Petroleum 1 (2015) 366–372

Contents lists available at ScienceDirect

Petroleum

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

Gas leakage mechanism in bedded salt rock storage cavern considering damaged interface

Jun Xiong [a,*], Xiaolan Huang [b], Hongling Ma [c]

[a] Civil and Environmental Engineering Department, University of Alberta, Edmonton, T6G2W2, Canada
[b] School of Civil Engineering and Architecture, Wuhan Polytechnic University, Wuhan, 430023, China
[c] State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, The Chinese Academy of Science, Wuhan, 430071, Hubei, China

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form
23 October 2015
Accepted 26 October 2015

Keywords:
Bedded salt rock
Gas leakage
Equivalent permeability
Numerical simulation

ABSTRACT

During the long-time operation of salt rock storage cavern, between its formations, damaged interfaces induced by discontinuous creep deformations between adjacent layers will possibly lead to serious gas leakage. In this paper, damaged interfaces are considered as main potential leakage path: firstly in meso-level, gas flow rule along the interface is analyzed and the calculation of equivalent permeability is discussed. Then based on porous media seepage theory, gas leakage simulation model including salt rock, cavity interlayers and interface is built. With this strategy, it is possible to overcome the disadvantage of simulation burden with porous-fractured double medium. It also can provide the details of gas flowing along the damaged zones. Finally this proposal is applied to the salt cavern in Qianjian mines (East China). Under different operation pressures, gas distributions around two adjacent cavities are simulated; the evolvement of gas in the interlayers and salt rock is compared. From the results it is demonstrated that the domain of creep damage area has great influence on leakage range. And also the leakage in the interface will accelerate the development of leakage in salt rock. It is concluded that compared with observations, this new strategy provides closer answers. The simulation result proves its validity for the design and reasonable control of operating pressure and tightness evaluation of group bedded salt rock storage caverns.

1. Introduction

Because of salt rock's low permeability and self-healing capacity, it is considered as suitable storage media for underground natural gas and oil. The sealability of salt rock is an extremely important safety indicator during the long time operation period. It is reported some disasters induced by damaged cavity that happened home and abroad. The leakage of gas will result in catastrophic influences on the environment and energy reserves.

Generally, it is noted that salt rock has extremely compact structure, low permeability and good ductility. Therefore pure salt mine is considered as an ideal selection for energy storage and high radiation disposal. However, most of Chinese salt mines have many thin interbeds. According to current literature [1–3], the existence of the interlayers has obviously adverse influence on the oil and gas storage operation. If energy storage cavities are built in this kind of formations, interface between different formations would be easily damaged by discontinuous creep deformations between salt rock and interbeds will lead to severe gas leakage during the long-time recycling operation [1]. Hence, it is considered that more attention should be paid to the integrity test and leakage stability evaluation in Chinese salt rock cavern construction.

* Corresponding author.
E-mail addresses: jxiong3@ualberta.ca (J. Xiong), huangxiaolan80@gmail.com (X. Huang), hlma@whrsm.ac.cn (H. Ma).

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.2015.10.008
2405-6561/

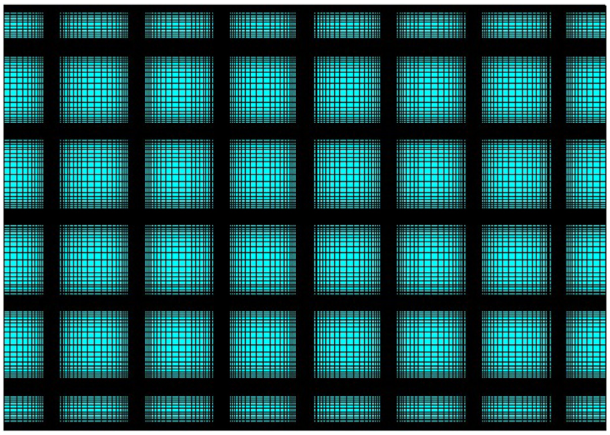

Fig. 1. Mesomechanics calculation model.

At home and abroad, much work has been done in the domain of permeability fluctuation under high operation pressure, creep and damage characteristic of pure salt rock [2–5] and their coupling fluid-mechanical responses [5–9]. However, when it comes to impure salt rock cavity, the related research just started in recent years. Especially the research emphasized on the influence of interlayers on the safety of salt cavern needs much more attention [10–12].

