# Advanced Environmental Technologies for Coal Permeability Enhancement

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## Project Objectives

1. **Identify stimulants that enhance coal permeability**
   - Liquid (Acids, Bases, Oxidants , $H_2O$-displacing oil)
   - Gas (Inert and reactive gases)
2. **Elucidate the mechanistic basis for coal response**
   - Mineral dissolution, alteration, plugging
   - Maceral infilling , plasticisation
   - Fracture induction, extension, dilation, stabilisation
3. **Assess the viability of the stimulation pathways**
   - Environmental compliance, cost efficacy, specificity

## Technological Pathways

1. **Demineralisation of natural fractures**
   - Calcite dissolution (HCl )
   - Clay dissolution-alteration (HF)
   - Oxidative dissolution of pyrite ($H_2SO_4$-$H_2O_2$)
2. **Degradation of coal maceral components**
   - Oxidative cleavage of organics ($H_2O_2$, $KMnO_4$ )
3. **Fracture creation and stabilisation**
   - Pneumatically-induced, mineral-stabilised (Air, $CO_2$, $N_2$, $O_3$)

## Scientific Approach

1. **Core stimulation studies ($k/k_o$)**
   - Probing tests (chemical screening)
   - Application test (CSG coal specific)
2. **Structural and mineralogical imaging ($\Phi_f$)**
   - X-ray µCT with GeoRef Core
   - Synchrotron X-ray
3. **Physico-chemical analyses**
   - Coal assays, SEM-EDS, ICP-OES, TOC XPRD, Optical imaging

## Publish Outcomes


1. Balucan, et al **2015.** The influence of cleat demineralisation on the compressibility of coal, **SPE-176960-MS**
2. Balucan, et al **2016.** Acid-induced mineral alteration and its influence on the permeability and compressibility of coal. ***J Nat Gas Sci Eng***
3. Balucan et al **2017.** Improving CSG productivity: X-ray µCT investigation of the effects of coal fracture decalcification. *In Preparation*
4. Balucan et al **2017.** Improving CSG productivity: Oxidative dissolution of fracture mineralisation and degradation of coal macerals. *In Preparation*


## Key Findings

### Dissolution of calcareous fracture infills

- decalcification increases $\Phi_f$ and $k$ - mineral plugging limits $k$ enhancement

