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Relative permeabilities for two-phase flow through wellbore cement fractures

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Relative permeabilities for two-phase flow through wellbore cement fractures

Objective: to obtain gas-oil relative permeabilities from simultaneous gas-oil flow tests on fractured cement specimens.

Leakage rates through wellbore flaws are affected by the presence of multiple fluids in fracture.

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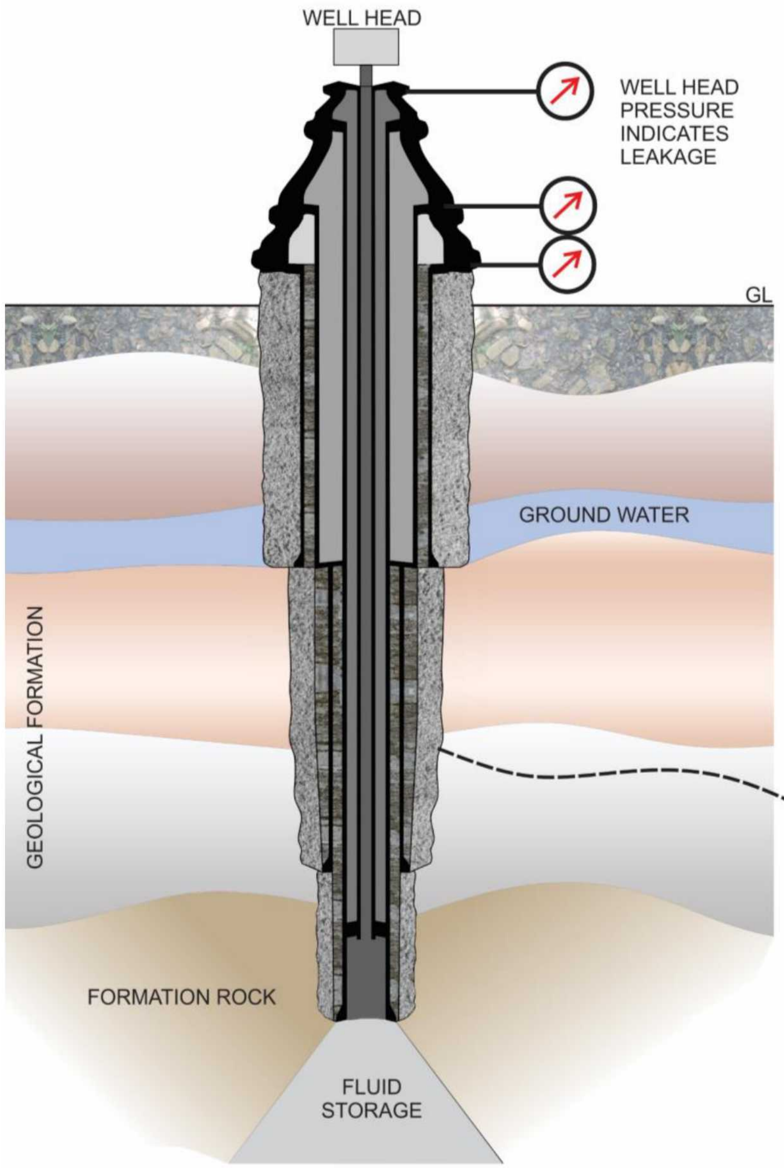
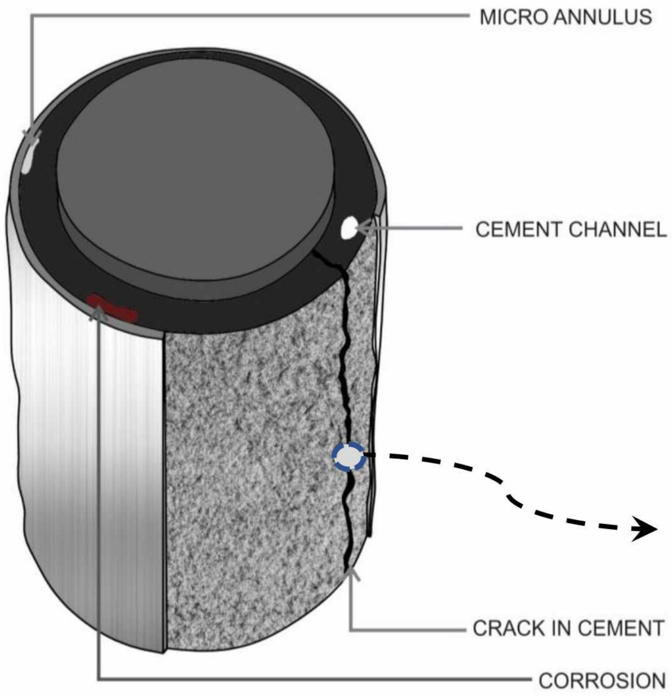
Upward leakage of fluid, through wellbore flaws.





