UQ Gas and Energy Transition Research Centre

Relative Permeability of Coal: Experiment and Model Development

Tiancheng Zhang[1], Yiran Zhu[1], Jimmy Xuekai Li[1], Victor Rudolph[2] and Zhongwei Chen[1,*]

[1]School of Mechanical and Mining Engineering, The University of Queensland

[2]School of Chemical Engineering, The University of Queensland

*zhongwei.chen@uq.edu.au

Introduction

Relative permeability models of coal are crucial for assessing CO_2 geological sequestration and coal seam gas extraction. While existing models primarily expressed relative permeability as the function of saturation, cleat and/or pore size, the impact of the effective stress changes were often overlooked. During the CO_2 injection or coal seam gas extraction, variations in pore pressure within coal seams occur, leading to changes in cleat characteristics, which in turns varies coal relative permeability. As a result, the static models may introduce significant uncertainty in estimating gas-water two-phase flow under varying effective stress conditions.

In this study, a suite of gas-water two-phase flow experiments were conducted on coal cores under different effective stresses using steady-state method, resulting in the corresponding evolution of relative permeability curves. Finally, an improved relative permeability model that incorporates effective stress impact was developed, offering a more reliable model based on direct laboratory data for evaluating the injectivity of CO_2 geo-sequestration and the productivity of coal seam gas wells.

Experimental Procedure

The schematic diagram of gas-water two-phase flow experimental system used for this work is shown in Figure. 1. The setup consists of a 38 mm core holder, four ISCO pumps, two check valves, two pressure transducers, a back pressure regulator, and a vacuum pump. It is designed to measure the relative permeability of water and gas in coal two-phase flow using the steady-state method.

