong decline.

2.1. Arps decline

For oil and gas wells with long production history and constant bottom hole flow pressure production, ARPS (1945) made a statistical study on the actual data of the mine. Using the relationship between cumulative production and time, when the oil and gas production enters the decline stage, the decline rate is expressed as:

$$D = -\frac{1}{q_t}\frac{dq_t}{dt} \tag{1}$$

Where: q_t - production of t in decline stage of gas field, 1104m^3/a; D -- decline rate, a^{-1}; dq_t/dt -- output conversion rate per unit time.

Arps decline can describe the production decline law of production wells when the bottom hole flow pressure is fixed and the production completely enters the boundary control period. The largest advantage of this method is that there is no need to understand the formation parameters and only need to analyze the daily production data. Therefore, this method is not suitable for the unstable production stage[12]. ARPS divided the production decline modes of gas wells into three types: exponential decline, hyperbolic decline and harmonic decline, and put forward the method of using chart fitting to determine decline parameters and predict future performance.

Table 1. Classification and expression statistics of Arps decline model.

Decreasing type	Exponential decline	Hyperbolic decline	Harmonic decline
Decline index	$n=0$	$0<n<1$	$n=1$
Decline rate	$D=D_i$	$D=D_i\left(1+nD_it\right)^{-1}$	$D=D_i\left(1+D_it\right)^{-1}$
Relationship between yield and time	$q=q_ie^{-D_it}$	$q=q_i\left(1+nD_it\right)^{1/n}$	$q=q_i\left(1+D_it\right)^{-1}$
	$\lg q=\lg q_i-\frac{D_it}{2.303}$	$\left(\frac{q_i}{q}\right)^n=1+nD_it$	$\frac{q_i}{q}=1+D_it$
Relationship between yield and cumulative yield	$N_p=\frac{q_i-q}{D_i}$	$N_p=\frac{q_i}{D_i(1-n)}\left[1-\left(\frac{q_i}{q}\right)^{n-1}\right]$	$N_p=\frac{q_i}{D_i}\ln\frac{q_i}{q}$
	$q=q_i-D_iN_p$	No linear relationship	$\lg=\lg q_i-2.303\frac{D_i}{q_i}N_p$

2.2. SEPD decline

Conventional analytical decline model is difficult to accurately describe the characteristics of tight sandstone gas reservoir because of its strong heterogeneity, high stress sensitivity and complex seepage mechanism[13]. During development, it is generally necessary to take stimulation measures to obtain industrial gas flow, which is mainly developed by fracturing vertical wells or multi-stage fracturing horizontal wells. The reservoir seepage mechanism is more complex and the production system is changeable. The conventional Arps decline model is difficult to predict its decline rate.

Valko (2009) proposed the SEPD decline model, expanded the exponential decline model to make its application more flexible and convenient. It is widely used in tight gas reservoir and shale gas reservoir. The model is as follows:

$$q = q_0 \cdot \exp\left[-\left(\frac{t}{\tau}\right)^n\right] \tag{2}$$

$$G_p = \frac{q_0\tau}{n}\left\{\Gamma\left[\frac{1}{n}\right]-\Gamma\left[\frac{1}{n},\left(\frac{t}{n}\right)^n\right]\right\} \tag{3}$$

Where, q represents daily gas production, 10^4m^3/d; q_0 represents the initial daily gas production, 10^4m^3/d; Gp is the cumulative gas production, 10^4m^3; t represents the production time, d; and n represent the eigenvalues of the model.

