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Full Length Article

Dimensional analysis and prediction of coal fines generation under two-phase flow conditions

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HIGHLIGHTS

- Dimensional analysis is conducted to predict coal fines generation in two-phase flow.
- Quantification of coal fines generation is conducted under different flow regimes.
- Impact of coal wettability and cleat geometry on coal fines generation is examined.
- Mitigation strategies for coal fines issue are proposed.

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ABSTRACT

Coal fines are generated during both the dewatering and Coal Seam Gas (CSG) production stages. This is due to the interaction between the fluid flow and the coal solids affixed to coal cleat surfaces. The generated coal fines may plug gas flow paths and reduce coal permeability. Although some investigations of the impact of water flow on coal fines generation were conducted, little research has been conducted into the generation of coal fines under water-gas two-phase flow condition. This is a typical flow type in the late dewatering and early CSG production phases. Two-phase flow requires higher pressure to initiate the fluid movement. Therefore, coal fines generation in two-phase flow conditions is expected to be very different from that in single-phase flow.

In this work, a fully coupled numerical model was developed, which integrated different flow regimes and the generation of coal fines. Coal cleat geometries were constructed using the Scanning Electron Microscopy (SEM) images taken from a set of coal samples collected from the Bowen Basin, Australia. The two-phase flow was simulated based on the Phase Field Method (PFM). Different flow regimes were examined, including water flow, gas flow, gas-drive-water and water-drive-gas scenarios. The coal fines generation was evaluated according to the combination of shear and tensile failure criteria.

The simulation results revealed that more coal fines were generated in two-phase flow compared to single-phase flow. The majority of coal fines were generated around the regions where residual phase was observed. This was attributed to the substantial force induced by significant pressure difference between the residual fluid and mobile fluid. Among different flow regimes, the gas-wet gas-drive-water scenario generated the greatest amount of coal fines, with over one order of magnitude more than any other scenarios. It was observed that the change of fluid phase composition inside the cleat created considerable pressure fluctuations (up to several kPa), which was unfavourable in controlling the production of coal fines. Based on the dimensional analysis, two dimensionless numbers, namely Capillary number (*Ca*) and Euler number (*Eu*) were found to define the coal fines generation process. A new criterion that could be used to evaluate coal fines generation was obtained. The findings from this study deliver a comprehensive knowledge of coal fines generation under different flow regimes, which provides useful guideline as to how to implement effective mitigation strategies to minimize coal fines induced production delays.

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1. Introduction

The life of a Coal Seam Gas (CSG) well typically consists three stages: (1) dewatering; (2) stable production; and (3) decline [1]. The flow regime inside coal seams varies at different stages. Coal seams are initially saturated with water under high pore pressure. The high water pressure locks CSG in coal matrices in the adsorption state [2]. Therefore, little gas is produced during the early dewatering stage, and the flow inside coal seams is regarded as single-phase water flow. As coal seams are progressively dewatered, at the late stage of the dewatering process, CSG production begins to accelerate while water production starts to decline, thereby, the flow is referred to as being gas-drive-water two-phase flow till the early stable production stage [3]. When CSG production reaches the late stable production stage, single-phase gas flow occurs in coal seams. This is also the case throughout the decline stage of CSG production [1]. Additionally, in the dewatering and the stable production phases, pressure transient testings may be conducted in place to obtain dynamic reservoir data, which is frequently associated with well shut-in [4]. During well shut-in, the build-up of water level and pressure may cease the desorption process, forming the water-drive-gas flow regime in coal seams. Based on these statements, the flow regimes during CSG production process can be summarised in Fig. 1.

One of the most important operational difficulties for CSG wells relates to production of coal fines, which reduces gas productivity and presents a substantial maintenance burden. Generally, coal fines are originated from coal cleats [5,6]. Some of the created coal fines can be migrated towards the well by the fluid flow, and deposit at the bottom of the well, burying in-seam pumps. In this case, frequent workovers are required to clean out the fines [7,8]. Some may settle down during the migration process inside coal cleats, narrowing or even totally plugging these natural fractures. This gives rise to significant reduction in permeability [9]. Both phenomena detrimentally impact the CSG production efficiency [10].