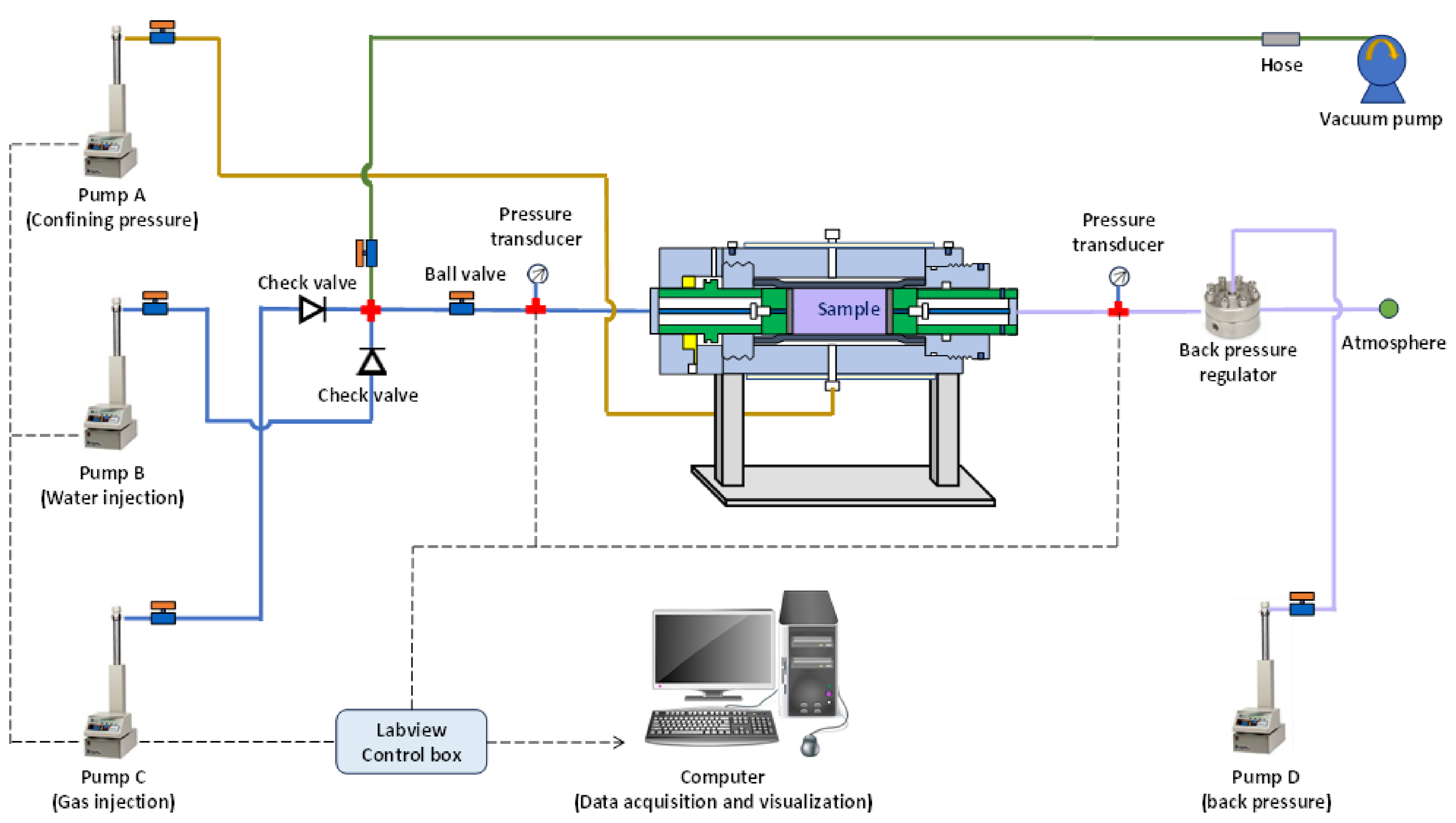

Figure 1: Gas-water two-phase flow experimental system.

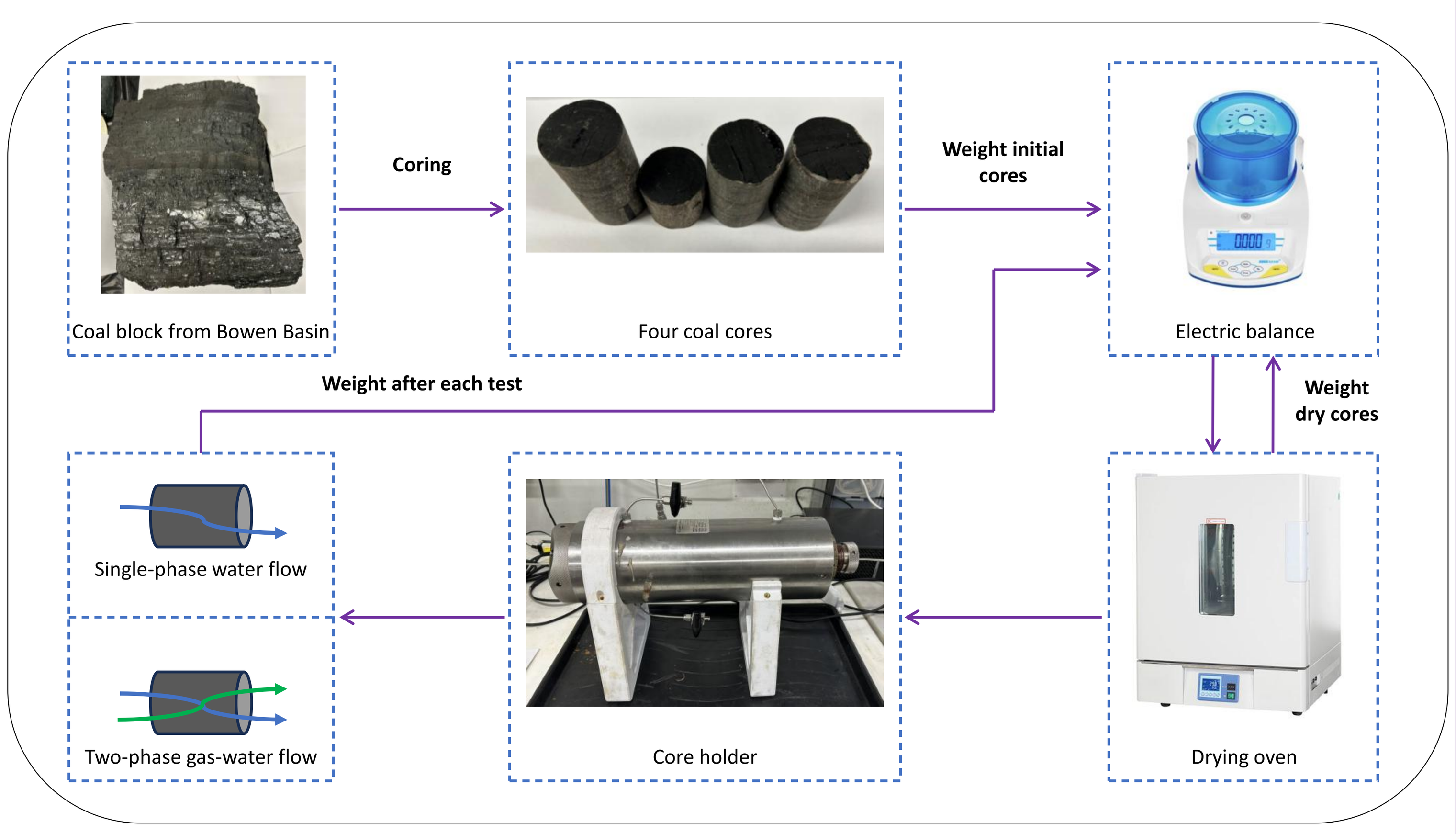

Figure 2: Experimental procedure flowchart.

