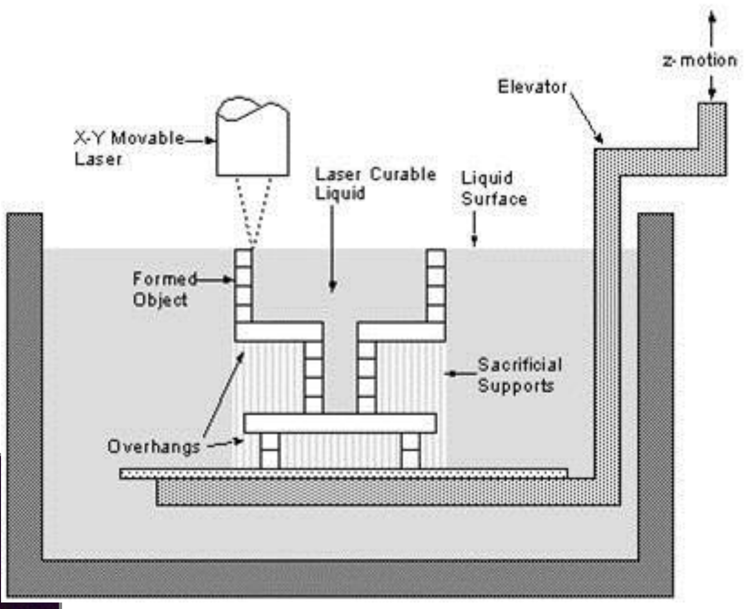
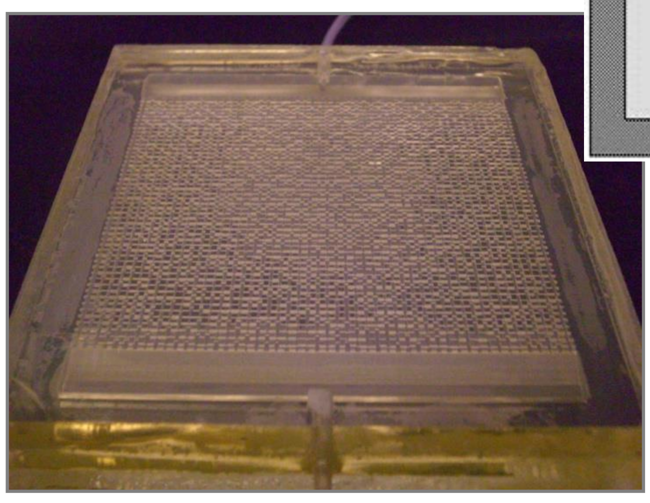
# Introduction

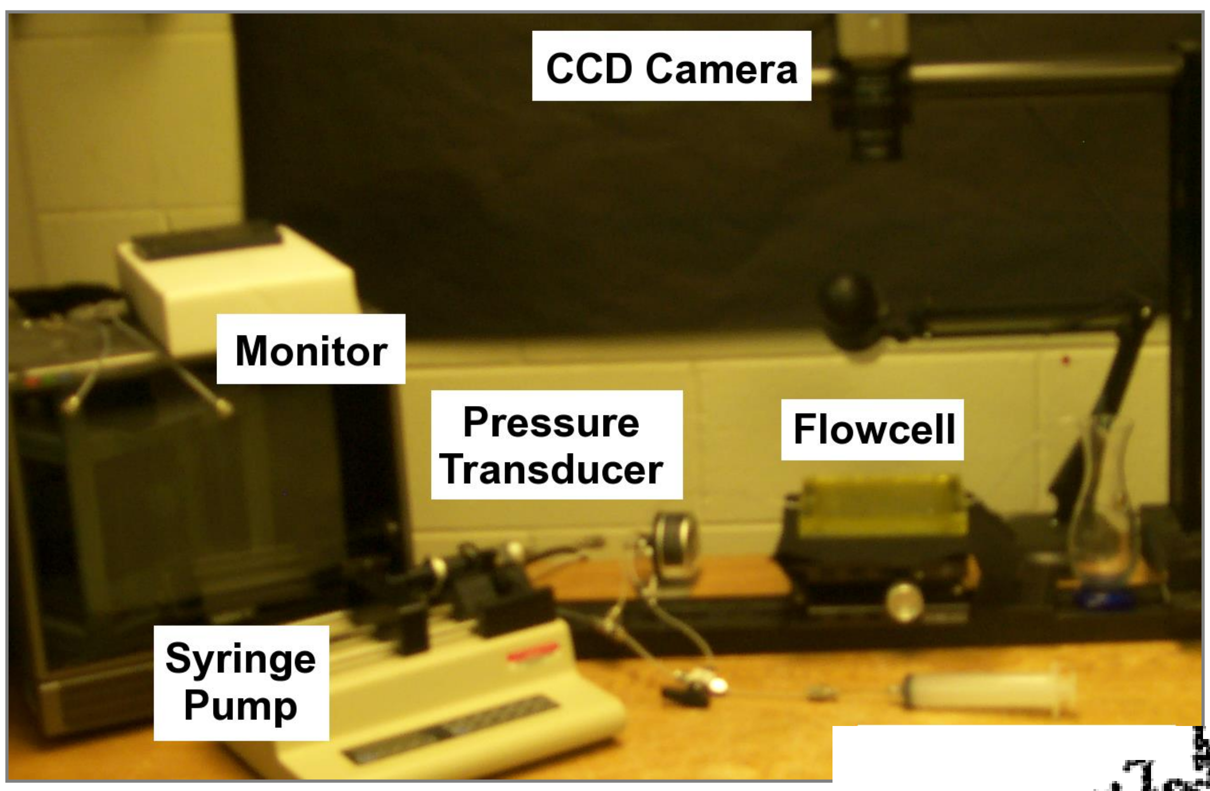
When multiple fluids flow through a porous medium, the interaction between the fluid interfaces can be of great importance. While this is widely recognized in practical applications, numerical models often disregard interactions between discrete fluid phases due to the computational complexity. And rightly so, for this level of detail is well beyond most extended Darcy Law relationships. A new model of two-phase flow including the interfacial area has been proposed by Hassanizadeh and Gray based upon thermodynamic principles. A version of this general equation set has been implemented by Niessner and Hassanizadeh. Many of the interfacial parameters required by this equation set have never been determined from experiments. The work presented here is a description of how the interfacial area, capillary pressure, interfacial velocity and interfacial permeability from two-phase flow experiments in porous media experiments can be used to determine the required parameters.

