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Determination of Non-Darcy Porous Flow Boundary Value in Formation Type III

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Abstract

With the oil industrialization area increasing and the fine Petrophysics block decreasing, the oil field is faced with the situation that isn't enough potential, thus it's necessary to begin effective developing in formation type III, which has high potential, strong heterogeneity and low permeability. It's important for reservoir development to understand porous flow law in formation type III. There is a large reserve in formation type III of X block in Daqing Oil Field, whose main formation type is thin and poor formation with thin thickness and poor Petrophysics. To find the boundary value for Non-Darcy porous flow in formation type III, we study the pressure number to recognize Non-Darcy porous flow and Non-Darcy porous flow index in characteristic curve for porous flow. We also study the Non-Darcy porous flow boundary value with two methods, pressure number method whose result is 107 mD, Non-Darcy porous flow index method whose result is 120 mD. The two values are similar, thus the Non-Darcy porous flow degree increases sharply when permeability is less than 10 mD. The study provides theory guide for improving residual oil potential and enhancing development effect in formation type III.

Key Words: Thin and poor formation; Non-Darcy porous flow boundary value; Pressure number; Non-Darcy porous flow index

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INTRODUCTION

La-Sa-Xing reservoir in Daqing Oil Field has entered into extra high water-cut stage, and formation type I and II went into tertiary oil recovery stage in turn, during which stage water flooding infilling is main method in formation type III, which including the thin and poor formation and unlisted formation. Injection-production contradiction is obvious in formation type III, which is solved by injection-production adjustment in polymer flooding. These measures improve the development effect in formation type III effectively and play an important role in understanding the porous flow rule and characteristic in formation type III and improving residual oil potential.

X block in Daqing Oil Field has large reserves, more well-developed layers, low permeability and thinner single layer in its formation type III. We can see from its formation type that the thin and poor formations are well-developed and the drilling layers and thickness account for over 70% for listed thin formation and independent unlisted formation. Formation type III mainly includes listed thin formation and unlisted formation. The listed thin formation mainly includes effective formation with net pay 0.2-0.4 m. The unlisted formation means the formations which are not included in the reserves during early developing stage of oil field and the poor formations with Petrophysics as oil patch and inrush. It shows certain oil production capacity after water flooding and infilling, which is one of the important objects of improving potential.

The difference between flow in thin and poor formation and that in listed thick formation is that the thin and poor formation has Lithology and Petrophysics with large variation range and serious heterogeneity. From the result of core threshold pressure gradient test, we can see that the porous flow in formation type III of X block is Non-Darcy flow, thus the boundary value of Non-Darcy porous flow in the formation can be determined with pressure number method and Non-Linear porous flow index method.

1. DETERMINE NON-DARCY POROUS FLOW BOUNDARY VALUE BY PRESSURE NUMBER METHOD

Considering Non-Darcy porous flow criterion, which is raised by Dr. Ruan Min from China University of Petroleum, we introduce the conception of "pressure number" to judge the Non-Darcy porous flow, whose formula as following:

$$\lambda_N = \frac{\mu^2 R}{K \rho r} \tag{1}$$

Where, K is permeability, μ is viscosity, ρ is density, R is pore diameter, r is throat diameter.

Pressure number λ_N means the flow difficulty of fluid with kinematic viscosity ν in porous media with aspect ratio r/R. When λ_N is smaller, which means pseudo-threshold pressure gets smaller, the law of porous flow gets close to Darcy flow. When λ_N is less than 2, pseudo-threshold pressure gets very small or near to zero, and the porous flow shows Darcy flow characteristic. When λ_N is larger than 5, the influence of pseudo-threshold pressure on porous flow can't be ignored, and the porous flow shows Non-Darcy characteristic[9]. Non-Darcy porous flow boundary value can be determined with above theory and lab result.

Calculate the pressure number of each core with constant rate mercury injection data as following:

Table 1
Pressure Number of Each Core in Constant Rate Mercury Experiment

Core	Porosity (%)	Permeability ($10^{-3}\mu m^2$)	Throat Diameter (μm)	Pore Diameter (μm)	Pressure Number (MPa)
d4c_06a	18.43	1.3	2.72	35.36	571.38
d4c_05a	19.07	4.97	3.10	36.28	134.56
d4c_14a	21.47	12.6	4.29	46.55	49.20
d4c_04a	23.73	15.3	3.81	41.31	40.49
d4c_11a	25.25	18.3	3.52	37.63	33.38
d4c_12a	25.62	29.8	4.58	47.72	19.98
d4c_09a	19.65	55.04	4.66	45.81	10.21
d4c_03a	26.03	88.4	5.08	48.30	6.15
d4c_13a	19.70	97.76	5.23	48.96	5.47
d4c_10a	23.88	109.26	5.20	48.69	4.90
d4c_02a	28.09	174	5.15	46.83	2.99
d4c_07a	28.61	190.7	5.13	46.09	2.95
d4c_01a	32.23	429	6.32	54.70	2.59
d4c_08a	33.16	554.08	6.70	55.64	1.11

