Decline Law of Gas Wells in Different Classes of Tight Sandstone Gas Reservoirs in Sulige Area

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Abstract: Taking a tight sandstone gas reservoir in Sulige area as an example, Arps analysis met hod is used to calculate production decline, and three production decline modes of exponential, hyperbolic and harmonic are explained in detail. The study shows that the decline law of different types of gas wells in a tight sandstone gas reservoir in Sulige area is similar, with exponential decline in the early stage of production and hyperbolic decline in the middle and later stages of production. Different types of reservoirs have different time to enter the boundary control flow, and class I gas well is shorter than class II gas well is shorter than class III gas well. The decline rate of gas wells in different reservoir types is different in different stages, but the decline rate in life cycle is basically the same.

Keywords- Sulige Gas Field; Gas Well production; Decline type; Decline Law

1 Introduction

The decline law is mainly used in the production prediction, calculation of recoverable reserves and research of gas field production planning during gas field development [1]. With the deployment of new wells, the investment of measures and the adjustment of scale, under the new development mode, the production trajectory of the gas field will inevitably have an inflection point, and the production decline law will also change. Sulige gas field has strong reservoir heterogeneity, poor effective sand body connectivity, and low controlled reserves per well. After gas wells are put into operation, gas well production is low, pressure drops rapidly, production declines rapidly, and production stability is poor [2]. Research on the production decline law of gas wells is the basis for mastering and analyzing the dynamics of gas wells. The change law of gas well production capacity can be used to predict the future production capacity and provide certain theoretical basis for oilfield exploitation [3]. Based on a large number of field data, this paper makes a deep study of the decline type and decline law of producing wells, and predicts the production decline law of gas fields on this basis.

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2 Gas well production decline type and decline exponent change rule

2.1 Decline type

The earliest systematic method for analyzing oil and gas production data was put forward by Arps in the 1950s, namely the classical exponential decline, hyperbolic decline and harmonic decline (Table 1). The Arps method is simple and easy to use. It is an empirical method that does not require knowledge of reservoir or well parameters and can be applied to different types of reservoirs. However, the limitations of this method are also obvious, one is that the predicted final recoverable reserves must assume that the historical production conditions will remain unchanged in the future, and the other is limited in the application of unstable (or unbounded) flow state [4-5].

The general mathematical formula of Arps production decline model is as follows:

$$q = \frac{q_i}{[1+nD_i(t-t_0)]^{1/n}} \quad (1)$$

Where:

q -- Production after t time decline, t (oil), $10^4 m^3$ (gas);

qi -- Initial decline production, t (oil), $10^4 m^3$ (gas);

n -- Decline exponent;

t -- Decline time in a (year), m (month), or d (day);

Di - Initial decline rate in a^{-1}, m^{-1}, d^{-1}, corresponding to time.

Table 1 Relevant formula of production decline law

Decline Type	Decline Exponent	Decline Rate	Basic Relationship		
			$q \sim t$	$G_p \sim t$	$G_p \sim q$
Exponential decline	$n = 0$	$D = D_i = const$	$q = q_i e^{-D_i t}$	$G_P = \frac{q_i}{D_i}(1 - e^{-D_i t})$	$G_P = \frac{1}{D_i}(q_i - q)$
Harmonic decline	$n = 1$	$D = D_i(1 + D_i t)^{-1}$	$q = q_i(1 + D_i t)^{-1}$	$G_P = \frac{q_i}{D_i} ln(1 + D_i t)$	$G_P = \frac{q_i}{D_i} ln\left(\frac{Q_i}{Q}\right)$
Hyperbolic decline	$0 < n < 1$	$D = D_i(1 + nD_i t)^{-1}$	$q = q_i(1 + nD_i t)^{-1/n}$	$G_P = \frac{q_i}{(1-n)D_i}[1 - (1 + nD_i t)^{n-1/n}]$	$G_P = \frac{{q_i}^n}{(1-n)D_i}(q_i^{1-n} - q^{1-n})$

When the decline exponent n=0, it is exponential decline. When 0=1, it is harmonic decrement; When n=0～1, it is hyperbolic decline [6]. Decline rate refers to the rate of production change per unit time, or the percentage of production decline per unit time, which represents the magnitude of production reduction of gas wells [7].

