UQ Centre for Natural Gas

Horizontal Coal Seam Gas Well Orientation Optimization: The Impact of Stress Regime

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Introduction

Australia is a key global Coal Seam Gas (CSG) producer, with 98% of CSG production being sourced from Queensland and the remainder share from the NSW (BREE, 2013). Due to the geographical distance between Australia and other continents, shipping the gas in a liquefied state (at –161ºC) known as LNG is a preferred means of gas export, which is around 25 million tons annually sourced from only Queensland's Coal Seam Gas fields. Thus, ensuring and maximizing the gas production efficiency of CSG plays a key role in maintaining Australia's LNG export trade as well as national gas supply to produce sufficient electricity for Australian households (BREE, 2013).

Borehole instability during drilling and gas production has been a major issue in maintaining CSG production efficiency worldwide (Okotie & Moore, 2011). Compared with conventional gas reservoirs, severe borehole instability in coal seams is basically caused by excessive horizontal stress loss due to the desorption of gas (Espinoza et al., 2015a; Liu & Harpalani, 2014), and the associated matrix shrinkage. The excessive deviatoric stress along the borehole can lead to borehole break-out and sand production issues which must be taken into account during field development plans (Espinoza et al., 2015b; Fan & Liu, 2018).

Due to the high complexity of the nature of coal (e.g., dual porosity, anisotropy, heterogeneity) and the complicated interactive process of gas-desorption and associated strain and stress transformations, a robust model coupling all these primary factors is crucial to investigate the permeability change and borehole stability issues.

Method and objective

Therefore, a dual-porosity and permeability model is considered for the coupled gas flow and coal deformation Finite Element numerical model (Figure 1). The numerical model can integrate different processes, including gas flow and deformation in matrices and coal cleats, gas desorption from coal matrices, and directional fracture permeability response to both effective stress and desorption-induced matrix shrinkage. Mohr-Coulomb failure criterion is assigned to the numerical formulation to investigate the break-out shapes and associated induced volumetric strain regarding different in-situ stress regimes around the horizontal CSG well for the stability analysis stage (Figure 2).
This study conducted a suite of simulation scenarios to investigate the impact of different drilling azimuths on the borehole instability and matrix and fracture permeability for optimizing horizontal CSG borehole orientation. A fully coupled dual porosity-dual permeability model was implemented in COMSOL Multiphysics Finite Element software. The input parameters of the model were derived from the geomechanical and reservoir parameters of the Goonyella Middle Seam of Bowen Basin in Queensland.

