Journal of Natural Gas Science and Engineering 27 (2015) 862–875

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Characterization of coal fines generation: A micro-scale investigation

Tianhang Bai [a], Zhongwei Chen [a, b, *], Saiied M. Aminossadati [a], Zhejun Pan [c], Jishan Liu [d], Ling Li [e]

[a] School of Mechanical and Mining Engineering, The University of Queensland, QLD 4072, Australia
[b] State Key Laboratory for GeoMechanics and Deep Underground Engineering, China University of Mining & Technology, Jiangsu 221116, China
[c] CSIRO Energy Flagship, Private Bag 10, Clayton South 3169, Australia
[d] School of Mechanical and Chemical Engineering, The University of Western Australia, 35 Stirling Highway, WA 6009, Australia
[e] School of Civil Engineering, The University of Queensland, QLD 4072, Australia

ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form
10 September 2015
Accepted 17 September 2015
Available online 21 September 2015

Keywords:
Coal fines generation
Microstructure characterization
Coal dewatering
Coalbed methane production

ABSTRACT

Coal fines are commonly generated as by-product during coalbed methane production mainly due to the interaction of coal with inseam water flow. A portion of the created coal fines may settle and plug the coal cleats and hydraulic fractures due to the gravity and coal pore size constraint. This could result in the reduction of coal permeability and blockage of coalbed methane wells or gas drainage boreholes. Despite the increasing awareness of the importance of understanding coal fines, limited research has been carried out on the characterization of coal fines creation. This study aimed to numerically characterize the generation process of coal fines in micro-scale coal cleats. The Scanning Electron Microscopy (SEM) images for a coal sample from Bulli Seam of the Sydney Basin in Australia were obtained and analysed to determine the actual cleat geometries and the characteristics of coal fines distribution. Then a fully coupled fluid-structure numerical model was developed to identify the creation process of coal fines at micro-scale. The impact of pertinent production conditions on coal fines generation was studied, including production pressure drawdown, temperature, coal fines Young's modulus and strength. The SEM images revealed that the particle size distributions of the coal fines in the examined cleats were in the order of hundreds of nanometres to several microns. The results of the numerical studies showed the coal fines production increased with pressure build-up, and decreased with increasing coal fines strength with more sensitivity compared with pressure. Critical values for production pressure drawdown were obtained, above which failure area began to expand; threshold values were also determined, below which remarkable reduction of coal fines production was achieved. Coal cleat geometry plays an important role in determining coal fines production. It was noted that exposed microstructures, cleat elbow regions and micro-fracture tips are more likely to generate coal fines. Based on these findings, guidance can be provided on the control of production conditions to mitigate coal fines issue, and new insight into where and how coal fines are created by inseam water flow can be achieved.

1. Introduction

Coal fines are small particles frequently found in coal seams (Magill et al., 2010; Marcinew and Hinkel, 1990), and their sizes are usually between tens of nanometres and tens of microns (Fan et al., 2015; Wei et al., 2015; Zou et al., 2014). With respect to the components of coal fines, Massarotto et al. (2013) employed comparative quantitative X-ray diffraction (CQ-XRD) to elucidate that coal material is still the major substance, but with higher fraction of clay minerals than coal seams. The clay minerals mainly include kaolinite and illite. Some other minerals involving pyrite and calcite were also found in coal fines (Chen et al., 2009; Turner et al., 2013), and the mineral contents vary with different coal fines samples (Marcinew and Hinkel, 1990).

Due to the presence of coal fines, although some of them are carried out by water or gas flow, some settle and plug the natural

* Corresponding author. School of Mechanical and Mining Engineering, The University of Queensland, QLD 4072, Australia.
E-mail address: zhongwei.chen@uq.edu.au (Z. Chen).

http://dx.doi.org/10.1016/j.jngse.2015.09.043
1875-5100/

Nomenclature

a	mean cleat aperture [m]
E	Young's modulus [Pa]
$\mathbf{E}$	rate of strain tensor
$\mathbf{F}_T$	load on solid surface induced by water
$\mathbf{I}$	identity tensor
l	effective flow length [m]
$\mathbf{n}$	outward normal vector
p	pressure [Pa]
PD	maximum pressure difference between inlet and outlet [Pa]
S	coal fines strength [Pa]
T	temperature [°C]
$\mathbf{T}$	deviatoric stress tensor
u	mean flow velocity [m/s]
$\mathbf{u}$	velocity field
$\nabla\mathbf{u}$	velocity field derivative tensor
V	coal fines production [m^3]
μ	dynamic viscosity [Pa·s]
ρ	density [kg/m^3]
$\sigma_{11}, \sigma_{22}, \sigma_{33}$	principal stresses [Pa]
$\sigma_{12}, \sigma_{23}, \sigma_{31}$	shear stresses [Pa]
σ_s	strength [Pa]
σ_v	von mises stress [Pa]
τ	stress in static fluid [Pa] in Eq. (3)
τ	stress in moving fluid [Pa] in Eq. (4)

