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Original research paper

New methodology for aquifer influx status classification for single wells in a gas reservoir with aquifer support☆

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Abstract

For gas reservoirs with strong bottom or edge aquifer support, the most important thing is avoiding aquifer breakthrough in a gas well. Water production in gas wells does not only result in processing problems in surface facilities, but it also explicitly reduces well productivity and reservoir recovery. There are a lot of studies on the prediction of water breakthrough time, but they are not completely practicable due to reservoir heterogeneity. This paper provides a new method together with three diagnostic curves to identify aquifer influx status for single gas wells; the aforementioned curves are based on well production and pressure data. The whole production period of a gas well can be classified into three periods based on the diagnostic curves: no aquifer influx period, early aquifer influx period, and middle-late aquifer influx period. This new method has been used for actual gas well analysis to accurately identify gas well aquifer influx status and the water breakthrough sequence of all wells in the same gas field. Additionally, the evaluation results are significantly beneficial for well production rate optimization and development of an effective gas field.

Keywords: Gas reservoir; Aquifer influx status; Diagnostic curves; Classification method; Rate transient analysis

1. Introduction

For gas reservoirs with strong bottom or edge aquifer support, the biggest problem is avoiding the aquifer to break through the gas well. Once it does, the gas well productivity largely decreases as a result of the continuous water production. Eventually, the gas well would shut down in the end. Thus, water production greatly affects gas well efficiency and gas recovery of the field. For that reason, reservoir engineers optimize the production rate by adjusting the choke size based on an accurate prediction of the aquifer breakthrough. In that way they extend the no aquifer influx period and make optimized development for balanced gas production in the whole gas reservoir; this can greatly enhance the gas field performance and recovery.

The studies on the edge and bottom of the water breakthrough time in gas reservoirs have been intensively conducted both locally and overseas [1–3]. These works introduced some water coning breakthrough time calculation formula based on simplified conceptual models. However, because of the heterogeneity in practical gas reservoirs and the continuous adjustment of the production plan, the results developed from the simplified models can barely be applied to practical situations. The results evaluated by various methods are varying as well; hence, it is difficult for engineers to choose appropriate methods for water invasion analysis. Some

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predictions on water breakthrough time were made by using material balance analysis and water invasion indicative curves [4–6], but these methods were restricted because of involving too much static and dynamic pressure plus production data. Furthermore, in order to get a better prediction, a certain degree of recovery should be achieved. The reality is that when some production wells begin to produce water, times of static pressure testing decreases and the recovery degree is low. Some researchers used typical well test log–log curves [7], and this method can only achieve a good prediction for edge water invasion alone. On the other hand, for the bottom water invasion, it is difficult, if not impossible, to use some type of well testing to analyze water influx. While the well testing cannot be conducted at certain time intervals, this method cannot be applied to every single well for a good prediction. Recently, Rate Transient Analysis (RTA) gets rapid development in the studies of reserves evaluation and reservoir characterization [8–14]. Using RTA in water invasion prediction is still in its infancy [15,16]. For this reason, water invasion prediction in gas reservoirs is one of the most difficult technological problems yet to be solved.

In order to solve the current technical problems in aquifer breakthrough prediction, this paper proposes a reliable method in the identification of aquifer influx status for single wells in a gas reservoir with aquifer support. This method classifies the status of aquifer influx mainly depending on RTA as well as divides the whole production history of each well into three periods: no aquifer influx period, early aquifer influx period, and middle-late aquifer influx period. The whole production rate and bottom-hole flowing pressure data of each well are used in this method, which can take the heterogeneity of gas reservoirs and production adjustment into account. Therefore, this method is deemed more accurate and applied to the actual situation. The three diagnostic curves for aquifer influx status identification are described below.

