A new method of Arps decline research - nonlinear fitting

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Abstract. Arps decline is widely used in the research and prediction of production decline law. At present, linear graphical is the conventional method of Arps decline research, which first determines the decline type and then determines the decline index. The judgment of decline type is subjective, and the determination accuracy of decline index is low, which affects the understanding of production decline law to a certain extent. Therefore, this paper proposes a nonlinear fitting for Arps decline research. The method determines the decline index first, and then determines the decline type. The accuracy of the decline index is high, and the judgment of decline type is more objective, which is conducive to the correct understanding of the production decline law. Taking Zizhou gas field as an example, the effect of two methods of Arps decline research is compared and analyzed, and the effectiveness of nonlinear fitting is verified, and good application results are obtained.

Keywords: Arps decline; Linear graphical; Nonlinear fitting; Decline index; Decline type.

1. Introduction

The law of production decline in oil and gas fields (or wells) is one of the important issues that field developers are generally concerned about. It is also a frequent research topic in the field of oil and gas reservoir engineering [1-2]. At present, the most commonly used research method is still the equation of production decline law proposed by Arps [3]. Production decline is divided into three types according to the size of decline index (n) : exponential decline (n=0), hyperbolic decline (0<n<1) and harmonic decline (n=1). These three kinds of decline are widely used in the research and prediction of the production decline law of oil and gas fields (or Wells) [4-7].

At present, linear graphical method is the conventional method to study Arps decline type. The main idea of this method is "according to the linear (or semi-log-linear, reciprocal linear) relationship between production and time or cumulative production and production. The linear diagram is used to judge the decline type first, and then the decline index is solved". However, in practical application, this method has two limitations. First, the judgment of descending type is subjective. The linear graphical method often determines the decline type from person to person, which may lead to the hyperbolic decline with n value close to 0 being mistaken for exponential decline, or the hyperbolic decline with n value close to 1 being mistaken for harmonic decline, thus misleading the understanding of production decline law. Second, the determination accuracy of decline index is low. For hyperbolic decline, due to the lack of linear (or semi-log-linear) relationship between production and time or cumulative production and production, the decline index can only be obtained by trial and error method, which is complicated and difficult to determine the decline index accurately. In view of the limitations of linear graphical method in the study of Arps decline, this paper proposes a nonlinear fitting method that determines the decline index first and then determines the decline type through the nonlinear fitting of production data. Taking Zizhou gas field as an example, the effect of two methods on Arps decline is compared and analyzed, and the validity of nonlinear fitting method is verified.

2. Linear graphic method

2.1 Method and principle

The linear graphical method determines the decline type based on the linear correlation of yield-time or cumulative yield-yield (Table 1). Among them: ① Decline index is the direct basis for judging the decline type. When n=0, it is decreases exponentially. When n=1, it is harmonic

decreasing; ② When 0<n<1, it is hyperbolic decline. The Q-T and NP-Q decline relationships and their linear correlations are also different for different decline types. ③ According to the linear correlation, all Arps decline types can be judged. The linear correlation graph is used to judge the exponential and harmonic decrement first, and then the hyperbolic decrement is judged by the elimination method. ④ For hyperbolic decline, it is difficult to determine the value of decline index n. At present, it can only be obtained by trial and error method based on linear relation, the process is complicated and the accuracy is difficult to guarantee.

Table 1 Arps decline types and decline relationships

Decline type	Decrement pass	Decline feature	Q to t relation	Np～q relation	Linear dependence	Comment
Exponential decrease	$\frac{D}{D_0}=(\frac{Q}{Q_0})^n$	n=0 D=D0	$Q=Q_0e^{-D_0t}$ or $\ln Q=\ln Q_0-D_0t$	$N_p=\frac{Q_0-Q}{D_0}$	①$\ln Q\sim t$ ②$N_p\sim Q$	n—Decline exponent; D0- Initial decline rate; D- Current decline rate; Q0- Initial decline rate; Q- Current production rate; Np- Regressive stage; t—decimal reduction time;
Harmonic decline		n=1 D<D0	$Q=Q_0(1+D_0t)^{-1}$ or $\frac{1}{Q}=\frac{1}{Q_0}+\frac{D_0}{Q_0}t$	$N_p=\frac{Q_0}{D_0}\ln\frac{Q_0}{Q}$	①$1/Q\sim t$ ②$N_p\sim\ln Q$	
Hyperbolic decline		0<n<1 D<D0	$Q=Q_0(1+nD_0t)^{-\frac{1}{n}}$	$N_p=\frac{Q_0^n}{(1-n)D_0}(Q_0^{1-n}-Q^{1-n})$	①$N_p\sim[1-(Q/Q_0)^{1-n}]$	