Table 1 shows that pressure number of most core is more than 5 MPa, which means fluid flow in the formation is Non-Darcy flow, whose aspect ratio-permeability relationship curve as Figure 1:

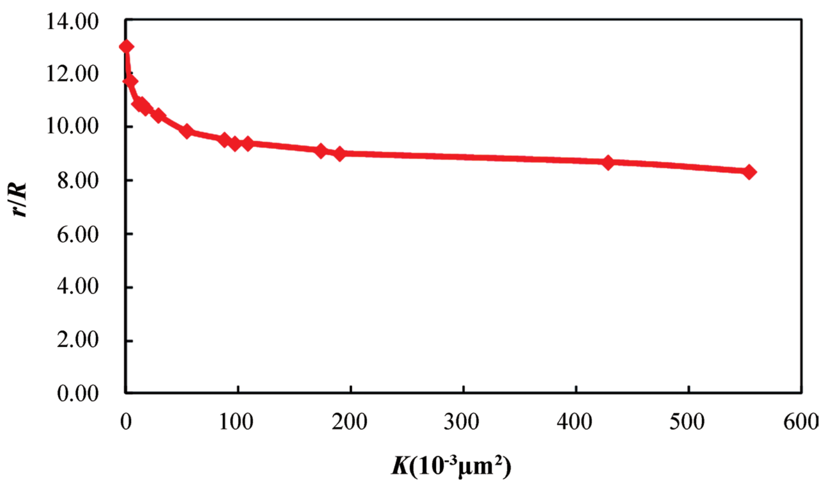

Figure 1
Aspect Ratio-Permeability Relationship

$r/R=13.167K^{-0.0721}$ (2)

Figure 1 shows that aspect ratio decreases with the increasing of permeability, when permeability is more than 100 mD, the decreasing of aspect ratio gets slow. When aspect ratio is great, big pore is surrounded by small throat, the oil (gas) in big pore can't pass small throat easily, while Jamin effect is strong, and the gas beads and bubbles must overcome more resistance to pass the small throat[10]. By formula (2), calculate the aspect ratio with the permeability in threshold pressure gradient test, and then get the pressure number. Combining the permeability and pressure number, the relationship between them is obtained as following:

$\lambda_N=752.38K^{-1.072}$ (3)

Thus, when pressure number is more than 5 MPa, corresponding permeability is $107.19\times10^{-3}\mu m^2$, that is the permeability boundary value for Non-Darcy flow is $107\times10^{-3}\ \mu m^2$,and the pressure number decreases with the increasing of permeability, while permeability is less than 10 mD, pressure number increases greatly with the decreasing of permeability.

2. DETERMINE NON-DARCY POROUS FLOW BOUNDARY VALUE BY NON-DARCY POROUS FLOW INDEX METHOD

From motion equation for Non-Linear porous flow, the velocity equation for fluid through the core is obtained:

$$v=\frac{K}{\mu}\left(\frac{dp}{dr}-\lambda_1\right)^n \tag{4}$$

Where, v is the velocity of fluid in core, 10^{-4} cm^3/s; K is permeability, 10^{-3} μm^2, μ is oil viscosity, mPa.s; λ_1 is threshold pressure gradient for porous flow in core, MPa/m, n is Non-Linear porous flow index.

Non-Linear porous flow index shows the Non-Linear degree of Non-Linear porous flow law, which shows as following in Non-Linear porous flow characteristic curve: when n increases, Non-Linear stage in characteristic curve extends, whose curvature gets smaller, the pressure gradient from Non-Linear stage to quasi linear stage gets larger, and the threshold pressure gradient gets larger also, which is needed when oil and water begin flow in formation[11]. Figure 2 is the porous flow curve for core 22, whose Non-Linear porous flow is 2.34.

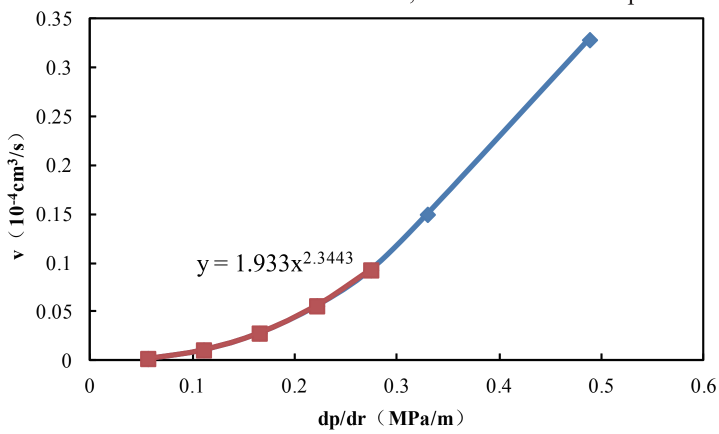

Figure 2
Porous Flow Curve for Core 22

Figure 3 is Non-Linear porous flow index-permeability curve got from porous curve of core in threshold pressure gradient test.

