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RESEARCH PAPER

Permeability characterization and directional wells initial productivity prediction in the continental multilayer sandstone reservoirs: A case from Penglai 19-3 oil field, Bohai Bay Basin

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Abstract: Based on study on the main factors affecting the initial productivity of directional wells in multilayer sandstone reservoirs of Penglai 19-3 oil field, a permeability interpretation model based on lithofacies constraint was established, and an initial productivity prediction formula for directional wells in offshore multilayer sandstone reservoirs was derived. Permeability and oil saturation are the main factors affecting initial productivity of directional wells in Penglai 19-3 oil field. Using core, scanning electron microscope, casting thin section, logging and production data, and a new permeability interpretation model considering the influence of macro sedimentary characteristics and microscopic pore structure was built. On the basis of permeability correction, resistivity increase ratio is introduced to characterize the effect of oil saturation, to modify the Vandervlis productivity formula of directional wells to get an initial productivity prediction equation suitable for continental multilayer sandstone reservoirs. The study results show that the permeability considering petrographic constraints and the production forecasting formula including resistivity increase ratio are more accurate.

Key words: multilayer commingled production; permeability characterization; oil saturation; directional well; initial productivity prediction; Penglai 19-3 oil field; Bohai Bay Basin

Introduction

The reservoirs in Penglai 19-3 oil field, Bohai Bay Basin, are typical continental multilayer sandstone. Giving consideration to both development effect and production cost, commingled production by directional well was adopted for a series of strata in the initial stage[1–3]. However, Penglai 19-3 oil field is complicated in geological conditions, large in reservoir vertical span and serious in reservoir heterogeneity, making it difficult to predict the initial productivity of oil well. The productivity prediction results will affect the drilling workload and investment scale, and is the key to rapid productivity construction and efficient development of this type of oil reservoirs[4].

At present, a lot of research has been conducted on permeability interpretation and directional well productivity prediction, but few researches have combined the two in multi-layer sandstone reservoir productivity forecast. In this study, based on the research on main factors affecting initial productivity of directional wells in multi-layer sandstone reservoirs, a permeability interpretation model based on lithofacies constraint is proposed, resistivity index is introduced to describe the influence of oil saturation, and a prediction formula for initial productivity of directional wells in offshore multi-layer sandstone reservoirs is deduced.

1. Overview

1.1. Geological features of the oilfield

Penglai 19-3 oil field, located at the northeast end of middle part of Bonan Uplift in Bohai Bay, is a faulted anticline developed on paleouplift and complicated by fault in the east of Tanlu fault zone (Fig. 1). The major oil pays are in the Neogene Guantao Formation and Lower Minghuazhen Formation, the reservoirs are composed of fluvial terrigenous clastic rock, while the target layers are dominated by arkose sandstone.

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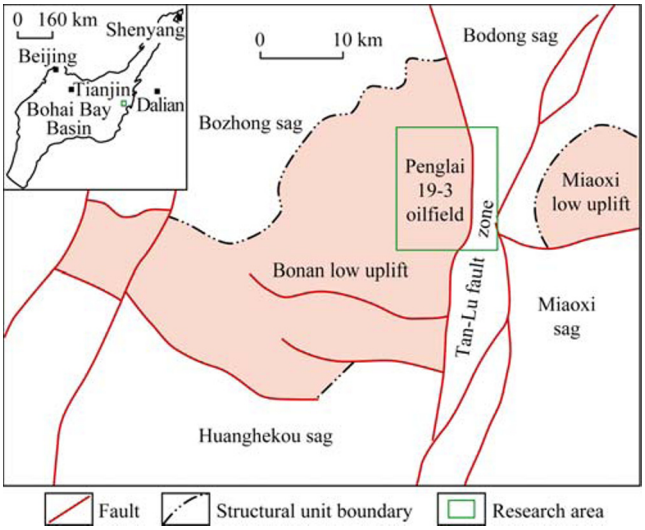

Fig. 1. Regional location of Penglai 19-3 oil field.