Results

1. Relative permeability curves

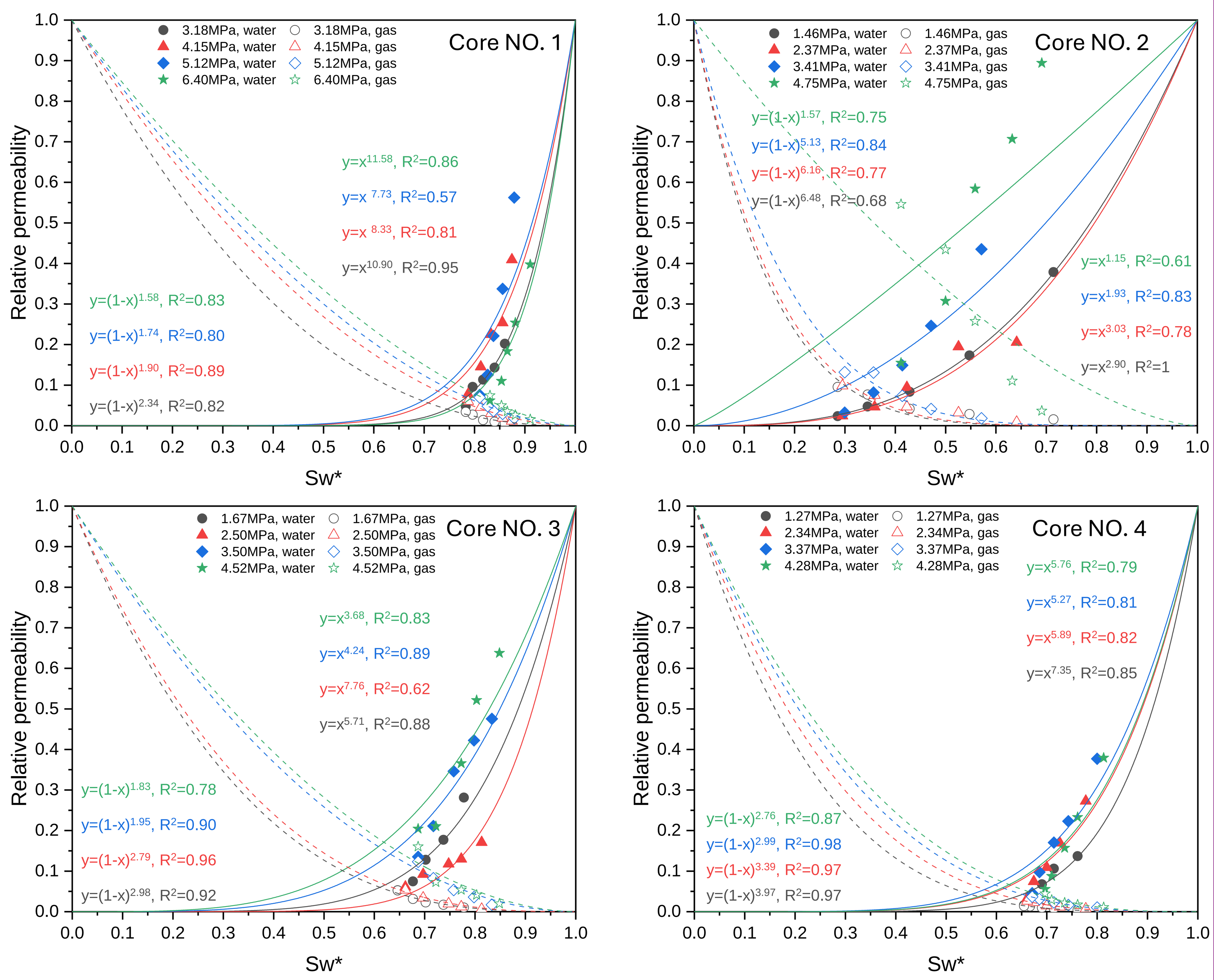

Figure 3: Relative permeability curves fitted by modified Brooks-Corey model..