In the analysis, the production time of gas wells is required to be long enough to find the production decline trend, which is suitable for the production situation of fixed bottom-hole flow pressure. Domestic gas fields (wells) generally adopt the mode of fixed production and pressure reduction during the main production period, and the production decline trend can only be identified in the middle and late period [8]. From the strictly flow section, the decline curve represents the boundary control flow section and cannot be used to analyze the unstable flow section in the early stage of production.

Compared with the whole, the exponential decline type has the fastest decline. The second is hyperbolic decline type; The slowest decline in production is harmonic decline. The decline type of oil and gas field (well) is not invariable, and generally conforms to the hyperbolic decline type in the middle of the decline stage. In the later stage of decline, it generally conforms to the harmonic decline type.

When analyzing the decline of a tight sandstone gas reservoir in Sulige area, the Arps decline equation analysis method is used to determine the decline analysis method of a single well by obtaining the change law of the decline exponent of different reservoir gas wells.

2.2 Decline exponent change rule

The relationship between Arps production and decline rate (1) is derived by time on both sides to obtain:

$$\frac{d_q}{d_t} = q_i\left(\frac{-1}{n}\right)(nD_i)(1 + nD_i t)^{\left(-\frac{1}{n}-1\right)} \tag{2}$$

Sorting out the above formula can be obtained:

$$\frac{d_q}{d_t} = -q_i D_i (1 + nD_i t)^{\left(-\frac{1}{n}-1\right)} \tag{3}$$

Decline rate is defined as:

$$D = -\frac{1}{q}\frac{d_q}{d_t} \tag{4}$$

By combining the formula of the relationship between Arps production and decline rate (3) and the definition of decline rate (4), we can obtain:

$$D = \frac{D_i}{(1+nD_i t)} \tag{5}$$

Sorting out the above formula can be obtained:

$$\frac{1}{D} = \frac{1}{D_i} + nt \tag{6}$$

By taking the time derivative on both sides, the relationship between the change of the decline exponent n and D can be obtained, namely:

$$n = \frac{d}{d_t}\left(\frac{1}{D}\right) \tag{7}$$

Based on the comprehensive consideration of gas reservoir controlling factors and sand body configuration in the study area, combined with logging interpretation results and gas test production, the study can be divided into three types of reservoirs: I, II and III. The change law of gas well decline exponent of different types of reservoirs is shown in Figure 1.

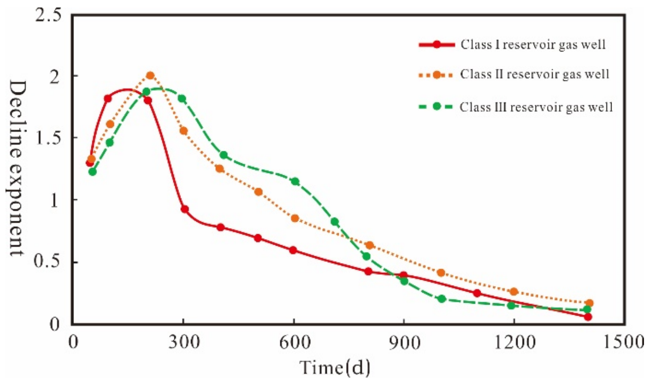

Figure 1. Decline Exponent Variation Law of Gas Well in Different Classes of Reservoirs

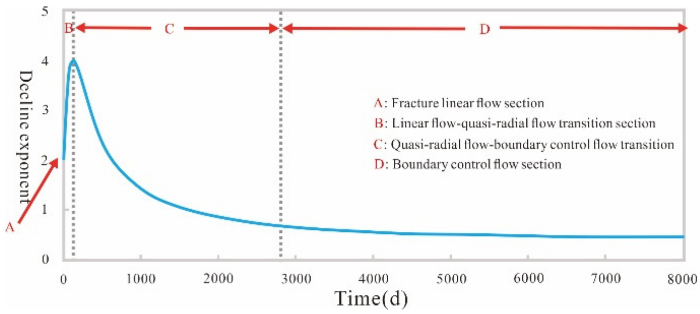

Figure 2. Decline Exponent Variation Law of Fractured Gas Wells in Different Sections

In this study, a fractured vertical well model was established to simulate the actual production situation of the gas well and obtain the production data of the gas well. The decline exponent was calculated using the above calculation method. It was found that with the change of the flow section, the decline exponent showed a changing trend of "rapid rise, continuous decline and stable". Before reaching the boundary control flow, the decline exponent is greater than 1, and after reaching the boundary control flow, the decline exponent tends to be stable, ranging from 0 to 1, as shown in Figure 2.

