Role of Rock/Fluid Characteristics in Carbon (CO_2) Storage and Modeling

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This report has not been reviewed for geologic nomenclature.

Preface

The presentation — *Role of Rock/Fluid Characteristics in Carbon (CO_2) Storage and Modeling* — was prepared for the meeting of the Environmental Protection Agency (EPA) in Houston, Tex., on April 6–7, 2005. It provides an overview of greenhouse gases, particularly CO_2, and a summary of their effects on the Earth's atmosphere. It presents methods of mitigating the effects of greenhouse gases, and the role of rock and fluid properties on CO_2 storage mechanisms. It also lists factors that must be considered to adequately model CO_2 storage.

The objectives of this presentation are to:

- highlight the consequence of increasing concentrations of greenhouse gases, particularly of CO_2, in the atmosphere,
- provide an understanding of how rock and fluid properties influence the storage of CO_2, and
- discuss the role of rock/fluid properties and other parameters in the modeling of CO_2 sequestration/storage.

Role of Rock/Fluid Characteristics in Carbon (CO_2) Storage and Modeling

Mahendra K. Verma, Ph.D.

EPA Workshop on Modeling for Geologic Carbon Storage

Houston, Texas

April 6-7, 2005

U.S. Department of the Interior
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Why Carbon Dioxide Storage ?

CO_2 is a greenhouse gas (GHG), and is considered to be the most serious GHG in the atmosphere.

- Main greenhouse gases: CO_2, CH_4, N_2O, PFCs, HFCs, SF_6
- Other greenhouse gases: CO, NO_X, NMVOCs, SO_X

Global warming is attributed to the increase in GHG concentration (particularly CO_2) in the atmosphere, possibly linked to the ever increasing use of fossil fuels to meet world's growing energy demand. Mitigation of GHG effects in the atmosphere could take place through:

- ❖ Improvement in fuel combustion and energy efficiency
- ❖ Increased use of alternative or renewable fuel
- ❖ Underground storage (geologic sequestration)

Underground storage of CO_2 has the most potential for reducing the effect of GHG.

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Some Facts About CO_2 (the main GHG gas)

- CO_2 content in the atmosphere is about 389 ppm and, despite its low concentration, it absorbs infrared radiation and enhances the greenhouse effect and global warming.
- CO_2 becomes toxic to humans and other animals when its concentration exceeds 5%.
- Volcanic activity, which contributed to initial CO_2 presence in the atmosphere, continues to contribute 145-255 million tons of CO_2 each year.
- Burning fossil fuels, such as coal and petroleum, is the leading cause of increased CO_2, and deforestation is the second major cause.
- Since the start of Industrial Revolution, atmospheric CO_2 has increased significantly.

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Concerns for Higher CO_2 Concentration in the Atmosphere

Concerns have been raised at different forums around the world, highlighting the seriousness of CO_2 emission into the atmosphere and the need for carbon sequestration/storage.

- In December 2004, Lawrence Summers, Harvard University President, emphasized the need for further research to find technological solutions that would allow the removal of excess CO_2 from the atmosphere, such as proposals to inject it underground or in the sea.
- International efforts are underway focusing on (1) the basics of the greenhouse effects and carbon capture/storage; (2) monitoring the Weyburn CO_2 project and Frio Brine pilot test to check if carbon sequestration technology could help slow global warming; (3) tackling CO_2 emissions from power plant. (Carbon Sequestration Newsletter, January 2005.

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Concerns for Higher CO_2 Concentration in the Atmosphere

- In December 2004, Professor Wallace Broecker of Columbia University said that extracting CO_2 directly from the air, liquefying it and then storing it offered the only realistic hope of preventing catastrophic climate change for the world. Alternative energy and energy conservation are going to fall far short of stopping the CO_2 build-up.
- DOE is soliciting proposals for the second phase of its Regional Carbon Sequestration Partnership Program, providing as much as $100 million over 4 years in Federal funds for partnerships of state agencies, universities, companies and national laboratories.
- The Canadian government is now calling for new proposals in the final round of the Pilot Emission Removals, Reductions and Learning (PERRL) Initiative, that is offering $5 million for research in these areas as well as in CO_2 capture and geological storage.