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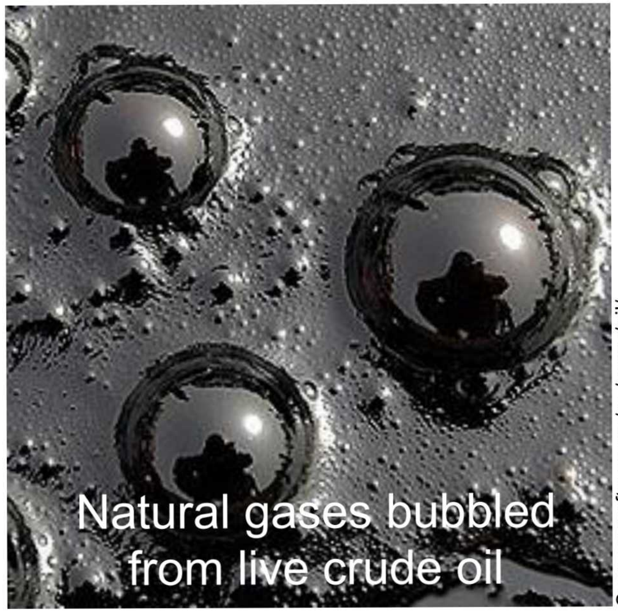
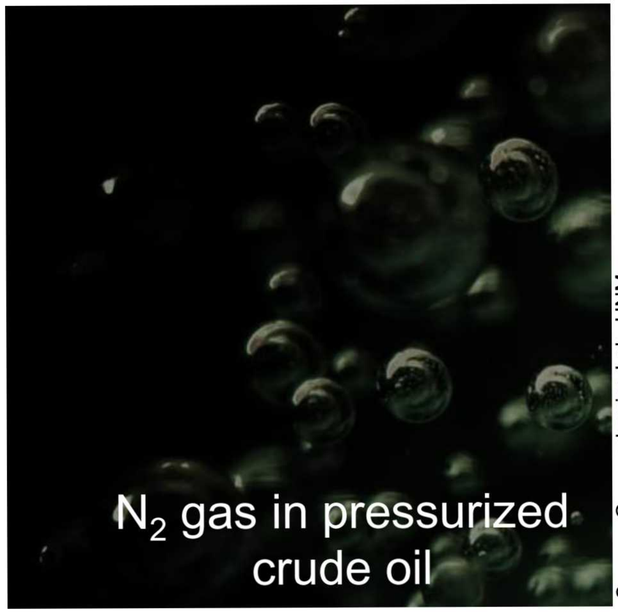
Source: Geomechanics Lab, UNM



Source: neftegaz.ru/en/news/oil/



Source: Geomechanics Lab, UNM

Source: depositphotos.com/178436602/

Multiple fluids are likely to exist in wellbore flaws depending on the facility the wellbore is associated with.

Materials and methods

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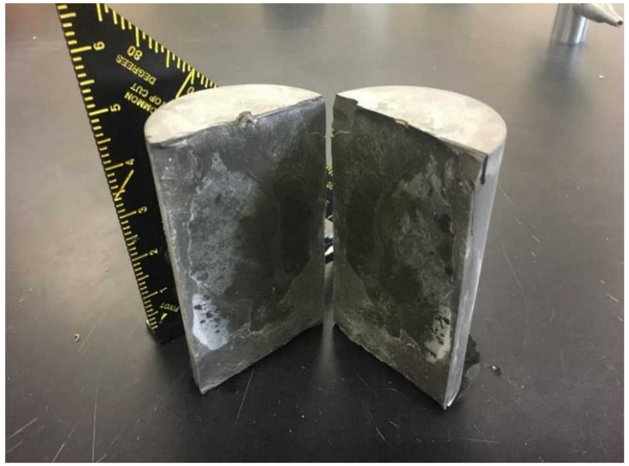
Specimen preparation

Prepared in accordance with ASTM C305-14

Tensile splitting (Brazilian test) equipment. Cylindrical cement sample is in load frame on left, control system is on right.

