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A new method for connate water saturation calculation using time-lapse logging data

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Abstract

Connate water saturation is an important parameter from well logging evaluation. In order to accurately determine reservoir connate water saturation using the time-lapse logging data, on the basis of the study of the mud filtrate dynamic invasion process and the dynamic change laws of reservoir parameters around borehole, this study established a logging response equation according to the volumetric element integration method. In this paper, the exponential water saturation relationships between water saturation and invasion time as well as the calculation algorithm of connate water saturation using the new dynamic response equation have been given. The results of two case studies from QingHai Oilfield have shown that the connate water saturation derived from the exponential water saturation relationships and the calculation algorithm of connate water saturation presented in this paper is in great agreement with the results from the field testing and results from mercury injection analysis.

Keywords: Dynamic response model; Time-lapse logging; Connate water saturation; Exponential function

1. Introduction

During well drilling process, invasion of mud filtrate will affect the reservoir in the region near the well. This is called formation damage. A persistent mud filtrate invasion can change the reservoir parameters and fluid distribution in the reservoir near the well. This will lead to the changes of the originally established relationships between reservoir parameters, reduce the accuracy of data interpretation and finally make it difficult to distinguish oil and gas pays from water pays using the traditional well logging tools (Lu, 1996). Time-lapse logging (repeated logging) is an effective way to improve well-logging interpretation. Using this technique, one can figure out the influence of fluid distribution around the well.

Chin et al. (1986) is the first, who used time-lapse logging while drilling method for formation evaluation. Donaldson and Chernoglazov (1987) developed a method characterizing the drilling mud invasion as a function of radial distance and time. The coefficient of filtrate dispersion and its variation were determined from experimental results. A finite difference solution of the radial form of diffusivity equation was then used in the analysis. Yao and Holditch (1996) developed a new technique to estimate reservoir permeability using time-lapse log data. Tobola and Holditch (1991; Holditch, 1998) applied this method in their field case study, and developed the PERM-LOG software. The major assumptions made in their software are: (1) reservoir is homogeneous and

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infinite, the outer boundary is infinite extent, the inner boundary is the borehole. (2) The wellbore pressure is constant and equal to the hydrostatic mud pressure. (3) The mudcake thickness is constant, but the cake permeability changes with time. (4) The mixing process between the mud filtrate and the formation water follows the convection transport process. Morriss et al. (1996) experimentally studied the change in resistivity as a function of time and distance in shale. They found that the resistivity obtained from the function of time and distance is in reasonable agreement with those predicted by the case of the dual water model in the early stages of the swelling, but diverges rapidly at longer times. Wang (1998) represented a method that uses time-lapse logging data of production well to calculate relative permeability. Gomes et al. (1999) analyzed the evolution of polarization horns and resistivity anisotropy in turbidite sandstone reservoir using time-lapse resistivity log responses. Zhang and OuYang (2000) did some researches on dynamic responses of resistivity logs, and represented a method for connate water saturation calculation.

Dalton et al. (2002) used real-time time-lapse logging for a drilling operation. They pointed out that the integration of time-lapse resistivity data and pressure data can identify the best permeability zones for geosteering production while drilling, isolate potential zones of loss and gains, identify the propagation of natural and drilling-induced fractures. Rohler et al. (2004) used ultransonic LWD caliper time-lapse logs to identify the development over sections of increased caliper dynamics and used resistivity-at-bit time-lapse logs to provide information on sections with fracturing dynamics in low-strength marls. Alpak et al. (2004) used time-lapse electromagnetic measurements acquired with an array induction logs and transient-pressure measurements to estimate petrophysical parameters of the formation.

This paper presents a new method to estimate reservoir saturation using time-lapse log data. Based on the dynamic changing trend of reservoir parameters, we construct an exponential water saturation function and a dynamic model of well logging response to reflect the changing trend of reservoir parameters around the borehole. Case studies show that the new dynamic water saturation model makes the saturation calculation results much more consistent with the true water saturation (in situ) in oil/gas net pays. These results were also confirmed by production and well testing data.

2. Dynamic changing model of reservoir parameters

The theory of mud filtrate dynamic invasion process is two-phase immiscible seepage through porous media. Considering the capillary pressure and ignoring gravity effect, the two-phase flow equation for water flooding process can be constructed (Zhang and Hu, 1993). Using the flow equation, we can derive the dynamic changing model of the reservoir pressure and saturation around the borehole (along the radial direction).

Fig. 1 illustrates the dynamic radial distribution of saturation along with the time (Sun, 2000). Yao and Holditch (1996) published the similar results shown in the Fig. 1. Based on these results and considering the effects of the invasion and contamination, we summarize the dynamic change laws of reservoir parameters around borehole below:

(1) During the process of drilling, the formation pressure descends exponentially in the radial

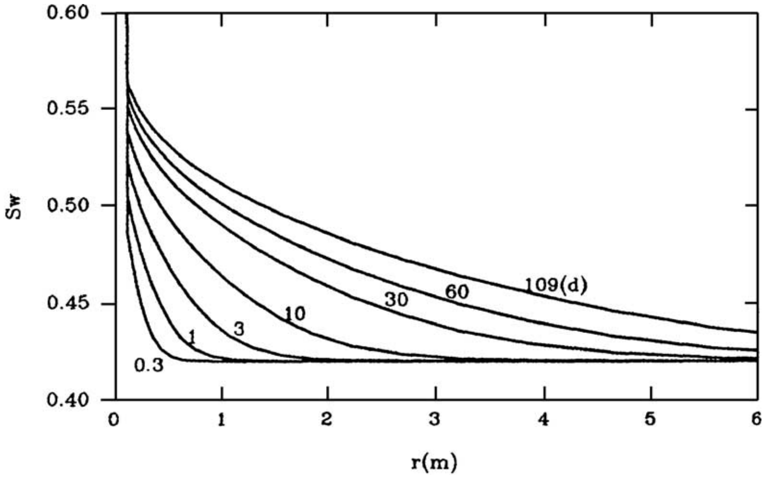

Fig. 1. Radial water saturation distribution with time. S_w—water saturation, r—radial distance from borehole.