An Investigation on Impact of Creep on Coal Permeability and Gas Drainage Efficiency

Author: Nima Noraei Danesh
PhD student in Mining Engineering
Advisory Team: Dr Zhongwei Chen, Dr Saiied M. Aminossadati, A/Professor Mehmet S. Kizil
School of Mechanical and Mining Engineering

1. Statement of Problem

Coal as a soft rock experiences compaction when pore pressure depletes and effective stress increases during Coal Seam Gas (CSG) drainage. The increase in effective stress during gas drainage causes the reservoir to undergo compaction (Schatz and Carroll, 1981). This mechanical induced compaction causes permanent deformation of coal microstructure and loss of porosity.

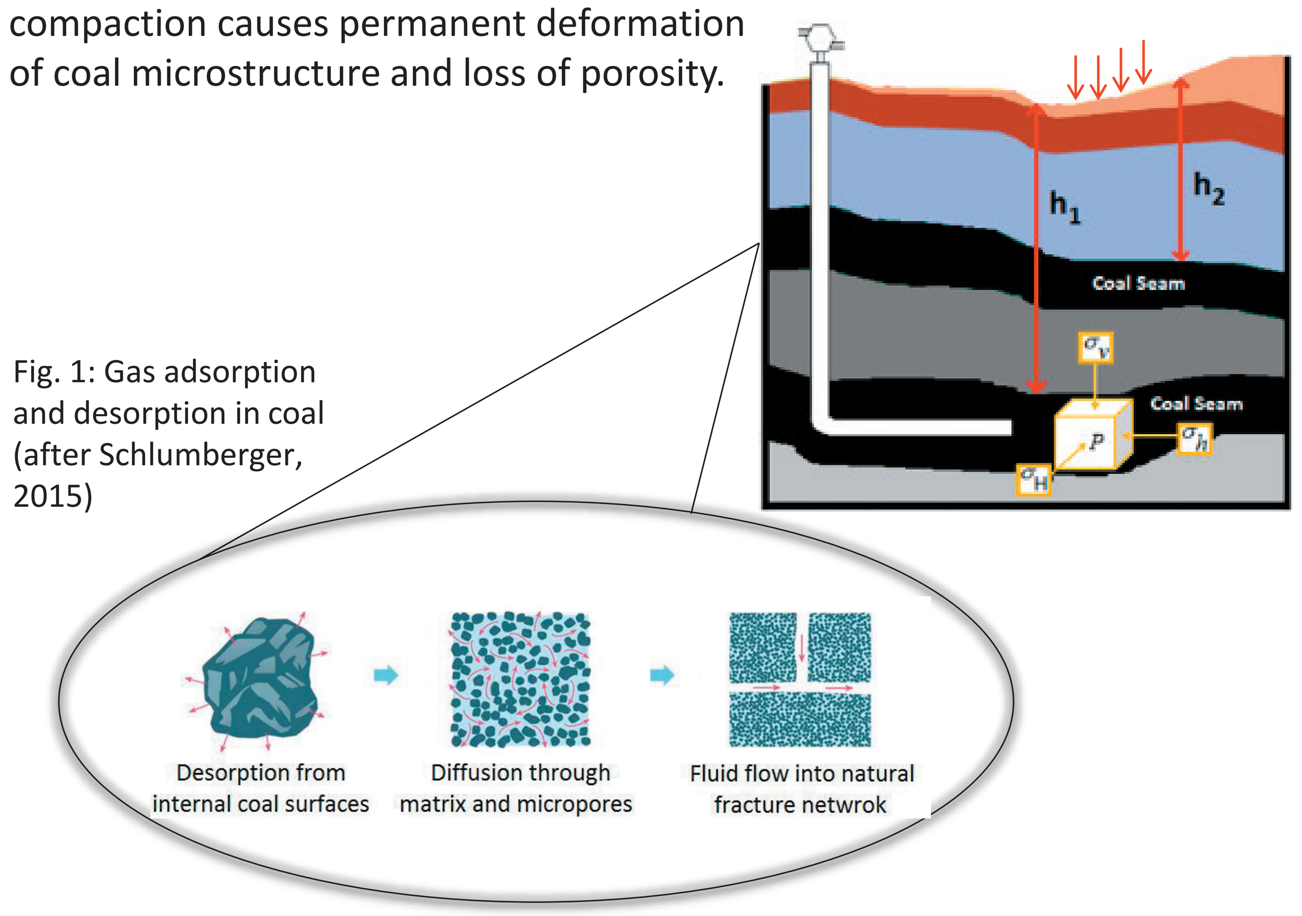

Fig. 1: Gas adsorption and desorption in coal (after Schlumberger, 2015)

2. Knowledge gap

The impact of creep, as a long-term phenomenon, on coal permeability has not been considered during gas drainage.