Curing of various cement cylinders in water tank



Sample after tensile splitting

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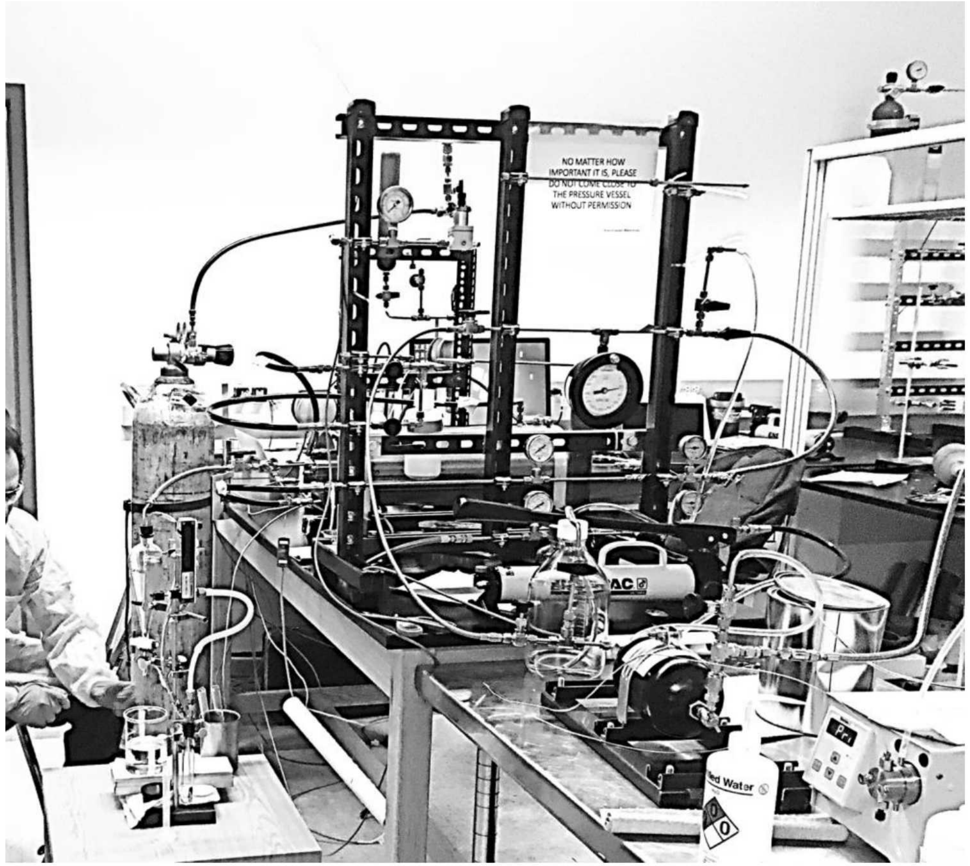
Simultaneous two-phase flow test

The simultaneous steady-state gas and oil flow through the fracture is used to find both oil and gas relative permeabilities under the same conditions.

Relative permeability, $K_{ri} = K_i / K$

Where *K* is the permeability of fracture in single phase flow (absolute permeability) and *Ki* is the effective permeability of an individual phase (phase permeability)



Laboratory setup for two-phase flow test

Relative permeability models

- The sum of relative permeabilities is equal to one, - **absence of phase interference** during the flow

- **Porous media approach**, where the pore space occupied by an individual phase is not available to the other phase.

- V**iscous coupling model**, where both phases of fluid interacts with each similar to two-phase flow in pipes.

