
Development status of threshold pressure gradient in china

Liang Wang¹, Haifeng Cheng¹, Xiaodong Fu², Yuechao Teng¹, Fengqi Wang¹

1 Northeast Petroleum University The formation mechanism of oil and gas reservoir and resource evaluation

Heilongjiang Province key laboratory, Daqing, Heilongjiang, China,163318

2 PetroChina West Drilling Cementing & Fracturing Engineering Company, Kalamayi, Xinjiang, China,864009

Abstract: The threshold pressure gradient brings lots of difficulties to the development of oil field, after analyzing a large number of documents, the article summarizes a variety of research methods to measure it and the influence to threshold pressure gradient with fluid and reservoir. And then the article takes a overview about the problem when the threshold pressure gradient is researched. Simultaneously, several applications about threshold pressure gradient are introduced in terms of oil production, and propose the outlook on it at last. To further study threshold pressure gradient lays a foundation.

Keywords: *Low-permeability reservoir; Threshold pressure gradient; Non-Darcy flow*

I. INTRODUCTION

In recent years, with petroleum continuing to be mined in china, most of oil fields have been mined in the middle-later period, oil production is declining. China has many oil-gas reservoirs with low and ultra-low permeability, according to the new and proved oil-gas reserves, oil-gas reservoirs with low permeability have accounted for 70%^[1]. Characteristics of these reservoirs are very low reservoir porosity and permeability. When fluid is flowing in low permeability reservoir, Darcy law does not be complied, permeability curve does not to pass through the origin. When fluid is flowing in low permeability cores, it will be hindered at the inlet, only when its entering pressure is greater than the pressure of its resistance, fluid can flow in the cores, this phenomenon is caused by threshold pressure gradient, BA Florin put forward the concept of threshold pressure gradient in 1951^[2]. Threshold pressure gradient increases the difficulty of oil development, in order to increase oil production, people make more effort to research in low permeability and unconventional reservoirs. The research of threshold pressure gradient used to analyze with a core in the laboratory at first, and then people take advantage of the regression of key parameters, such as flow and pressure, to establish threshold pressure gradient model, now, it combines with production practice in engineer applications and be used in oil production. Research of threshold pressure gradient has made a great progress. But there are some problems, for example,

when getting on laboratory experiment, it can not be completely simulate with the condition of subsurface reservoir, besides, in the research of numerical simulation theory, just a portion of reservoir and fluid parameters are used, so numerical simulation established is not particularly integrity. Threshold pressure gradient needs further to be studied.

II. RESEARCH STATUS AND PROBLEMS OF THRESHOLD PRESSURE GRADIENT IN CHINA

A Measuring threshold pressure gradient, it uses generally steady-state method, namely pressure-flow method. But the steady-state method's flaw is difficult to accurately measure small flow, which is easy to cause errors. And it need take much time to wait until infiltrating fluid is stable. Compared to steady-state method, non-steady state method takes less time to measure threshold pressure gradient, but it is not high accuracy at times. Among measurements of threshold pressure gradient, one is measuring minimum threshold pressure gradient, Chengyuan Lü proposed capillary balance method, which is not only easy to operate but also demands less on the hardware, after combining pressure-flow method, this comprehensive measurement can be a good method to measure threshold pressure gradient^[3]. To combine with a variety of methods is the trend of measuring threshold pressure gradient. People continue to improve the research methods of threshold pressure gradient, for example, Fan Wu proposed it was different for threshold pressure gradient with clean or bound water core, and then he proposed optimization methods to measure threshold pressure gradient^[4]. The optimization methods play a great role in reducing the measurement error. Threshold pressure gradient is not only in single-phase fluid, but also in two-phase fluid, through a large number of experiments, Aifen Li proposed threshold pressure gradient of two-phase fluid was much greater than of single-phase fluid, and then she successfully established a numerical model of two-phase fluid^[5]. In oil production, the numerical model of two-phase fluid is more suitable for conditions of subsurface reservoir. The research of threshold pressure gradient is not only in the macroscopic aspects, but also in the microscopic aspects. By using NMR and rate-controlled mercury penetration method to analyze core aperture and pore throat, Wei Xiong proposed aperture and pore throat to influence of threshold pressure gradient^[6]. From the microscopic aspects to research threshold pressure gradient, it is further and more practical significance to establish the model of threshold pressure gradient. In addition to laboratory experiment methods, Yuewu Liu also summed up numerical experiment and well test analysis method to measure threshold pressure gradient. Numerical experiment method is simple and efficient, but this method must rely on distribution of formational pore throat and some comparative experiments. Well test analysis method reflects dynamically the reservoir variation, but its

