Prediction of breakdown pressures and fracture propagation surfaces in a rock material subjected to hydraulic fracturing using intact specimens and specimens with a replicated crack

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Abstract

Hydraulic fracturing is a mechanical process widely implemented by many resource industries to change the properties of rock material below the surface of the Earth. This method induces fracturing in a rock mass by injecting highly pressurised fluid into the crust. These resultant fractures can enhance the rock permeability and hence increase the efficiency of hydrocarbon extraction and geothermal energy production. Rock masses have pre-existing discontinuities, which act as weak planes for hydraulic fracturing. As such, the ability to predict the fracture propagation resulting from the interaction between these pre-existing cracks and the pressurised fluid is important to design effective hydraulic fracturing treatments. In addition, the maximum internal fluid pressure that the rock can withstand during this process provides an important parameter to assist these predictions. Therefore, the main research reported in the thesis focuses on the prediction of the hydraulic fracture propagation surfaces from the pre-existing cracks intersecting a pressurised section of a borehole, as well as the prediction of the maximum internal breakdown pressures of intact and discontinuous brittle rock materials.

The prediction of the propagation of arbitrarily orientated, pressurised cracks has been addressed by various numerical methods. However, published research on the crack propagation prediction using three dimensional analytical techniques is very limited. One such technique is proposed in this research, which only uses trivial computational time compared with other numerical simulations. This method could assist the design of hydraulic fracturing stimulations by providing a solution quickly for industry. The proposed analytical approach has been validated against a numerical method to ensure accuracy. Studies showed that the predicted propagating crack consistently realigned eventually perpendicular to the minor principal stress direction after the initial tortuous propagation that is dependent on the crack configuration and in-situ stress conditions.

In addition, there has been limited experimental research conducted to investigate the behaviour of pre-existing cracks intersecting a pressurised borehole section. In this research, a comprehensive set of experiments were conducted aiming to quantify the influence of the shear stress on the breakdown pressures and the resultant propagation surfaces of a circular crack intersecting a borehole. The study showed that by increasing the induced shear stress, produced by the combination of different external triaxial stresses, the realignment process of the hydraulic fracture propagation surface occurred more rapidly. However, it was found that under the shear stress conditions tested, this component had little influence on the measured breakdown pressures.

For the prediction of breakdown pressure, a new approach based on the theory of critical distances is proposed in this research. The proposed method assumes that a pressurised crack is formed at a critical distance into the material prior to the unstable crack propagation. The breakdown pressure is calculated using an analytical approximation of the mode I stress intensity factor for this pressurised crack, which significantly reduces the complexity of the prediction. The prediction using the proposed approach aligns well with the measurement in our experiments as well as with published results from other hydraulic fracturing experiments performed externally.

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Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma, in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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