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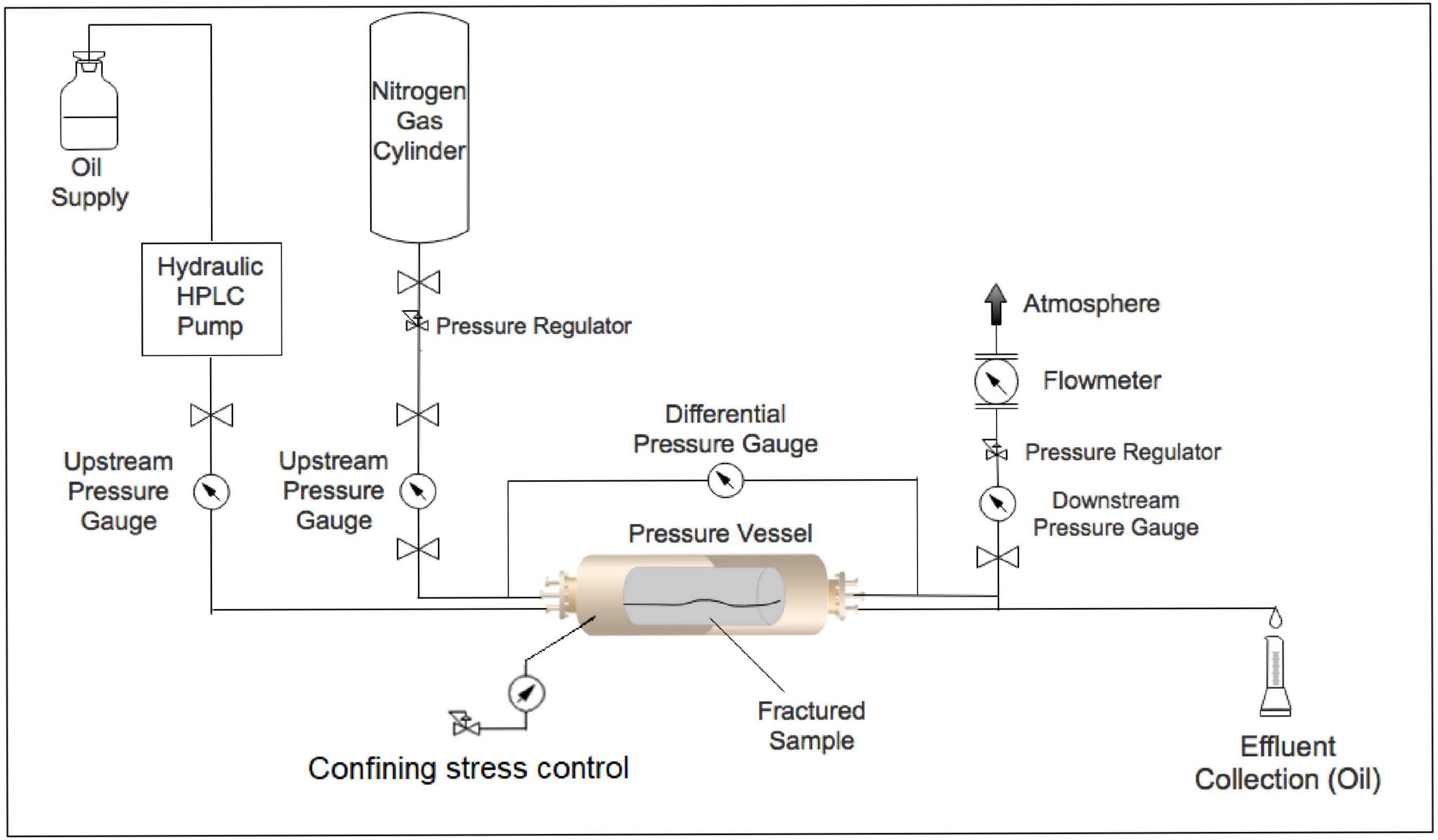
Relative permeability models

Relative permeability model	Most commonly used model	Most commonly used mathematical expression*
Absence of phase interference	X - curve	$Krl = 1 - Krg$
Porous media approach	Corey's model (Power law)	$Krg = \left(1 - \sqrt[4]{Krl}\right)^2 \left(1 - \sqrt[2]{Krl}\right)$
Viscous coupling model	Pipe flow model	$Krl = \frac{1}{2}\left(1 - \sqrt[3]{Krg}\right)^2 \left(2 + \sqrt[3]{Krg}\right)$

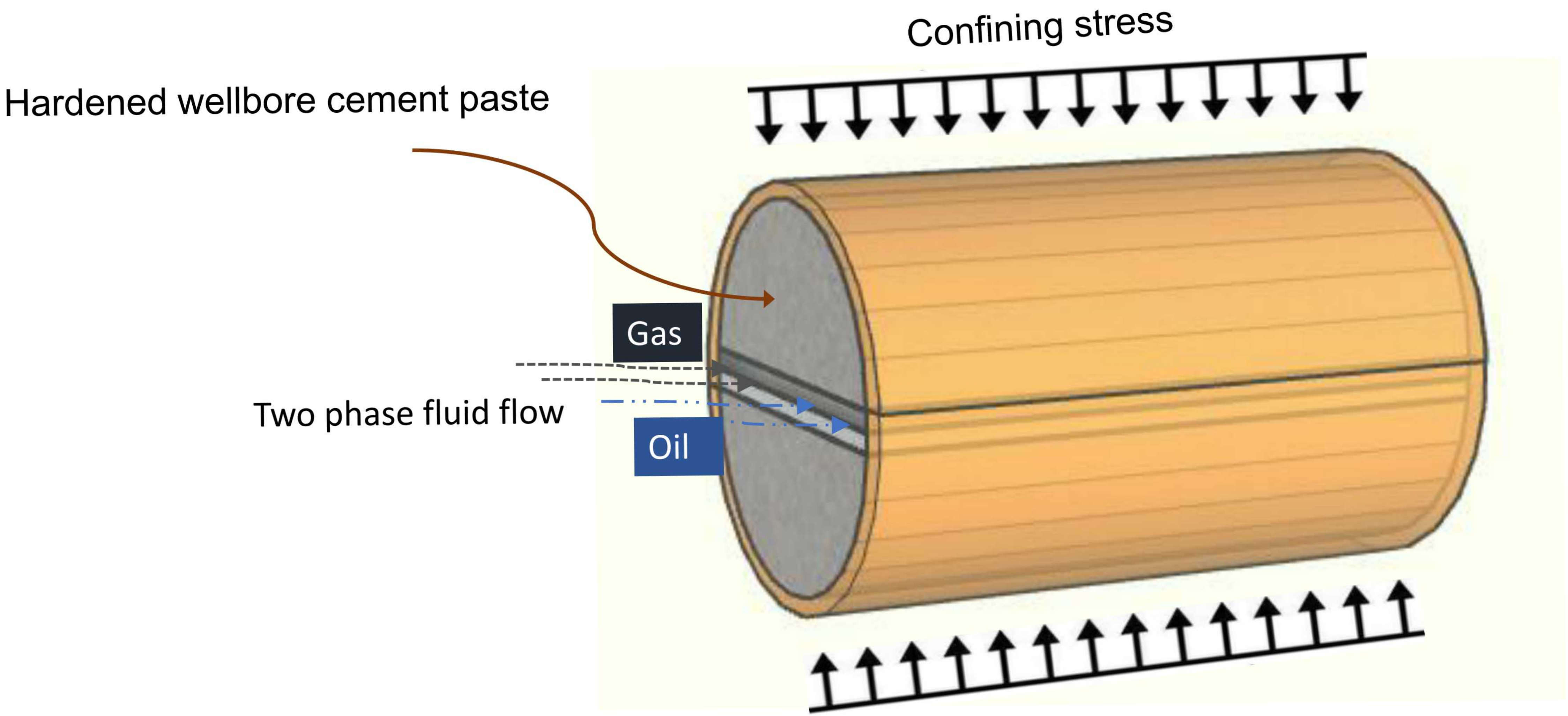
*Note: *Krl* is the relative permeability of liquid, and *Krg* is the relative permeability of gas.