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Concerns for Higher CO_2 Concentration in the Atmosphere

- Policy issues:
  - Europe seeks a new accord with U.S. on global warming (Bloomberg, December 15, 2004)
  - UK initiative on climate change (Guardian, December 10, 2004)
  - Sequestration Credits - Climate Policy 4 (January, 2004)
  - Cinergy releases report on potential impact of greenhouse gas regulation (Business Wire, December 1, 2004)
  - Edison International asks regulators to address global warming on a national level (Business Wire, December 7, 2004)
  - Seven US power companies set voluntary GHG targets (U.S. News Wire, December 13, 2004)
  - The Bush energy plan would require power plants to capture 90% of their emissions for underground storage by 2012 (October 2004)

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CO_2 Properties

◆ Molecular weight	44
◆ Boiling Point (14.7 psia)	-109.3 ^oF
◆ Critical pressure	1071 psia
◆ Critical Temperature	87.9 ^oF
◆ Sp. gravity of liquid CO_2	0.827
◆ Sp. gravity of CO_2 gas	1.52 (Air = 1)
◆ Compressibility (14.7 psia)	0.9943
◆ Appearance	colorless
◆ Solubility in water	0.145 gm in 100 gm water

- Solid CO_2 (dry ice) at temperature below –108.4 ^oF
- Liquid CO_2 only at pressures above 5.1 atmosphere
- Gaseous CO_2 at atmospheric pressure

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Underground Storage of CO_2

Controlling the overall levels of CO_2 in the atmosphere has become an international priority, and hence underground storage of CO_2 , which offers the most potential, has become very critical.

- Oil reservoirs: As part of enhanced oil recovery (EOR) methods, small volume of CO_2 can be stored in the early life of an oil field and long-term large volumes stored at depletion.
- Gas reservoirs: CO_2 could be injected into depleted gas reservoirs for storage. It could also be injected at the bottom of gas column, if studies warrant, for improving gas recovery in an active gas field, and for CO_2 storage.
- Aquifers: Some of them could offer substantial storage capacity. Formation water salinity affects the storage capacity, and hence the need to know water salinity.

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Underground Storage of CO_2

- Oil Reservoirs: CO_2 injection has been successfully applied as an EOR for additional oil recovery. Known examples:
  - The Permian Basin (SACROC project): CO_2 injection began in 1972; oil production in 2002 was about 20,000 bbl/day (Ricketts, 2002).
  - Weyburn Oil field, Canada: In 2000, a demonstration project was initiated to investigate the feasibility of storing CO_2 in this 44-year-old field. The CO_2 is shipped in via a pipeline from the Dakota Gasification Company's plant in Beulah, N.D to Weyburn. Some facts: Estimated incremental recovery is about 130 million barrels of oil, giving a net storage of 7 to 8 Mscf of CO_2 per barrel of oil (Hughes, 2003).

    Some of the main goals of the Weyburn project:
    - Study the economics of underground storage, beyond that for EOR
    - Evaluate potential problems – water pollution and CO_2 leakage

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Underground Storage of CO_2

- Gas reservoirs: The depleted gas reservoirs are good sites for CO_2 storage. A detailed study on oil and gas pools in Western Canada has been done by Bachu and Shaw (2004).

- CO_2 injection in aquifer: Norway was the first country to impose tax on CO_2 emission. It encouraged CO_2 sequestration on a large scale, e.g. CO_2 injection in deep salt water formation in Sleipner field in the North Sea (Norway Sector). Injection commenced through one horizontal well in 1996. An amine process was used for removing CO_2 from gas (Torp and Brown, 2004).