2.3. Duong decline

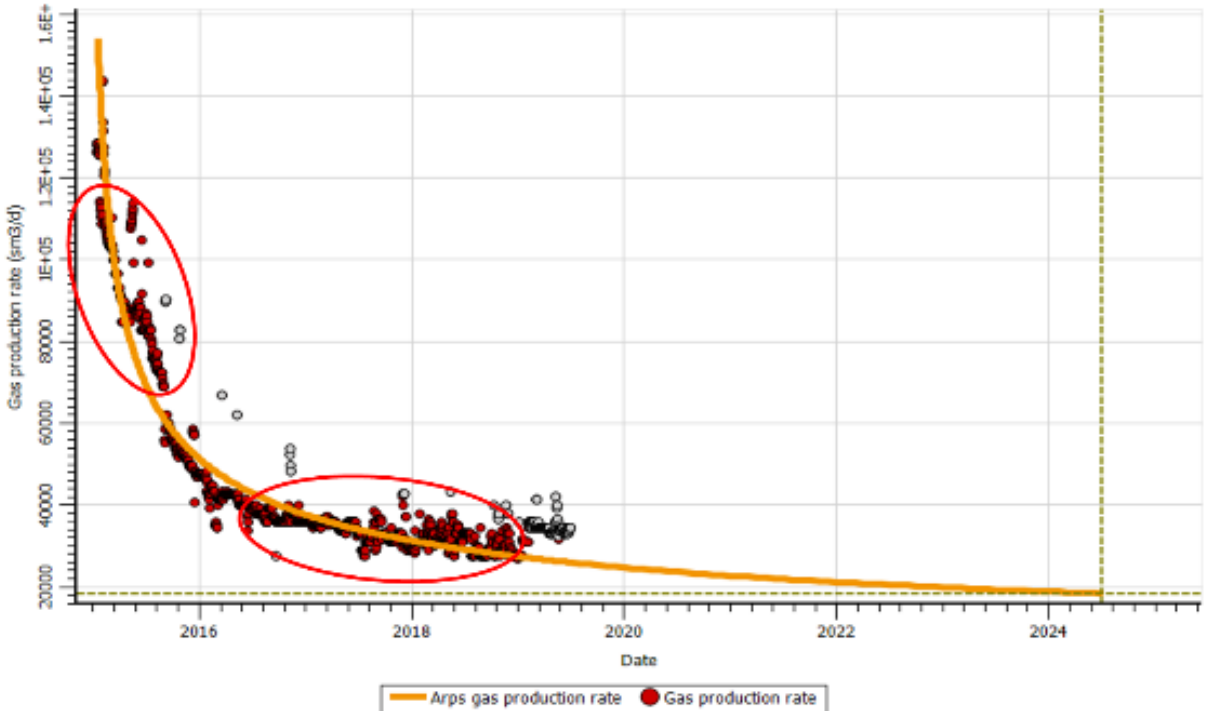
The Duong model is based on the assumption that fracture flow is dominant and the matrix contribution is negligible. The fracture area increases with time and plays a supporting role in fracture flow. Duong believed that pressure depletion in the fracture network may reactivate existing faults or fractures. Regardless of the fracture type, the double ogarithm plot of velocity and cumulative production over time will produce a unit slope straight line. The gradient greater than 1 may be due to the change of flow pattern and field operation. The time rate relationship can be calculated from the intercept and slope values of the log log curve and the initial rate. Duong's model is as follows:

$$q(t) = q_i t^{-m_{D_{nn}}} \exp\left[\frac{a_{Dng}}{\left(1-m_{Dng}\right)}\left[t^{\left(1-m_{Dng}\right)}-1\right]\right] \tag{4}$$