disadvantage is the method need take longer time on the on-site construction and higher costs^[7]. Including laboratory experiment, all of three methods can not faultlessly measure threshold pressure gradient. Threshold pressure gradient is also in the ultra-low permeability reservoir, Songquan Li got on a physical simulation experiment about threshold pressure gradient, and then he established nonlinearity mathematical model of single-phase and two-phase, in addition, the model was also used in the reservoir engineering simulation^[8]. Combined with simulation application of reservoir engineering, numerical model were applied to oil field to increase oil recovery. People also research on threshold pressure gradient of unconventional reservoirs^[9-10]. For instance, Hao Kang researched influential factor of threshold pressure gradient in volcanic rock, and then he found if volcanic reservoir permeability was lower, the threshold pressure gradient would be greater^[9]. His discovery provides a reference to research threshold pressure gradient of volcanic and unconventional reservoirs in the future. Recently, on the basis of previous studies, Hongen Dou found threshold pressure gradient was not changing along with the entire development process. The new knowledge can solve a problem which has long been plagued for people by the non-Darcy flow, simultaneously, reservoir engineering analysis and numerical simulation will be greatly simplified^[1]. Besides, threshold pressure gradient also combines with production practice in engineer applications and is used in oil production.

B From the 1980s, threshold pressure gradient was studied in china, people have acquired some knowledge. One knowledge is the relationship between threshold pressure gradient and gas log permeability is linear, simultaneously, threshold pressure gradient is larger along with flow capacity and pore throat radius decreasing, viscosity and tortuosity increasing^[11]. The second knowledge is threshold pressure gradient decreases after the first increase along with SW increasing^[8]. The third knowledge is threshold pressure gradient is larger along with bound water saturation increasing, and then oil-wetting threshold pressure gradient is larger than water-wetting threshold pressure gradient^[12]. Another knowledge is threshold pressure gradient of two-phase fluid is greatly larger than of single-phase fluid^[6].

C At present, measurement standards of threshold pressure gradient have not been yet formed in china, besides, formation environment can not strictly be simulated, such as alkalinity acidity of injected water, salinity, temperature and so on, which all affect measurement results of threshold pressure gradient^[9]. Moreover, many variations of the parameter are ignored during the measurement. Most importantly, after summarizing the results of previous research, Hongen Dou found results measured by laboratory experiment were higher than the true value^[1]. The numerical models of threshold pressure gradient are established in ideal conditions, and the actual reservoir conditions are ignored. When fluid is flowing through the low permeability reservoirs, it can produce Jamin effect, microscale effects, etc, and sensitive effect of low permeability reservoir is also strong, numerical

models generally consider only a single effect and is relatively simple. Besides, the own conditions of the reservoir, such as cracks and clay minerals, are very difficult to be determined and often be overlooked. Therefore, when establishing the numerical model, people should strictly simulate formation conditions to improve the accuracy of the model, and then build a comprehensive model of threshold pressure gradient.

III. THE APPLICATION IN THE DEVELOPMENT OF OIL AND GAS

A The application of threshold pressure gradient in predicting and increasing oil production

When fluid is flowing in low permeability reservoir, because of threshold pressure gradient, it will encounter impediment to consume a part of the formation energy, which decreases oil production to cause deviations of the production forecast. During formation pressure dropping, formation produces elastic and plastic deformation to make porosity and permeability decrease, which results in greater threshold pressure gradient^[8]. When threshold pressure gradient is greater, oil production declines faster. It makes a more influence on productivity prediction. In addition, threshold pressure gradient can be also applied in terms of oil recovery ratio, for example, fracture can increase oil production. If overlying formation pressure is destroyed during fracture, it will cause high-speed disappearance of the formation pressure, which can accelerate the speed of production disappears. To prevent this situation, people need use threshold pressure gradient to calculate the size of the formation pressure, which will increase oil production^[13].

