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Research article

Quantitative calculation of GOR of complex oil-gas-water systems with logging data: A case study of the Yingdong Oil/Gas Field in the Qaidam Basin☆

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Abstract

In the Yingdong Oil/Gas Field of the Qaidam Basin, multiple suites of oil-gas-water systems overlie each other vertically, making it difficult to accurately identify oil layers from gas layers and calculate gas-oil ratio (GOR). Therefore, formation testing and production data, together with conventional logging, NMR and mud logging data were integrated to quantitatively calculate GOR. To tell oil layers from gas layers, conventional logging makes use of the excavation effect of compensated neutron log, NMR makes use of the different relaxation mechanisms of light oil and natural gas in large pores, while mud logging makes use of star chart of gas components established based on available charts and mathematical statistics. In terms of the quantitative calculation of GOR, the area ratio of the star chart of gas components was first used in GOR calculation. The study shows that: (1) conventional logging data has a modest performance in distinguishing oil layers from gas layers due to the impacts of formation pressure, hydrogen index (HI), shale content, borehole conditions and invasion of drilling mud; (2) NMR is quite effective in telling oil layers from gas layers, but cannot be widely used due to its high cost; (3) by contrast, the star chart of gas components is the most effective in differentiating oil layers from gas layers; and (4) the GOR calculated by using the area ratio of star chart has been verified by various data such as formation testing data, production data and liquid production profile.

Keywords: Qaidam Basin; Yingdong Oil/Gas Field; Mud logging; Logging; Excavation effect; NMR; Oil and gas layer differentiation; GOR

1. Introduction

Located in the Yingxiongling region of the western Qaidam Basin, the Yingdong Oil/Gas Field ranks the second among the four integral oil and gas fields discovered there in recent years, the production of which all reach hundred million tons. It features long hydrocarbon-bearing intervals, large cumulative thickness of oil and gas layers [1] and relatively thin single layers. Oil and gas layers are difficult to identify due to the well-developed faults in the Yingdong Oil/Gas Field [2] and the vertical stacking of multiple oil-gas-water systems. Gas layers are perforated as oil layers now and then, which greatly increases the pressure of surface oil lines. Meanwhile, oil/gas reservoir pressure decreases rapidly due to the production of high GOR reservoirs. The above-mentioned factors are not good for the development of these reservoirs. Therefore, it is urgent to address the issue of oil and gas layer identification and quantitative GOR calculation for the Yingdong Oil/Gas Field.

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2. Reservoir overview

2.1. Reservoir lithology and petrophysical properties

The reservoirs are medium in compositional maturity, medium−high in textural maturity, fine in grain size, low in matrix content, medium-low in cement content, and weak in diagenesis. Reservoir rock, relatively stable in type, is lithic feldspar sandstone. Fine in grain size, the sandstone is mainly medium sandstone-siltstone, with an average cement (mainly calcite) content of 7%. The reservoir pores are well-developed and quite even in distribution with fine connectivity. The reservoir space is composed of intergranular pores, followed by dissolution pores and a small amount of fissures, accounting for 81.7%, 15.5% and 2.8% respectively. The reservoirs have a porosity of 10.0%−23.0%, 20.4% on average, and a permeability of 0.1−500 mD, 124.9 mD on average.

2.2. Reservoir temperature and pressure

The reservoirs have a geothermal gradient of 3.08 °C/(100 m), representing normal temperature system. According to the field measured 26 data points of temperature versus depth, the fitted formula of temperature and depth is written as:

$$T = 10.428 + 0.0308D(R = 0.9550) \quad (1)$$

where T is formation temperature, °C; D is formation depth, m.

The formation pressure gradient is 1.07 MPa/(100 m), representing normal pressure system. According to the field measured 26 data points of pressure versus altitude, the fitted formula of pressure and altitude is written as:

$$p = 31.479 + 0.0107H(R = 0.9849) \quad (2)$$

where p is formation pressure, MPa; H is altitude of measured point, m.

2.3. Reservoir oil and gas properties

The surface crude is identified as light medium-viscosity oil, with an average density of 0.842 t/m^3, average viscosity of 9.4 mPa s, average paraffin content of 14.0%, average gasoline content of 10.1%, average kerosene & diesel content of 28.3%, average setting point of 30.0 °C, average wax precipitation point of 45.0 °C, and average initial boiling point of 144.0 °C. The oil PVT test demonstrates that the DGOR (dissolved gas-oil ratio) is 20.7−99.0 m^3/m^3, 74.0 m^3/m^3 on average under original formation pressure.

The gas has a relative density of 0.638, average methane content of 88.05%, average ethane content of 3.78%, average propane content of 1.63%, average heavy hydrocarbon content C_4^+ of 1.48%, average nitrogen content of 4.65%, and average carbon dioxide content of 0.41%. The gas PVT test shows that the gas has a volume factor of 0.007 08−0.011 93, density of 0.061−0.101 t/m^3, viscosity of 0.013 7−0.015 6 mPa s, and deviation factor of 0.837 9−0.870 1 (0.854 0 on average) under original formation pressure, representing dry gas.

3. Qualitative identification of oil and gas layers

3.1. Differentiation of oil and gas layers with conventional logging

Resistivity [3] and excavation effect of compensated neutron logging [4,5] are often used to identify oil and gas layers in conventional logging.

However, the resistivity of oil and gas layers principally reflects reservoir petrophysical properties rather than oil or gas properties when the oil and gas layers have similar water saturation. In addition, the invasion depth of fresh water drilling fluid varies significantly due to relative high formation water salinity in the Yingdong Oil/Gas Field and relatively large petrophysical difference of different reservoirs. Resistivity mainly reflects reservoir petrophysical properties and drilling fluid invasion under comparative water saturation [6], but doesn't show obvious differences between oil layers and gas layers, so resistivity is not suitable for the Yingdong Oil/Gas Field.

The excavation effect of compensated neutron logging method is based on the assumption that the compensated neutron logging porosity will decrease and the apparent porosity of acoustic and density loggings will increase in gas layers, so there will be some differences between the porosity measured by compensated neutron logging and the apparent porosity measured by acoustic and density loggings in gas layers. However, different gas layers are different in formation

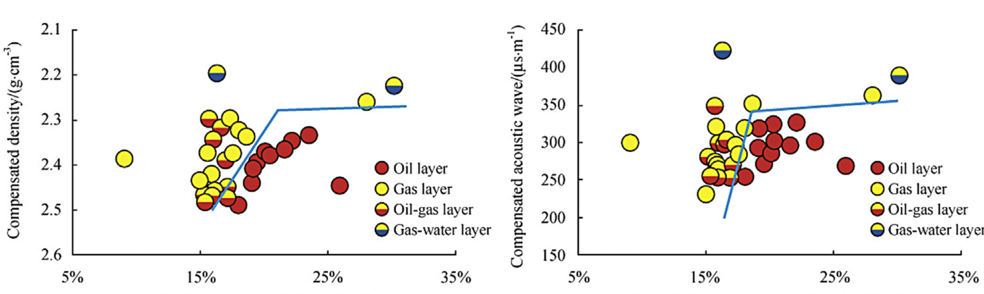

Fig. 1. Oil and gas layer identification crossplot with excavation effect of compensated neutron logging.