Simultaneous two-phase flow test



Simplified schematic of the two-phase flow test configuration

Simultaneous two-phase flow test



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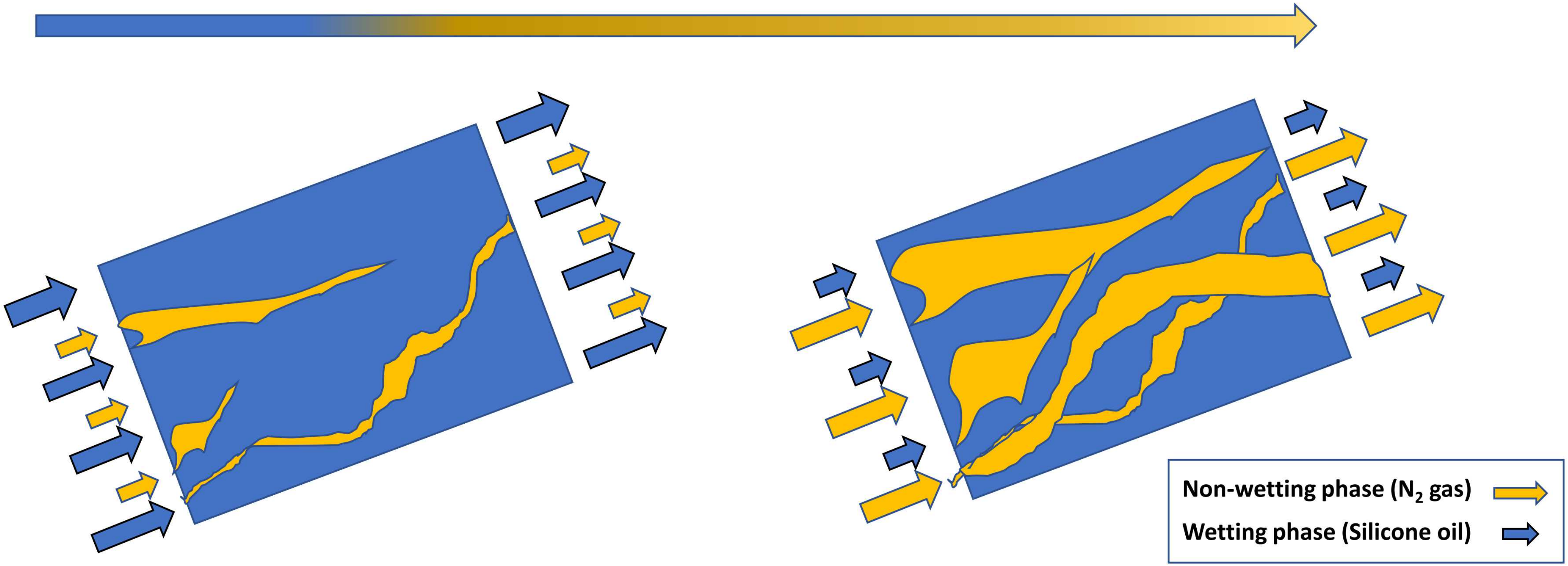
Simultaneous two-phase flow test

Increasing gas flow and decreasing oil flow.