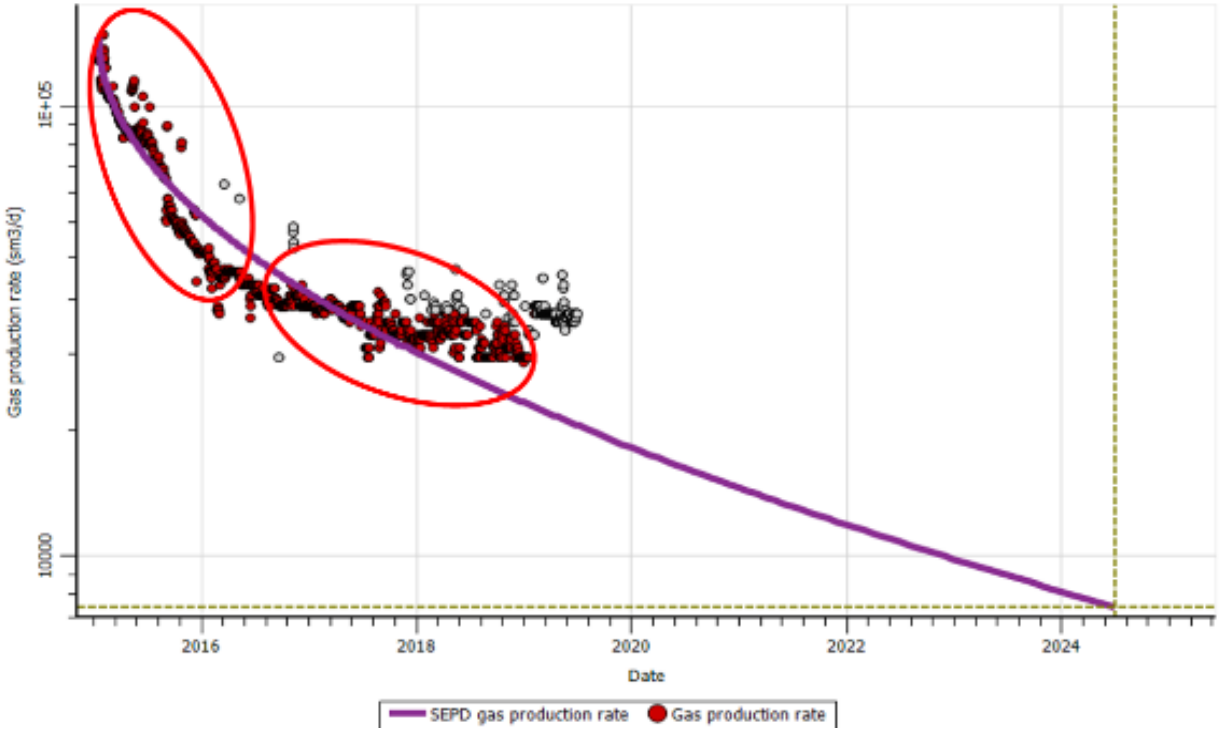
Other models, such as power-law index, stretching index and logistic growth, explain the later deviation. This deviation also occurs when a terminal descent is applied to the modified hyperbolic relationship. Therefore, the EUR estimate of Duong model will be higher unless a restrictive variable is also imposed. The linear flow assumption of Duong model may be true in some cases, but it usually needs to be modified to deal with the changes of flow pattern (i.e. transition flow, SRV depletion, interference, etc.).