2.2 Method application

Zizhou gas field in Ordos Basin is a large tight sandstone gas field, the main production layer is Shan2 member of Shanxi Formation [8-9]. With complex geological conditions and strong reservoir heterogeneity, the gas field has obvious characteristics of low porosity, low permeability, low abundance and low production [10-12], low gas well production, rapid pressure drop, and short or no stable production period. According to the initial production of gas Wells in the study area, it can be divided into three categories: Class I well daily gas > 3×104m3, Class II well daily gas 1×104m3 ~ 3×104m3, class III well is <1×104m3. Among them, the mining status of Class I Wells is better, and generally decline after 4a production, and its production curve is shown in Figure 1.

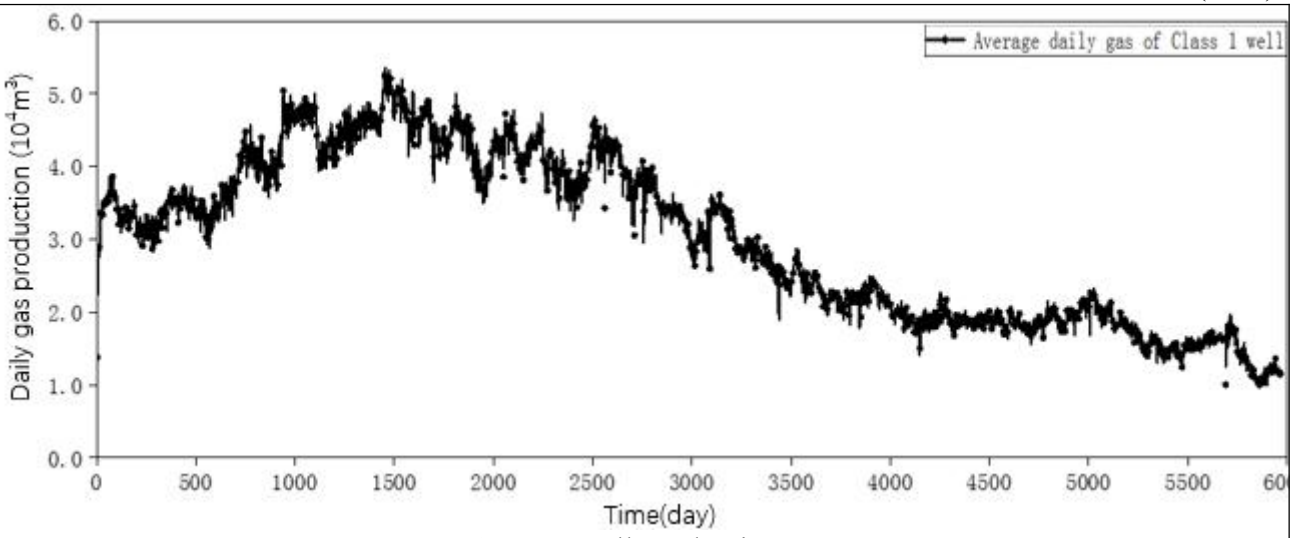

FIG. 1 Gas well production curve

Using linear graphical method to draw $\ln Q \sim t$、$1/Q \sim t$ linear correlation plots (FIG. 2 to FIG. 3) respectively to determine the decline type. The comparison between FIG. 2 and FIG. 3 shows that the fitting coefficient of the gas well $\ln Q \sim t$ is 0.9252, which is significantly greater than the $1/Q \sim t$ fitting coefficient of 0.8802, and is initially judged to be decreasing exponentially. However, are gas Wells hyperbolic decline? This also needs $N_p \sim [1-(Q/Q_0)^{1-n}]$ to be further determined by trial n value according to the relation, but the process is more complicated.