Loading and Boundary Conditions

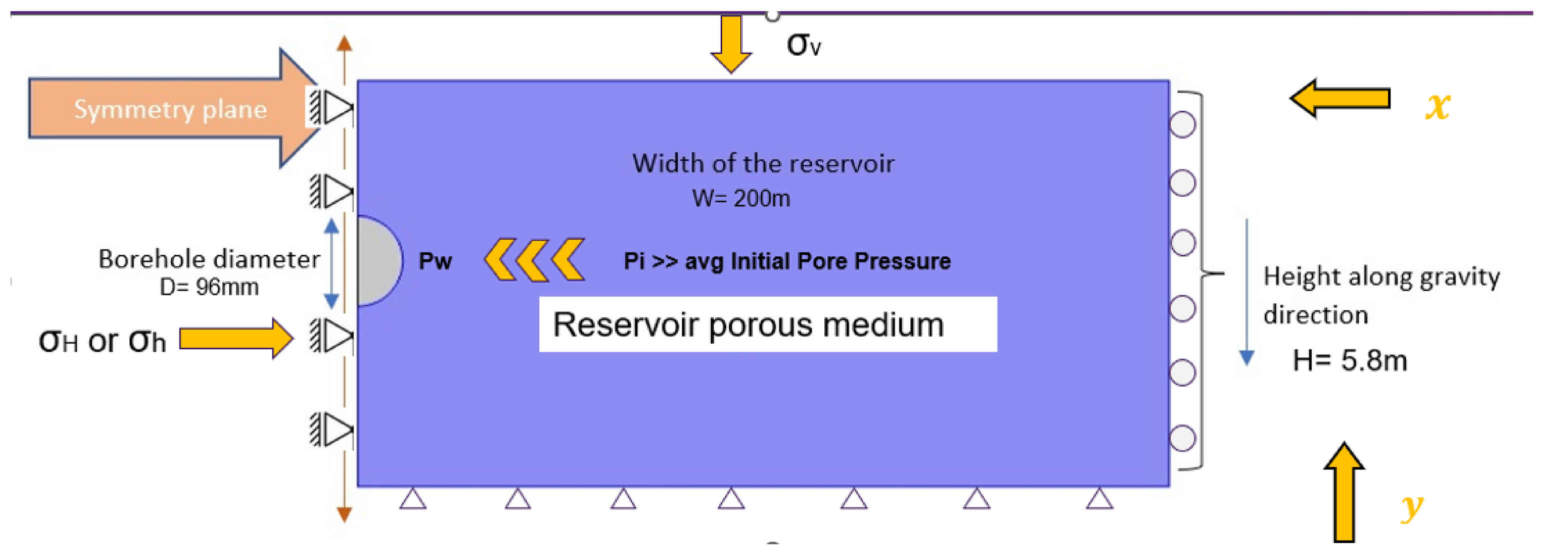

Figure 1: Loading and boundary conditions of the proposed model

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Results

Volumetric strain cut-off line and breakout criteria

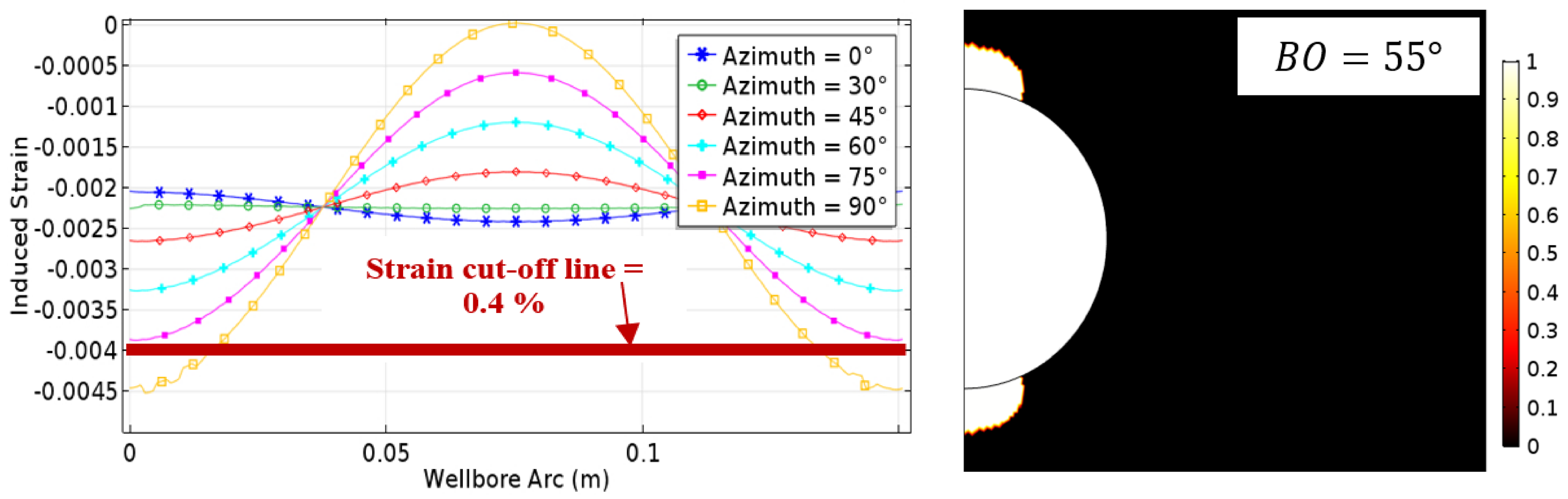

Figure 2 (a): Induced volumetric strain around the borehole in different azimuth angles with regard to failure strain cut-off line

(b): Breakout shape

Results

Effect of borehole azimuth angle on coal permeability

Based on the simulation results, drilling along the minimum horizontal stress led to a significant increase in directional fracture permeability ratio up to 40 times near the borehole. In contrast, drilling along the maximum horizontal stress results in a permeability ratio of up to 20 times, about half of drilling along minimum horizontal stress. Figure 3 compares the effect of all simulated borehole azimuth angles on the directional permeability ratios. The results show that increasing borehole azimuth angle from zero to 90 leads to an increase in fracture permeability ratios from around 20 times up to approximately 40 times in both x and y directions (Figures 3 and 4).