The oil layers are 63–151 m thick, and above 50 km^2 in oil-bearing area. With abundant faults on the plane, the reservoirs have complex oil and gas distribution and pressure system, and multiple sets of oil-water systems longitudinally, representing structural layered reservoir with edge water. The stock tank oil is characterized by higher density and viscosity, and low freezing point, while in-place oil is characterized by higher saturation pressure, small difference between formation pressure and saturation pressure, moderate dissolved gas/oil ratio, and severe biodegradation and water washing[5].

1.2. Productivity at appraisal stage

The test results of 10 times in 6 appraisal wells of Penglai 19-3 oil field are listed in Table 1.

It can be seen from Table 1 mobility and specific productivity have a good correlation, and can meet the requirement of productivity prediction of development well in the initial stage. However, for offshore oilfields of several hundred million tons, appraisal wells have fewer productivity data points, shorter testing time, slightly overestimated productivity, and smaller coverage. Thus, development wells that have put into production need to be studied to get a better understanding on the productivity of the oilfield.

1.3. Productivity at development stage

It can be seen from the initial productivity of 73 development wells developed in multi-layer commingled production that have put into production in Penglai 19-3 oil field that the mobility and specific productivity index are poorly correlated (Fig. 2).

2. Main influencing factors of initial oil well productivity

2.1. Reservoir permeability

Permeability is the most important parameter reflecting the physical property of reservoirs[4]. The conventional method of obtaining permeability is to get porosity from electric logging interpretation first, then establish petrophysical interpretation model according to the relationship between porosity and permeability measured from core laboratory test, finally the permeability is calculated by using porosity from logging. Penglai 19-3 oil field is a continental multilayer sandstone oil reservoir, where affected by both macroscopic depositional environment and microcospic diagenesis, the reservoirs have strong heterogeneity, and complex micro-pore structure. The porosity and permeability of over 300 core samples from lab test have poor correlation (Fig. 3), making the permeability obtained from conventional logging interpretation model inaccurate, thus affecting negatively the correlation between productivity and mobility of development well.

2.2. Fluid properties

PVT experiment on Penglai 19-3 oil field Guantao Formation fluid shows that the oil is conventional thin oil under reservoir conditions (Table 2). Under the pressure difference

Table 1. Statistics on productivity of appraisal wells in Penglai 19-3 oil field

Layer	Perforation interval/m	Oil layer thickness/m	Daily oil production/(m^3·d^{-1})	Pressure difference/MPa	Water cut/%	Skin factor/f	Specific productivity index/(m^3·(d·m·MPa)$^{-1}$)	Permeability/10^{-3} μm^2	Viscosity of crude oil/(mPa·s)	Mobility/(10^{-3} μm^2·(mPa·s)$^{-1}$)
Ng	998.0–1 011.0 1 022.0–1 061.5	25.3	54.1	0.7	0	–1.0	2.6	1 060	39	27
Ng	1 259.5–1 275.0 1 278.0–1 285.0	14.1	65.6	0.8	0	–0.3	6.0	5 980	80	75
Ng	1 128.5–1 150.0	13.8	112.4	1.2	0	0	6.7	1 250	13	94
Ng	1 318.0–1 329.0	11.8	135.2	1.5	0	1.1	8.9	3 362	25	134
Ng	1 232.0–1 468.0	57.9	30.7	5.4	0	–0.9	0.1	117	182	1
Nm	993.0–1 005.5	11.8	16.9	1.3	0	–1.7	0.9	468	79	6
Ng	1 254.0–1 276.0	5.3	30.1	2.9	0	–1.0	1.7	743	45	16
Ng	1 329.5–1 343.0	9.8	7.2	0.9	0	0.3	0.8	1 538	79	19
Ng	1 130.0–1 163.0	14.8	5.7	2.5	0	–1.2	0.1	238	382	1
Ng	1 349.0–1 379.9	7.6	112.9	4.0	0	–2.3	2.6	173	11	16