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Rock/Fluid Characteristics

The following rock properties of a formation will play an important role in subsurface storage of CO_2:

- Effective porosity and its distribution
- Presence of fractures/faults, and their orientation
- Reservoir heterogeneity
- Lithology and pore size distribution
- Capillary pressure curve
- Initial water and/or oil saturations
- Residual water and/or oil saturations
- Permeability and its distribution
- Relative permeability for CO_2 - formation fluid(s)

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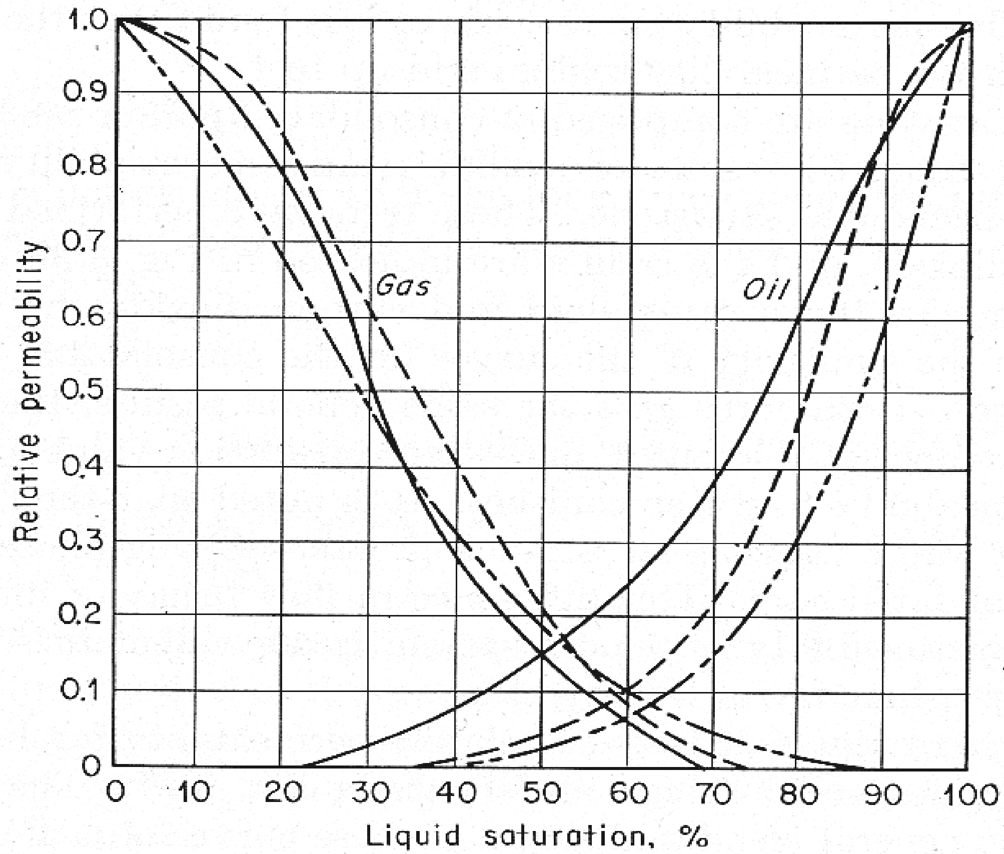

Relative permeability to gas and oil for West Texas dolomites (Bulnes and Fitting, 1945)