3. Study on decline law and characteristics of gas wells in southeast Sulige gas field

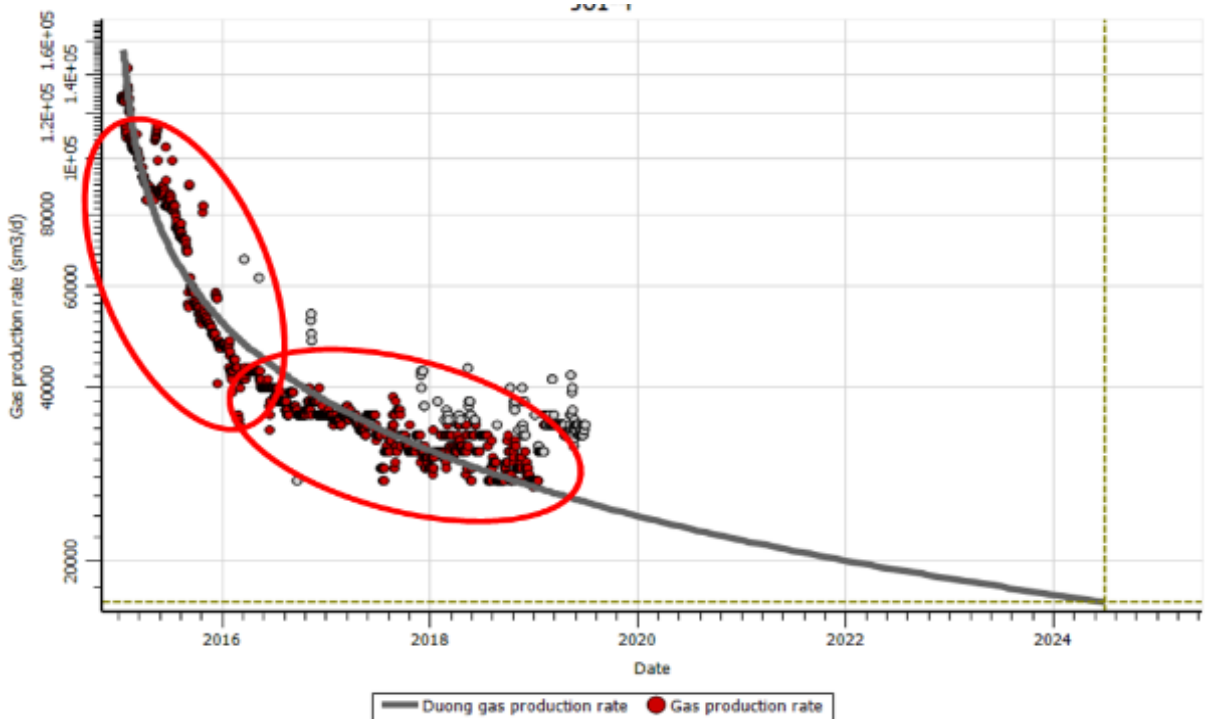
With the increasing production time of gas wells, the application of traditional decline analysis method in the actual production curve highlights some problems. According to the fitting results of the actual production data of well A (Fig.1), the production history of well A can't be well fitted by the three traditional decline models, and the annual gas output predicted in the later stage of production is inconsistent with the actual value. The annual gas output predicted by different decline methods is either high or low.



(1) Arps decline fitting.



(2) SEPD decline fitting.



(3) Duong decline fitting.

Figure 1. Fitting result of actual production data of well A.

The production data of pressure vertical wells in different production years are aligned, and the average production of vertical wells in each production year is calculated, as shown in the figure. The production and decline rate change characteristics of tight gas wells at home and abroad are investigated[14]. Combined with the actual production practice of gas wells in southeast Sulige gas field, the gas wells have obvious three-stage characteristics in the production process, rapid decline in the initial stage, continuous and stable production in the middle stage and intermittent production in the later stage of production. The production change laws of gas wells in these three stages are quite different.

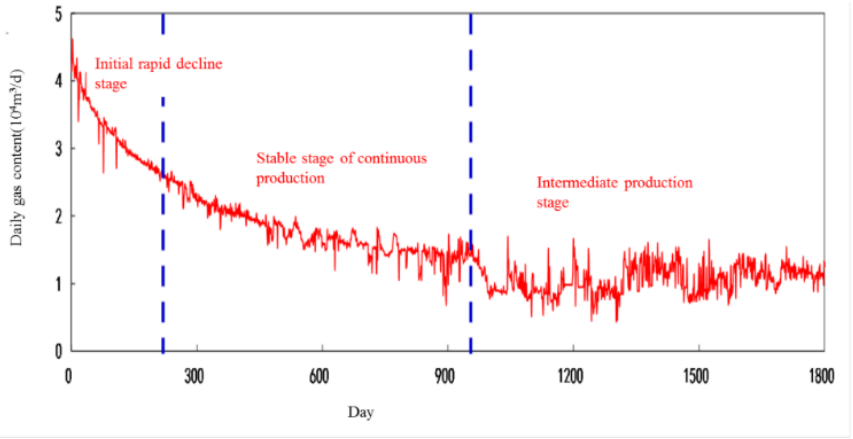


Figure 2. Change trend of annual gas production of typical tight gas wells

Early stage of gas well production: rapid decline, production time 1-3 years; Mid production period: the decline rate slows down and the production duration is 4-10 years; Later stage of production: the well opening rate is 50%, the decline rate is almost unchanged, and the production duration is 4-8 years. Evaluating the variation characteristics of decline rate in stages is a major feature of tight gas well production.