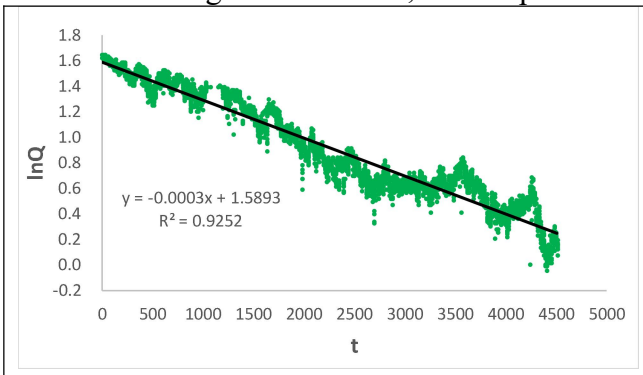

FIG.2 Exponential decline $\ln Q \sim t$ linear correlates

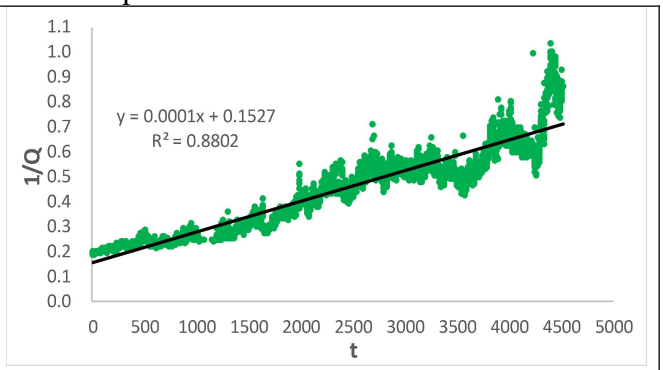

FIG. 3 Harmonic decline $1/Q \sim t$ linear correlates

3. Nonlinear fitting method

3.1 Method and principle

Decline index (n) is the core of Arps decline research, and it is also the direct basis to judge the decline type and determine the decline law. In view of the limitation of linear graphical method in calculating the decline index, this paper proposes a nonlinear fitting method that determines the decline index first and then determines the decline type through the nonlinear fitting of production data. The specific methods are as follows: (1) Based on the gas well production curve, the nonlinear fitting function of ORIGIN software is used to perform the nonlinear fitting of three production decline modes, namely exponential, hyperbolic and harmonic, respectively. (2) For the matching effect, according to the fitting coefficient (R2), determine the decline index and judge the type of production decline; ③ According to the judgment results, the production decline formula of gas well is established, the decline rate is calculated, and the production decline law is analyzed.

3.2 Method application

FIG. 4 shows the fitting results of the production curve of Class I Wells in Zizhou gas field. It can be seen that the gas well index and hyperbolic fitting coefficient are both greater than 0.9, and the fitting effect is good, but the hyperbolic fitting coefficient is higher (0.927), which is comprehensively judged to be the hyperbolic decline type. This kind of well generally starts to decline after 4a production, with a decline index of 0.266, initial decline capacity of 53,800 square meters/day, initial daily decline rate of 0.0378%, and initial annual decline rate of 12.6%.