2. Improved Relative Permeability Model

$$k_{rw} = (S_w^*)^{N_w} \quad \text{and} \quad k_{rg} = (1 - S_w^*)^{N_g} \tag{1}$$

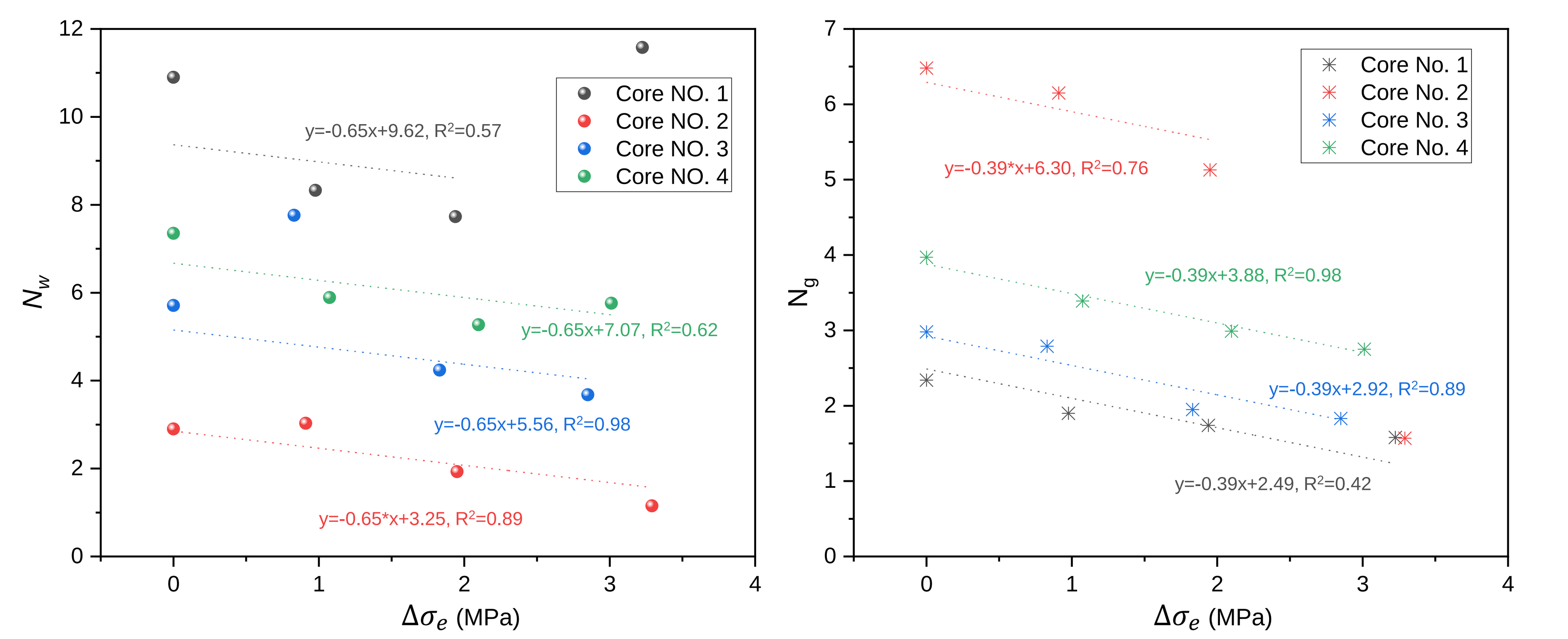

Figure 4: Corey exponents N_w and N_g changes with effective stress.

- **The Improved Relative Permeability Model:**

$$k_{rw} = S_w^{*\left(-5C_f\Delta\sigma_e + \left(\frac{k_0}{k_{ref}}\right)^{0.45} + 2\right)} \tag{2}$$

$$k_{rg} = (1 - S_w^*)^{\left(-3C_f\Delta\sigma_e + \frac{7k_{ref}}{k_0} + 3\right)} \tag{3}$$

where, k_0 is the permeability at the initial effective stress of σ_{e0}, C_f is the cleat compressibility, $\Delta\sigma_e$ is the effective stress change.

Conclusions

- As effective stress increases, water mobility decreases, leading to higher residual water saturation. Simultaneously, the relative permeability of both water and gas increases with rising effective stress.
- The improved relative permeability model of coal incorporates the impact of effective stress, cleat compressibility and initial permeability, and better captures the complex physical processes.