Petroleum xxx (2017) 1–12

Contents lists available at ScienceDirect

Petroleum

journal homepage: www.keaipublishing.com/en/journals/petlm

A review of multiscale expansion of low permeability reservoir cracks

Liuke Huang [a], Jianjun Liu [a, *], Youjun Ji [a], Xiaoping Gong [b], Liangkai Qin [c]

[a] School of Geoscience and Technology, Southwest Petroleum University, Chengdu, 610500, China
[b] Northeast Sichuan Gas Recovery Plant, Sinopec Southwest Oil and Gas Company, Langzhong, 637400, China
[c] School of Civil Engineering, Southwest Jiaotong University Hope College, Chengdu, 610400, China

A R T I C L E I N F O

Article history:
Received 13 May 2017
Received in revised form
9 August 2017
Accepted 4 September 2017

Keywords:
Crack propagation
Multiscale coupling
Multiscale modeling
Microcrack
3D printing

A B S T R A C T

The study of rock crack propagation by multi-scale method is of great significance to comprehensively and accurately understand the law of rock crack evolution. In this paper, the theoretical, experimental and numerical methods from macroscale, mesoscale and microscale used for crack propagation in recent years are summarized and analyzed. Firstly, the evolution mechanism of the crack and the related research status are analyzed from a single scale. Secondly, multi-scale theory, modeling, meshing algorithm and macro-mesoscopic parameters are reviewed in the multi-scale coupling method. Through the analysis of the results published in recent years, it is considered that the following aspects need to be further studied: the characteristic parameters of the rock are different at different scales, so the extraction of the characteristic parameters under different scales is essential to modeling and coupling; the heterogeneity of rock and the prefabrication of cracks are greatly affected by human factors, so that 3D printing will be a good breakthrough to build the model of crack owing to its accurate control on the distribution and the size of cracks. The internal stress field of the rock is complex and varied, and the generation and expansion of the microcracks in the process of crack propagation are closely related to the surrounding environment. Therefore, it is of great importance to combine theoretical, experimental and numerical research with practical engineering.

1. Introduction

According to the analysis of existing oil and gas reserves in China, the development stage of unconventional oil and gas reservoirs will gradually coming, and low permeability reservoirs will be the main development object. The low permeability reservoirs are the result of sedimentation, diagenesis and tectonism, and it has the typical characteristics of low maturity sediment, low pore throat radius, poor reservoir property, strong pressure sensitivity, developed fracture and strong heterogeneity [1]. Due to the fracture development and the distribution space complexity, it is difficult to develop low-permeability oil and gas fields. The interaction between the pore pressure in the rock mass and the original fracture causes the stress state of the rock mass to change, causing the destroy of grains at micro-scale, nucleation and expansion of the microcracks at meso-scale, and the extend and penetrate of microscopic new crack or the original at macro-scale. The crack propagation process runs through the macro-scale, meso-scale and micro-scale, and it is the main reason for the destruction of the rock mass, and these microcracks are the main reservoir space and transport channel of in the low permeability reservoir [2,3].

Therefore, the macro-scale mainly studies the elastic deformation, plastic deformation and rock failure stage of the rock, that is, the crack mainly undergoes the process of crack closure, elastic stage, stable crack growth and crack growth. The nucleation, propagation path, length, opening and angle of the crack before failure need to be explained from the mesoscopic point of view. The stress field distribution of the crack tip, crack nucleation and propagation condition need to be further studied from the microscale point of view. The destruction of the rock is the process that the initiation, nucleation and expansion of the microcracks caused by the atomic bond breakage at first, and then forming the crack,

* Corresponding author.
E-mail address: liujj0906@163.com (J. Liu).
Peer review under responsibility of Southwest Petroleum University.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.petlm.2017.09.002
2405-6561/

the final failure of the main crack. The crack propagation process is that caused microcracks form to be main cracks, and the main cracks are developed to the macroscopic cracks, and then the macroscopic cracks evolve to failure. The process is caused to be cracked singular field by intergranular dislocation slip intergranular at the micro-scale, also by the external load of the stress field at the macro scale. At the mesoscopic level, we mainly study the mesoscopic evolution of the fault process area and the meso-geometric characteristics of the fault path, that is, the development of the crack direction in the microscopic view, and the bridge connections between the macro-scale and micro-scale.

Therefore, combining with the actual development of low-permeability reservoirs at present, there are important theoretical significance and application value to carry out multi-scale modeling of core fractures and multi-scale research on the formation, extension and closure of core microcracks, and to apply them to oil and gas exploitation for improving the oil injection effect, improve the final recovery rate and the overall development level of the oil field [4]. However, the research on the multi-scale expansion of fractures in low permeability reservoirs is not deep enough, especially the multi-scale mechanism of rock failure expansion and the quantitative description method, which have not the experimental method and theoretical analysis system. In this paper, the main progresses in the study of multi-scale expansion of low-permeability reservoirs at home and abroad are expounded from the aspects of macro-scale, meso-scale, micro-scale and multi-scale coupling, the difficulties and challenges are analyzed and then the research direction and new ideas is provided in future.

