PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 43, Issue 4, August 2016
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2016, 43(4): 672–678.

RESEARCH PAPER

Cumulative production curve method for the quantitative evaluation on the effect of oilfield development measures: A case study of the nitrogen injection pilot in Yanling oilfield, Bohai Bay Basin

DONG Wei[1], JIAO Jian[1,*], XIE Shijian[2], LYU Cuiyan[2], CUI Gang[2], MENG Jie[2]

1. Energy Resources, Chengdu University of Technology, Chengdu 610059, China;
2. No. 1 Oil Production Plant, PetroChina Huabei Oilfield Company, Renqiu 062552, China

Abstract: To evaluate the effect of oilfield development measures quantitatively, based on the theory of Arps production decline, this study deduced a linear relation between the product of cumulative production with production time (N_pt) and production time (t), and established the cumulative production curve method for quantitative evaluation on the effect of development measures. The nitrogen injection pilot in Yanling oilfield was taken as an example to calculate the recoverable reserves before and after the nitrogen injection, and through the variation of recoverable reserves, the effect of the nitrogen injection on actual production was quantitatively evaluated. Similarity analysis of decline curve shape in the late period shows that the method is not restricted by decline types and the relationship curve between N_pt and t in the late development is always tending to a straight line. The cumulative production curve method is not only suitable for single wells but also not restricted by reservoir types. Combined with derivative curve in diagnosis, it reflects the microscopic variations of the slope in the straight line segment and the variations of recoverable reserves and the process of reserve producing. The single wells in the Yanbei nitrogen injection pilot were evaluated quantitatively using the cumulative production curve method, the results show that: the nitrogen injection causes obvious productivity increase of the oil wells in the hillside of the buried hill, productivity decrease of the oil wells at the top of buried hill, and little influence on the productivity of oil wells in the margins of burial hill.

Key words: development effect; quantitative evaluation; cumulative production; recoverable reserves; Bohai Bay Basin; Yanling Oilfield; nitrogen-injection pilot

Introduction

Yanling oilfield is a block bottom water reservoir of buried hill with two blocks, the South and North, where the reservoir is the dolomite of Wumishan Formation in the Jixian System. After 12 years production, Yanling oilfield has a composite water cut of up to 96.5% and disperse remaining oil. Therefore, a pilot nitrogen injection test was carried out in the north of Yanling oilfield (hereinafter referred to as Yanbei)[1–2]. After the nitrogen injection, the well has been re-opened and resumed production for up to 18 years, achieving very good effect.

In this study, taking the nitrogen injection pilot in Yanbei as an example, based on the theory of Arps production decline[3–4], a method of cumulative production curve for quantitative evaluation of development measure effect has been established. By comparing with the method of production decline curve[5–6] and water drive curve[7], the advantages of cumulative production curve method has been elaborated. The method has been used in different types of oil and gas reservoirs, providing a new means for the evaluation of the development measure effect in oil-gas fields.

1. Methods commonly used to evaluate development measure effect

The purpose of oil-gas field development is to maximize the recovery ratio and optimize the economic benefit, so production measures are often adjusted in the development process, and effect analysis and evaluation of the production measures are conducted accordingly. Current methods for evaluating the effect of development adjustment plans and production measures include composite curve analysis of oil production, production decline curve, water drive curve, material balance, well test analysis and numerical simulation, etc. The latter three methods are theoretical calculation methods with complex technical principle, more data needed, larger

Received date: 04 Dec. 2015; **Revised date:** 31 May 2016.
* **Corresponding author.** E-mail: jiaojian6688@foxmail.com

workload, and longer cycle. The former three methods are empirical analysis methods, using the actual production data, simple and quick, and more commonly used, but they have their limitations too.

In this study, taking the nitrogen injection pilot in Yanbei as an example, the methods of production decline curve and water drive curve, and the new method in this paper have been used to evaluate the effect of the nitrogen injection, and compared with each other.

After nitrogen injection, the Yanbei pilot has seen drop of oil-water contact and composite water cut, increase of oil production, with annual oil production higher than that before nitrogen injection for nine consecutive years. The production decline curve of Yanbei was the type of exponential decline before the nitrogen injection, with an annual decline rate of 23.6%. After the nitrogen injection, the production decline curve changed into the type of harmonic decline with an annual decline rate of 15.0%–6.6%, indicating that the nitrogen injection has slowed down the rate of production decline in this area significantly (Fig. 1). Since the nitrogen injection, the pilot has been produced for 18 years, with a total oil production of 19.94×104 t, and an oil recovery increment of 2.02%.