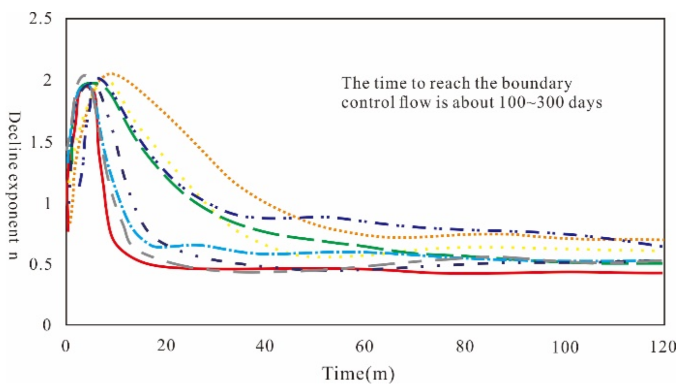

Figure 3. Deline Exponent Variation Trend of Typical Class I Wells

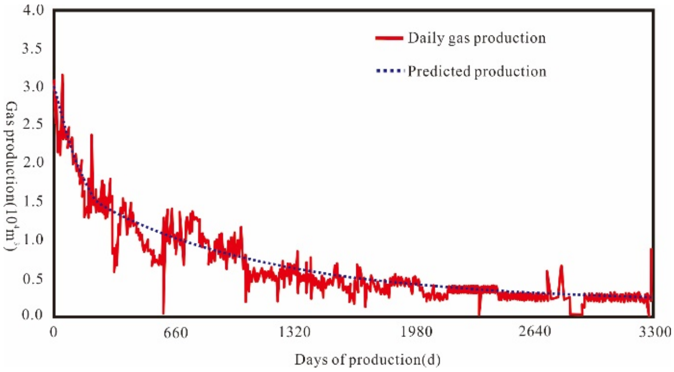

Figure 4. Staged Decline Analysis of Typical Class I Reservoir Gas Wells

3 Decline analysis of different types of gas wells

3.1 Class I reservoir gas well

3.1.1 Single-well decline analysis

The decline exponent of Class I reservoir gas well can be divided into two sections, and the decline analysis of single well should be carried out in sections. In the initial stage of large fluctuation, the decline exponent is between 1～2, and the decline analysis can be used Arps exponential decline analysis. In the stable stage, the decline exponent is between 0.4～0.8, which is in line with hyperbolic decline. The decline exponent enters a stable stage, and the gas well production enters the boundary control flow within 100～300 days, as shown in Figure 3 and Figure 4.

3.1.2 Class I reservoir decline law

By pulling daily gas production of Class I reservoir gas wells for days to fit the pulling curve of Class I reservoir gas wells, Class I wells decline by 17.4% in the initial stage, 13.6% in the first three-year, 12.0% in the first five-year, and 8.6% in the life cycle, as shown in Figure 5 and Figure 6.

