

Laboratory Scale Research for CO₂ Sequestration in Coal Beds

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Deep, unmineable coal beds are an attractive geological option for the sequestration of CO₂. Coal surfaces have strong affinity for CO₂ that enhances the desorption of methane from coal; hence, sequestration is combined with enhanced natural gas production. Design of CO₂ sequestration operations requires accurate conceptual and numerical models. This project focuses on laboratory investigation of combined CO₂ storage and enhanced coalbed methane recovery systems. One direction our project is heading is to improve our understanding of the physical behavior of gases adsorbed on coal. We explore the nonideal behavior of adsorbed gas so that better constitutive models of gas-adsorbate phase behavior are developed. We also explore the transport of gas and countercurrent gas diffusion in coal using noninvasive imaging techniques.

Gas Adsorption on Coal and Permeability Evolution of Coal

Motivation

One issue of particular interest for gas injection into coal beds is the permeability change of the coal beds in the process of gas injection and production. Two mechanisms are believed to cause the permeability of coal to change: changing of effective stress and sorption induced strain. Better understanding of gas (especially multi-component gas mixtures) adsorption on coal is the key to understand and model the second effect. The real adsorbate solution model is considered to be thermodynamically consistent and more realistic to represent multi-component adsorption.

Ideal Adsorbate Solution (IAS) Model

$$py_i = p_i^0(\Pi, T)x_i$$

p = adsorption pressure;
 y_i = mole fraction of component i in the free gas phase;
 x_i = mole fraction of component i in the adsorbed phase;
 n_i = moles of component i in the adsorbed phase;
 Π = spreading pressure;
 p_i^0 = equilibrium pressure for pure component i adsorption corresponding to the solution spreading pressure Π ;
 T = temperature;
 ϕ_i = fugacity coefficient of component i in the vapor phase, accounting for the nonideality of the vapor;
 γ_i = activity coefficient of component i in the solution phase, accounting for the nonideality of the adsorbate solution;
 f_i^0 = equilibrium fugacity for pure component i corresponding to spreading pressure Π .

Real Adsorbate Solution (RAS) Model

$$py_i\phi_i = f_i^0(\Pi, T)\gamma_i x_i$$

Activity Coefficient:

$$\gamma_i \equiv \frac{a_i}{x_i} \quad \text{where } a_i \equiv \frac{f_i(T, p, x)}{f_i(T, p^0, x^0)}$$

Three-Constant Model for Activity Coefficient:

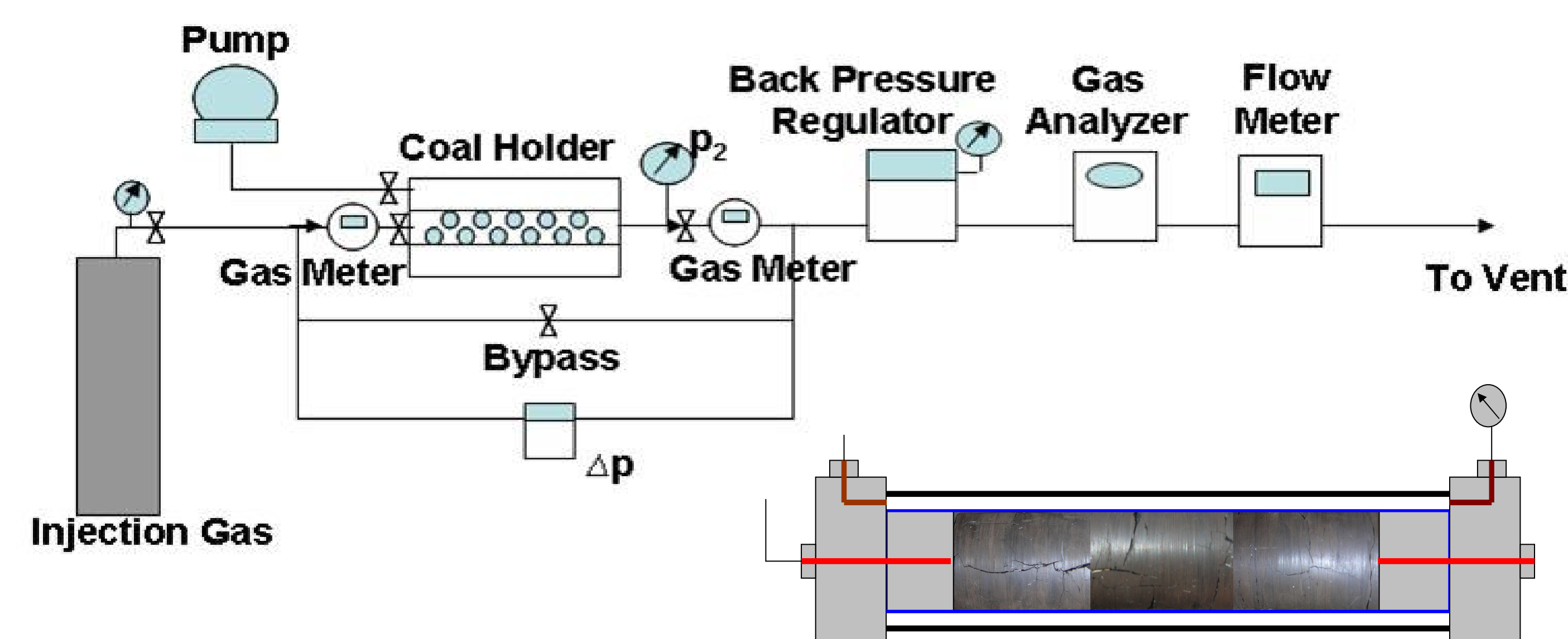
$$RT \ln \gamma_i = (A + BT)(1 - e^{-C\psi})x_j^2 = A_v[1 - e^{-C\psi}]x_j^2, \quad i \neq j$$

$$\text{where } \psi = \frac{\Pi A}{RT} = \int_0^{f_i} n_i \cdot d \ln f_i$$

New Experiments

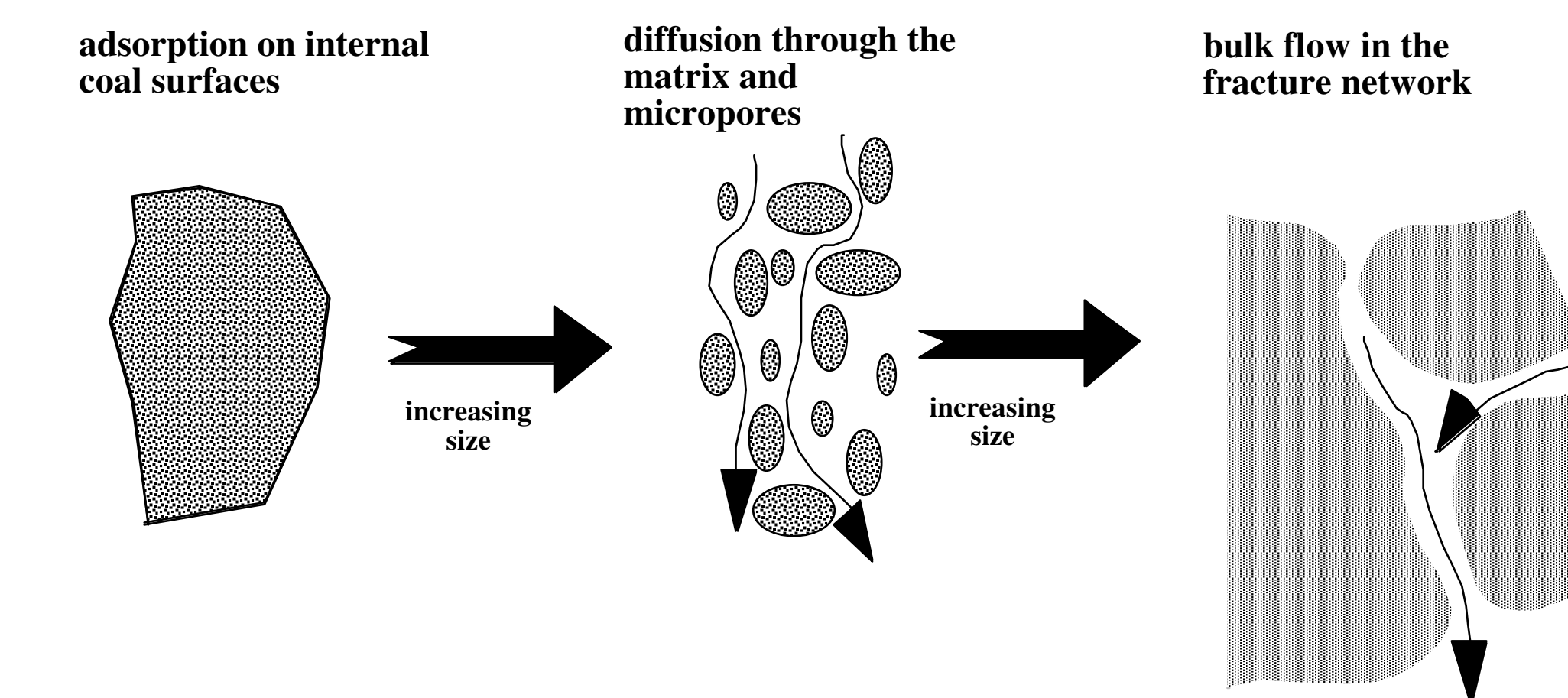
- Cylindrical composite coal core made from drilled coal plugs;
- Measurements:
 - permeability change due to injection of different gases at different pore pressure;
 - multi-component gas adsorption on coal: measuring the amount of adsorption and the composition of the adsorbed phase to test the validation of RAS model;
 - swelling of coal due to gas adsorption: measuring the volume change of the coal core due to gas injection.