$k_v/k_{v0}$ = 172 $k_v/k_{v0}$ = 1.24

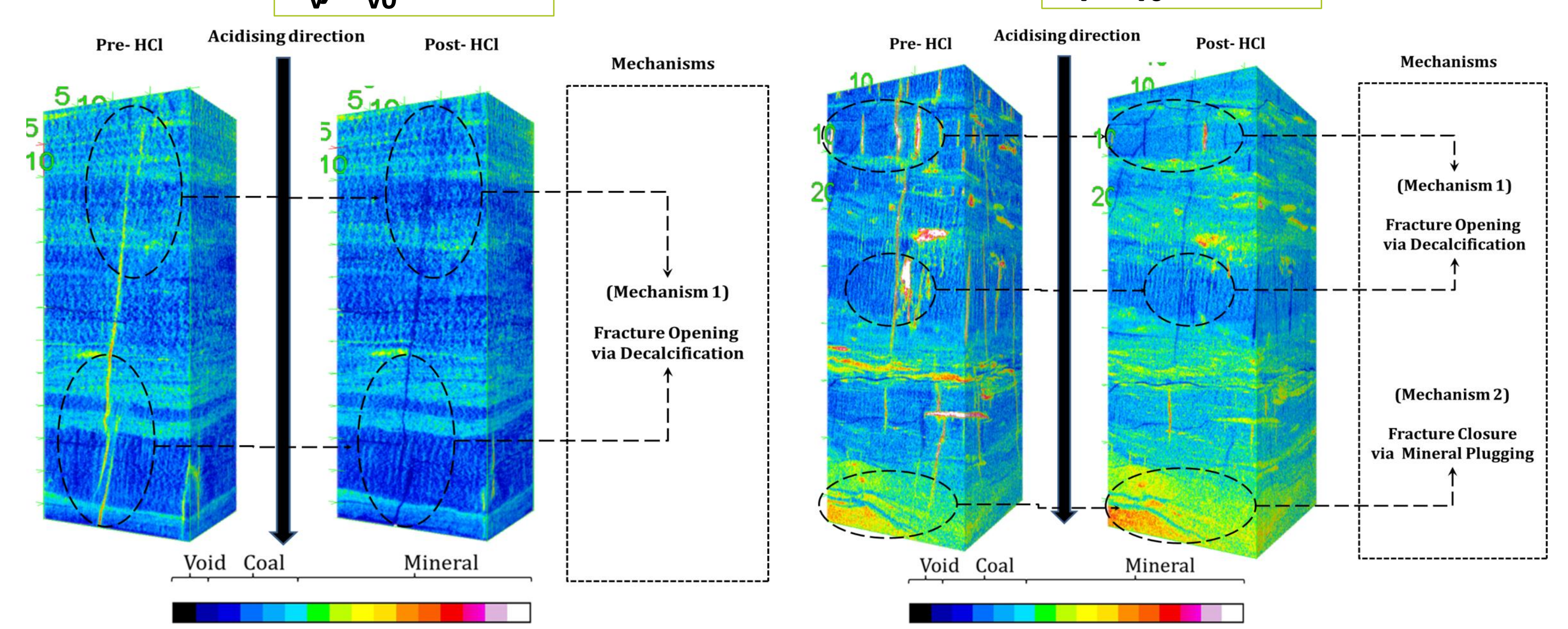


**Figure 1. X-ray µCT visualisation of CSG cores pre and post HCl injection and the $k$ - influencing mechanisms.**

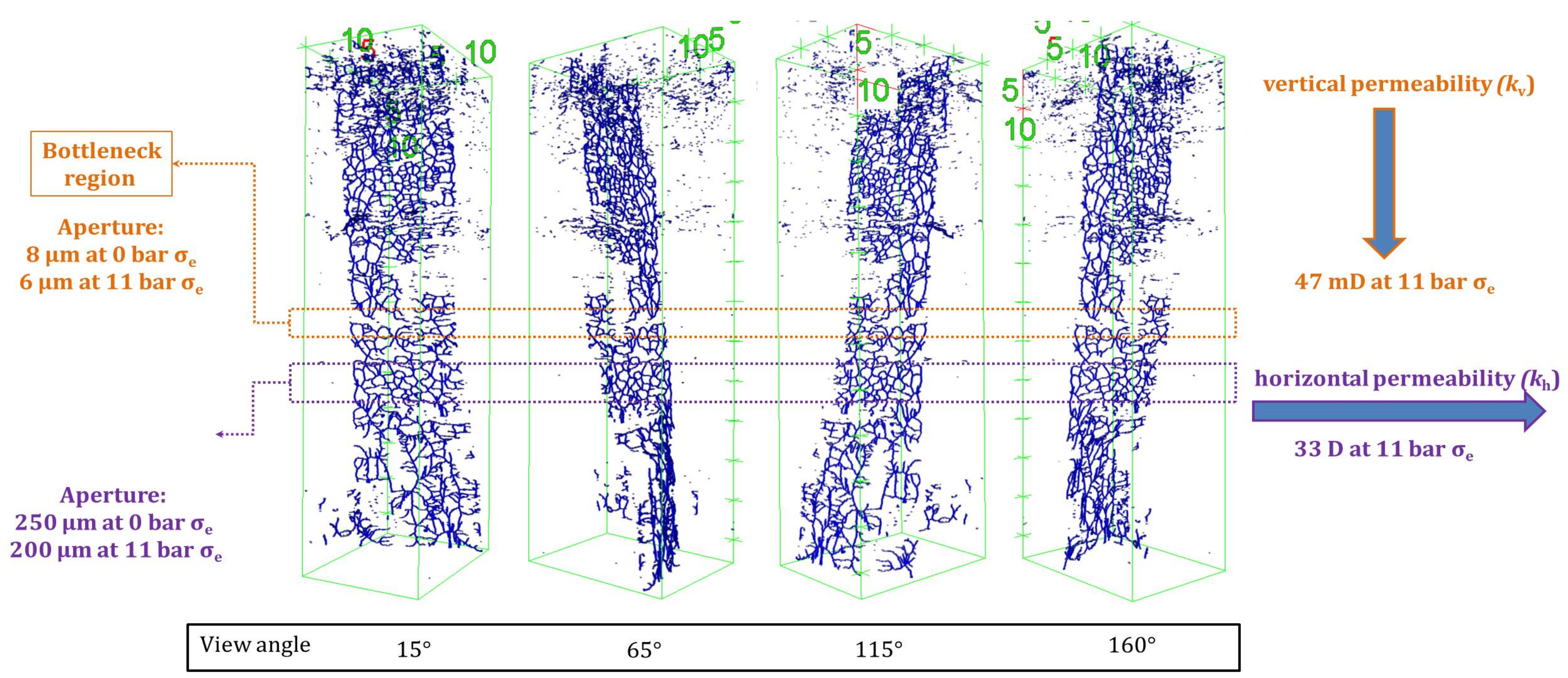


**Figure 2. Skeletised 3D visualisation of a decalcified fracture shown at various angles as rotated along the z axis. The measured vertical ($k_v$) and estimated horizontal ($k_h$) permeabilities as well as the structures (bottlenecking for $k_v$, continuous fracture for $k_h$) that are likely to dictate fluid flow are also shown.**