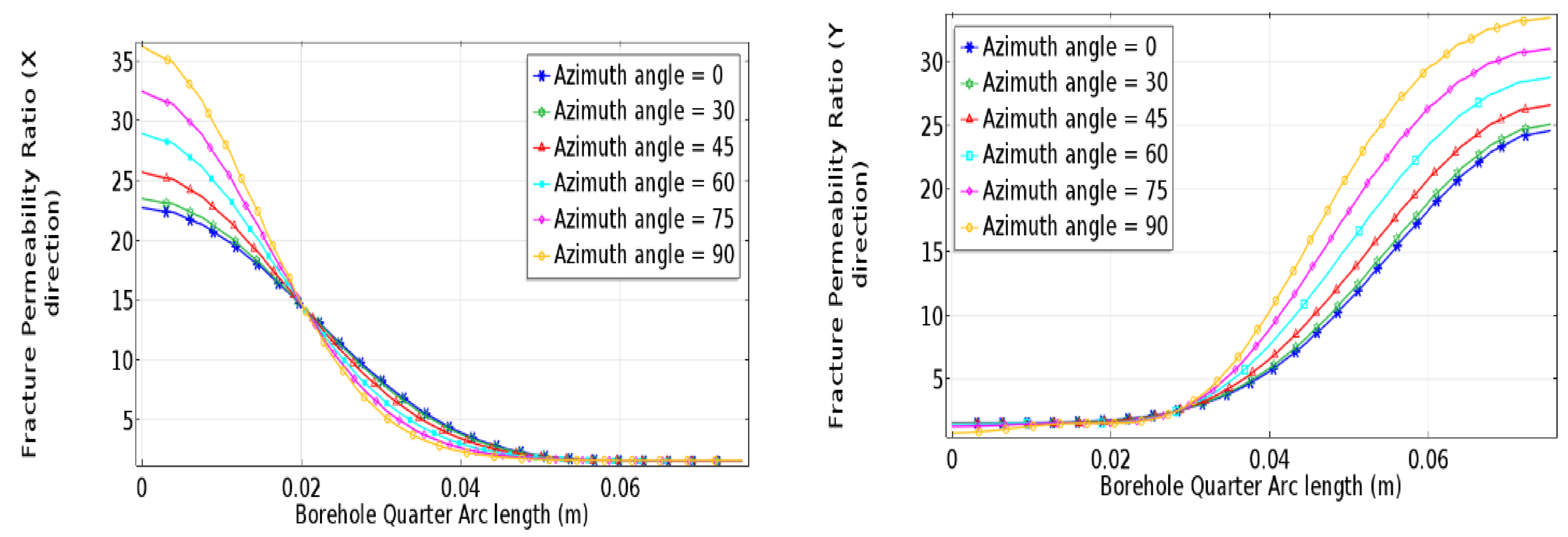

Figure 3: Directional fracture permeability ratios (X/Y directions), with regard to different azimuth angles

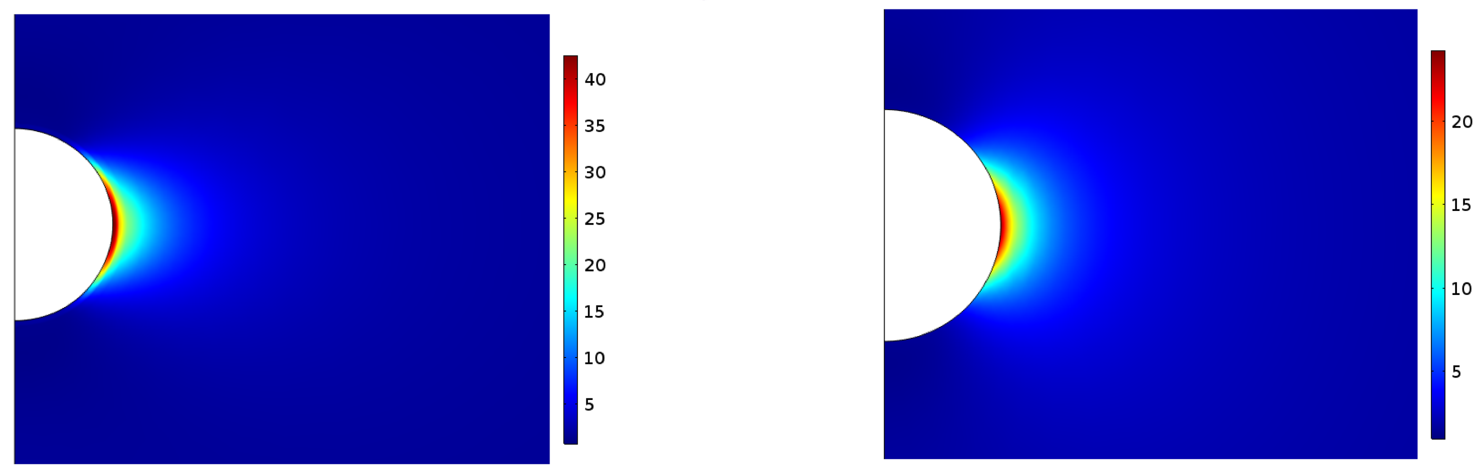

Figure 4 (a): Directional fracture permeability ratio, Azimuth angle = 90 deg, borehole along maximum horizontal stress

(b): Directional fracture permeability, Azimuth angle = 0 deg, borehole along minimum horizontal stress

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Coal seam gas drilling direction optimization

The results show that drilling parallel to the maximum horizontal stress direction neither achieves the best stability of the borehole (Figure 2) nor maximizes the permeability ratio (Figure 3). Drilling along the minimum horizontal stress direction would maximize the permeability ratio, but it has the worst stability. As shown in Figure 5, the optimal drilling direction window considering both permeability ratio and borehole stability is recommended to be between 45– 60°.