Variation characteristics of early decline rate: the initial production of tight gas wells is relatively high, the production decreases rapidly and the decline rate is large. After fitting several decline models, the early production conforms to the exponential decline model. However, if the exponential decline model is adopted in the whole stage, the later production of the model is much lower than that of the time, which is not in line with the characteristics of tight gas production.

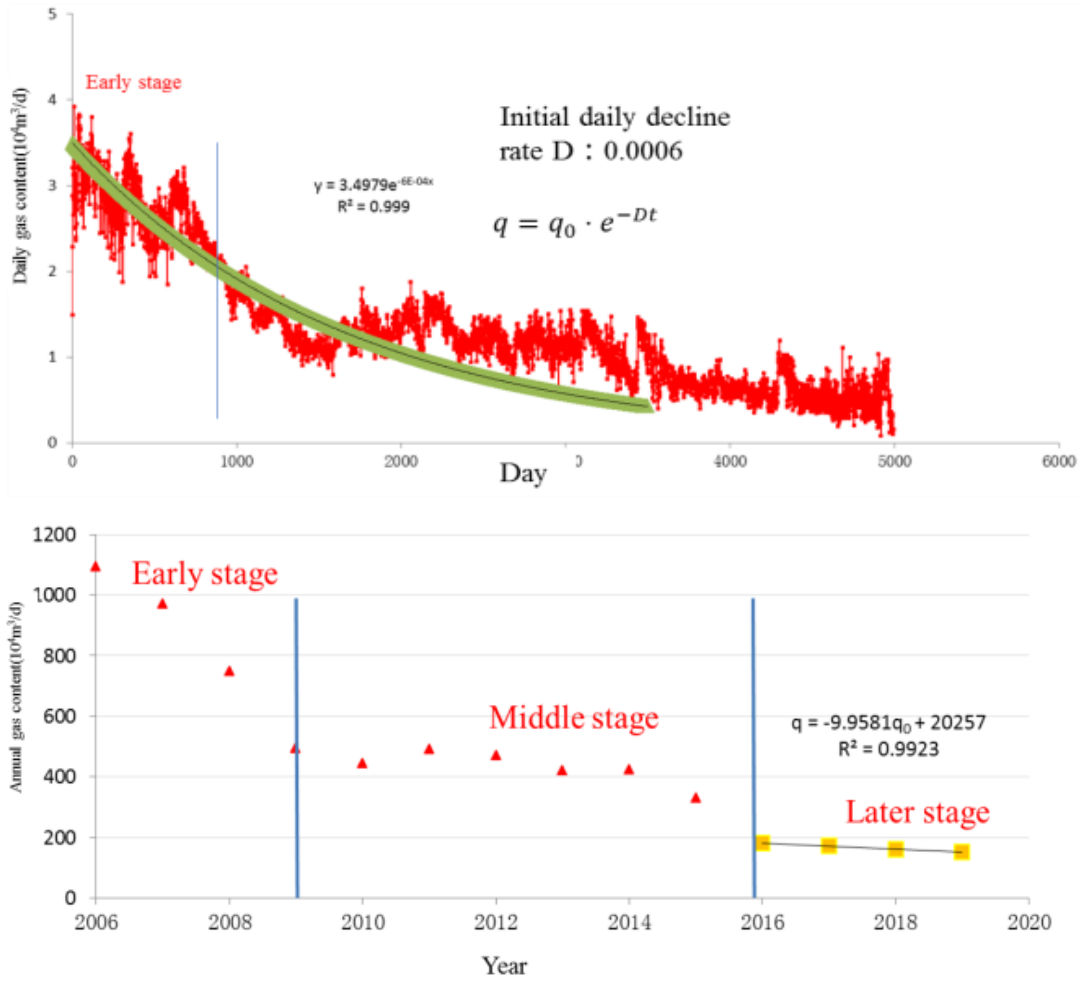


Figure 3. Variation curve of decline rate in early and middle stage

Variation characteristics of medium-term decline rate: after the gas well enters the medium-term, it starts a relatively stable production stage for a long time, and the decline of production pressure slows down. At this time, the variation law of decline rate conforms to depletion decline.

