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RESEARCH PAPER

Stress sensitive experiments for abnormal overpressure carbonate reservoirs: A case from the Kenkiyak fractured-porous oil field in the littoral Caspian Basin

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Abstract: According to the characteristics of overpressure carbonate reservoirs of the Kenkiyak pre-salt oil field in the littoral Caspian Basin, cores were made artificially and the stress sensibility of matrix cores and cores with non-packed, semi-packed and fully packed fractures were analyzed. The method of gas measurement was used in the experiment. The confining pressure of the sample cores was first increased and then decreased. When the confining pressure became stable, porosity and permeability data from each pressure point were obtained to analyze stress sensibility of cores. The results showed that the stress sensibility of these four types of cores with a descending order is cores with non-packed fractures, cores with semi-packed fractures, cores with packed fractures, and matrix cores. With the decrease in packing degree of core fractures, the stress sensitivity of core permeability increased and the recovery degree of permeability decreased; the recovery degree of porosity and permeability of the matrix cores and cores with fully packed fractures was high with the recovery of pressure and these two types of cores showed elastic-plastic features. By contrast, the recovery degree of porosity and permeability of cores with partly packed and unpacked fractures was lower and these two types of cores showed plastic features. With the increase of confining pressure, the variation of porosity and permeability showed relatively regular exponential variations.

Key words: carbonates; abnormally high pressure; stress sensitivity; fracture packing; permeability variation

Introduction

The Littoral Caspian Basin is one of the main petroliferous basins in the world, with large overpressure carbonate reservoirs including Kenkiyak pre-salt, Tengiz, Karachaganak, etc. as the main fields in this basin. Such reservoirs have high initial formation pressure and large formation pressure coefficients. As the pressure of the reservoirs is decreased during depletion production, the effective stress on rock matrixes will be greatly increased, thereby causing remarkable elastic-plastic deformation of rocks[1], reducing the reservoir's physical property parameters including porosity, permeability, etc. and clearly affect the development effect of reservoirs.

Located in the eastern margin of the Littoral Caspian Basin, the Kenkiyak pre-salt reservoir is an overpressure carbonate reservoir, with a burial depth of 4 100–4 200 m, the formation pressure as high as 80 MPa, the pressure coefficient of 1.84[1], has a low porosity (11.5%) with an ultra-low permeability (0.82×10^{-3} μm^2). Reservoir fractures are developed non-uniformly, and the types of reservoirs mainly consist of the porous type[2–3] and fractured-porous type. The packing degree of fractures varies: most fractures formed earlier are fully packed fractures, and most fractures formed later are semi-packed or unpacked ones. The reservoir is developed using the depletion production mode. As the formation pressure decreases, the productivity of oil wells decreases quickly. The reservoir shows strong stress sensitivity [4–5], and stress sensitivity varies a lot in different fracture-developed zones. Since the number of cores is limited, in this paper, artificial cores are used to simulate the variation of natural cores with confining pressure. In addition, the stress sensitivity variation of cores with different fracture development degrees and fracture packing degrees are analyzed, and the stress sensitivity of overpressure fractured-porous carbonate reservoirs is evaluated.

1 Experimental method and procedure

The stress sensitivity of matrix porous reservoirs and fractured-porous reservoirs with different facture packing degrees was evaluated under increasing and decreasing confining pressure.

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1.1 Preparation of artificial cores

The data of the porosity and permeability of natural cores were first acquired to serve as the reference for the porosity and permeability of artificial cores. Actual core samples were derived from the carbonate reservoirs in three coring wells in the Kenkiyak Pre-salt oil field. The cores are characterized by low porosity and ultra-low permeability (Table 1). The average porosity is 6.99% and the average gas measurement permeability is 0.67×10^{-3} μm^2.

Quartz sands of different grain sizes mixed with natural carbonate rock powder according to certain proportion were compacted at 10–25 MPa, cemented by calcium carbonate, and then dried in a 90 °C thermotank; after being cooled, the mixtures formed the artificial cores with a certain pore structure, which represent matrix cores of porous reservoir without fractures. According to the statistics concerning fracture attitudes, fractures of the artificial cores were made and packed to different degrees for the purpose of simulating unpacked, semi-packed and fully packed cases [6–7]. The porosity and permeability of the artificial cores are shown in Table 2.

1.2 Experimental Procedure

During the experiment, the method of gas measurement was used and nitrogen gas was applied as the test fluid. The formation pressure of the reservoir was decreased by 40–45 MP and the effective stress of rocks was increased to 45 MPa at most, so the highest applied confining pressure was set as 45 MPa [8]. During the experiment, the confining pressure (p) of the artificial core samples was gradually increased from 3 MPa to 10 MPa, 20 MPa, 30 MPa, 40 MPa and 45 MPa and then decreased to 40 MPa, 30 MPa, 20 MPa, 10 MPa and 3 MPa; in the initial state (confining pressure was 3 MPa), the porosity was ϕ_0 and the permeability $\boldsymbol{K_0}$. After being stabilized, the porosity ($\boldsymbol{\phi}$) and permeability ($\boldsymbol{K}$) of each pressure point were measured.

For each sample, the stress sensitivity of permeability and porosity of the matrix core was first measured; then external force was applied to the side of the core, so that the core was fractured longitudinally and a through-facture was formed to measure the stress sensitivity of permeability and porosity of the fractured cores; a large quantity of coarse sands were packed into the fracture to simulate the cores with semi-packed fractures and to measure the stress sensitivity of permeability and porosity; finally fine quartz powder and calcium carbonate powder were packed into the fractures, thus reducing the fracture permeability, simulating the core with fully

Table 1 Porosity and permeability of cores in the reservoir of the Kenkiyak pre-salt oil field

Well No.	Core No.	Porosity/ %	Gas measurement permeability (10^{-3} μm^2)	Initial permeability/10^{-3}μm^2
7001	6-8	4.07	3.244	0.214
	7-21	5.19	0.018	0.017
	7-29	5.54	0.014	
	6-33	3.25	0.250	0.178
8001	218	6.96	0.139	0.079
	302	7.30	0.062	
	362	7.71	0.992	0.047
8016	683	12.29	0.037	0.012
	484	7.91	1.716	0.975
	676	9.73	0.179	

Table 2 Basic data of artificial cores

Core No.	Matrix		Unpacked		Semi-packed		Fully packed	
	Porosity/%	Permeability/ 10^{-3} μm^2	Porosity/%	Permeability/ 10^{-3} μm^2	Porosity/%	Permeability/ 10^{-3} μm^2	Porosity/%	Permeability/ 10^{-3} μm^2
3-8	11.36	9.09	11.82	29.03	17.52	37.73	16.58	27.44
3-9	7.85	16.67	10.69	40.22	12.18	24.34	11.10	17.15
3-10	6.73	0.04	7.64	514.33	7.33	13.43	3.07	0.01
3-11	5.93	2.39	6.85	115.66	7.95	977.56	9.39	1.66
3-12	11.83	6.77	12.92	137.80	12.37	59.97	10.89	4.75
3-13	5.88	0.35	6.71	1.16	6.53	0.74	6.84	0.08
3-14	21.43	10.0	22.44	44.98	15.43	19.24	15.06	7.62
3-15	8.48	0.05	11.79	31.61	15.70	61.31	11.89	23.63
3-16	18.62	0.05	17.62	15.80	12.71	23.84	12.20	0.03
3-17	10.46	0.08	10.93	25.65	10.46	27.68	10.16	33.80
3-18	16.07	0.81	16.35	1.19	16.61	0.20	16.49	0.14