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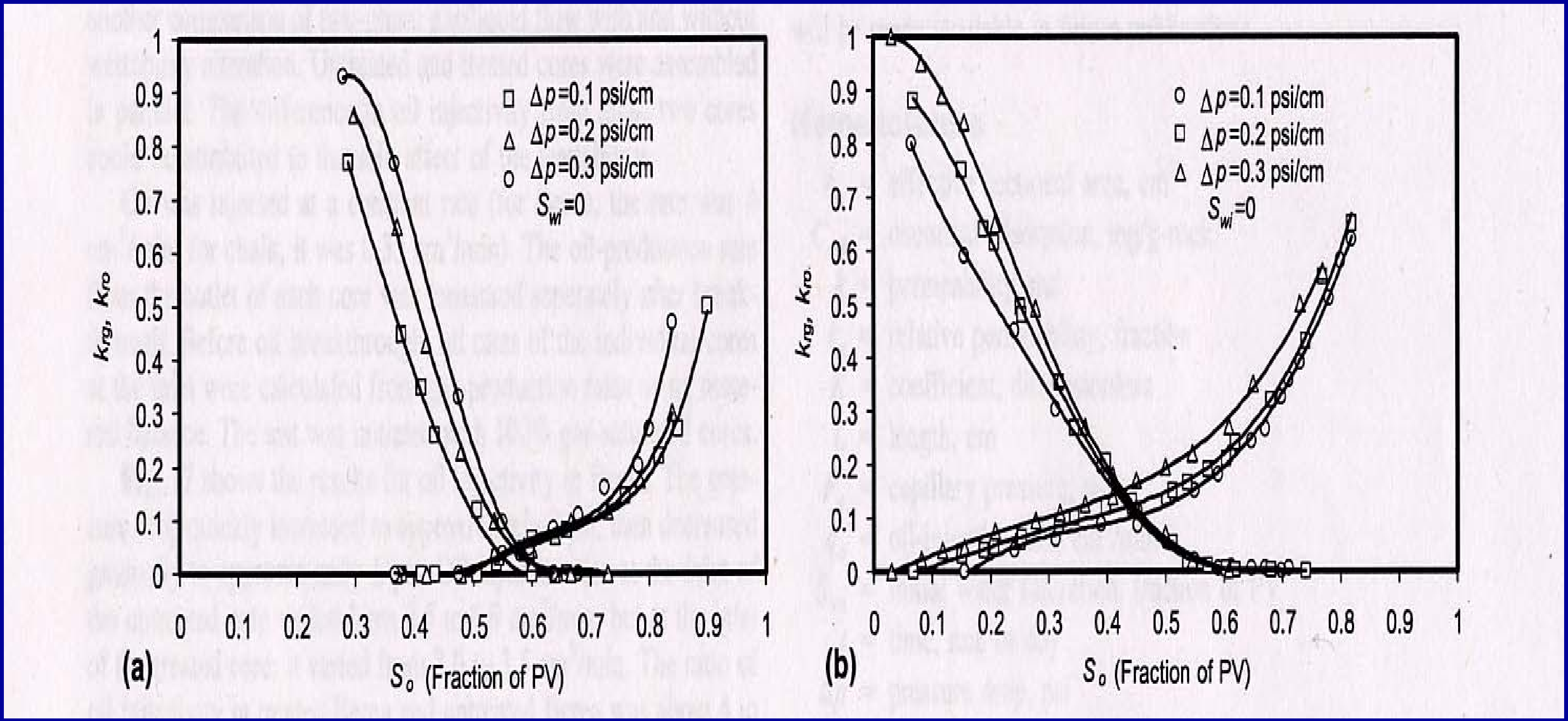

Effect of viscous forces on gas and oil relative permeabilities for treated