2. Research on macroscopic, mesoscopic and microscopic crack propagation

Rocks are formed under the complex geological structure in nature, the internal particles are complex and unevenly distributed, and they also contain microcracks, microvoids and even large fracture, including the defects from microscopic, mesoscopic to macroscopic scales, the defects have great influence on the integrity of the rock structure. The mechanical properties mainly show that the internal stress distribution is not uniform under the external load, and the properties of the rock are different under different scales. Therefore, it is of great significance to study the deformation and failure of cracks in the different scales of rock, which is of great significance to the study of rock deformation and deformation [5]. The failure of the rock is a macroscopic reflection of the crack initiation and the propagation of the crack in the microcracked state. The crack propagation process in the uniaxial compression experiment is shown in Fig. 1 [6,7]. The interaction between the cracks and the penetration is the failure of the atomic bond to produce local weakening and eventually form the rock. The whole microcrack propagation process is from the microscopic to the mesoscopic to the macroscopic scale, and its microcosmic, mesoscopic and macroscopic damage theory are shown in Table 1 [8,9].

2.1. Macroscopic crack propagation

Due to low permeability reservoir rocks have low permeability characteristics, it is necessary to improve the reservoir permeability that is a commonly used method for fracture reconstruction of reservoir in order to improve the oil recovery, which is also an important factor in the research of the hotspot. Rock is a kind of heterogeneous material with internal micro cracks, micro pores and grain boundaries, which can cause local stress concentration in force. It will have local damage when the strength of materials is lower than the value of stress concentration. The local crack tip will be subjected to the concentrated stress in the region, and the crack in the local area will expand at a certain distance. The heterogeneity of the rock makes the internal stress distribution more complicated. The crack is the evolution along any path on the macro-scale, so that the material on both sides of the crack changes from the initial continuous state to the discontinuous state. The failure is a damage evolution, the formation and propagation of cracks and fracture until the occurrence of the campaign process. Many researchers have mainly carried on the theoretical research, experimental research and numerical simulation [10–12].

In the study of macroscopic scale theory of crack propagation, the scholars have used the theoretical methods such as linear elasticity, elastic-plasticity, viscoelastic-plastic mechanics, macroscopic fracture mechanics and macroscopic damage mechanics, and established the relevant macroscopic theoretical model and judgment criterion [13–15]. The main theory of macroscopic scale crack propagation is based on fracture mechanics and damage mechanics. The fracture mechanics mainly includes the linear elastic fracture mechanics, which is based on the criterion of crack propagation in I, II and III stress intensity factors, the interface fracture mechanics, which is based on the interface crack of the strain energy release rate or the stress intensity factor, and the elastic-plastic fracture mechanics, which is based on the J integral criterion [16]. Damage mechanics mainly uses the thermodynamic theory and the elastoplastic theory to carry out the phenomenological analysis of the damage process. The damage evolution equation is established by defining the specific damage variable, and the damage constitutive equation is established based on the equivalent principle (strain equivalent, stress equivalent or energy equivalent), and the damage variable and damage energy rate are used as the judgment criterion of crack propagation [17]. The classical fracture criterion ignores the nonsingular stress term (T stress) on the analysis of crack initiation angle and strength. On the basis of fully considering the effect of non-singular stress term (T stress) on crack propagation, Tang et al. restudied the crack propagation law of I, II and I-II of brittle fracture of rock material by using maximum circumferential stress criterion [18,19]. The traditional theory of strain energy density factor is that the crack propagates in the direction of minimum distortion energy density in tension stress field, however, the natural rock mass is generally subjected to compressive stress. Therefore, Shi et al. amended the strain energy density theory to the compression rock, the friction between crack faces also being took into consideration additionally, and based on the modified theory, they analyzed the effects of crack angle, confining pressure and crack surface friction on crack propagation angle [5].

Under the external load, the interaction between microcracks, microvoids and other defects in the macroscopic fractured rock mass determines the form and properties of the rock failure [20,21]. So it is important to study the mechanical properties and crack distribution of rock to study the failure of rock, that is, the experimental study is the key to crack propagation. In recent years, scholars have used the image processing technology and compression experiments to study the crack propagation process, failure mode and the strength of the sample with the pre-cracked rock and without the pre-existing cracks. The crack in the rock mass is susceptible to perturbation and the prefabrication of crack is difficult. The mechanical properties of fractured rock mass are generally studied by physical model test using similar materials with transparent uniform properties, such as glass and resin. In the prefabricated crack test, the researchers studied the crack propagation and failure processes of single, two and multiple prefabricated cracks in uniaxial and triaxial compression experiments with different angle, different combinations and different spacing