New Experimental Setup:



Determination of Coal Properties with X-ray Computed Tomography

Model Development



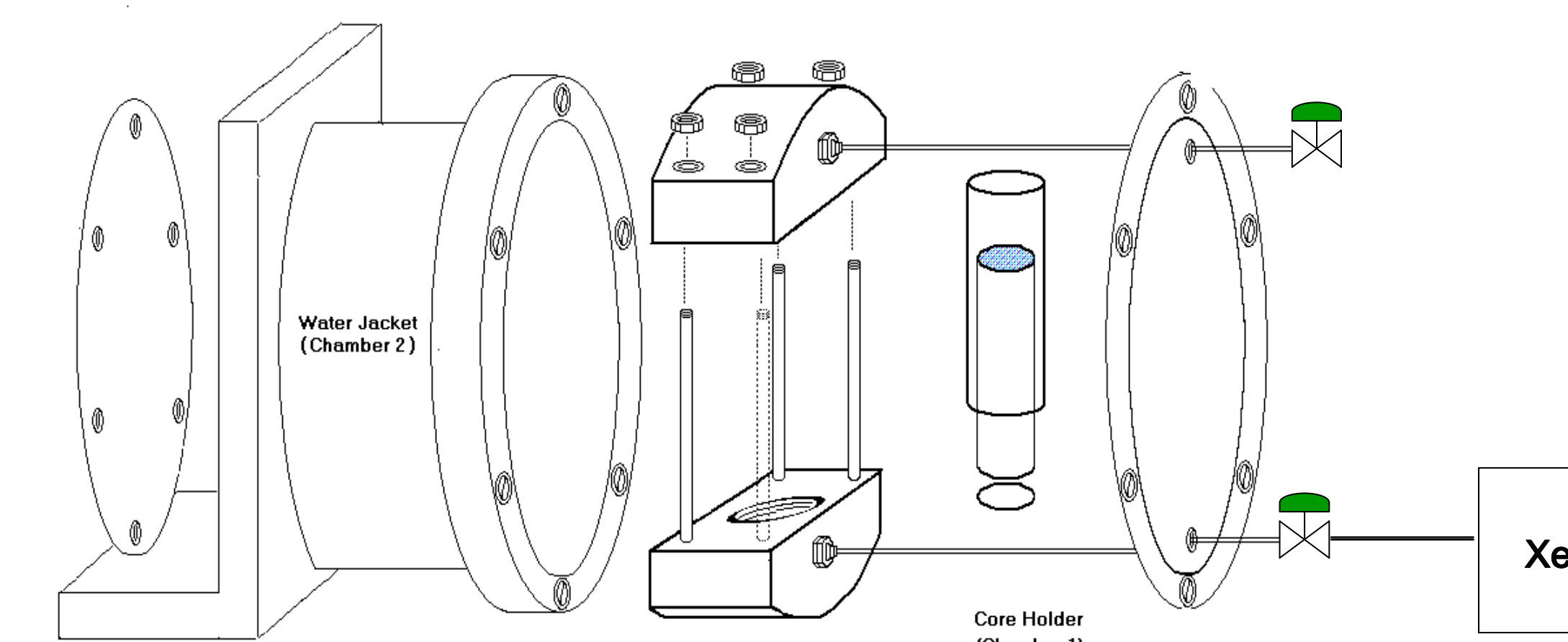
Coal beds are fractured and a variety of length and transport time scales are evident. The porous medium is divided logically into low permeability matrix and interconnected fracture systems. Gas diffusion is clearly a key mechanism, however, the interplay of scales makes it difficult to:

- ascertain the interplay of advection and diffusion;
- time for gas to transport from micropores to fracture network.

Coal matrix permeability and porosity cannot be reliably determined by standard techniques. Coal's characteristic dual porosity must be assessed in order to obtain proper representation of the gas storage and desorption occurring inside the matrix.

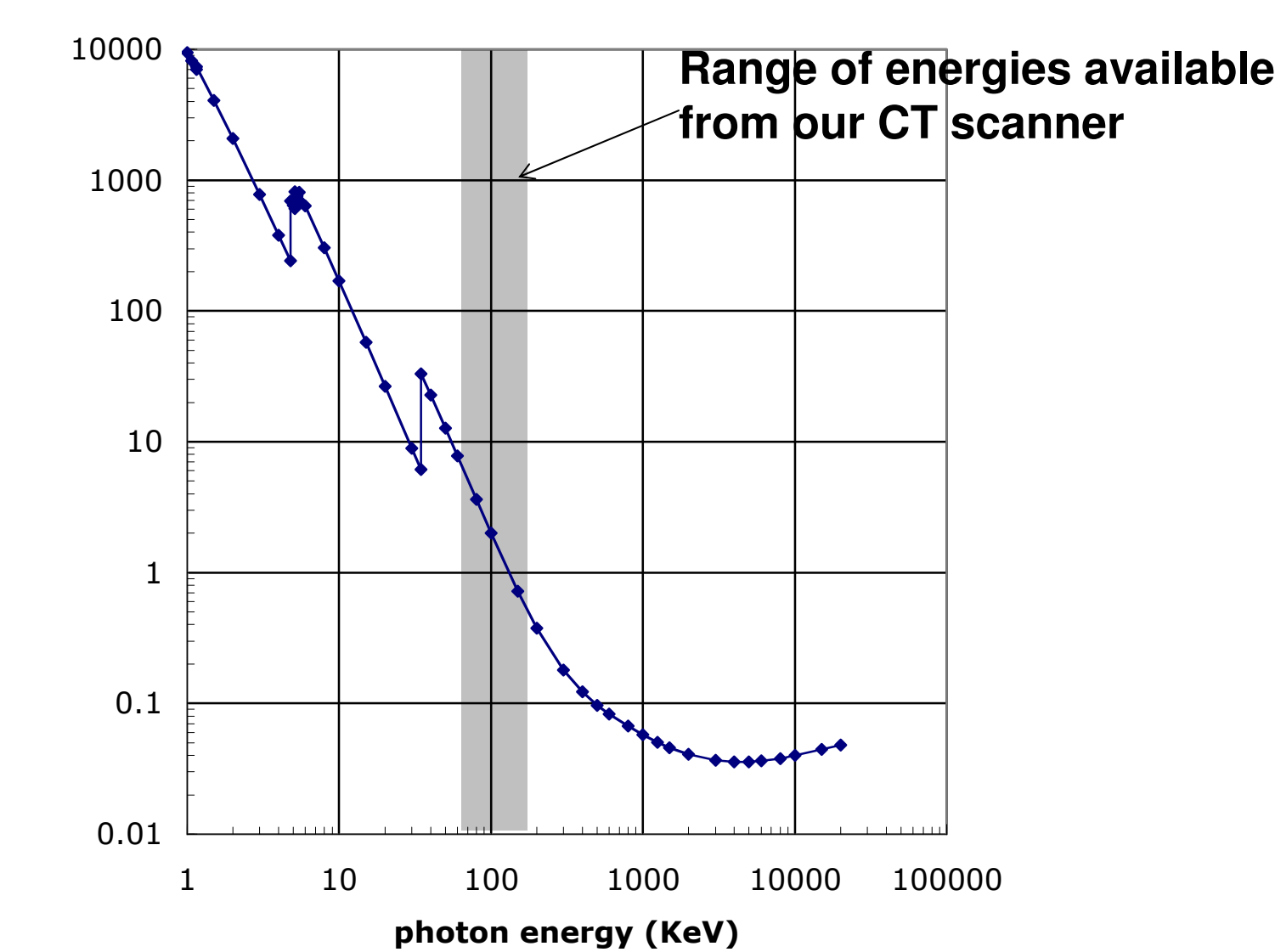
Experimental Approach for Property Determination