It is noted that seepage mechanism of high pressure gas in the interbedded salt rock is extremely complicated. How to build appropriate infiltration model and corresponding numerical simulation strategies are the key issues during the assessment of potential salt rock storage cavity and possible leakage volume. In this paper, damaged interface is taken as focal point. In meso-level, the evolvement of microcracks and broken rock particles in the damaged zones is simulated. Through this process, gas flow law along the interfaces is analyzed and its equivalent permeability is given. After that, based on porous media seepage theory, gas leakage model considering wall salt rock, interlayers and interface is built. With this strategy, the simulation burden is much easier than porous-fractured double medium; and it also can provide the gas flow mechanism along the damaged zones, which means it will simulate the percolation process of gas flow in salt rock, interbeds and damaged zones with a better way. Finally, combined with the cavity in Qianjiang mines, the damaged creep simulation model is built. Especially, this calculation model will consider the wall rock damaged zones in reasonable details. Under different operation pressures, gas distributions of two adjacent cavities are demonstrated; the evolvement of gas in the interlayer and salt rock is compared.

2. Equivalent permeability of damaged zones

Damaged zones of surrounding rock are regarded as the most possible leakage path for the gas in storage cavity. Especially when shear failure occurs at the interface between interbed and salt rock, there will be obvious slippage here, which means a damaged zone consisting of microcracks and broken rock particles are coming into being. In this section, based on fluid mechanics equation, mesomechanics calculation model for the damaged areas, and its equivalent permeability is provided too [13].

2.1. Heading flow equation of gas in microcracks

Navier-Stokes equation is employed for the flow mechanism of gas in fractures. For the migration of viscous fluid, if its flow velocity is u, pressure is p and density is ρ, according to the corresponding derivation (gravity is neglected), N-S equation for incompressible fluid is as follows:

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) + \nabla p - \nabla\cdot\left[\mu\left(\nabla\mathbf{u} + \nabla\mathbf{u}^{\mathrm{T}}\right)\right] = 0 \tag{1}$$

$$\nabla\cdot\mathbf{u} = 0 \tag{2}$$

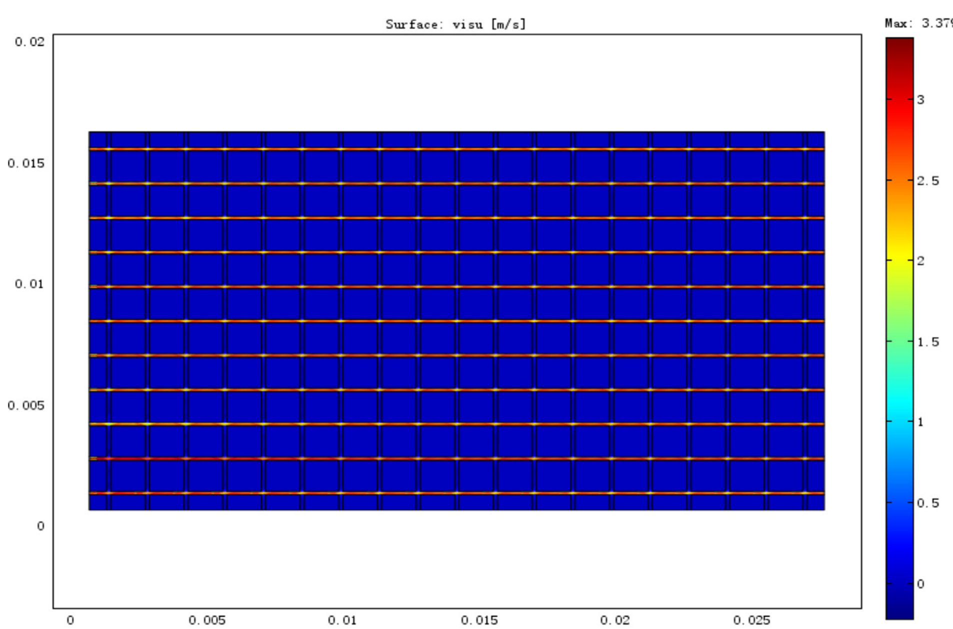

Fig. 2. Gas velocity field with 50 μm crack width.