and untreated Brea sandstone with 2% FC-722
(Tang and Firoozabadi, 2002)

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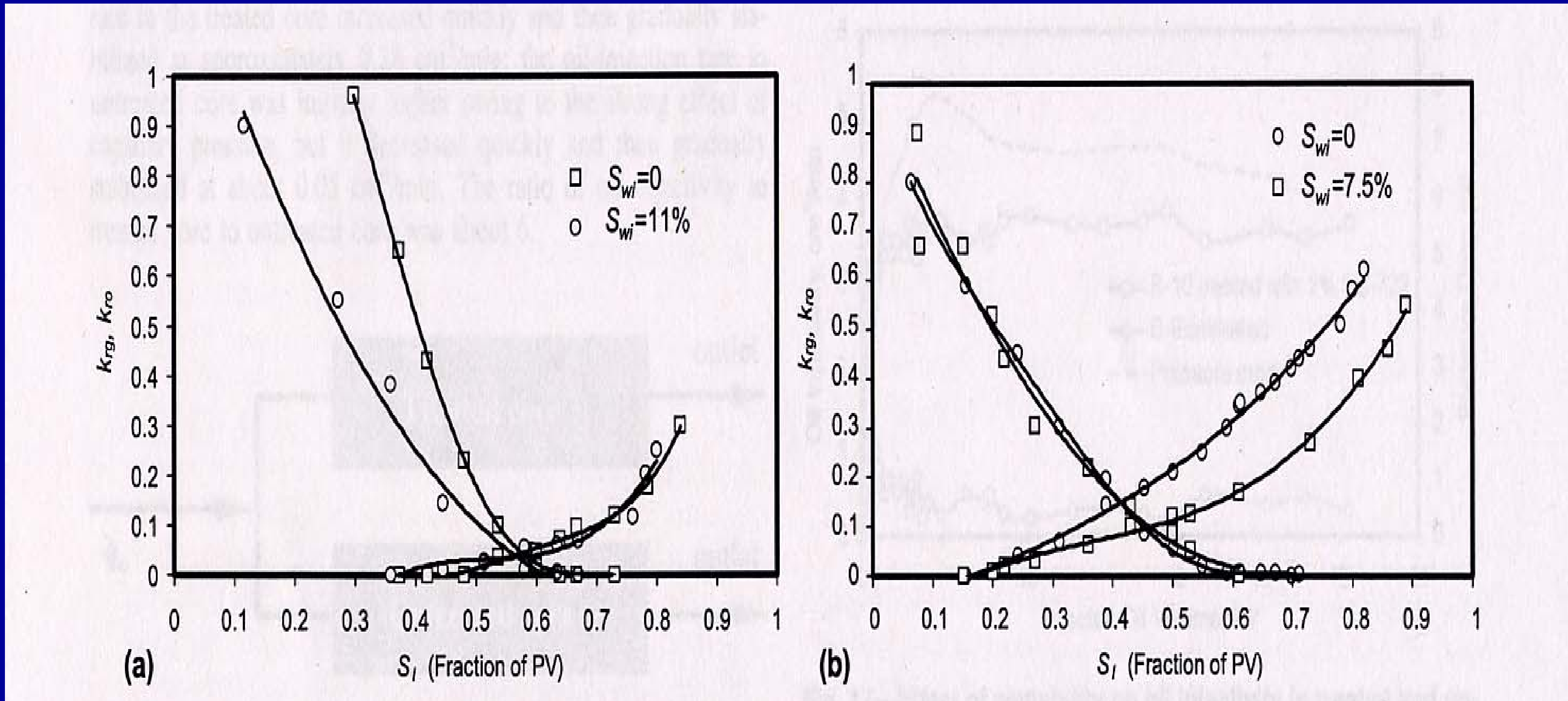