B The application of threshold pressure gradient in well network layout and optimization

Because of threshold pressure gradient, the magnitude of inject water is decreased to lead to lower oil production. When formation pressure gradient is greater than or equal to the threshold pressure gradient, injection-production pattern can be effectively controlled, according to threshold pressure gradient, people can determine the ultimate injection-production well spacing^[14]. On this basis, combining percolation theory, flow rate of source equidistant is minimal in the same flow lines, when flow rate of mainstream line reaches minimum, pressure gradient is minimum^[15]. Therefore, by using this method, it can be reasonable to regulate pattern well spacing to to achieve the maximum displacement efficiency under considering driving pressure. So layout and optimization of well network all need to consider threshold pressure gradient.

C The application of threshold pressure gradient in horizontal well production

Threshold pressure gradient plays a great role in horizontal well production of gas reservoirs with low permeability, Fuquan Song proposed loss of gas increased linearly along with threshold pressure gradient increasing. When threshold pressure gradient existing, the larger threshold pressure gradient became, the lower horizontal well yielded^[16]. Many people research on the application of threshold pressure gradient in horizontal

well production. For example, Xiao Guo researched on the influence of horizontal well production by introducing threshold pressure gradient and stress sensitivity. He found when threshold pressure gradient reached 0.00025MPa/m, horizontal gas production would be reduced 77%, so he reminded, when people forecast horizontal well production, the impact of threshold pressure gradient must be considered^[17]. Jian Xiong compared the slip effect and threshold pressure gradient to impact of the horizontal well production, and then he found, in the first stage of developing, threshold pressure gradient played a major role and the ability it affected horizontal well production was approximate decrease^[18].

IV. RESEARCH TRENDS AND PROSPECTS

The theory of threshold pressure gradient is constantly perfect and laboratory equipment measured threshold pressure gradient is also more sophisticated, trend of measuring threshold pressure gradient should combine a variety of measurement tools, on the one hand, this method takes less time to measure threshold pressure gradient, on the other hand, experimental results will be more accurate and measurement error is greatly reduced. And then people are able to establish more comprehensive threshold pressure gradient model, which will provide a greater assistance for engineering applications and increase oil-gas production. Unconventional reservoirs such as tight oil and tight gas, their reserve assessments, arrangement of well network and a variety of ways to increase production are all inseparable from threshold pressure gradient. In the future, threshold pressure gradient will have a broad application prospects in unconventional oil-gas fields .

V. CONCLUSIONS

Firstly, this article summarizes research methods and influencing parameters of threshold pressure gradient, simultaneously, the problems are also proposed during measuring threshold pressure gradient. Secondly, on the basis of previous studies, research direction of threshold pressure gradient is roughly proposed, when measuring threshold pressure gradient, people should combine with a variety of measurement tools, and then it also needs to add to the numerical experiment and test interpretation method, by this way, the accuracy of threshold pressure gradient can be greatly improved. Thirdly, the article puts forward comprehensive numerical model of threshold pressure gradient should be established to consider a variety of effects caused by fluid flowing in low permeability reservoir, such a comprehensive model is able to play a more role in oil production. Threshold pressure gradient can not be ignored in oil production. However, there are also some flaws in the experimental measurements and theoretical study, it needs to be further improved.