# Experiments

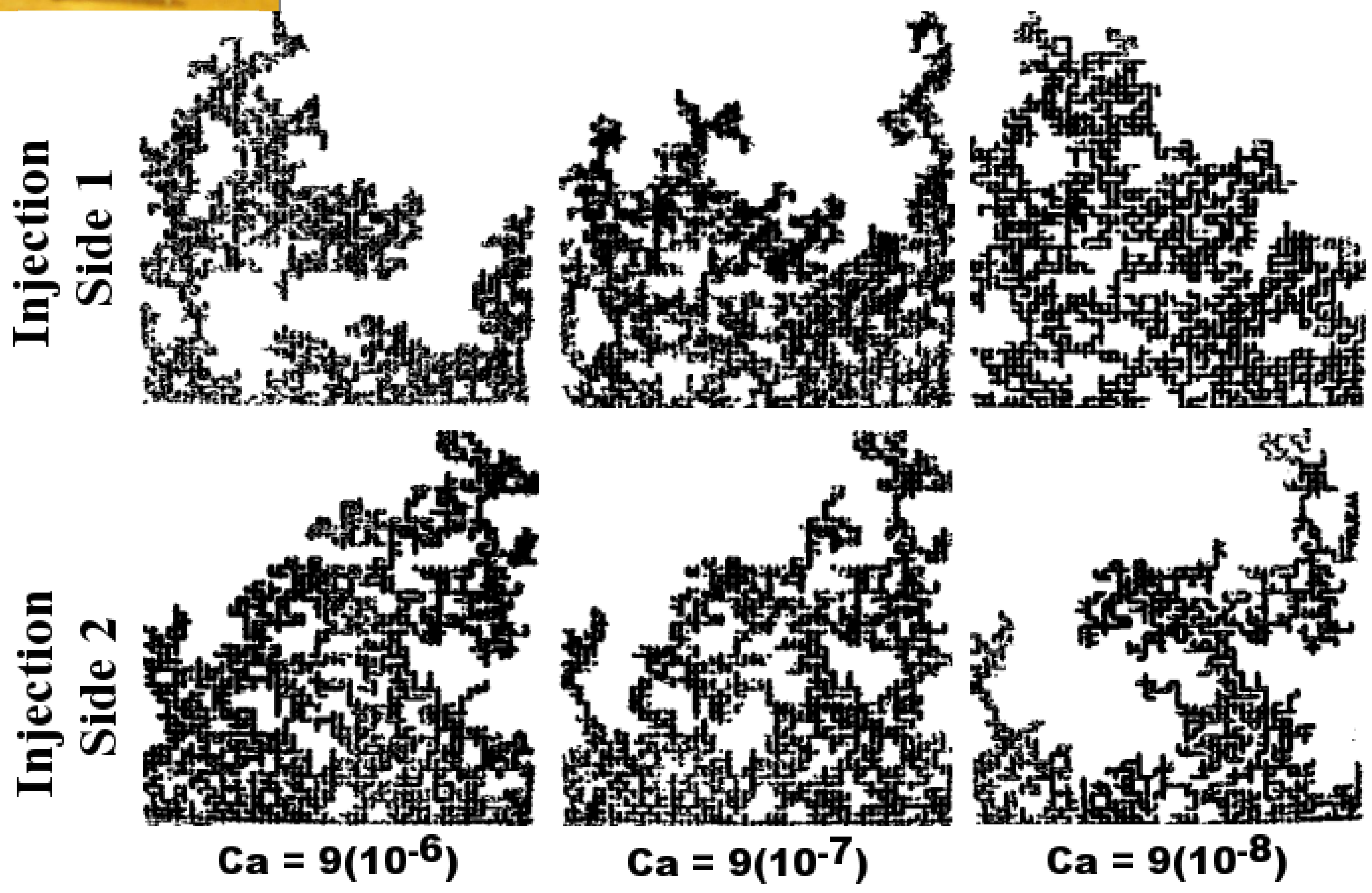
- Porous flowcell created using stereolithography.
- Variable throat heights, for greater range of pore level resistances.
- 10.16 by 10.16 cm viewable matrix.
- 5000 throats.
- Computer-generated geometry.






- Air injection into water.
- Constant rate injection via syringe pump.
- Grey scale images from CCD camera.
- Time to breakthrough, 5 min to 10+ hours.
- 2000 to 5000 images per experiment.



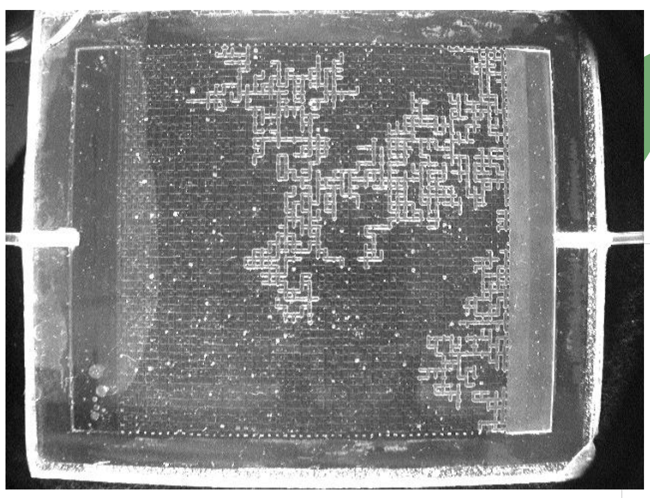

- Batch image processing performed on grey-scale images.
- Isolates the injected air.
- Constant rate injection, Q = 0.2 to 0.002 $^{ml}/_{min}$, with

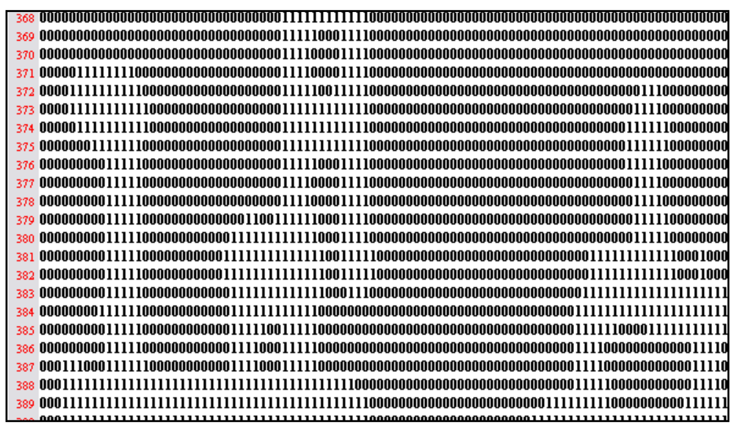
# Image Processing

• Conversion of black and white images to binary text files.