After the nitrogen injection, the water drive curve of Yanbei had an obvious drop in the slope of the straight line segment[8–10], and apparent increase in recoverable reserves and recovery ratio. The recoverable reserves and recovery calculated by the straight line segment of "A" type water drive curve increased by 22.44×10^4 t, and 2.27% respectively. The recoverable reserves and recovery calculated by the straight line segment of "B" type water drive curve increased by 20.47×10^4 t and 2.07% respectively, indicating that the recoverable reserves have obviously increased by the nitrogen injection in Yanbei (Fig. 2).

Although the water drive curve can be used to directly and quantitatively evaluate the effect of development measures, the curve becomes upwarping when the water cut is more than 95%, and there is controversy in the academic circle at present over whether the straight line segment of the upwarping portion can still be used. The curve turns upwarping in the

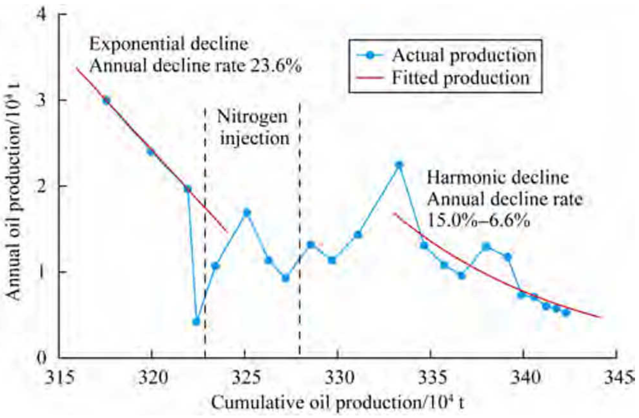

Fig. 1. Characteristics of production decline curve before and after the nitrogen injection of Yanbei.

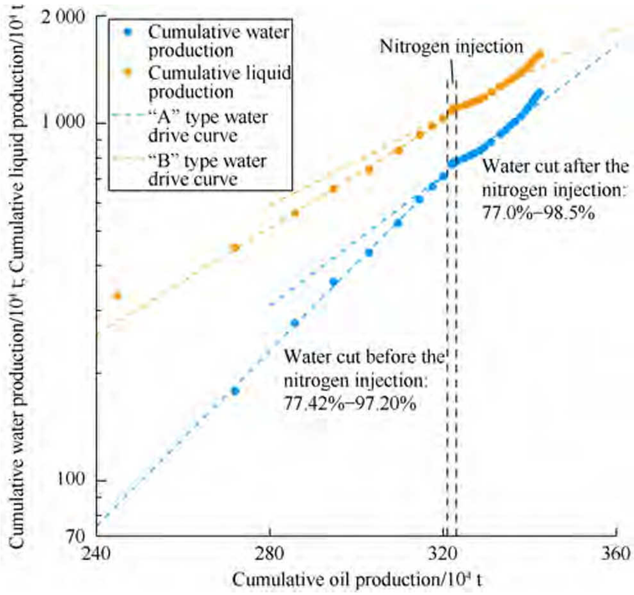

Fig. 2. Characteristics of A and B water drive curves before and after the nitrogen injection of Yanbei.

straight line terminal (composite water cut 95.0%–98.5%) after the nitrogen injection as shown in Fig. 2. If the method of water drive curve can be used to evaluate the effect of development measures is controversial, so the method of reservoir engineering evaluation not affected by this factor needs to be developed.

2. Method of cumulative production curve

The ultimate goal of oil-gas field development is to achieve maximum recovery under the premise of ensuring economic efficiency[11], in other words, to maximize the recoverable reserves under certain geological reserves. For one set of well pattern, any development adjustment and measures must ensure that the recoverable reserves under the control of the well pattern will not reduce. Whether the recoverable reserves increase or not is a decisive index in effect evaluation.

Among the above evaluation methods, only water drive curve method can calculate recoverable reserves quickly and directly, but it can not be used when water cut is extremely high (more than 95%). Therefore, based on the theory of production decline analysis, a new method calculating the recoverable reserves is needed to evaluate the effect of various development measures quickly and directly.

According to the theory of Arps production decline, hyperbolic decline is the most representative type of production decline, in which the decline type with decline index n=0.5 is be called "attenuation decline". According to the type of hyperbolic decline[1–2],

$$Q = \frac{Q_i}{\left(1 + nD_i t\right)^{1/n}} \tag{1}$$

Making n=0.5, we obtain the relationship between the type of production and time:

$$Q = \frac{Q_i}{\left(1 + 0.5D_i t\right)^2} \tag{2}$$

Taking the integral of the both sides of equation 2,