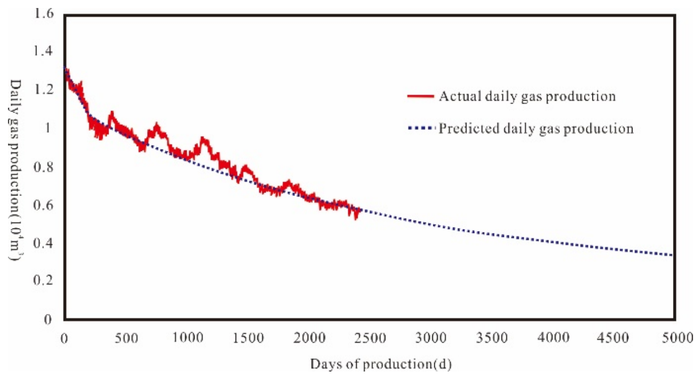

Figure 5. Decline Fitting Curve of Class I Wells

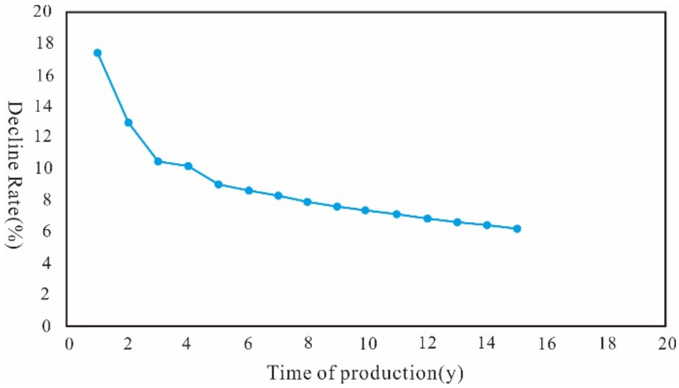

Figure 6. Prediction of Life Cycle Decline Rate of Class I Wells

3.2 Class II reservoir gas well

3.2.1 Single-well decline analysis

The analysis of the change rule of the decline exponent of Class II reservoir gas well can also be divided into two sections, and the decline analysis of single well should be carried out in sections. In the initial stage of large fluctuation, the decline exponent is between 0.5～2, and the Arps exponential decline analysis is adopted. In the stable stage, the decline exponent is between 0.2～0.8, which is in line with hyperbolic decline. Gas well production enters the boundary control flow within 30～40 months, as shown in Figure 7 and Figure 8.

3.2.2 Class II reservoir decline law

By pulling the daily gas production of Class II reservoir gas wells for days to fit the pulling curve of Class II reservoir gas wells, Class II wells decline 22.9% in the initial stage, 15.8% in the first three-year, 13.0% in the first five-year, and 8.8% in the life cycle, as shown in Figure 9 and Figure 10.