• Map the known flowcell matrix geometry onto this 'image'.

• The resulting lattice of invaded throats allows the location and size of the individual interfaces to be determined.





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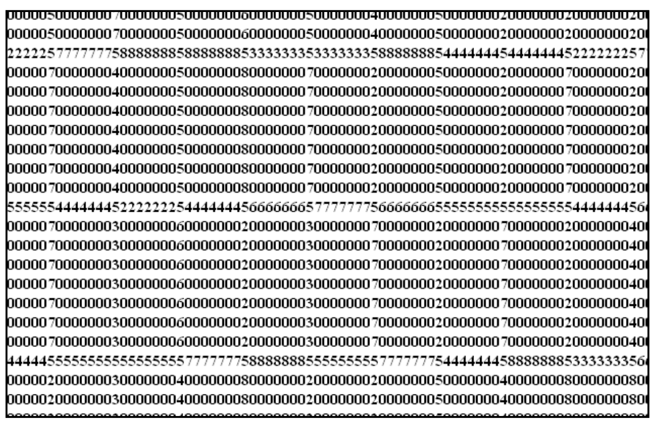

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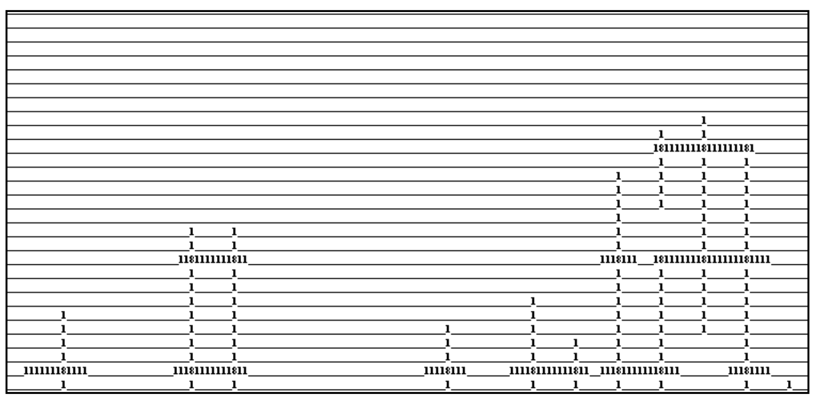
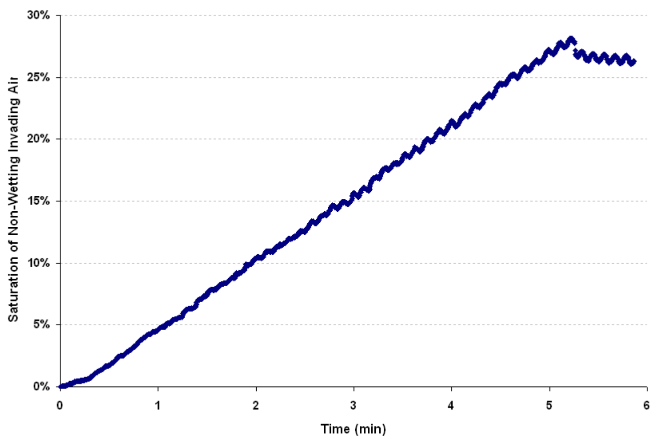
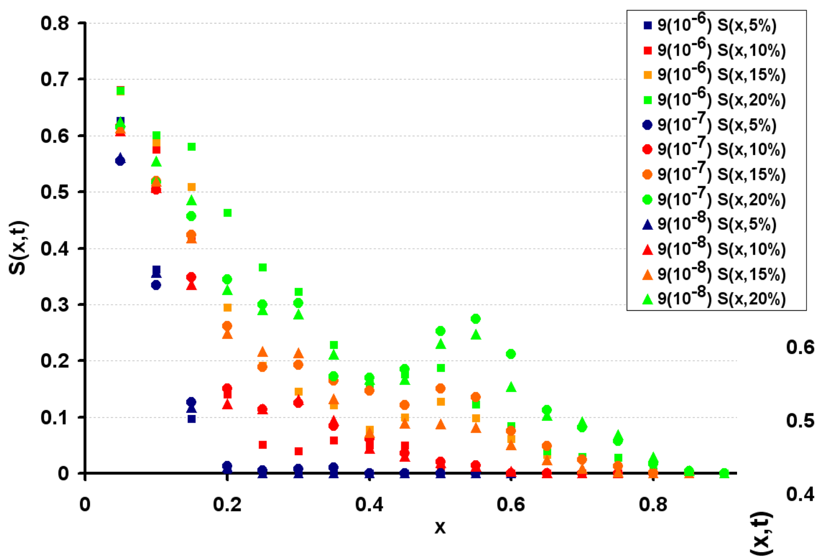