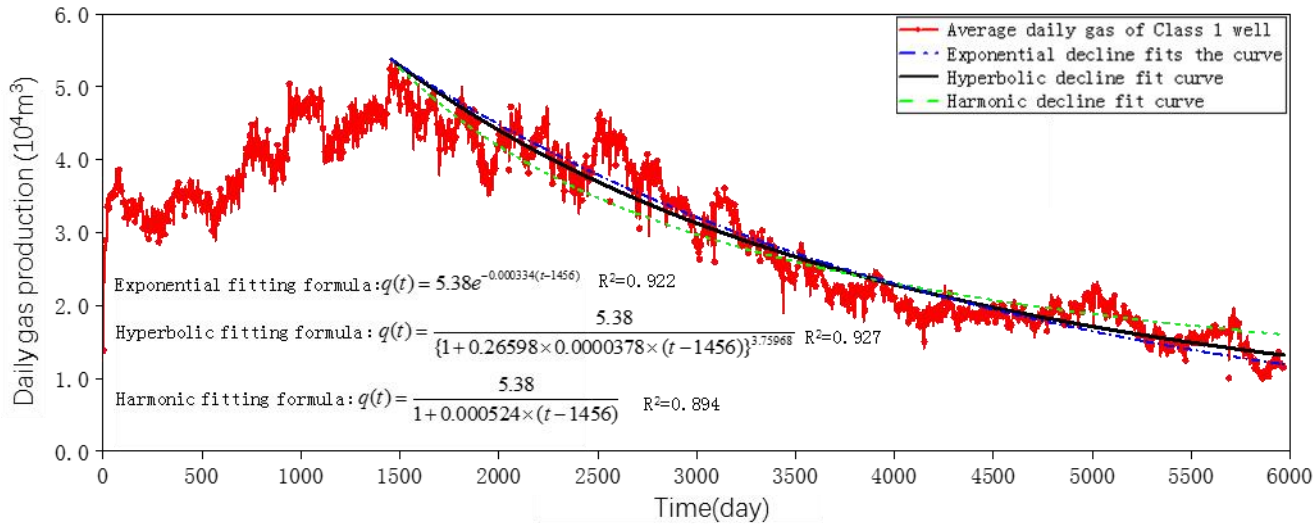

FIG. 4 Nonlinear fitting diagram of gas well production curve

4. Reliability verification of nonlinear fitting method

The nonlinear fitting results show that the decline index of Class I Wells in Zizhou gas field is 0.266, which belongs to hyperbolic decline type. In order to verify this result, a linear correlation graph (FIG. 5) with a decline index of 0.266 was drawn, and the linear graphical method was used to further judge the decline type of gas Wells. By comparing FIG. 2 and FIG. 5, it can be seen that both have good correlation, but the fitting coefficient of the gas well is 0.9424 which is significantly larger than the fitting coefficient of the gas well (0.9252), and should be judged as hyperbolic decline.

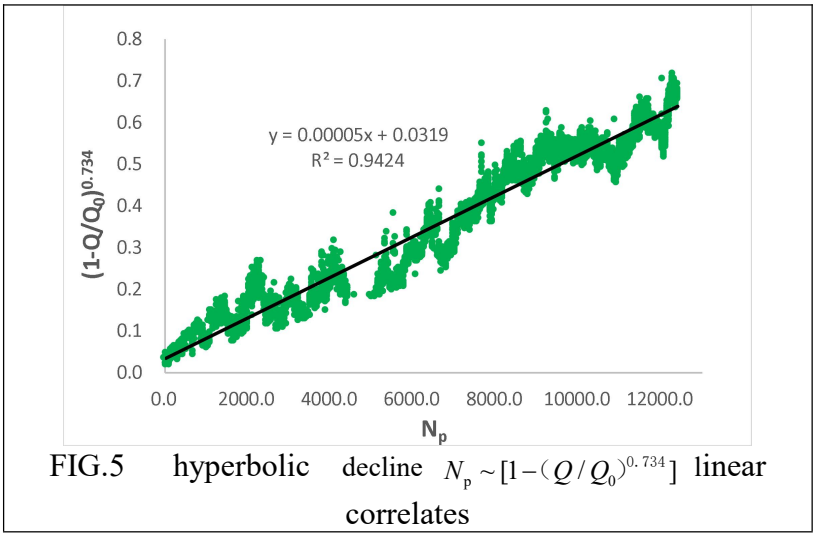

FIG.5 hyperbolic decline $N_p \sim [1-(Q/Q_0)^{0.734}]$ linear correlates

The accurate judgment of decline type is helpful to the correct understanding of production decline law. Because exponential decline is a constant decline rate decline, and hyperbolic decline is a gradual decrease in the decline rate. In this case, if the gas well is calculated according to the exponential decline, its annual decline rate is 10.5%, and the effective production life of the gas well is 30a. If the hyperbolic decline is calculated, the initial annual decline rate is 12.6%, and the effective production life of the gas well is 40a.

5. Conclusion

(1) Linear graphical method "first determine the decline type, then determine the decline index", the decline type judgment is subjective, and the decline index determination accuracy is low, to a certain extent affect the production decline law understanding.

(2) Nonlinear fitting method, "first determine the decline index, and then judge the decline type", the decline index is obtained with high precision, and the decline type judgment is more objective, which is conducive to the correct understanding of the production decline law.

(3) Decline index (n) is the core of Arps decline research, and also the direct basis for judging the decline type and determining the decline law. From a probability point of view, exponential decrement of n=0 or harmonic decrement of n=1 are after all cases, while hyperbolic decrement of 0<n<1 May be more common.

(4) The conventional linear graphical method is difficult to accurately calculate the decline index, while the nonlinear fitting method is relatively direct and simple, and has certain advantages in the accurate calculation of the decline index.

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