2. The first diagnostic curve of aquifer influx

The first diagnostic curve of the aquifer influx is based on the Agarwal-Gardner flowing material balance curve of the Rate Transient Analysis (RTA), which is mainly used for evaluating well original gas in place (OGIP) at present. Its ordinate axis is the normalized production rate $q/\Delta p_p$, which is defined by the following equation:

$$\frac{q}{\Delta p_p} = \frac{q}{p_{pi} - p_{pwf}} \tag{1}$$

where $p_p = 2\int_0^p pdp/\mu Z$

q: Current well production rate, m^3/d; p: Bottom-hole flowing pressure (BHFP), MPa; μ: Gas viscosity, mPa·s; Z: Dimensionless deviation factor; p_{pi}: Pseudo-pressure of the initial pressure; p_{pwf}: Pseudo-pressure of BHFP.

The difference between pseudo-pressure of the initial pressure and pseudo-pressure of the BHFP is $\Delta p_p = p_{pi} - p_{pwf}$. The ordinate is the current gas production rate divided by the current pseudo-production-pressure difference, which can be roughly considered as the productivity index. The abscissa axis is $2qt_{ca}p_i/((C_t\mu Z)_i\Delta p_p)$, where $t_{ca} = (\mu C_g)_i/q\int_0^t q(t)/\overline{\mu}\,\overline{c}_g dt$.

C_t, C_g: total compressibility and gas compressibility, MPa^{-1}; t_{ca}: Pseudo-material balance time, dimensionless; t: Production time, day; $\overline{\mu}$: Average gas viscosity at that time, mPa·s; $\overline{C_g}$: Average gas compressibility at that time, MPa^{-1}; The subscript i means initial value.

The abscissa axis is approximately considered as the cumulative gas production of well divided by the current production pressure difference. This diagnostic curve should be a straight line for the closed and constant volume gas reservoir without any edge or bottom aquifer support. In addition, its intersection with the abscissa axis is the OGIP of the gas reservoir. Reservoir engineers mainly focus on their evaluation of OGIP while neglecting its application in the production performance analysis and diagnostics. Since this curve takes full advantage of daily gas production rate and pressure data, its shape and variation fully reflect well production performance as well as the change of reservoir fluid flow conditions. For gas reservoirs with aquifer support, the diagnostic curve may show three periods: no aquifer influx period, early aquifer influx period, and middle-late aquifer influx period (Fig. 1).

The period in which aquifer influx was absent means that gas flow or the drainage area can't reach the aquifer or gas production is not evidently affected by the aquifer cusping or conning; therefore, the first corresponding diagnostic curve is still a line. After a certain period of production, the reservoir pressure considerably decreases, and the edge and bottom water flow into the inner part of the gas reservoir, this makes the reservoir pressure decline slower than that of the no aquifer influx period. Once the aquifer support plays a substantial role in the gas well production, the gas well will transition to the early aquifer influx production period. During this period gas well productivity (the ordinate of the diagnostic curve) is affected, which means $q/\Delta p_p$ tends to increase. Meanwhile, because aquifer flows into the gas reservoir, reservoir pressure

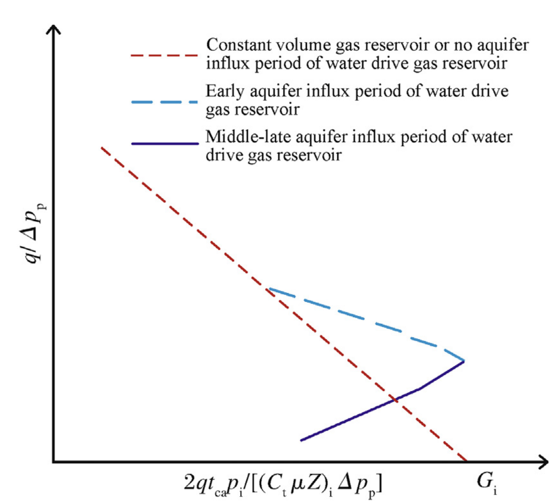

Fig. 1. The first aquifer influx diagnostic curve for gas wells.