# Saturation Profiles

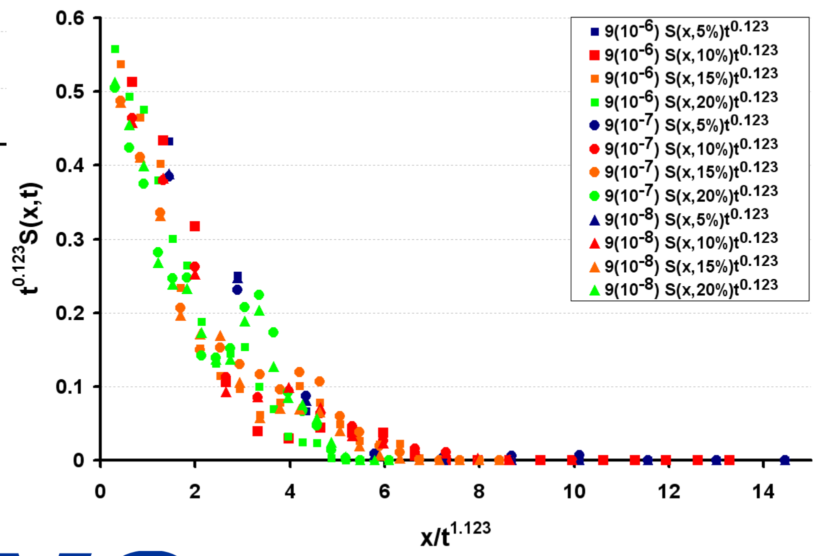
• Knowledge of the invaded throats enabled the calculation of saturation as a function of the time.




•The saturation profiles were also determined, as a function of the total amount of injected fluid.

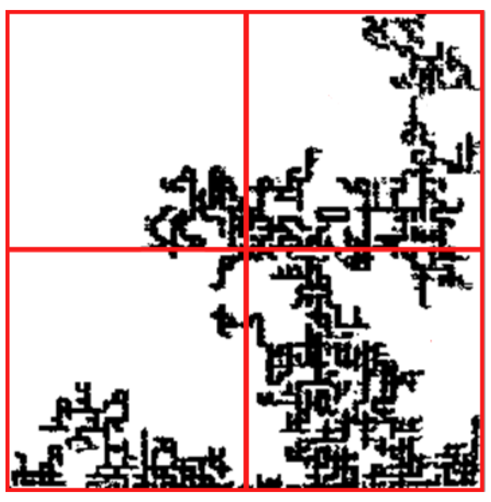



• A fractal scaling of the saturation profiles using the predictions of Ferer et al. was attempted, and fair agreement was observed.

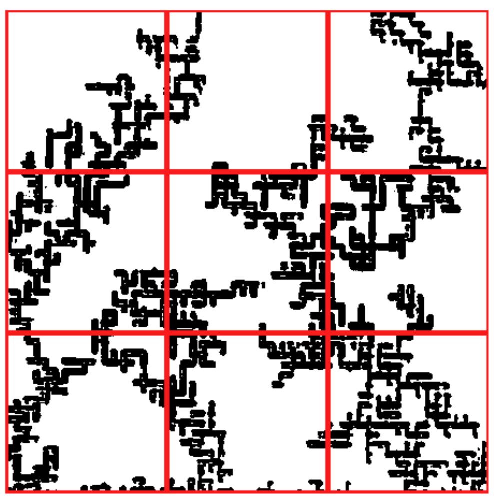



# Representative Elemental Volumes

n = 2



n = 3



## Porosity of REVs

| n | average [%] | minimum [%] | maximum [%] | standard deviation [%] |
|---|---|---|---|---|
| 2 | 35.89 | 35.41 | 36.71 | 0.57 |
| 3 | 35.61 | 34.23 | 37.21 | 0.92 |
| 4 | 35.99 | 34.16 | 38.82 | 1.28 |
| 5 | 35.77 | 32.08 | 38.87 | 1.66 |

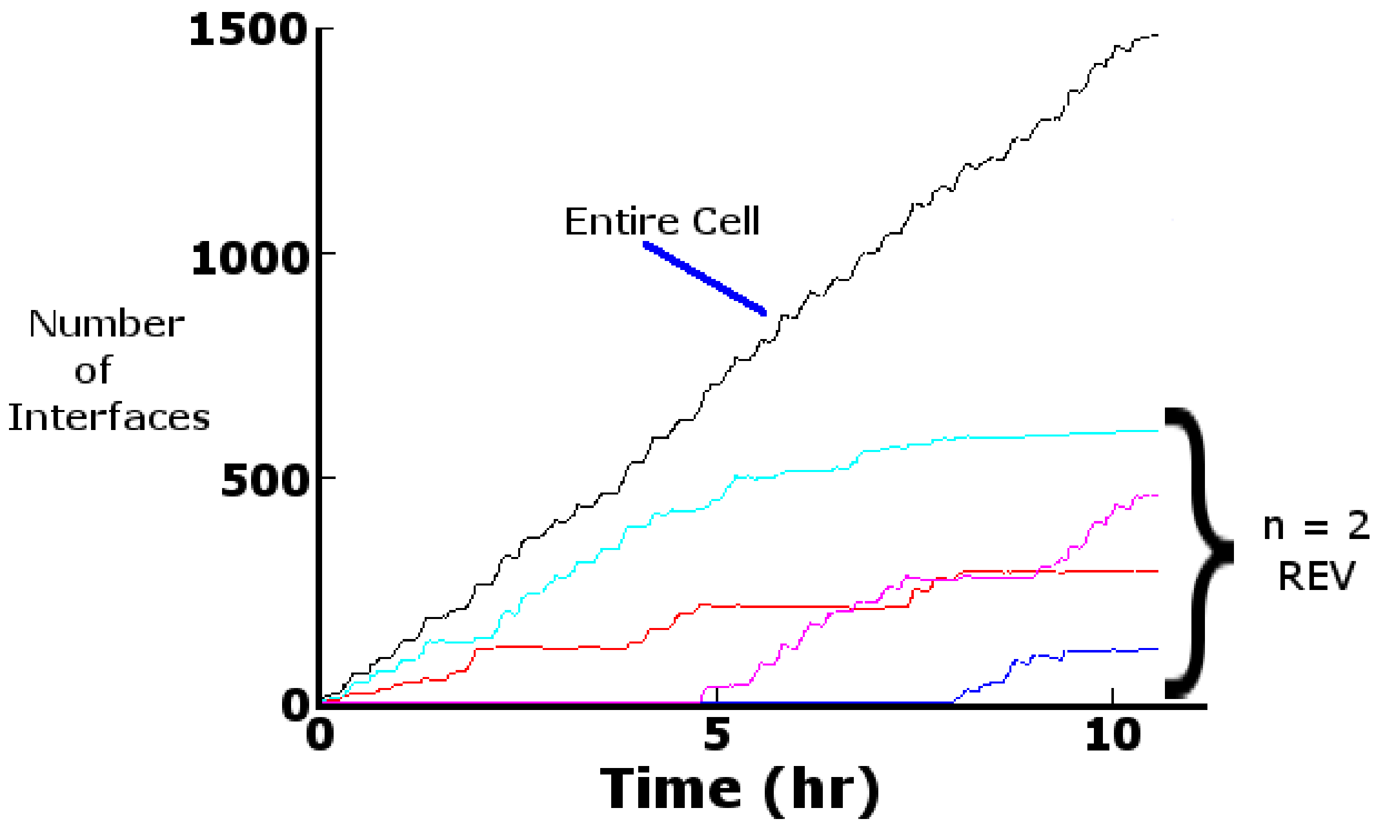
• To get more information from the data, analysis was performed on different sized REVs.