Variation characteristics of decline rate in the later stage: after the gas well enters the later stage, affected by intermittent production (gas supply, drainage and gas production in winter), the well opening rate of the gas well is less than 50%. If the decline model in the early and middle stage is used, the fitted production is higher than the actual gas production. After analysis, it is recommended to use the change of annual gas output with time to evaluate the decline rate in the later stage.

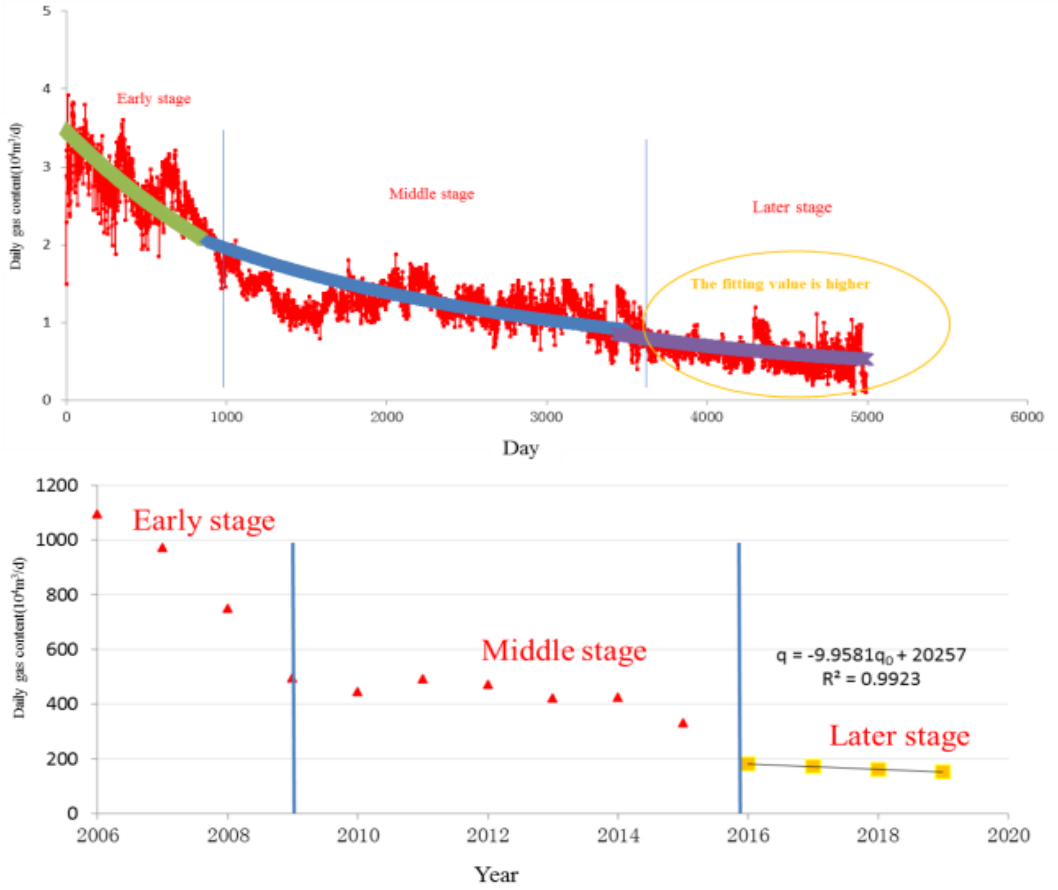


Figure 4. Variation curve of decline rate in later period

The production profile is made according to the decline law as follows:

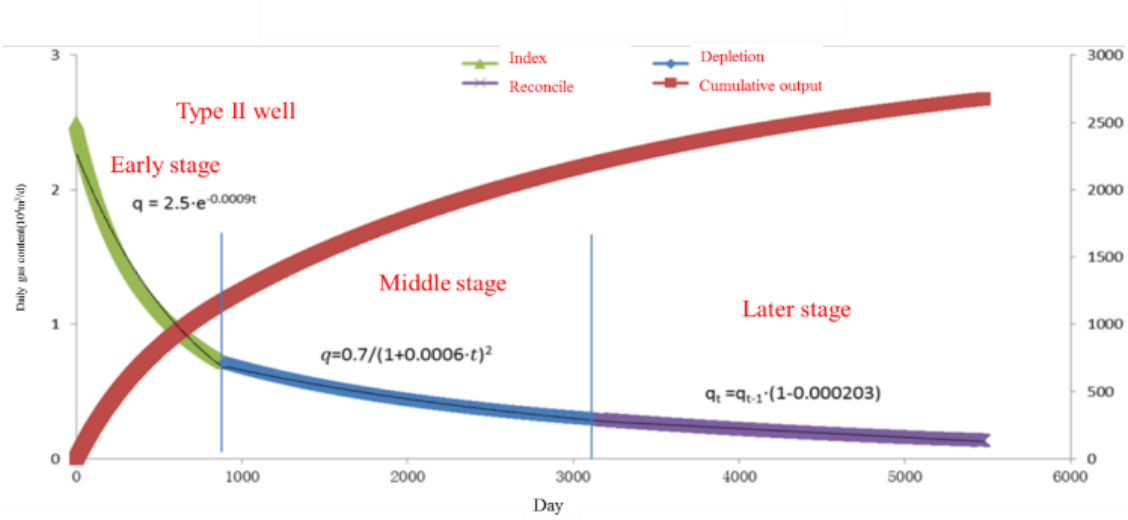


Figure 5. Profile of daily gas production and cumulative gas production of class IIwell.

Table 2. Calculation results of decline rate of different types of wells in different periods.

Well type	early stage		
II	Decreasing law	Daily decline rate D	Daily decline rate formula
	Exponential decline	0.0009	$q= 2.5e^{-0.0009t}$
	middle stage		
	Decreasing law	Daily decline rate D	Daily decline rate formula
	Exhausted decline	0.0006	$q=0.7/(1+0.0006\cdot t)^2$
	late stage		
	Decreasing law	Daily decline rate D	Daily decline rate formula
	Linear decline of annual gas production	7.4	$q_t = q_{t-1}\cdot(1-0.000203)$

If divided according to the whole life cycle of the gas well, the initial stage of production is about 2 years. In the initial stage of production, the average casing pressure is 11.12 MPa, the average pressure drop rate is 0.012 MPa/d, and the average daily gas production is $0.91\times10^4m^3$/d, the stage cumulative gas production is $670.4\times10^4m^3$, accounting for 42.6% of the final cumulative gas production, and the unit pressure drop production is $74.41\times10^4m^3$/MPa; The continuous production period is 6.15 years in total, with a long time, an average pressure drop rate of 0.0018MPa/d and an average daily gas production of $0.34\times10^4m^3$/d, the stage cumulative gas production is $752.2\times10^4m^3$, accounting for 47.8% of the final cumulative gas production, and the unit pressure drop production is $185.7\times10^4m^3$/MPa; The intermittent production period lasts for 2.82 years, the initial casing pressure is 5.19 MPa, the average pressure drop rate is 0.0004 MPa /d, and the daily gas production is 0.147 ×MPa/d, the stage cumulative gas production is 151.33×MPa, accounting for 9.6% of the final cumulative gas production, and the unit pressure drop production is $388.03\times10^4m^3$/MPa; Waste output $0.0549\times10^4m^3$/d, waste casing pressure 4.8 MPa.

4. Conclusion

(1) At present, the methods commonly used to analyze the production decline law of unconventional natural gas wells such as tight gas at home and abroad mainly include Arps decline rate, SEPD decline and Duong decline;

(2) The casing pressure and production of tight gas wells in southeast Sulige gas field decrease simultaneously due to downhole throttling measures. The fitting effect of a decline method on the decline law of gas wells is poor, which cannot reflect the real production characteristics of gas wells;

(3) Based on the data of fracturing vertical wells, the production decline characteristics of gas wells in southeast Sulige gas field are summarized, and a three-stage fitting method is proposed to analyze the production decline law of gas wells in southeast Sulige gas field. The early production conforms to exponential decline, the middle production conforms to depletion decline, and the later production conforms to linear decline.

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