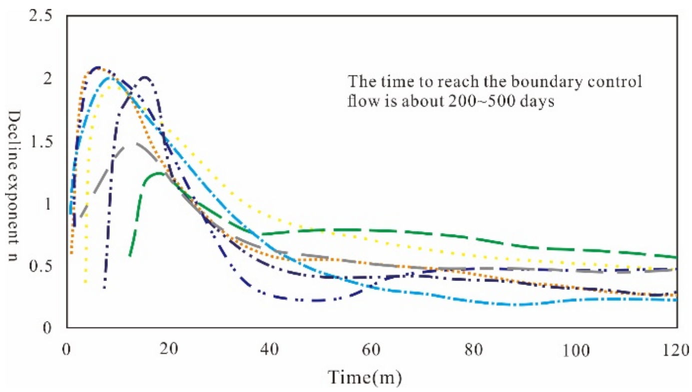

Figure 7. Decline Exponent Variation Trend of Class II Wells

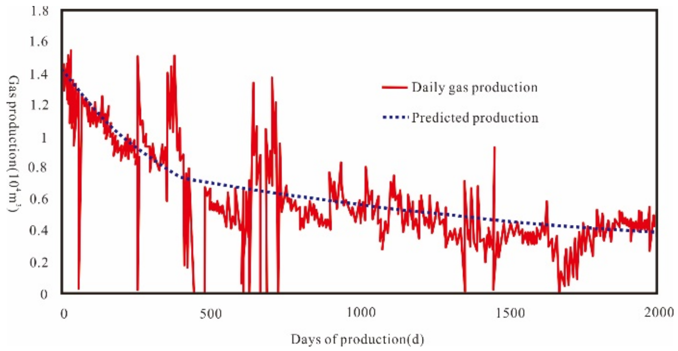

Figure 8. Staged Decline Analysis of Typical Class II Reservoir Gas Wells

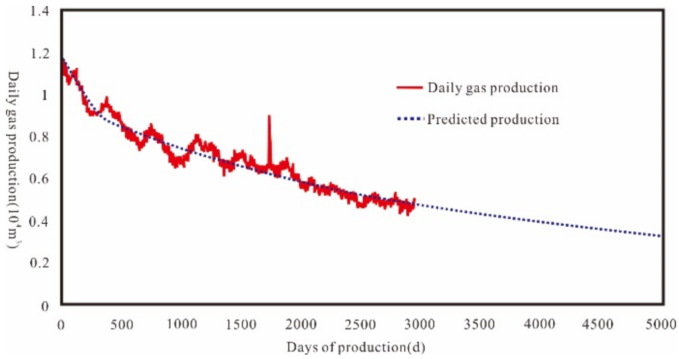

Figure 9. Decline Fitting Curve of Class II Wells

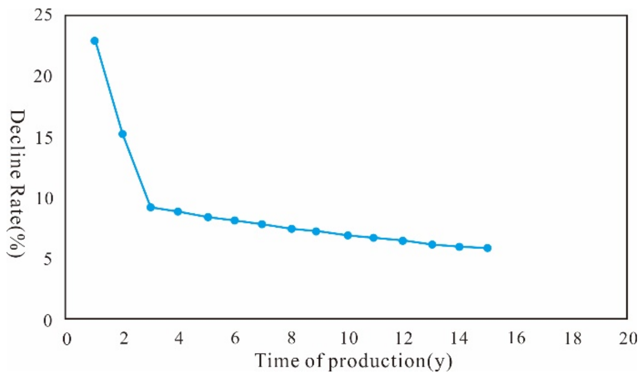

Figure 10. Prediction of Life Cycle Decline Rate of Class II Wells

3.3 Class III reservoir gas well

3.3.1 Single-well decline analysis

The analysis of the variation law of the decline exponent of class III reservoir gas wells can also be divided into two sections, and the single-well decline analysis should be carried out in sections. In the initial stage of large fluctuation, the decline exponent is between 0.2 and 2, and the Arps exponential decline analysis is adopted. In the stable stage, the decline exponent is between 0.1 and 0.6, which is in line with hyperbolic decline, and the gas well production enters the boundary control flow within 40 months, as shown in Figure 11 and Figure 12.

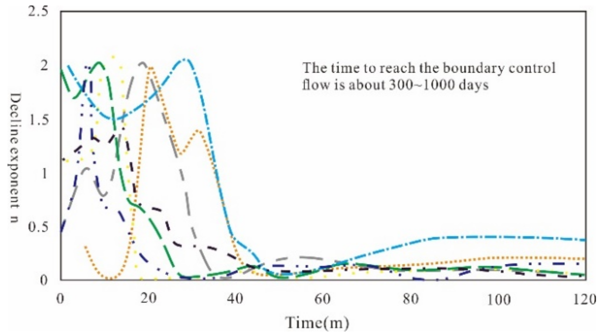

Figure 11. Decline Exponent Variation Trend of Typical Class III Wells

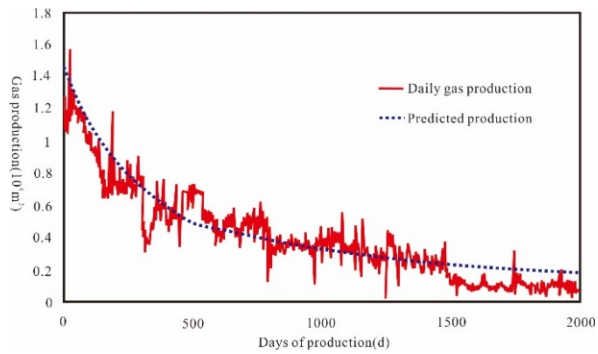

Figure 12. Staged Decline Analysis of Typical Class III Reservoir Gas Wells

3.3.2 Class III reservoir decline law

By pulling daily gas production of class III reservoir gas wells for days and fitting the pulling curve of class III reservoir gas wells, Class III wells decline by 25.0% in the initial stage, 16.7% in the first three-year, 13.1% in the first five-year, and 9.0% in the life cycle, as shown in figure 13 and figure 14.