Effect of initial formation water saturation (S_{wi}) on gas and oil relative permeabilities for treated and untreated Brea sandstone (Tang and Firoozabadi, 2002)

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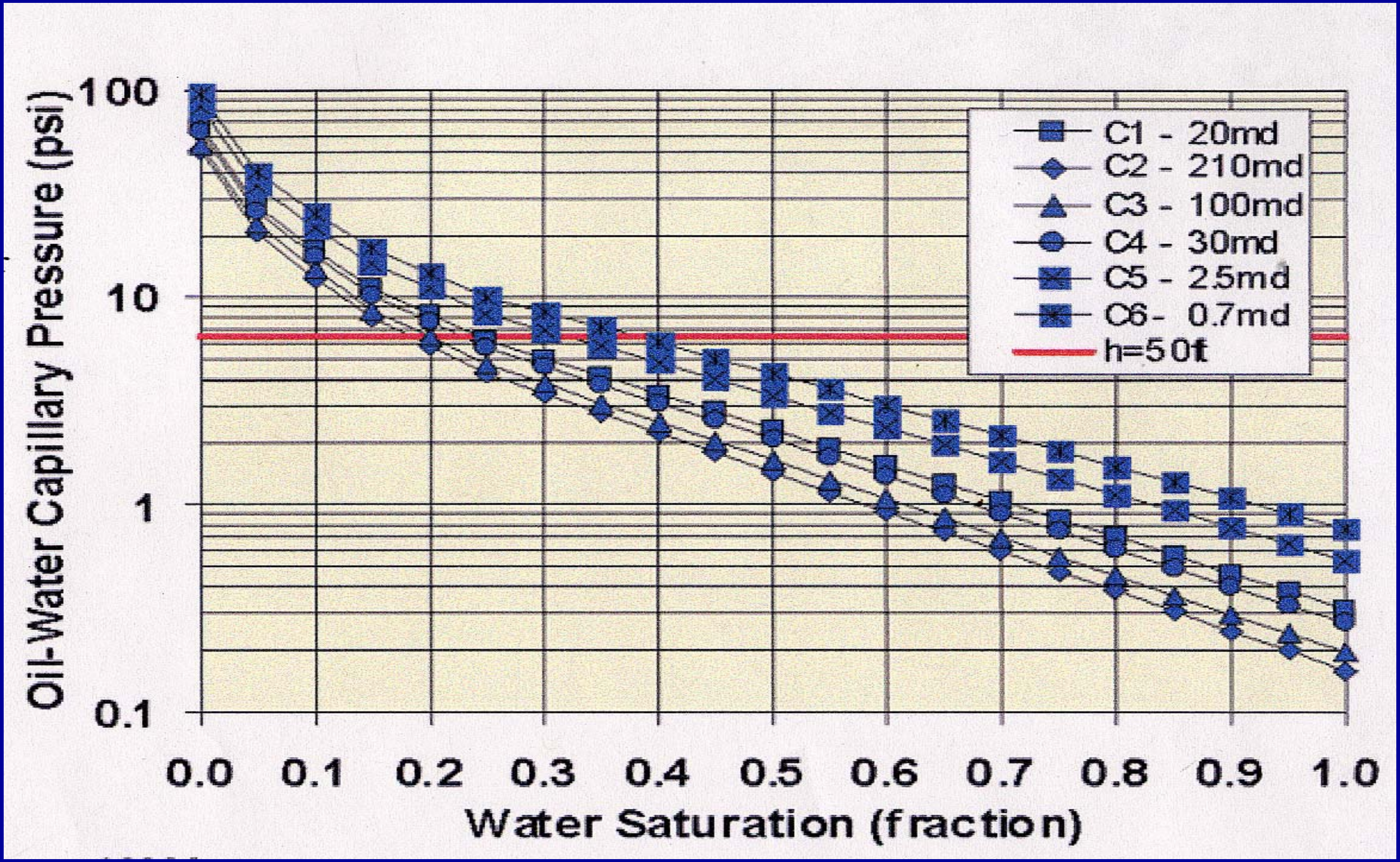