Dual-scan method provides the opportunity to determine porosity distribution using image subtraction from gas saturated and vacuumed samples.

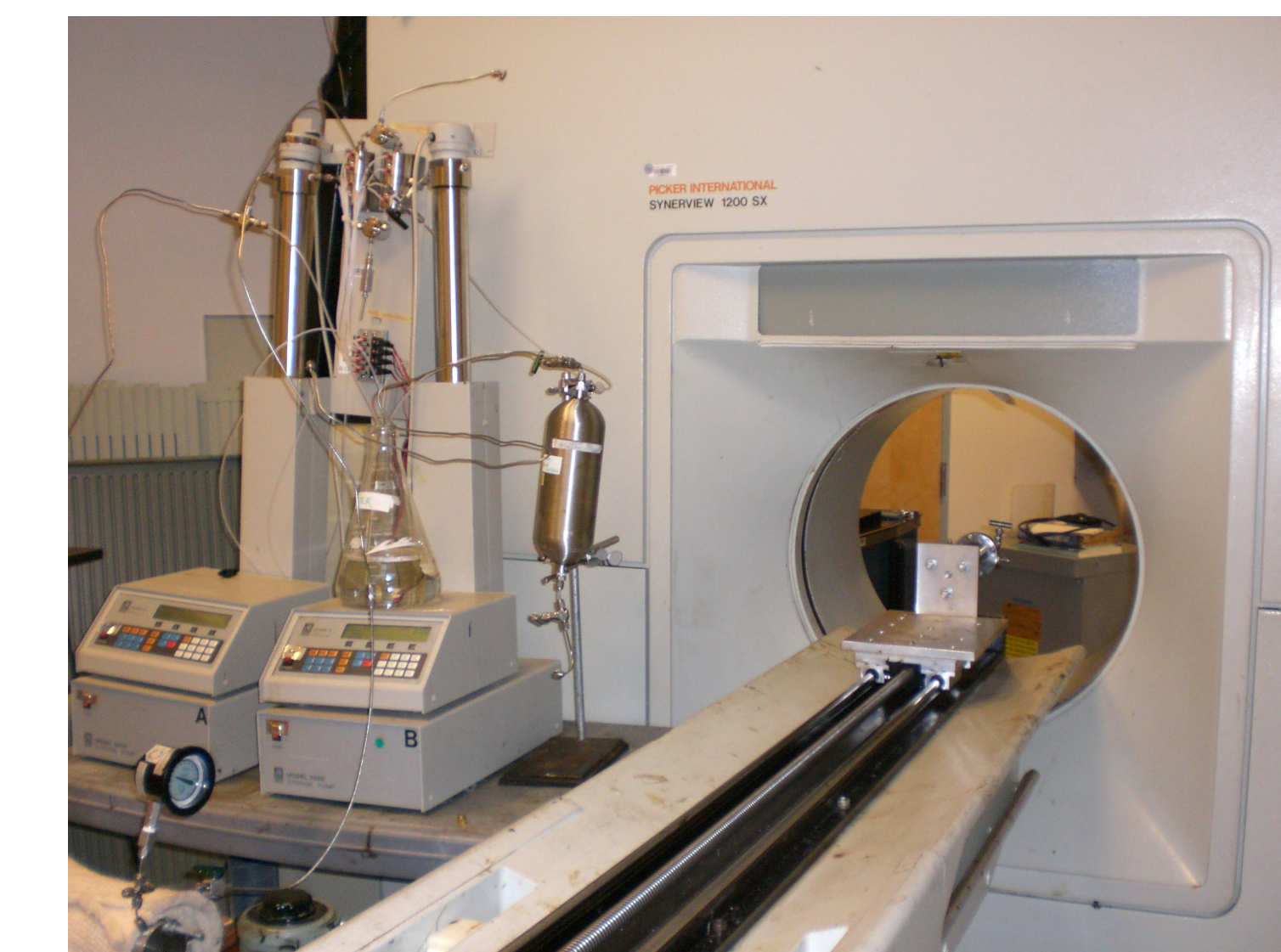


Schematic of proposed experimental apparatus

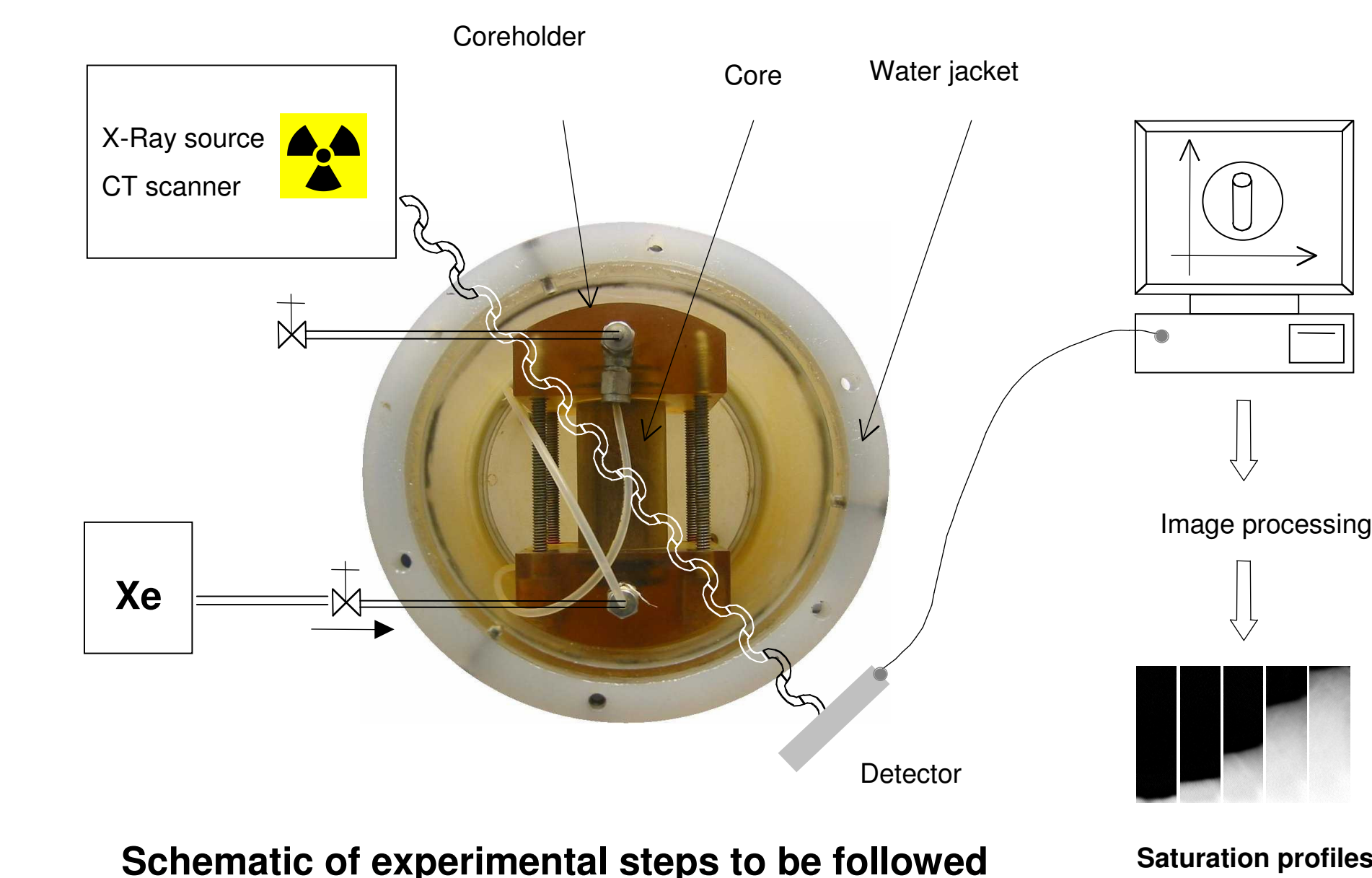
Attenuation of X-rays by Xenon



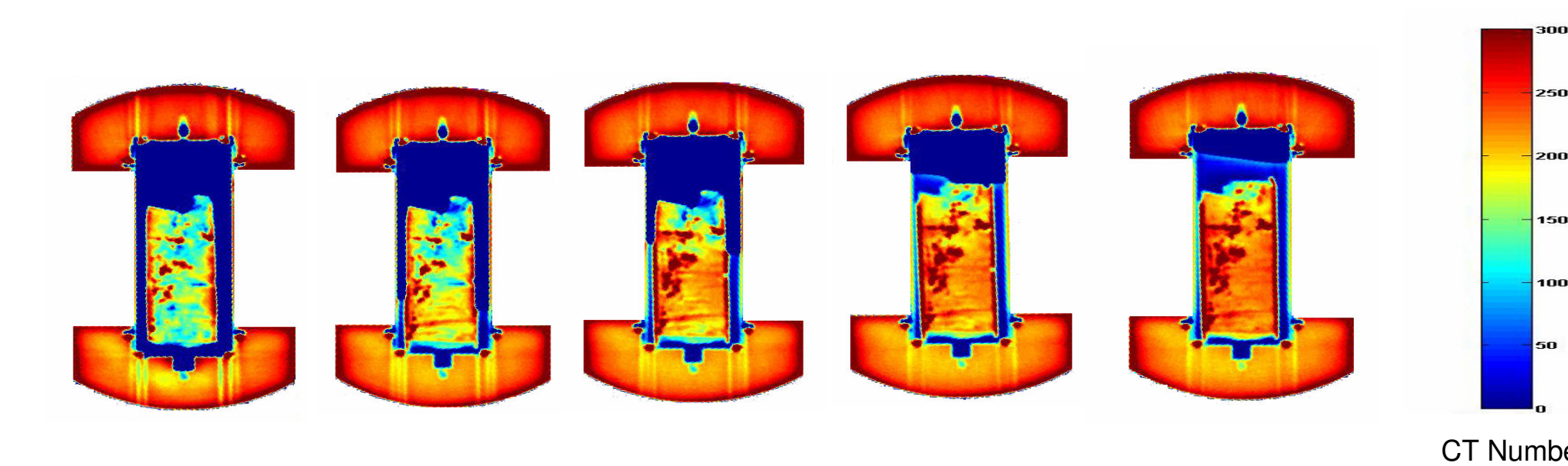
Xenon is a radio opaque gas that provides great contrast for quantitative imaging of the progress of gas transport. Natural gas is transparent to X-rays and it is potentially possible to monitor countercurrent diffusion.



CT scanner equipment to be used for the experiments



Schematic of experimental steps to be followed



Example of images obtained from proposed experimental apparatus