Investigations have been conducted into the characterisation of coal fines. The sizes of coal fines majorly range from hundreds of nanometres to hundreds of microns [5,6]. Apart from coal material, clay minerals, mainly including kaolinite and illite, are also found in coal fines, making the density higher than that of coal seam [11,12]. Marcinew and Hinkel [13] reported that the mineral contents may vary from different samples of coal fines.

In order to evaluate the impact of coal fines on CSG production efficiency, Guo et al. [14] performed water core flooding tests to monitor real-time permeability variations. Effluents with coal fines were collected and analysed in terms of concentration. Moreover, slow decline of permeability had been observed, which corresponded to the amount of coal fines production. Huang et al. [15] reported that the wettability of formation fines influences the movement of these small particles in water.

The wettability of coal and coal fines plays an important role not only in determining two phase interaction, but also in controlling coal fines migration behaviour. Zou et al. [16] assessed the effect of wettability on coal fines migration, suggesting that the more hydrophilic the coal fines are, the more easily they can migrate with water. They also concluded that the settlement of coal fines in flow conduits dramatically reduced the fracture conductivity. Nevertheless, these studies remain at the stage of single-phase water flow, studies on the behaviour of coal fines in gas flow or water-gas two-phase flow has yet to be found.

The wettability of coal has also been investigated, indicating that coal material can be both water-wet and gas-wet, which is contingent on coal rank, pressure, temperature, etc. [17–19]. It is suggested that the higher the rank, pressure and temperature, the more hydrophobic the coal material. Therefore, the wettability is changeable under in-situ conditions corresponding to varying reservoir pressure and temperature, and altering the pH of the fluids in coal seams to alkaline. The higher the pH, the more water-wet the coal material [20].

Understanding the mechanism of coal fines generation is essential for developing mathematical models to gain insights into this complex phenomenon, and designing proper treatment to manage the migration of fines. Two major force categories are commonly considered to be responsible for the generation and migration of coal fines: hydrodynamic force and colloidal force. The release of

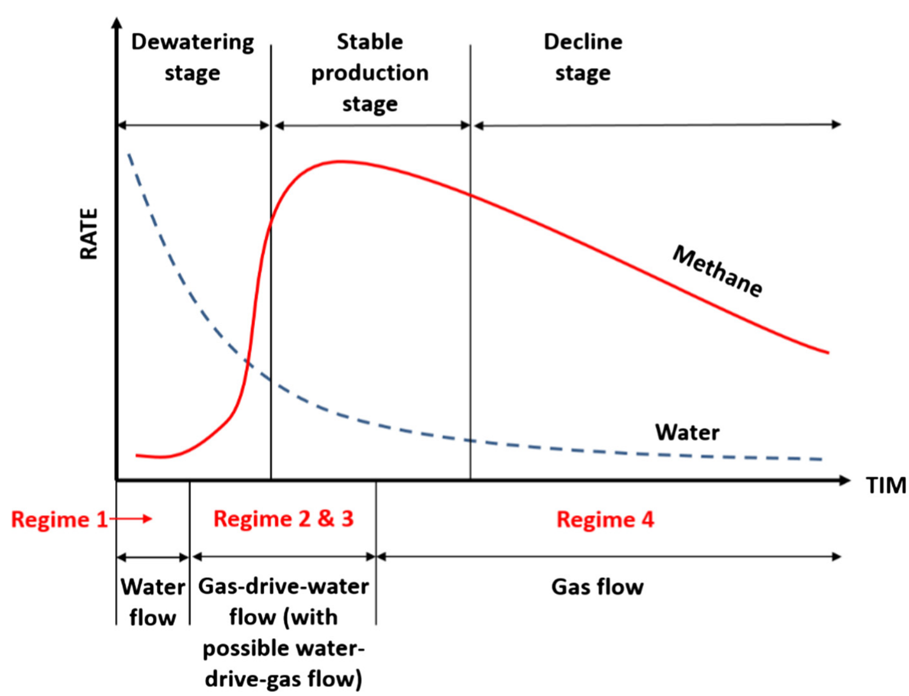

Fig. 1. CSG production stages and corresponding flow regimes in coal seams. Adapted from Moore [1].