3. Methodology

3.1. Experimental study of impact of creep on permeability using a tri-axial rig (Fig. 2)

Capabilities and characteristics:

- Axial stress > hydrostatic stress (axial stress is additional to hydrostatic stress, $\sigma_{TA}=\sigma_H+\sigma_A$)
- Axial displacement and radial gauges

Coal sample:

- High volatile bituminous (Bowen Basin)
- Vertical sample


Fig. 2: Experimental rig

3.2. Development of a permeability model and numerical simulation

- A new permeability model including viscoelastic deformation of coal has been developed by incorporating viscoelastic term of Nishihara model (Nishihara, 1952) in stress-strain equation suggested by Jaeger et al. (2007) for anisotropic poroelastic media.

The developed model can be presented as follows:

$$k = k_0 e^{-3c_f\left[\left(\frac{E_{ex}E_{vex}}{E_{ez}E_{vez}}\right)\left(\frac{\mathrm{E}_z}{\mathrm{E}_x}\right)\left(\frac{\nu_{zx}+\nu_{xy}\nu_{zy}}{1-\nu_{xy}^2}\right)(-\alpha\Delta P)-\frac{E_{ex}E_{vex}\Delta\varepsilon_x^s}{(1-\nu_{xy})(\mathrm{E}_x)}\right]}$$

where,

$$\mathrm{E}_x = E_{vex} + E_{ex}\left[1-\exp\left(-\frac{E_{vex}}{\eta_{vex}}t\right)\right] \quad ,\mathrm{E}_z = E_{vez} + E_{ez}\left[1-\exp\left(-\frac{E_{vez}}{\eta_{vez}}t\right)\right]$$

where, E_v and E_{ve} are the elastic and viscoelastic moduli, respectively. η_e and η_{ve} denote the viscosity coefficients. Also, subscripts e and ve denote elasticity and viscoelasticity.

4. Results and discussion

A test was carried out to investigate the effect of the creep induced by change in effective stress on coal permeability during desorption of methane gas. When the coal sample reached equilibrium under constant hydrostatic and axial stress condition, the pore pressure was reduced to simulate gas drainage. Effective stress was changed in three steps from 0.99 MPa to 0.49 MPa and 0.43 MPa by changing pore pressure under constant axial and confining stresses (Fig. 3).

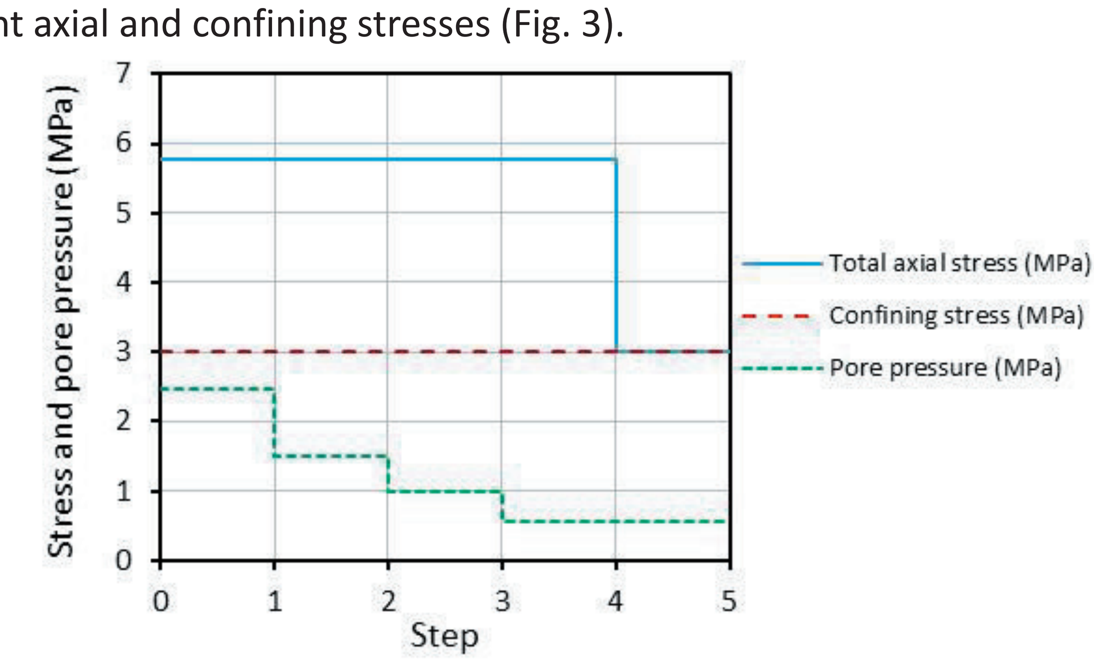

Fig. 3: Axial and confining stresses and pore pressure

Permeability was measured at stages where strain rate approximately zeroed due to equilibrium of desorption process and effective stress (shown in Fig. 4 in red dots). Meanwhile, other parameters such as hydrostatic stress, axial load, and temperature (35°C) are maintained constant. Once the pressures across the sample were reduced to a certain level, pore pressure started to equilibrate at the introduced pressure. Then, a relatively long time (a couple of days) was given to the sample to stabilize. Permeability measurements were conducted when equilibrium was reached (pore pressure has stabilized). The strain measured after pore pressure depletion (desorption) reflects an instantaneous compaction followed by transient compaction (viscoelastic compaction). Instantaneous strain occurs as the sample undergoes elastic deformation as a consequence of drop in pore pressure and increase of effective stress. Then, the strain gradient begins to decelerate when pressure reaches equilibrium and sample experiences viscoelastic deformation.