### Oxidative dissolution of pyrite

- pyrite dissolution increases $\Phi_f$ and $k$

$k_h/k_{h0}$ = 4.15

| Parameters, unit of measure | Pre-Stimulation Production | Flow Injection Stimulation | Post-Stimulation Production |
|---|---|---|---|
| $k$, µD | 163 ± 16 | 383 ± 143 | 678 ± 39 |
| $\sigma_e$, bar | 5 | 5 | 5 |
| $\Delta P$fluid, bar | 6 | 6 | 6 |
| pH, units (± 0.1) | 6.4 | 1.1 | 1.2 |
| S, ppm (± 0.472) | 4 | 3941 | 4393 |
| Fe, ppm (± 0.209) | 6 | 88 | 42 |
| TOC, ppm (± 10) | 12 | 25 | 19 |

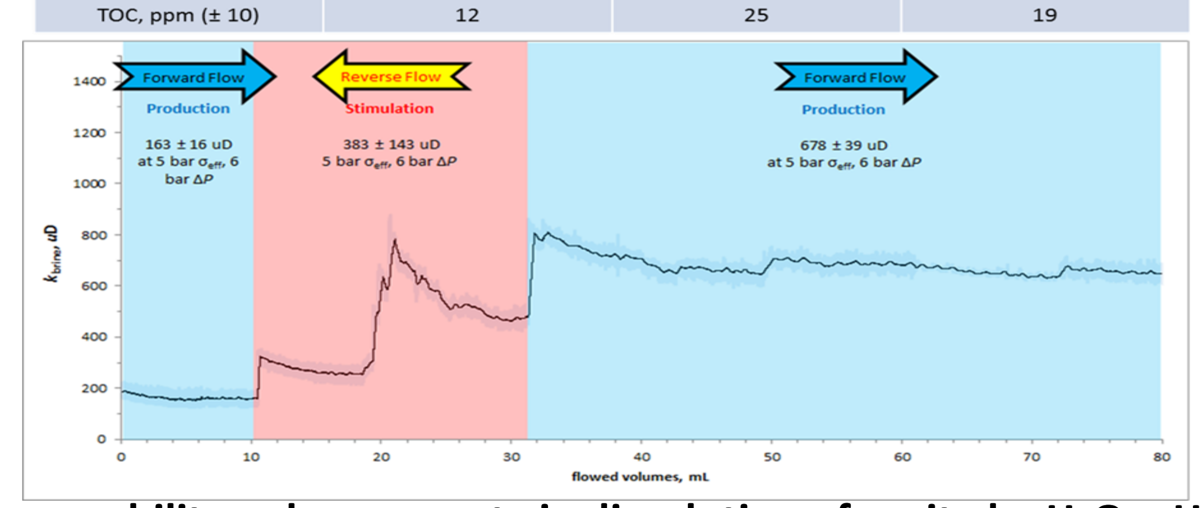


**Figure 3. Permeability enhancement via dissolution of pyrite by $H_2O_2$ - $H_2SO_4$.**

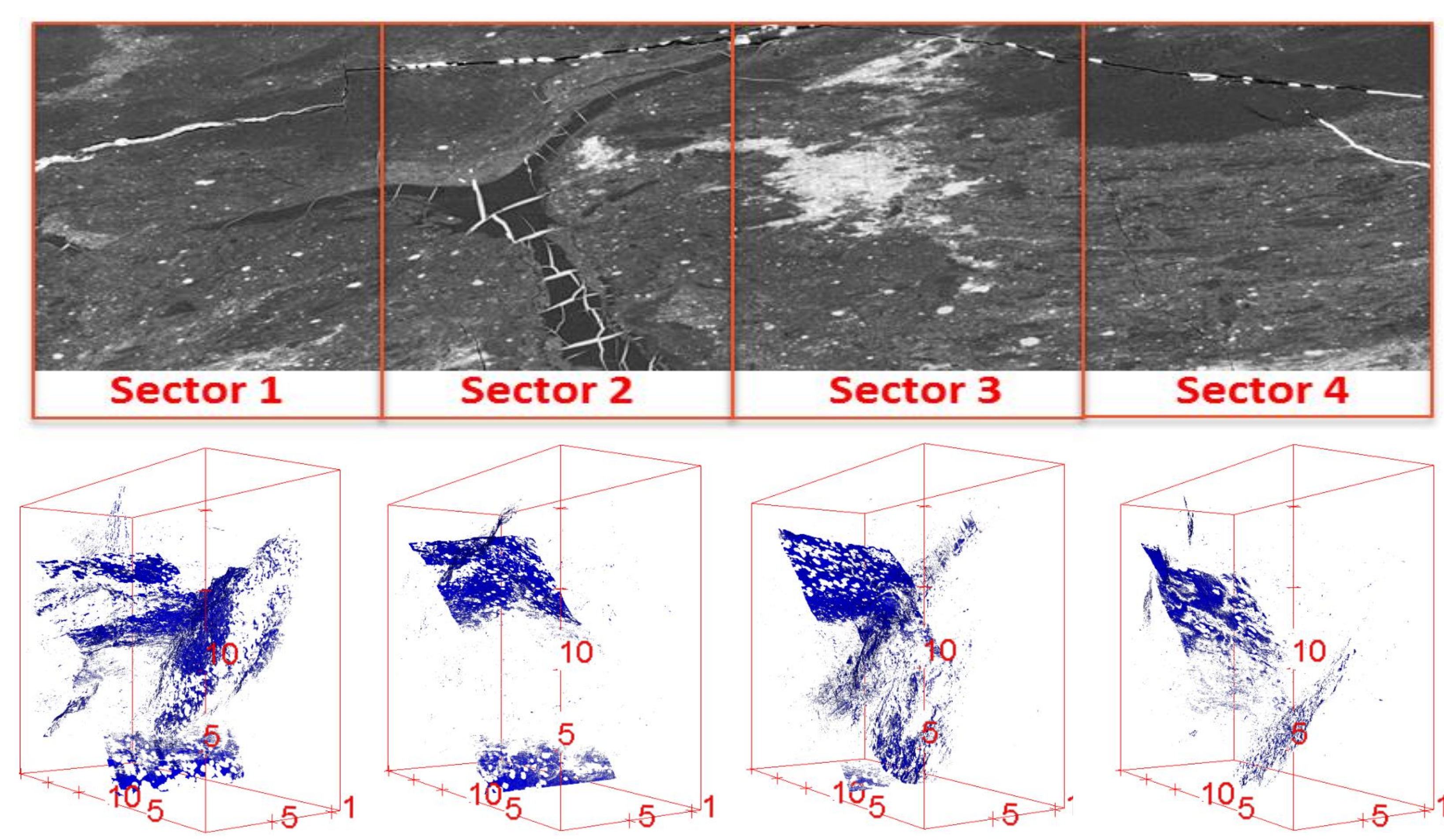


**Figure 4. Mapping the permeability pathway of the $H_2O_2$-$H_2SO_4$ stimulated coal core using Synchrotron radiation. The 3D visualisation of the permeability pathway (blue, voxel resolution = 11 µm) for each sector are shown.**

### Oxidative cleavage of organics

- oxidative cleavage increases $\Phi_f$ and $k$
- mineral deposition decreases $\Phi_f$ and $k$

$k_h/k_{h0}$ = 2.50

| Parameters, unit of measure | Pre-Stimulation Production | Flow Injection Stimulation | Post-Stimulation Production |
|---|---|---|---|
| $k$, µD | 10 ± 6 | 3 ± 4 | 25 ± 6 |
| $\sigma_e$, bar | 5 | 5 | 4 |
| $\Delta P$fluid, bar | 7 | 8 | 7 |
| pH, units (± 0.1) | 6.7 | 7.4 | 6.9 |
| S, ppm (± 0.472) | - | - | - |
| Fe, ppm (± 0.209) | - | - | - |
| TOC, ppm (± 10) | < 10 | 450 | < 10 |