• Cell subdivided into n x n REVs.

• The porosity was used as an initial estimate of how much variation between REVs there is.

• For REVs with n < 4, quite similar.

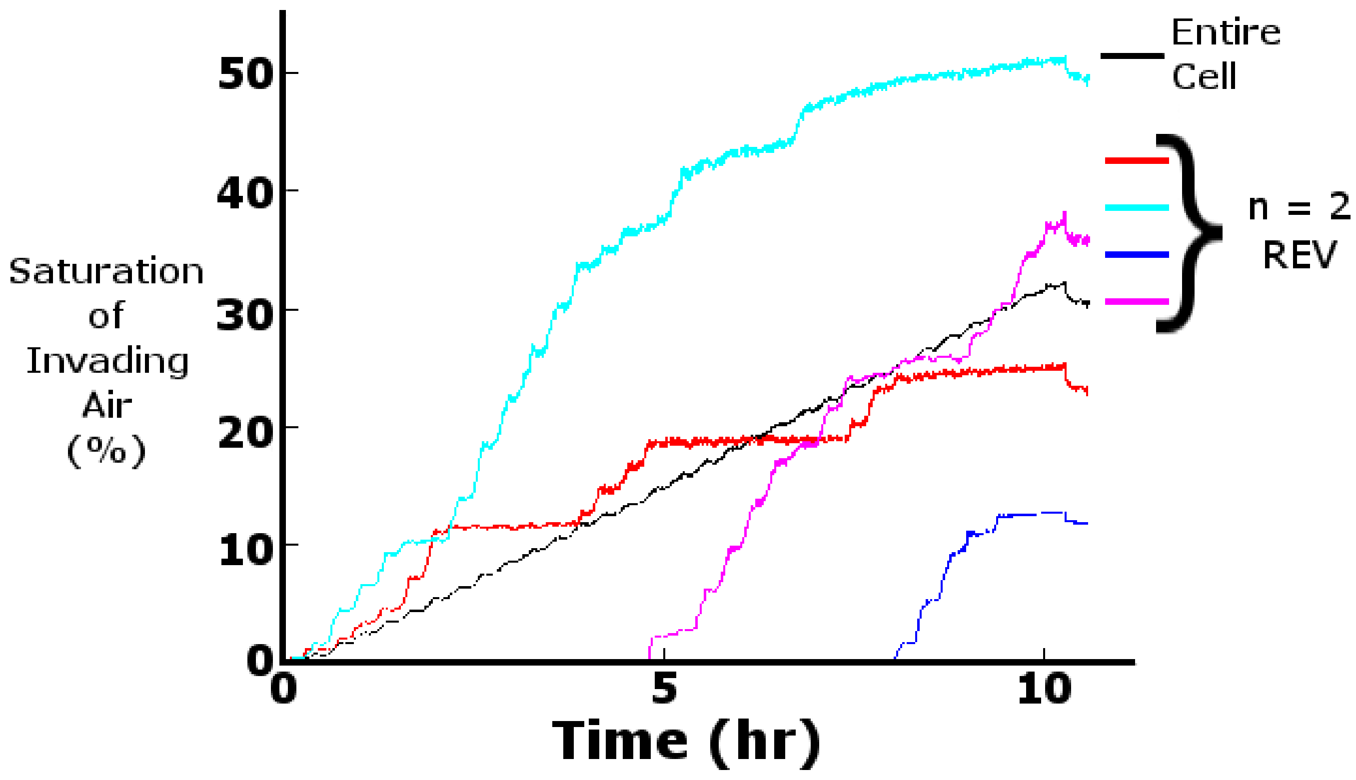
# Interfacial Area

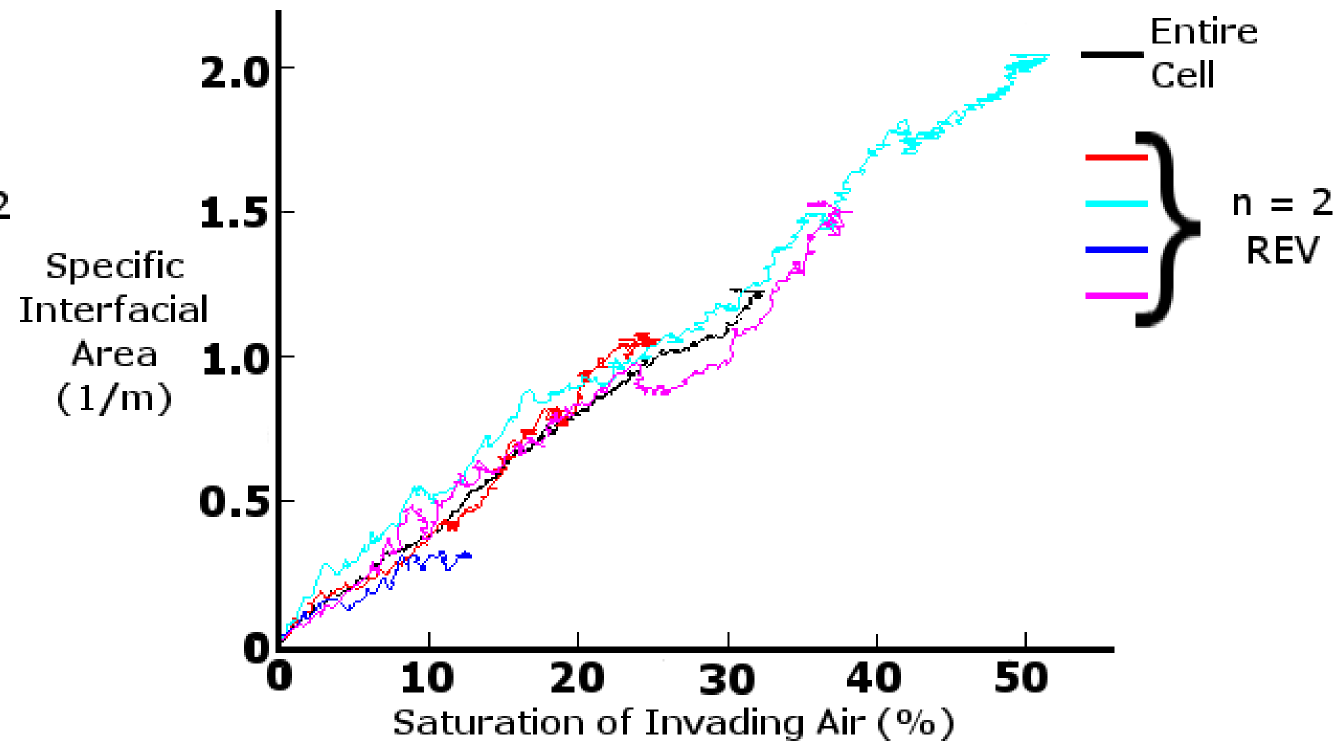



• Individual interfaces were identified from the digitized images.