Plan view of fracture face (for illustration purpose only)

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Simultaneous two-phase flow test

Evaluate the role of aperture size and nature of fracture

Wetting fluid	Non-wetting fluid	Confining stress (MPa)
Silicone oil (Viscosity 10 cSt)	Nitrogen gas	3.45
Silicone oil (Viscosity 10 cSt)		13.80
Silicone oil (Viscosity 20 cSt)		3.45

Absolute permeability measurements of the fracture

Confining stress (MPa)	Permeability (m^2)	Mean hydraulic aperture (μm)
3.45	7.08×10^{-14}	40
13.80	2.26×10^{-14}	27

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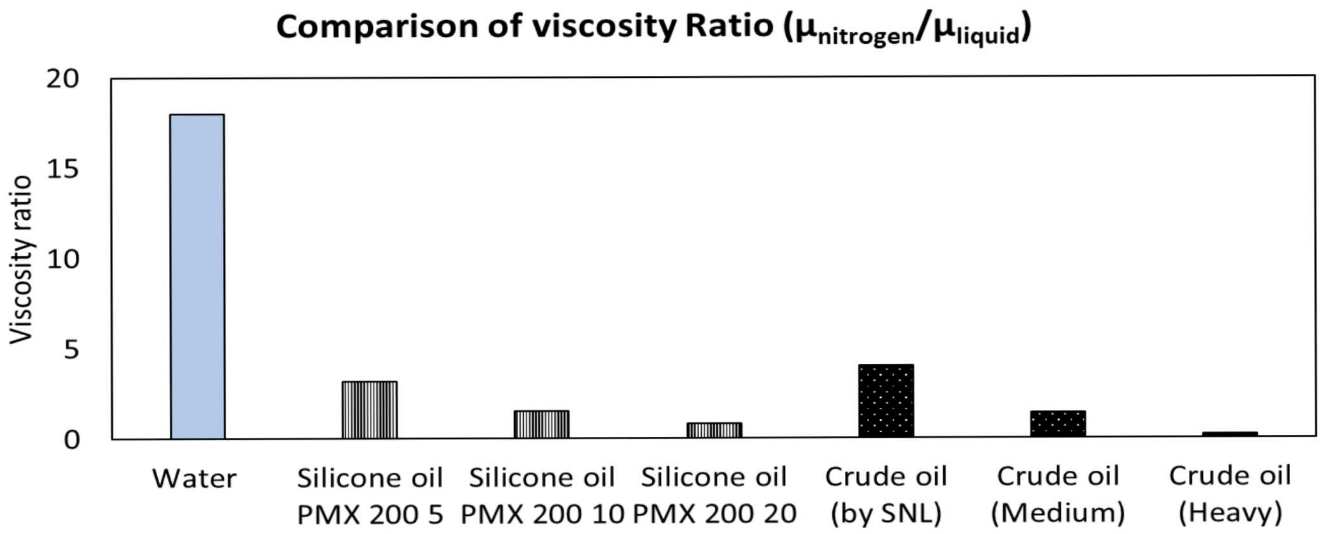
Simultaneous two-phase flow test