Capillary pressure versus water saturation
(DuBois, Byrnes, and Watney, 2001)

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Rock/Fluid Characteristics

Subsurface storage of CO_2 will also depend on the properties of formation fluid and CO_2, as well as their impact on their behavior.

- Oil gravity and solution gas-oil ratio – for oil reservoirs
- Gas gravity and natural gas liquid (NGL) content – for gas reservoirs
- CO_2 solubility in oil is very high and is a function of oil composition, reservoir pressure and temperature
- Swelling and viscosity of oil as a function of CO_2 in solution
- Miscibility pressure for CO_2 and hydrocarbon system
- Water has a higher solubility for CO_2 than for hydrocarbon or non-hydrocarbon gases (such as nitrogen)
- CO_2 solubility in water is a function of water salinity, pressure, and temperature
- Flow properties of fluid (oil/water) depend on the quantity of CO_2 in solution

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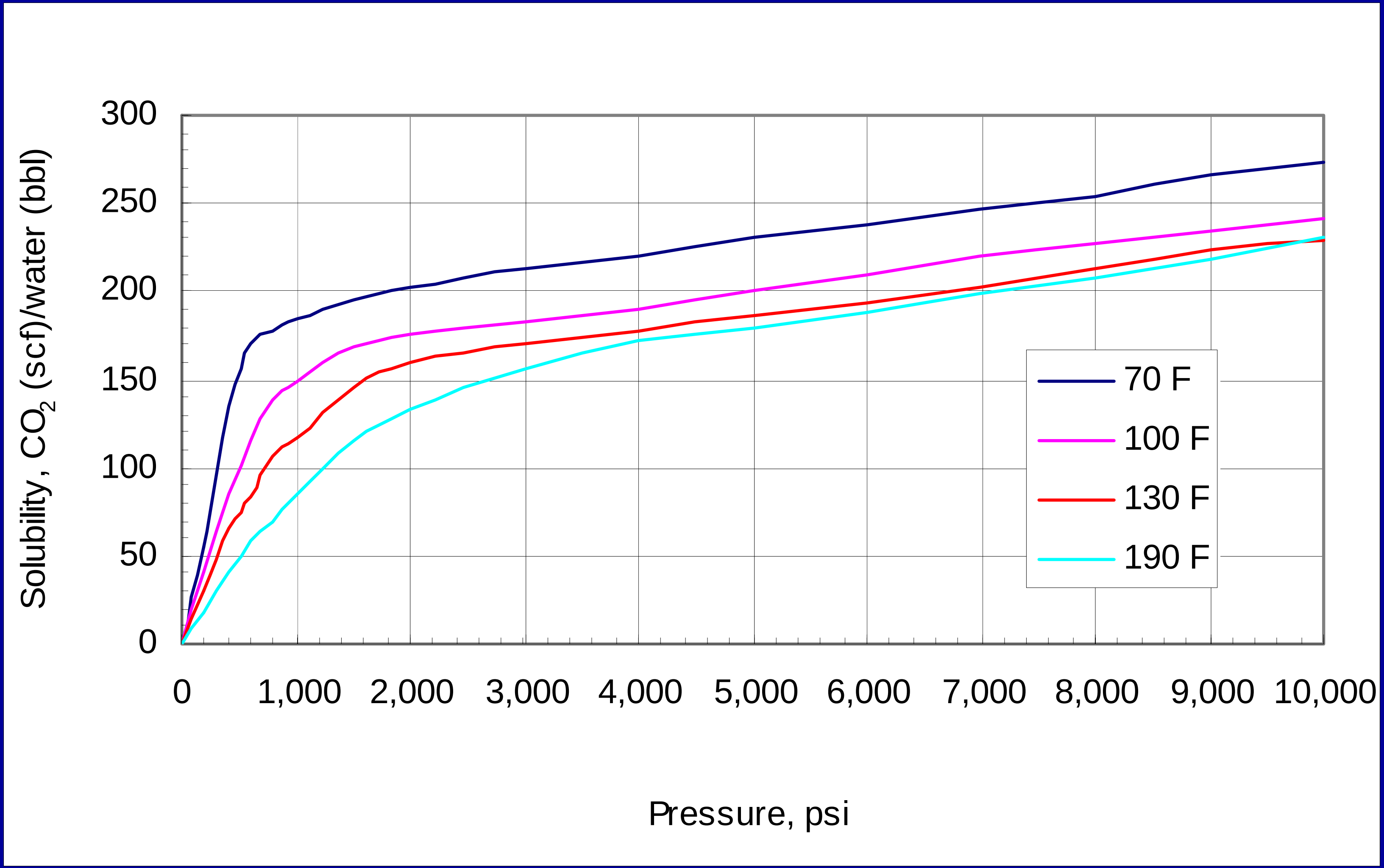

Solubility of carbon dioxide in fresh water (Carr and others, 2003)