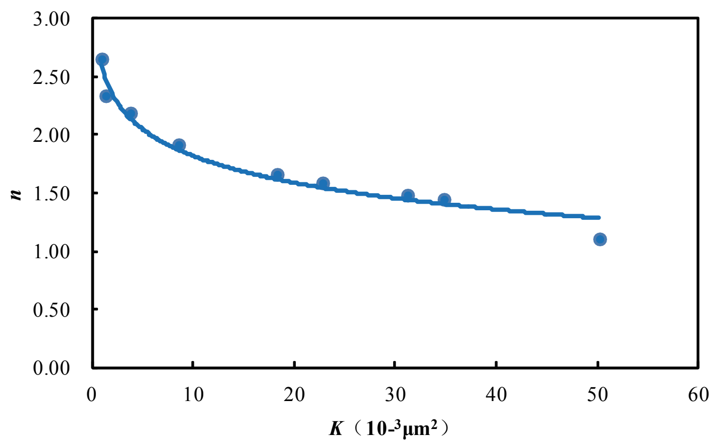

Figure 3
Non-Linear Porous Flow Index-Permeability Relationships

Figure 3 shows that, all the porous flow index is larger than 1 and less than 3, with the decreasing of permeability, the index gets larger, and their relationship agrees with equation (5):

$$n = -0.3311n(K)+2.5836 \quad (5)$$

When n=1, flow rate-pressure gradient curve is a straight line, that is the flow is Darcy linear flow. Therefore, n=1 is the critical value between Darcy linear flow and Non-Darcy linear flow. Calculate K with n, we get $K=119.62\times10^{-3}\mu m^2$, i.e. when permeability is less than 120 mD, the flow is Non-Linear flow, and when it's less than 10 mD, Non-Linear porous flow index increases greatly with the decreasing of permeability.

CONCLUSION

(1) Discuss on two method to determine Non-Darcy porous flow boundary value in formation type III.

(2) The permeability boundary value for Non-Darcy flow is 107 mD by pressure number method, which is 120 mD by Non-Linear porous flow index method. The two values are similar, thus the Non-Darcy porous flow degree increases sharply when permeability is less than 10 mD.

REFERENCES

[1] Cheng, J. C. (2006). Progress and Further Area of EOR in Daqing Oilfield during "the 10th Five-Year Plan". *Petroleum Geology and Exploitation in Daqing*, *25*(1), 18-22.

[2] Lu, L. Q., & Zuo, S. L. (2009). Discussion on Development Model of Formation Type III in La-Sa-Xing Oilfield in Daqing. *Journal of Jiamusi University* (*Natural Science Edition*), *27*(6), 888-892.

[3] Zhao, L. Z., & Zhou, G. H. (2007). Research on Effective Fracturing for Polymer Flooding in Formation Type III in South Saertu Block in Daqing Oilfield. *Petroleum Geology & Oilfield Development in Daqing*, *26*(3), 115-118.

[4] Huang, Z. S. (2006). Optimization on Polymer Flooding Objectives and Formations in Formation Type III in North Saertu Oilfield. *25*(Supplement), 83-86.

[5] Zhao, G. (2008). Reasonable Injection-Production Ratio in Polymer Flooding in Formation Type III in Daqing Oilfield. *32*(1), 108-111.

[6] Zhang, Y. G. (2008). *Polymer Flooding by Stages and by Quality Field Test in Formation Type III of Sa I+II Pay Zones in West-Middle Sazhong Block* (Doctoral dissertation). Northeast Petroleum University.

[7] Li, X. (2010). *Polymer Flooding Field Test in Formation Type III* (Doctoral dissertation). Northeast Petroleum University.

[8] Zhang, X. Q., Guan, H., & Wang, H. T. (2006). Polymer Flooding Practice in Formation Type III in Daqing Oilfield. *Petroleum Geology and Exploitation in Daqing*, (3), 374-376.

[9] Ruan, M., Li, X. F., & Feng, Y. (2009). A New Method to judge Non-Darcy Flow in Formation with Low Permeability. *Journal of Xi'an Petroleum University* (*Natural Science Edition*), *24*(4), 39-41.

[10] Wang, R. F., Shen, P. P., Song, Z. Q., & Yang, H. (2009). Microscopic Pore Throat Characteristic in Sand Reservoir with Extra Low Permeability. *Acta Petrolei Sinica*, *30*(4), 560-563.

[11] Zhao, H. (2006). *Non-Linear Porous Flow Theory and Application in Low Permeability Reservoir* (Doctoral dissertation). Daqing: Daqing Petroleum Institute.