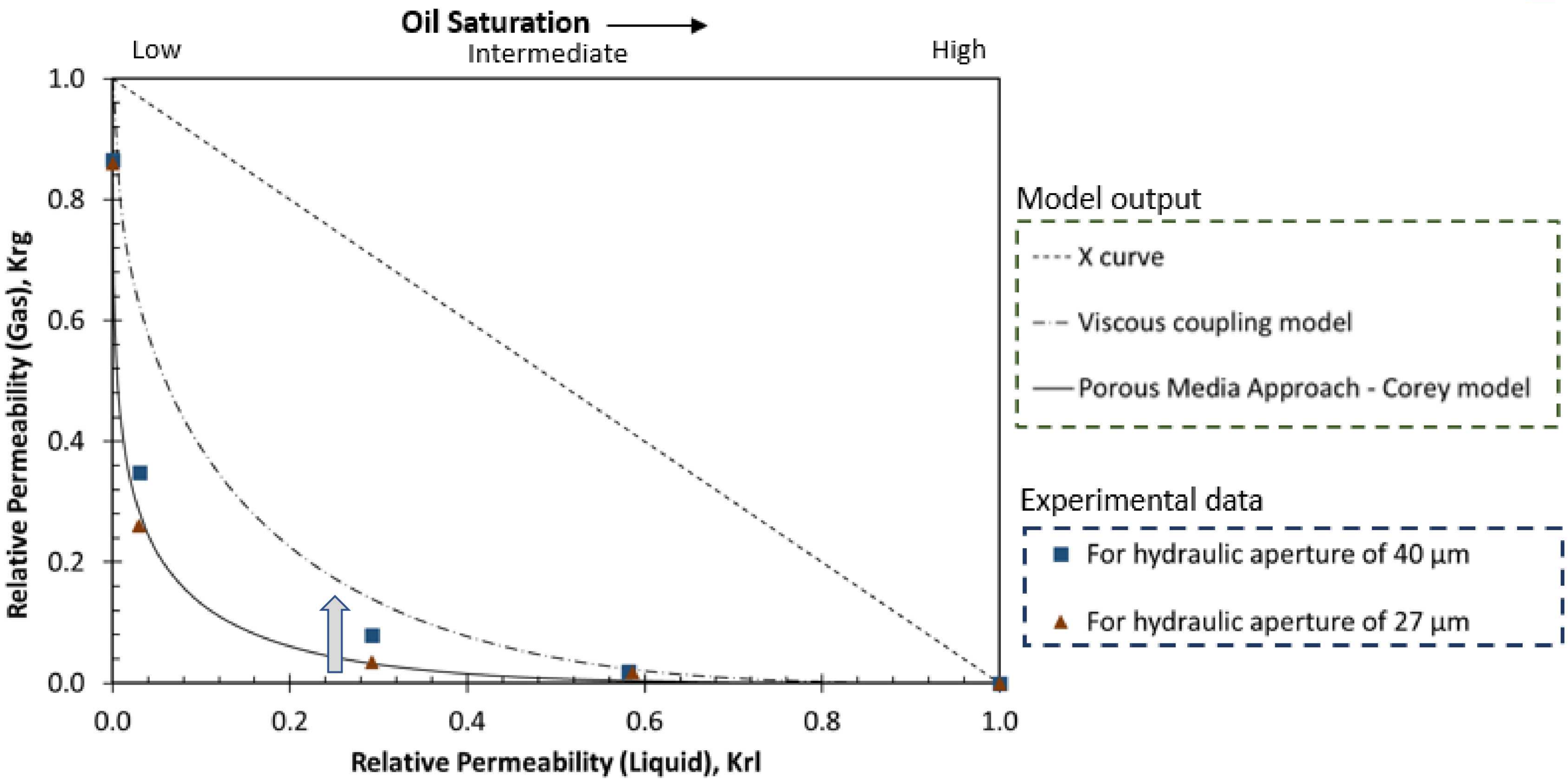
Evaluate the role of viscosity ratio

Wetting fluid	Non-wetting fluid	Confining stress (MPa)
Silicone oil (Viscosity 10 cSt)		3.45
Silicone oil (Viscosity 10 cSt)	Nitrogen gas	13.80
Silicone oil (Viscosity 20 cSt)		3.45

Brookfield RST-CC Rheometer



Results



The relationship between wetting (l) and non-wetting (g) relative permeabilities (Kr) for different fracture apertures (experimental data and model output).

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Pressure sensitive film

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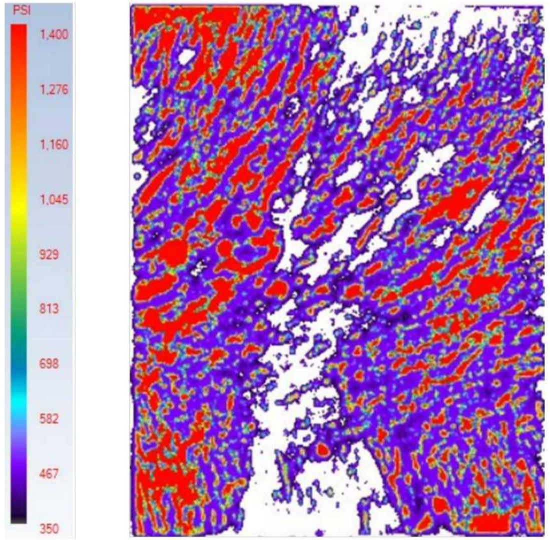
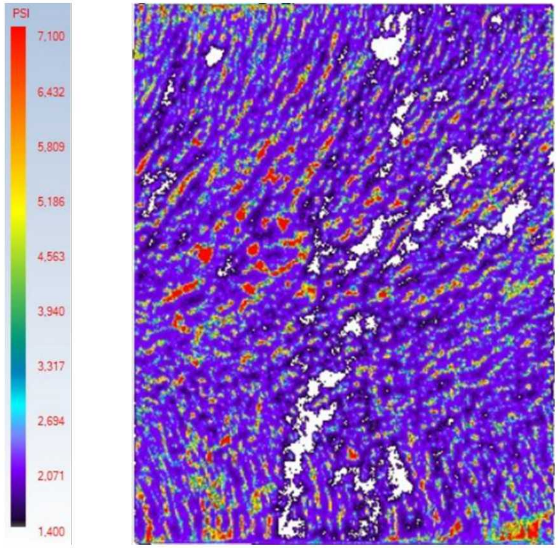
Change in contact area with confining stress observed using pressure sensitive film

Pseudo color representation of the specimens

The contact area increased about 12% due to the increase in applied confining stress.