• The area of each interface was approximated by the area of the throat.

• The specific interfacial area Is observed to increase linearly with increasing saturation during the initial drainage of the flowcell.




# Capillary Pressure

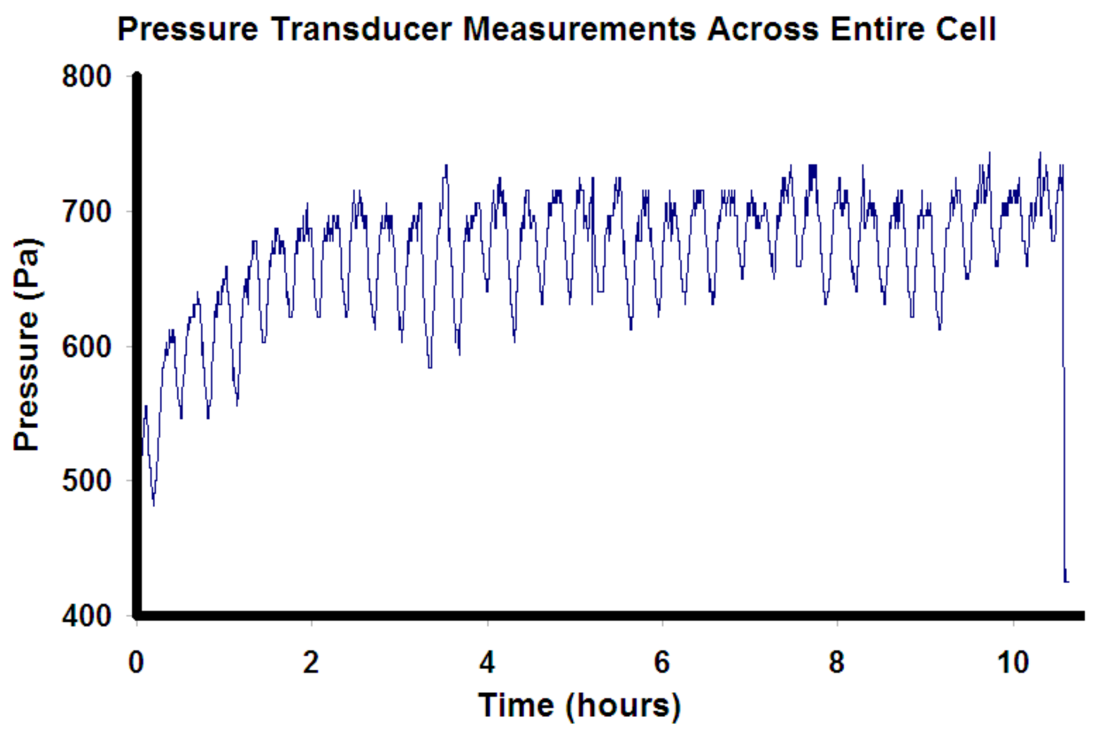
• The capillary pressure of each interface was calculated with $P_c \approx 2\sigma\left(h_t^{-1} + w_t^{-1}\right)$