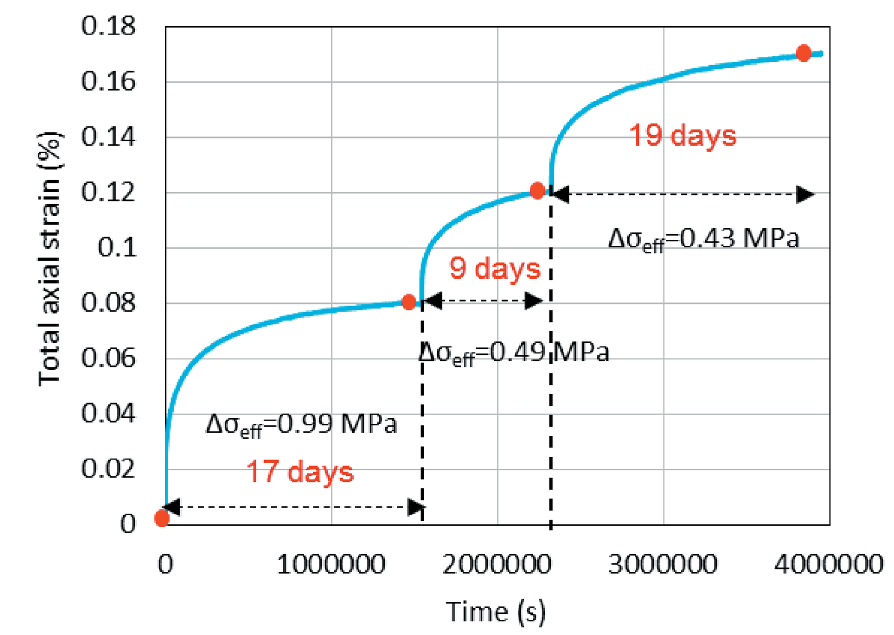

Fig. 4: Axial strain vs. time for effective stresses of 0.99 MPa, 0.49 MPa, and 0.43 MPa

Fig. 5 shows permeability change with a) pore gas pressure and b) time. The permeability drops at each step change in effective stress and no permeability rebound was observed.

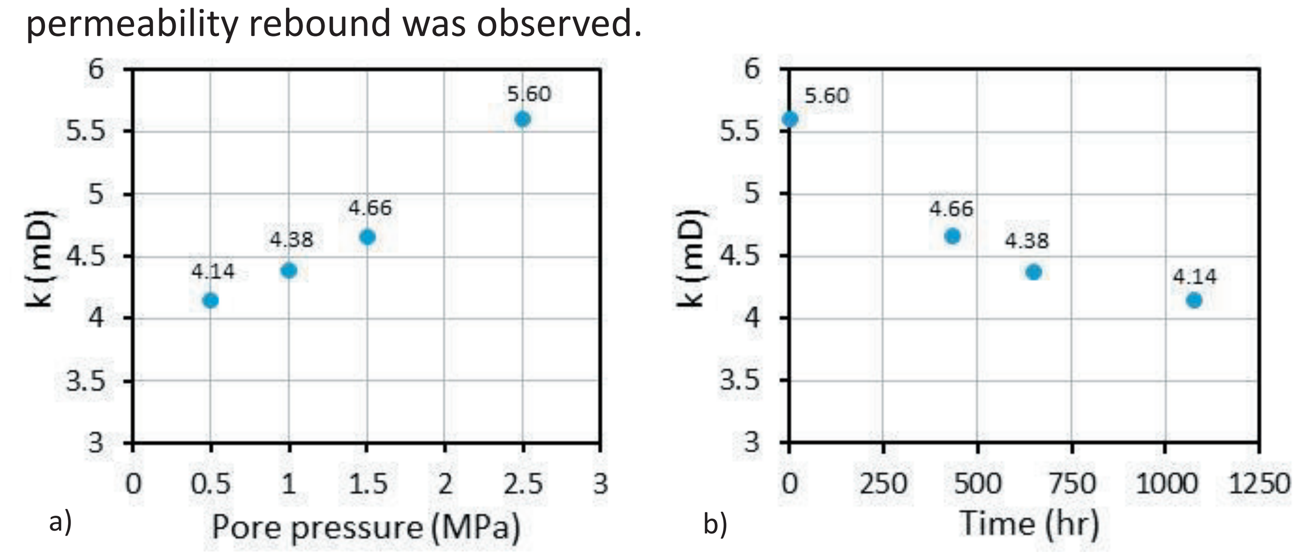

Fig. 5: a) Permeability vs. pore pressure, and b) permeability vs. time

5. Conclusions

The experimental results of desorption test using methane show that increase in effective stress with pressure depletion leads to continuous decline in permeability due to time-dependent deformation. Viscoelastic creep as a partially irrecoverable mechanism can cause significant decrease in permeability during gas drainage. The findings of this study may contribute to a better understanding of the impact of creep on coal permeability as a critical factor influencing gas drainage.

6. Acknowledgements

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7. References

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