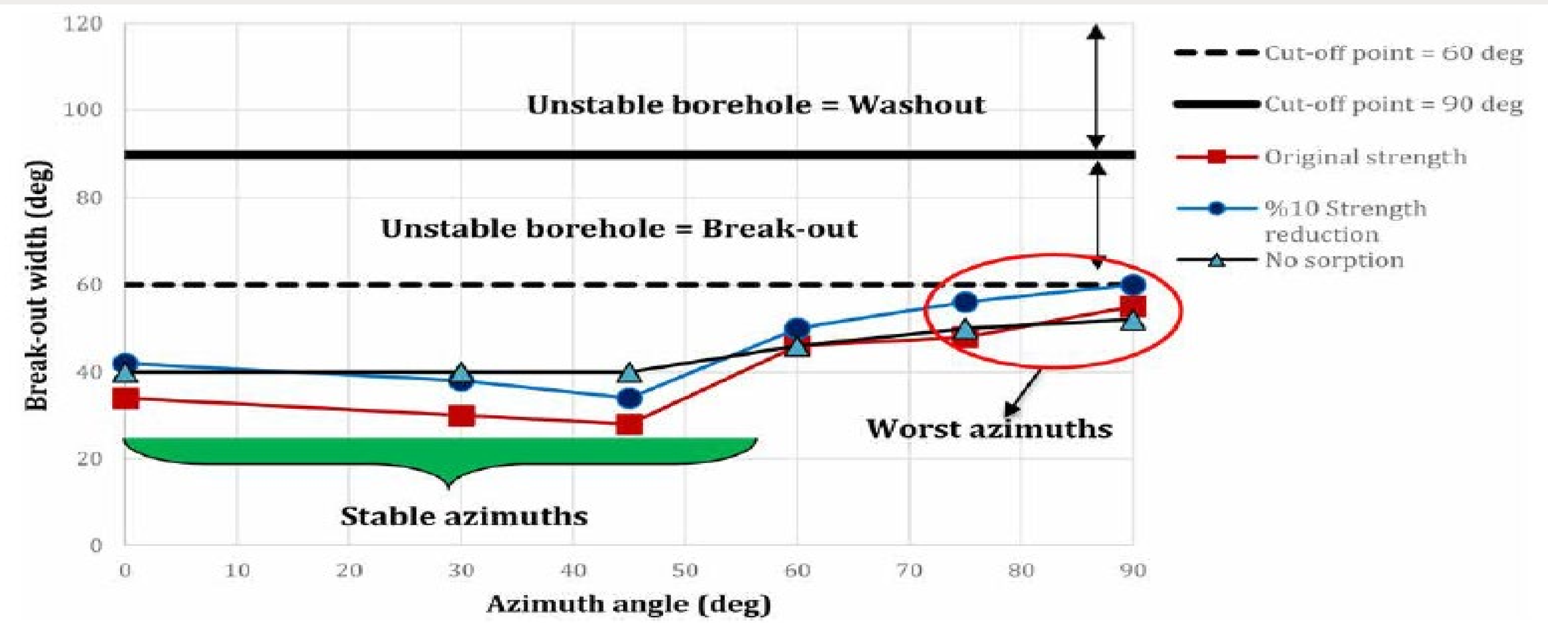

Figure 5: Borehole breakout width versus borehole azimuth angle

Conclusions

(i) Changing the azimuth from the maximum horizontal stress direction to the minimum horizontal stress direction results in an increase in fracture permeability ratios from around 20 to 40. The effect on the matrix permeability ratio is similar but with a much smaller ratio.

(ii) The impact of the drilling azimuth on borehole break-out width, which is a major indicator of borehole instability, is also evident. By quantifying break-out width in different cases, the least favorable drilling direction window is at an azimuth angle between 75° and 90°. A drilling azimuth window between 0° and 60° results in a much smaller break-out width.

(iii) Taking both permeability variation and the risk of borehole instability, for the studied coal seam, the optimal drilling azimuth window is recommended to be between 45–60°. The angle is site-specific and varies depending on the strength of the coal seam.

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