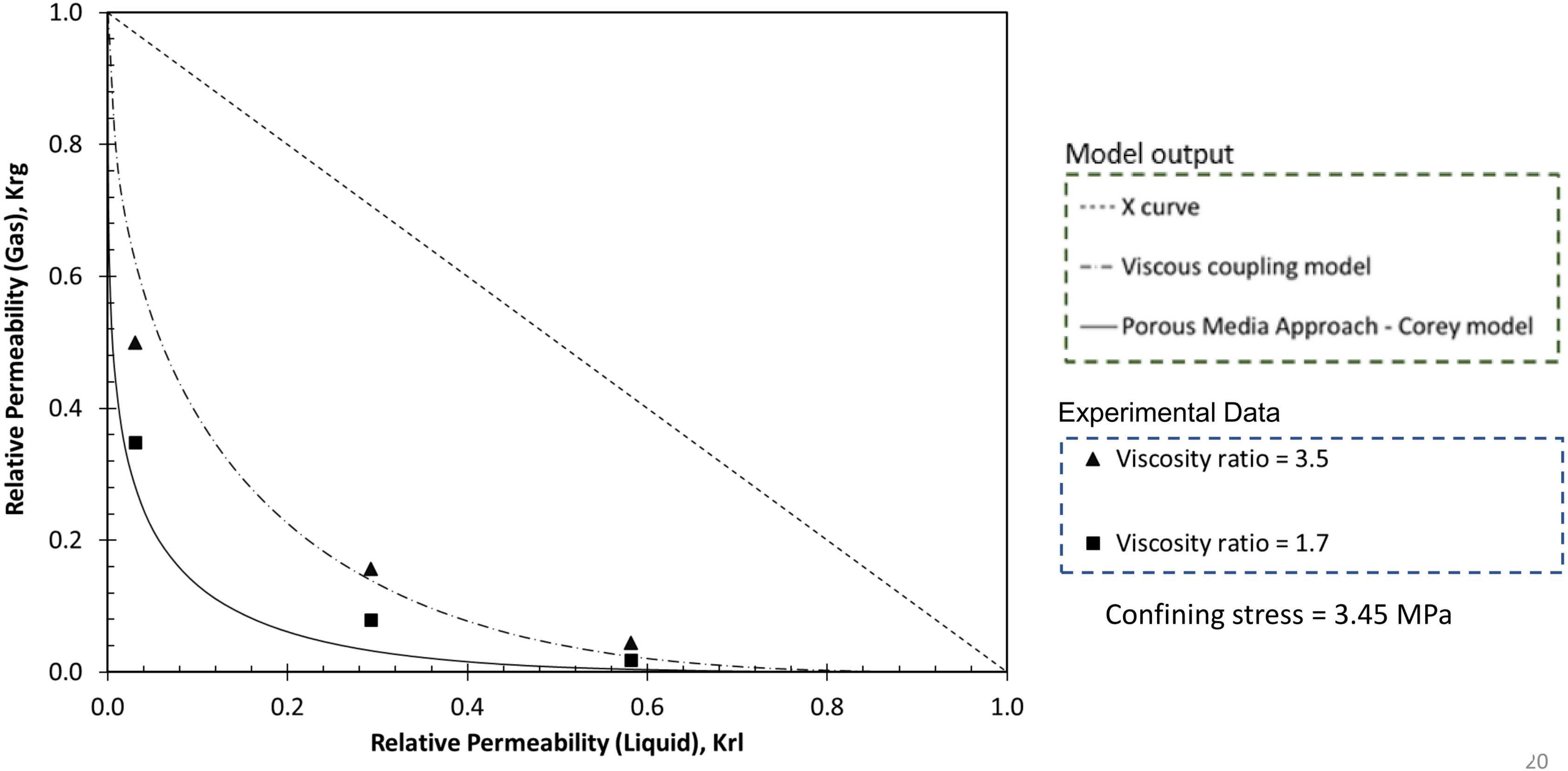


At 3.45 Mpa (500 psig) confining stress



At 13.8 Mpa (2000 psig) confining stress

Relative permeabilities (for two different values of M) obtained from experimental studies and conceptual models often used by industry



Conclusions

- The two-phase flow relative permeability is not solely a function of saturation.
- The sum of wetting and non-wetting phase permeabilities is smaller than one.

There is very significant phase interference. Therefore, the simplest models for relative permeability are not applicable.

- Relative permeability varies with fracture aperture, which controls the amount of fluid flow, flow path geometry and tortuosity.
- The relative permeability of the non-wetting phase varies with the viscosity ratio.

The measured relative permeabilities mostly fall between the porous media and viscous coupling models, depending on viscosities of the fluids and the geometric character of the fracture.

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Acknowledgments

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