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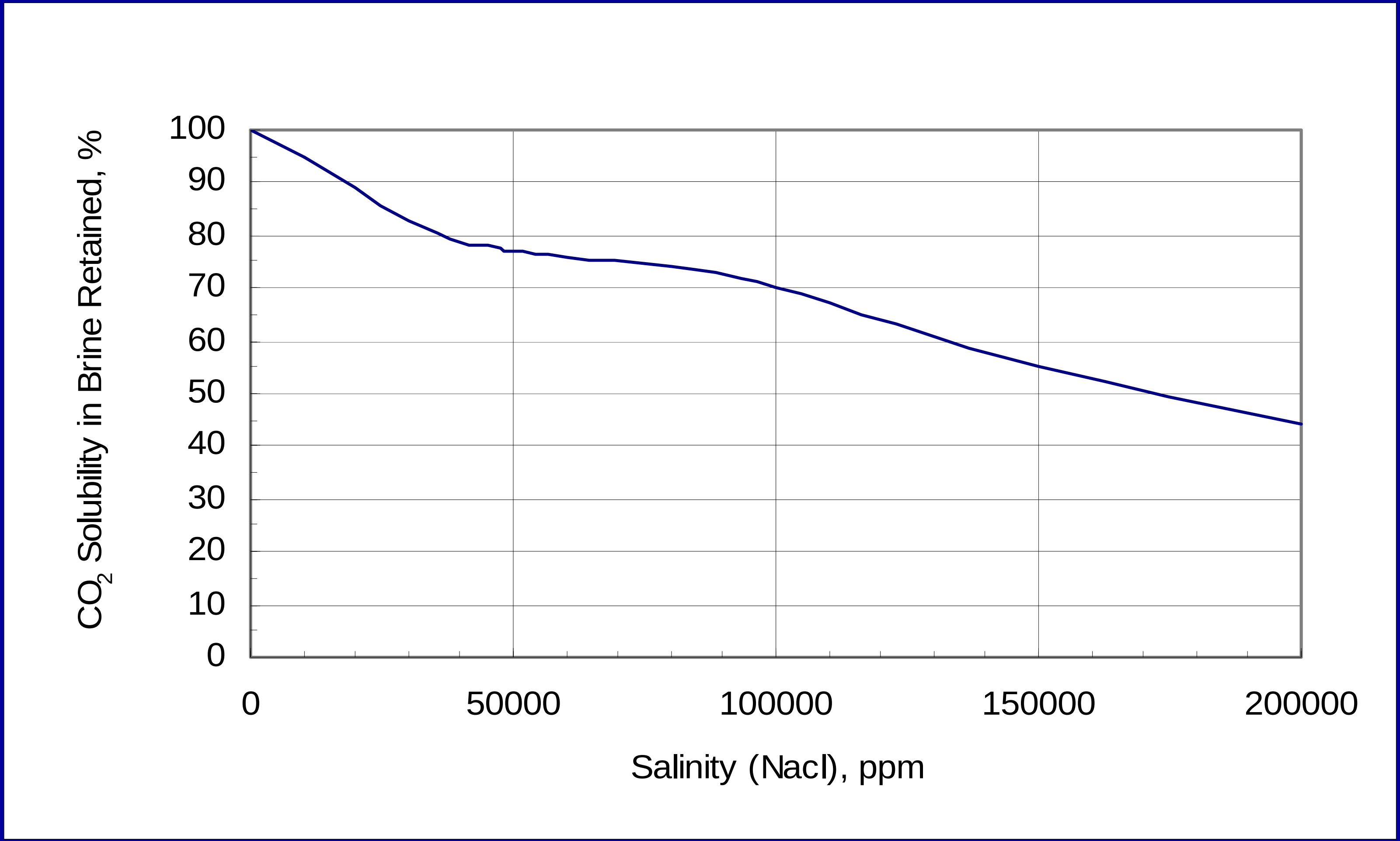

Effect of salinity on the solubility of carbon dioxide in water (Carr and others, 2003)

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CO_2 Solubility in Oil and Brine

Given below are the relative solubility of CO_2 in oil, water and brine.

	Oil	Water	Brine (200,000 ppm)
CO_2 solubility, scf/bbl	950	145	65
(2,000 psia, 150^{o}F)			

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CO_2 Storage – Modeling

A compositional simulator would be a preferable option for better understanding of operational problems and for quantification of storage capacity of a target reservoir. Reservoir data for aquifers is generally not available complicating CO_2 injection.

Basic information required for modeling CO_2 sequestration:

- Structural contour map
- Isopach map of reservoir
- Reservoir characterization – lithology, layering, and homogeneity
- Initial pressure across the reservoir
- Porosity and permeability maps
- Relative permeability data by layer
- CO_2 solubility data for oil and for formation water
- Well completion information

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CO_2 Storage – Modeling

- Other useful information for simulation
  - Integrity of cap rock and pressure limits – seismic data and, if possible, Formation Micro-Imager (FMI) logs
  - Consideration of horizontal versus vertical wells as injectors
  - Type of oil reservoir (solution gas/gas cap/water drive); and has the reservoir been waterflooded
  - Aquifer volume and the level of aquifer support in case of gas reservoirs
  - Knowledge of formation lithology and, if any, its reactivity with CO_2
  - Number of injection wells available and their rate of injection
  - Corrosion problems
  - CO_2 source, and cost of extraction and transportation
  - Level of infrastructure in the region

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Conclusions

- The effect of greenhouse gases (specifically CO_2) in global warming is a matter of great concern and should be addressed at the highest level in each country.
- Rock/fluid properties of the formation play an important role in the study of CO_2 injection into and storage in oil/gas reservoirs and aquifers.
- Reservoir simulation is the best tool for defining CO_2 injection rates and quantifying storage capacity of target reservoir; thereby help in decision making to initiate CO_2 sequestration project.
- Identify aquifers and depleted oil/gas reservoirs for CO_2 storage through a review of all known aquifers and oil/gas reservoirs.

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