REFERENCES

- [1] Hongen Dou, Shiyang Ma, Chunyou Zou, Shangli Yao. Correct understanding to threshold pressure gradient in low and ultra-low permeability reservoir[J]. *Scientia Sinica(Terrae)*, 2014, 08:1751-1760.
- [2] Gorbunov AT. (Shubao Zhang translates). Beijing: Petroleum industry press, 1987, 181.
- [3] Chengyuan Lü, Jian Wang, Zhigang Sun. An experimental study on starting pressure gradient of fluids flow in low permeability sandstone porous media[J]. *PETROLEUM EXPLORATION AND DEVELOPMENT*, 2002, 29(2) : 86 –89.
- [4] Fan Wu. Experimental condition optimization of threshold pressure gradient of core[J]. *Henan Petroleum*, 2006 (05)
- [5] Aifen Li, Min Liu. Experimental Study on threshold pressure gradient of oil-water two-phase seepage in low permeability reservoirs[J]. *Journal of Xi'an Shiyu University(Natural Science Edition)*, 2010(11)
- [6] Wei Xiong, Qun Lei, Xiangui Liu, Pseudo threshold pressure gradient to flow for low permeability reservoirs[J], *PETROLEUM EXPLORATION AND DEVELOPMENT*, 2009 (4)
- [7] Yuewu Liu, Zhenhua Ding, Fengzhen He. Three methods to determine Threshold pressure gradient in low permeability reservoir. *Well Testing*, 2002, 04:1-4+74.
- [8] Songquan Li, Linsong Cheng, Xiousheng Li, Fei Hao. Non-linear seepage flow models of ultra-low permeability reservoirs[J]. *PETROLEUM EXPLORATION AND DEVELOPMENT*, 2008, 05:606-612.
- [9] Hao Kang, Xinmin Song, Bo Liu, Zhendong Lei, Hua Li. The study on influential factor of threshold pressure gradient in volcanic reservoir[J]. *Science Technology and Engineering*, 2014, 13:35-38.
- [10] Wei Tian, Weiyao Zhu, Huayin Zhu, Mingchuan Wang, Ruiming Wang. The influential factor of threshold pressure gradient in tight sandstone[J]. *Fault-Block Oil & Gas Field*, 2014, 05:611-614.
- [11] Quanlin Wang, Mei Tan, Dongliang Lü, Debing Peng, Fenzhuan Guo. An experimental study on threshold pressure gradient in low permeability reservoirs[J]. *Petroleum Geology and Recovery Efficiency*, 2011, 01:97-100+117-118.
- [12] Youfu Wang, Gang Wang, Shukai An, Wei Zhao, Hui Jin. Experimental study to influential factor of threshold pressure gradient with rock in low permeability reservoirs[J]. *Journal of Oil and Gas Technology(Journal of Jiangnan Petroleum Institute)*, 2006, 03:112-113+446.
- [13] Fei Hao, Linsong Cheng, Chunlan Li, Tirao Zhou, Yunjie Yao. The study on threshold pressure gradient in extra-low permeability reservoir[J]. *Journal of Southwest Petroleum Institute*, 2006, 06:29-32+113.
- [14] Fuping Tang, Hai Tang, Beibei Yu, Jian Zheng, Dongliang Lü. The determination of the

- injection-production well spacing with the consideration of the start-up pressure gradient[J]. Journal of Southwest Petroleum University, 2007, 04:89-91+194.
- [15] Xihua, Wang. Using Start-up pressure gradient to Calculate Low-permeability Reservoir's Biggest Producer-injector Spacing[J]. FAULT-BLOCK OIL&GAS FIELD, 2003(06)
- [16] Fuquan Song, Ciqun Liu. The Performance of Horizontal Well With Starting Pressure Gradient in Low Permeability Reservoirs[J]. Journal of Xi'an Petroleum Institute, 1999,03:18-21+4-5.
- [17] Xiao Guo, Yong Wu. Threshold pressure gradient and stress sensitivity to influence of horizontal well performance within low permeable reservoir[J]. Oil & Gas Geology, 2007, 28(4):539- 543.
- [18] Jian Xiong, Ping Guo, Lingfeng Li. Impact of slippage effect and start-up pressure gradient on deliverability of low-permeability gas reservoirs[J]. Journal of Daqing Petroleum Institute, 2011, 02:78-81+120-121.