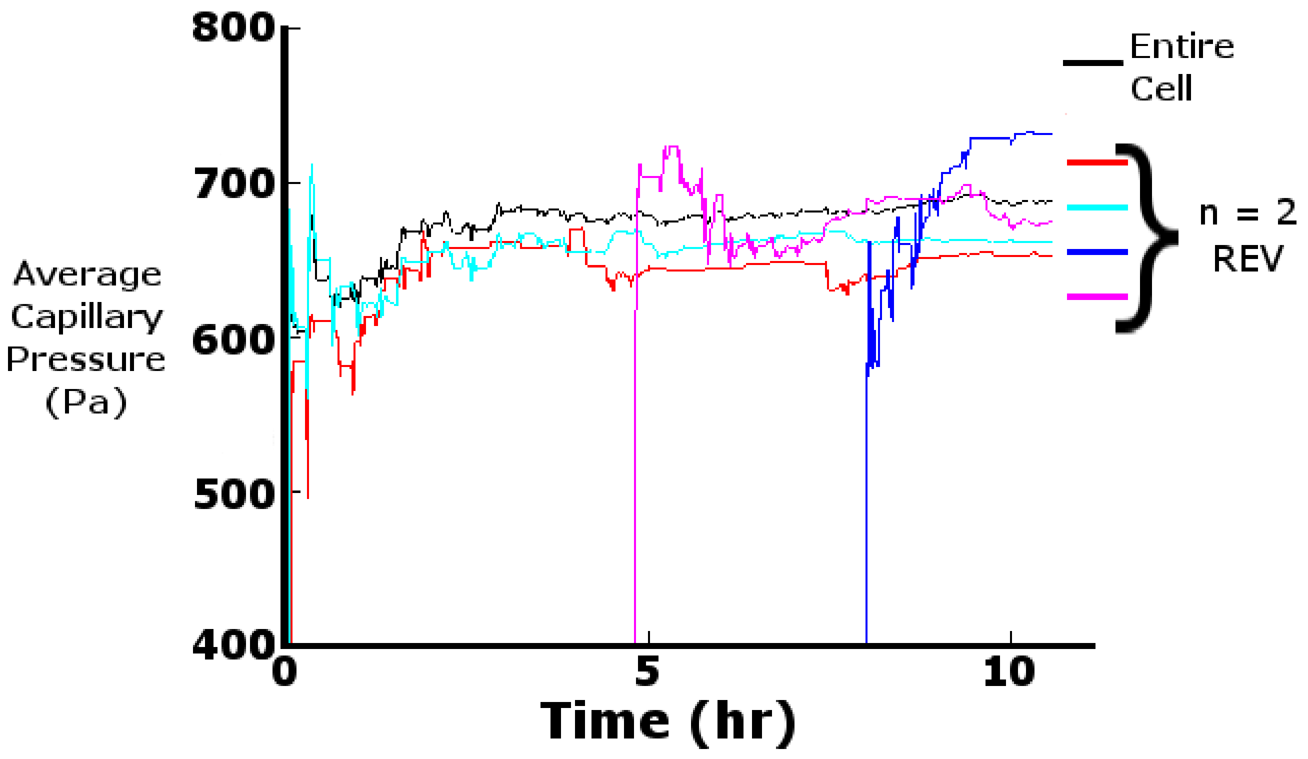
• Calculated $P_c$s were averaged over the entire flowcell, as well as within the REVs.

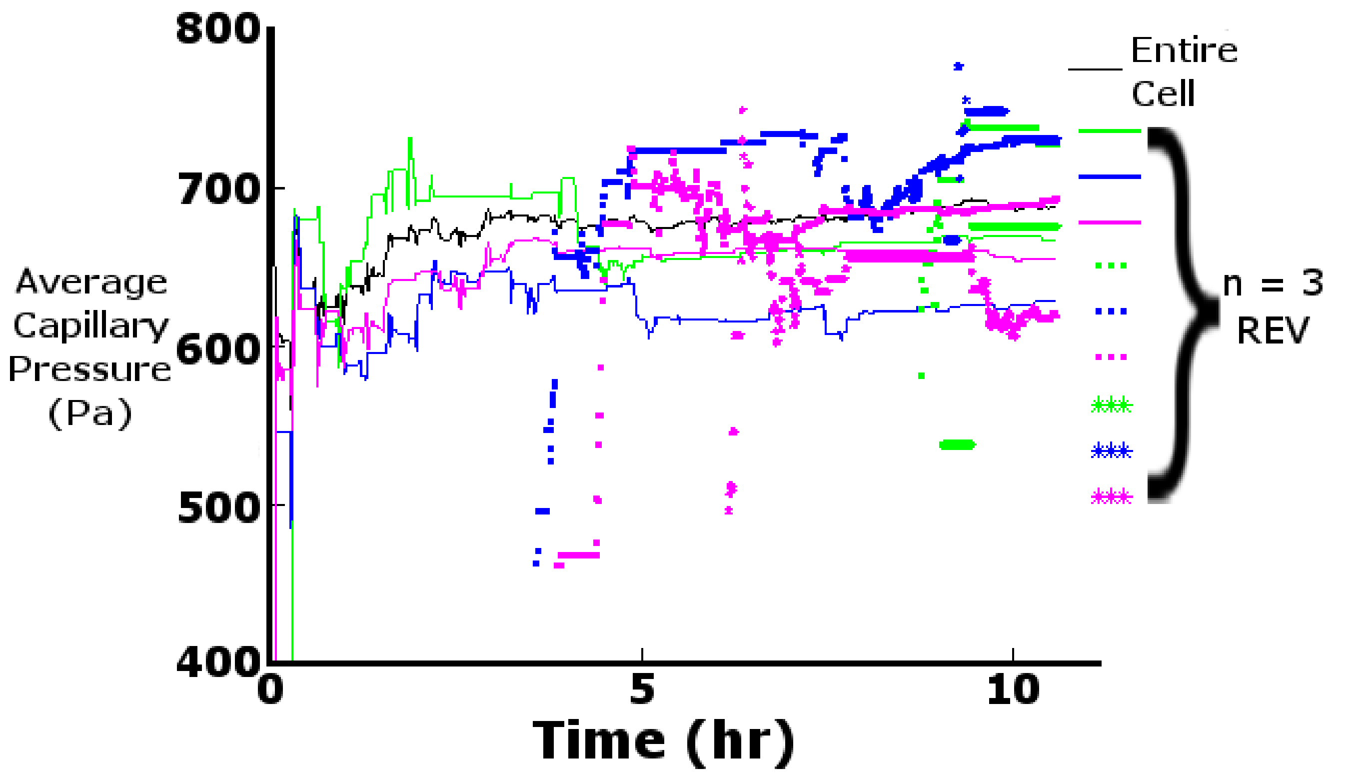
$$p_c = \frac{\sum P_c}{\# Interfaces}$$

•The average capillary pressure was approximately constant throughout the experiments, similar to what was measured by the pressure transducer.

• Calculations of $p_c$ in REVs with n = 2 and 3 were observed to follow similar behavior, with a greater amount of variation due to the smaller number of throats being averaged.