cleats, hydraulic fractures and even pumps because of the gravity and constraints of pore size or coal microstructures (Huang et al., 2012; Wang and Lan, 2012). This may result in a remarkable reduction of coal reservoir permeability, and even blockage in coalbed methane wells or gas drainage boreholes. This can be considered as one of the reasons for significant reduction of coalbed methane production or gas drainage efficiency that in turn causes delays in the subsequent mining operations (Black, 2011; Li et al., 2010; Magill et al., 2010; Narah, 2007; Okotie and Moore, 2010; Palmer et al., 2005; Zhang et al., 2011; Zou et al., 2014).

Although Massarotto et al. (2013) proposed that a portion of coal fines are suspected to be from overburden or interburden, it is generally considered that coal fines are originated from micro flow channels, namely coal cleats (Hou et al., 2014; Marcinew and Hinkel, 1990). It is also suggested that coal fines are mainly produced in soft coal layers (Cao et al., 2012).

Laboratory and field studies were conducted on formation fines in porous media for oil and gas reservoir engineering (Hibbeler et al., 2003; Miranda and Underdown, 1993; Muecke, 1979; Nguyen et al., 2010; Qiu et al., 2008). Some research studies focused on the mechanisms of coal fines generation (Lagasca and Kovscek, 2014; Liu et al., 2012; Marcinew and Hinkel, 1990; Wang and Lan, 2012). The common finding of earlier studies is that coal fines mainly come from inherent solid coal particles that are free in flow conduits, elastic self-regulating effect due to external pressure change, and mechanical collision induced by drilling and water flushing (Marcinew and Hinkel, 1990; Wang and Lan, 2012). A number of studies indicated that coal fines are mainly generated during the dewatering phase and they are produced continuously with water production (Chen et al., 2009; Hou et al., 2014; Li et al., 2010; Zhang et al., 2011). It is known that coal fines experience failure and detach from coal cleats due to high initial water production rate in the dewatering phase (Okotie and Moore, 2010; Palmer et al., 2005). It is noted that coal fines can also be created during gas production (Hou et al., 2014; Magill et al., 2010). A variety of gas and water production parameters contribute to the production of coal fines. Different impacts of varying production conditions, including production pressure drawdown, flow velocity of the carrier media and mechanical properties of coal fines, such as strength, on coal fines creation were evaluated by several researchers through laboratory and field investigations. Zou et al. (2014) performed an experiment on coal fines migration in proppant packs during dewatering process, suggesting higher flow velocity creates more coal fines, and therefore, brings more severe damage to the fracture conductivity. Cao et al. (2012) conducted an experiment on coal fines migration using varying pressure differences, concluding that higher pressure difference carries out more coal fines, and there is a critical pressure difference that initiates the migration, however they did not mention the pressure that generates coal fines. Wei et al. (2013) evaluated coal fines production by field investigation and pointed out that the well completion technology, extraction system and coal seam structure control the coal fines generation. Nevertheless, little has been done on comparing the effects of different parameters on coal fines production.

Regarding the mathematical and numerical modelling, some researchers investigated formation fines migration in porous media (Civan, 2007; Khilar and Fogler, 1998; Koyama et al., 2008; Mirshekari et al., 2013). Bedrikovetsky et al. (2011) developed an analytical model for strained fine particles in the petroleum engineering practices. Zeinijahromi et al. (2011) derived a mathematical model for fines migration in the petroleum field, including one-phase and two-phase flows. Wang et al. (2013) combined hydrodynamics, porous media theory and rock mechanics to develop a mathematical model for coal fines migration. Most of these studies were dealing with the problem of fines migration, while little research has been conducted with the aim of characterizing coal fines generation.

In this study, based on SEM images, fully coupled numerical simulations were developed to investigate the characteristics of coal fines generation under different production conditions with varying microstructures of coal. The scope of this study includes coal fines generated by inseam water flow during the dewatering phase. Since the dewatering process is pressure-driven, the effects of production pressure drawdown, temperature and the mechanical properties of coal fines, such as Young's modulus and strength on coal fines generation, were studied.

2. Governing equations

2.1. Failure criterion

The von Mises criterion was widely used for the failure of coal (Kumar 2008; Varnes, 1962; Zhu et al., 2014). This criterion was applied to investigate the failure zones in this study. Given that both the normal and shear components of the water stresses are applied on the cleat surfaces, the von Mises stress is therefore calculated as (Mises, 1913):