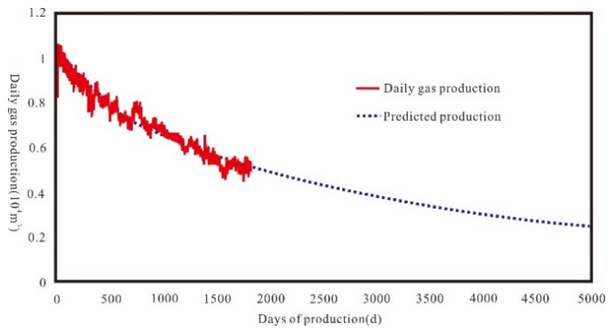

Figure 13. Decline Fitting Curve of Type III Wells

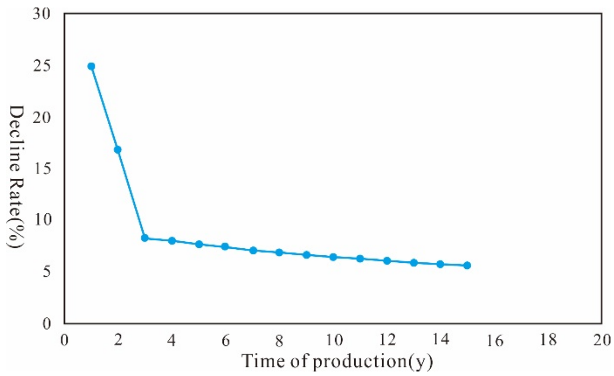

Figure 14. Prediction of Life Cycle Decline Rate of Class III Wells

3.4 Comparison of decline rates of different classes of vertical wells

The single-well decline method of gas wells of different reservoir classes is the same, and the decline law is similar. The two-stage decline feature of a single well is obvious, with exponential decline in the early stage of production and hyperbolic decline in the middle and late stages of production, as shown in Figure 15.

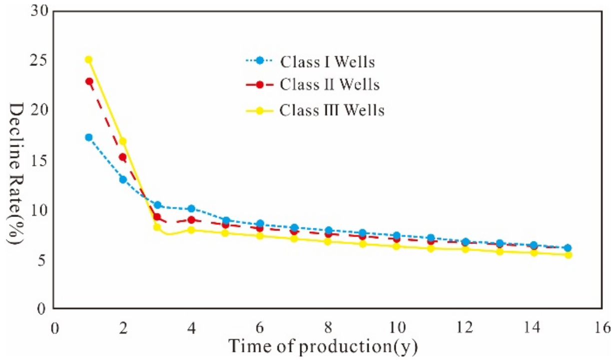

Figure 15. Comparison of Decline Rates of Different Vertical Wells

Differences in reservoir physical properties lead to differences in the time for different classes of reservoir gas wells to enter the boundary control flow. The time increases successively from 10 to 30 months for class I wells, 30 to 40 months for class II wells, and 40 months for class III wells, as shown in Table 2.

Compared with class I/II vertical wells, the formation physical properties of class III vertical wells are relatively poor, and the fracturing effect is not as good as class I/II vertical wells, so class III vertical wells should reach quasi-steady state at the latest. However, some class III wells still enter the boundary control flow section in advance, and the early flow section is chaotic and unstable, mainly because these vertical wells experience more intermittent shut-in and peak load shut-in in the production process, which has an impact on the flow state of these wells.

The Arps decline analysis method is mainly used to calculate the decline rate of gas wells in this paper. The data are calculated by pulling together the gas wells of different classes of reservoirs, and the gas wells are calculated by all the gas wells in production.

Table 2 Comparison of decline rates of different classes of vertical wells

Blocks	**Classification**	**Time to enter the boundary control flow**	**Initial decline rate %**	**Three-year average decline rate %**	**Five-year average decline rate %**	**Full life cycle decline rate %**
A block	Type I reservoir	10-30 months	17.4	13.6	12.0	8.6
	Type II reservoir	30-40 months	22.9	15.8	13.0	8.8
	Type III reservoir	40 months	25.0	16.7	13.1	9.0
Sulige gas field	Vertical well	36 months	23.6	21.9	20.7	16.2

4 Conclusions

(1) The single-well decline method of gas wells with different reservoir classes is the same, and the decline law is similar. The single-well is divided into two stages with obvious decline characteristics, and the initial production is in line with exponential decline, while the middle and late production is in line with hyperbolic decline.

(2) The difference in reservoir physical properties leads to the difference in the time for different classes of reservoir gas wells to enter the boundary control flow, with class I (10-30 months) < class II (30-40 months) < class III (40 months).

(3) There are differences in decline rates in different stages of gas wells with different reservoir classes, but the decline rates in the life cycle are basically the same.

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