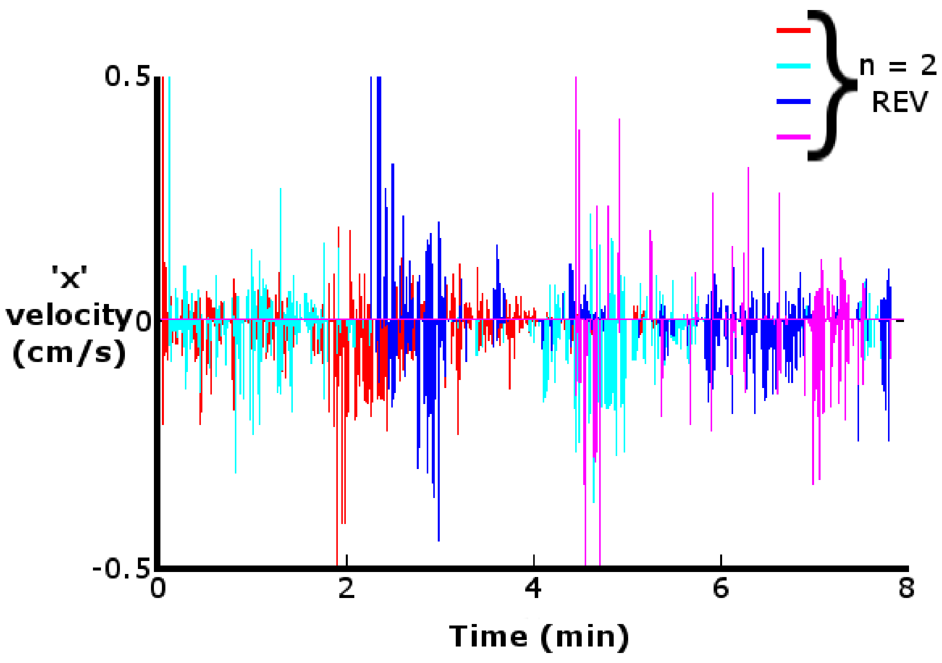



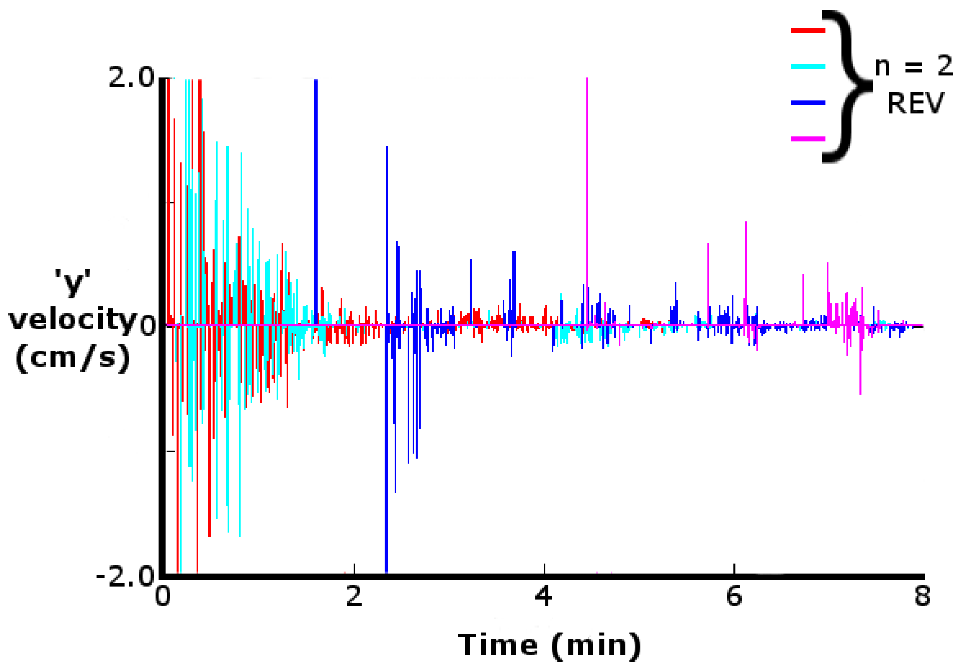
# Interfacial Velocity

• Calculations of the interfacial velocity are currently plagued by the large scale ‘bursting’ behavior of the invading fluid, making the determination of an appropriate $\Delta t$ to average the interface location over difficult, using the following equations,

$$v_x = \frac{1}{I_x}\sum_{i=1}^{I_x}\frac{\Delta x}{\Delta t} \qquad v_y = \frac{1}{I_y}\sum_{i=1}^{I_y}\frac{\Delta y}{\Delta t}$$

• Velocity calculations using these equations fluctuate frequently, over a wide range.




• Once a proper method of describing the interfacial velocity is determined, we plan to describe the interfacial production, $E_{wn}$, and the interfacial permeability, $K_{wn}$.

$$E_{wn} = \frac{\partial a_{wn}}{\partial t} + \nabla\cdot\left(a_{wn}\underline{v}_{wn}\right) \qquad K_{jj,wn} = -\frac{v_{j,wn}}{\frac{\partial a_{wn}}{\partial j}} \quad j = Direction$$

# Conclusions

This work, while on-going, has shown the possibility of digitizing images within translucent porous media and identifying the location and behavior of interfaces under dynamic conditions. Using the described methods experimentally derived interfacial functions to be used in larger scale simulations are currently being developed. In summary, the following conclusions can be drawn,

• By mapping a pore-throat geometry onto an image of immiscible fluid flow, the saturation of fluids and the individual interfaces between the fluids can be identified.

• The resulting saturation profiles of the low velocity drainage flows used in this study are well described by a invasion percolation fractal scaling.

• The interfacial area between fluids has been observed to increase in a linear fashion during the initial invasion of the non-wetting fluid.

• The average capillary pressure within the entire cell and representative elemental volumes were observed to plateau after a small portion of the volume was invaded.

# Acknowledgements


The work of D. Crandall was funded by the National Research Council through a Research Associateship Program Award at the National Energy Technology Laboratory in Morgantown, WV USA. This work was funded by the German research foundation (DFG). J. Niessner and S.M. Hassanizadeh are members of the International Research Training Group NUPUS, financed by the DFG and The Netherlands Organization for Scientific Research (NWO). Thank you to the DFG (GRK 1398) and NWO (DN 81-754) for their support.

Additional gratitude is extended to Martin Ferer for his aid with the fractal scaling and to Goodarz Ahmadi for his initial and ongoing support of this partnership.


# References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