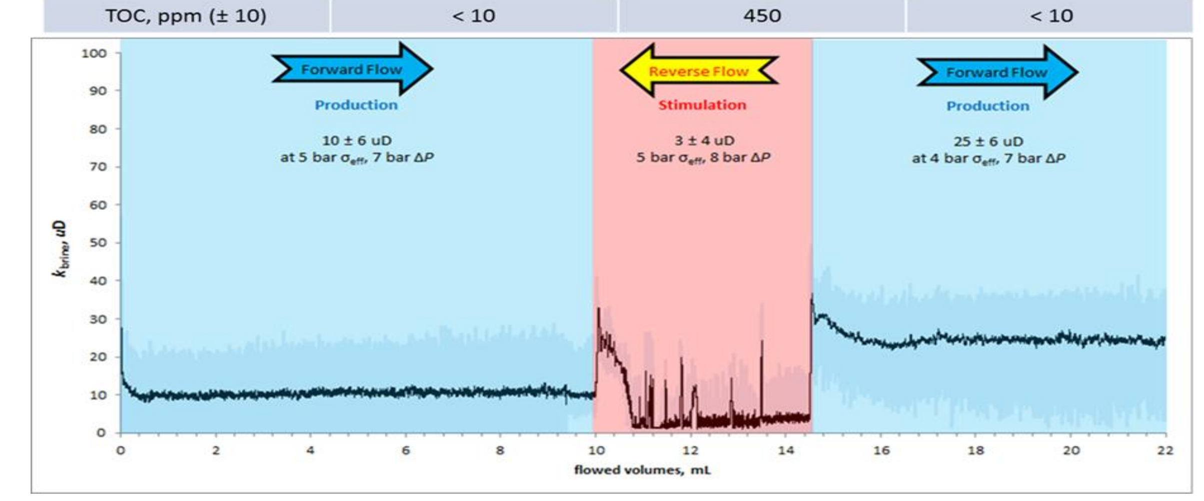


**Figure 5. Permeability enhancement due to the oxidative degradation of macerals in coal by $H_2O_2$ stimulation.**

$k_h/k_{h0}$ = 0.11

| Parameters, unit of measure | Pre-Stimulation Production | Flow Injection Stimulation | Post-Stimulation Production |
|---|---|---|---|
| $k$, µD | 35 ± 5 | 6 ± 4 | 4 ± 4 |
| $\sigma_e$, bar | 5 | 5 | 4 |
| $\Delta P$fluid, bar | 8 | 8 | 8 |
| pH, units (± 0.1) | 6.5 | 10.1 | 9.6 |
| S, ppm (± 0.472) | - | 19 | - |
| Fe, ppm (± 0.209) | - | 27 | - |
| TOC, ppm (± 10) | < 10 | 530 | 340 |

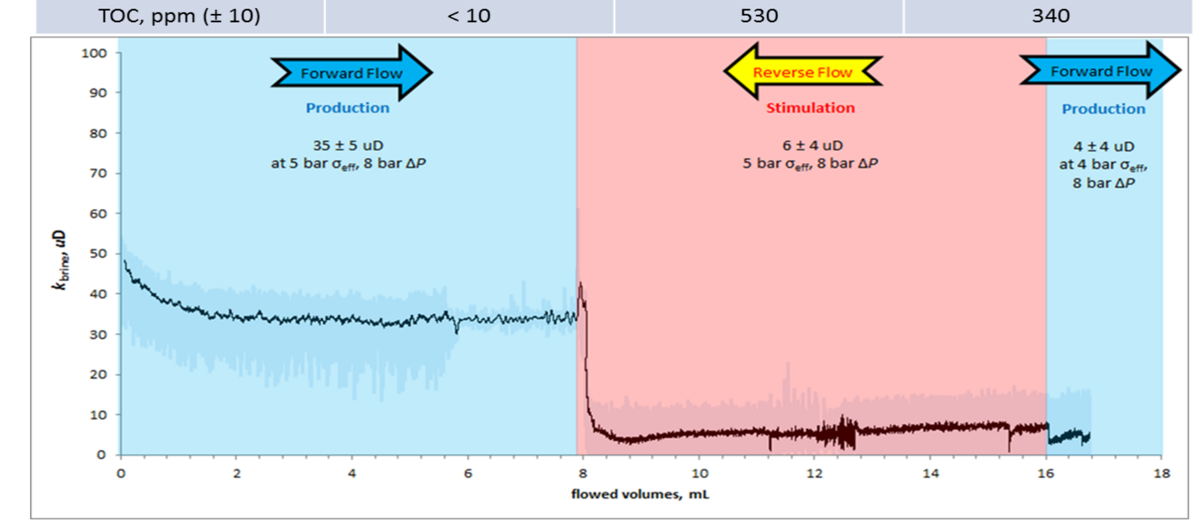


**Figure 6. Permeability deterioration due to $MnO_2$ deposition in coal after $KMnO_4$ – KOH injection.**