Using Micromodels to Understand the Flow of Two Fluids

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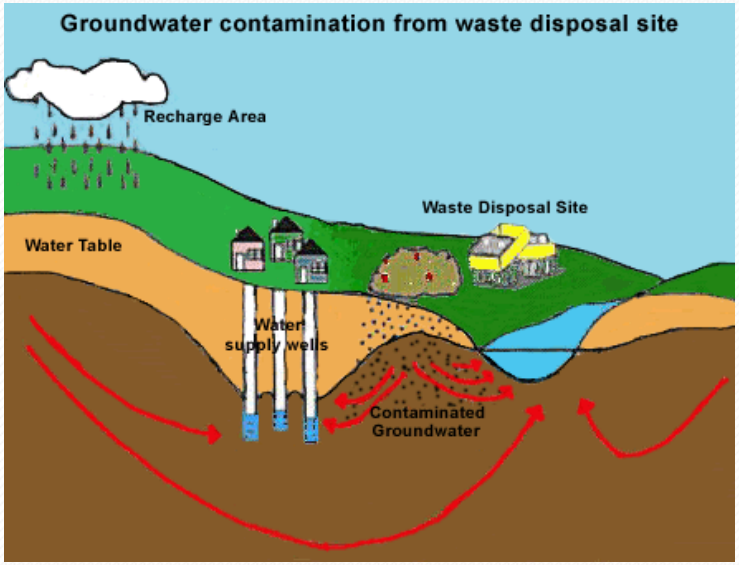
Working with Professor Pyrak-Nolte and Chris Petrovich

Fluid Dynamics

- Darcy's Law works for one fluid flowing through porous media, but not two

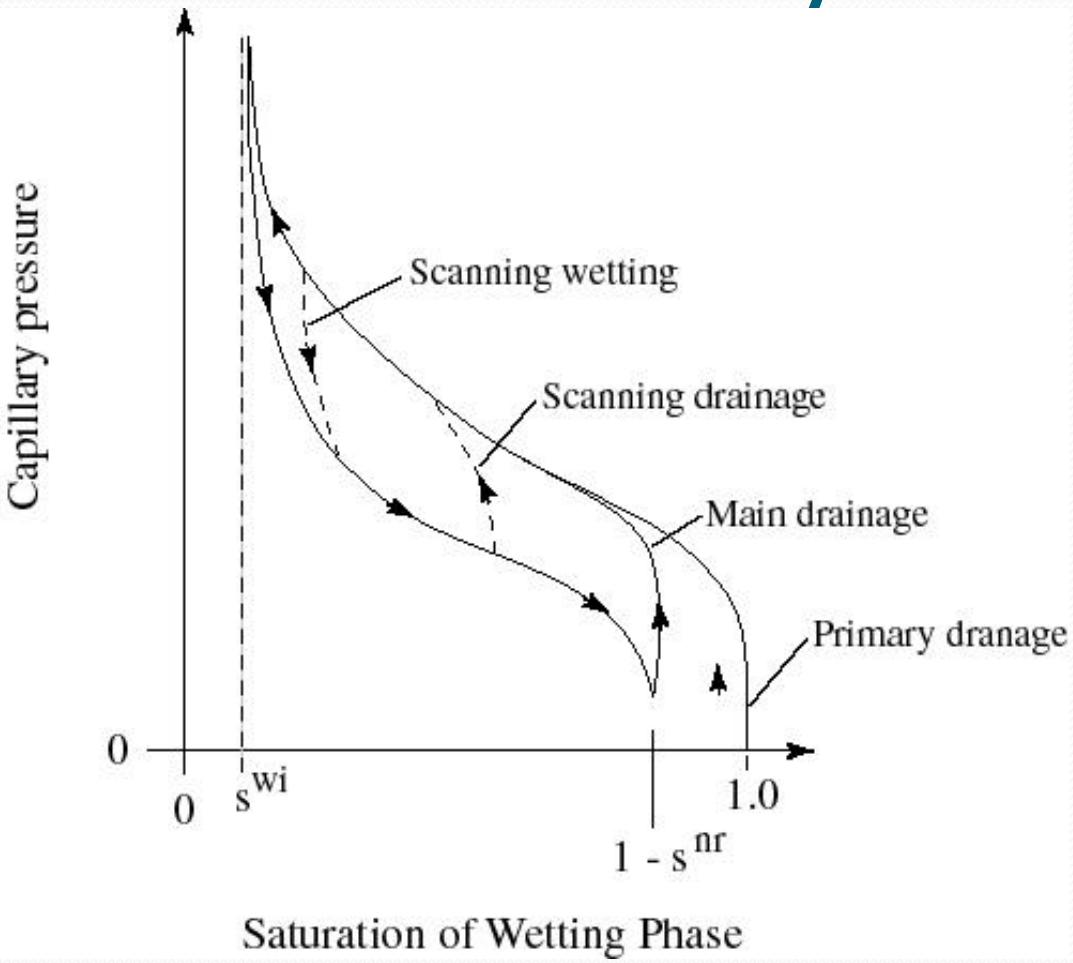
$$Q = \frac{-\kappa A}{\mu}\frac{(P_b - P_a)}{L}$$

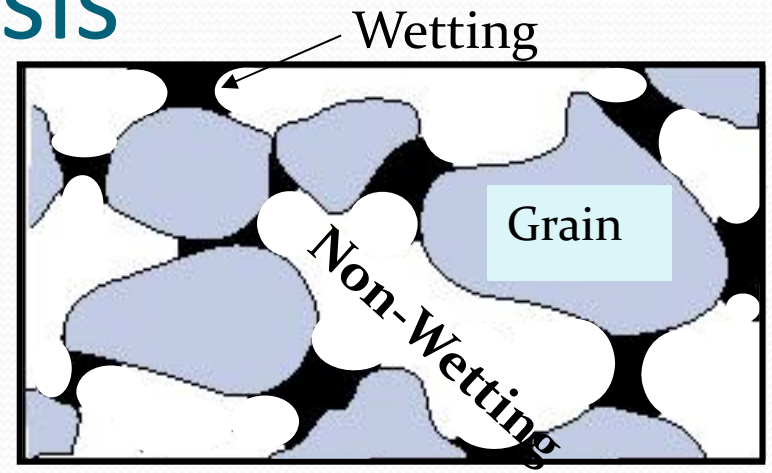
- Interfacial Area per Volume (IAV)
- Useful for ground water contamination, chemical mixing, oil

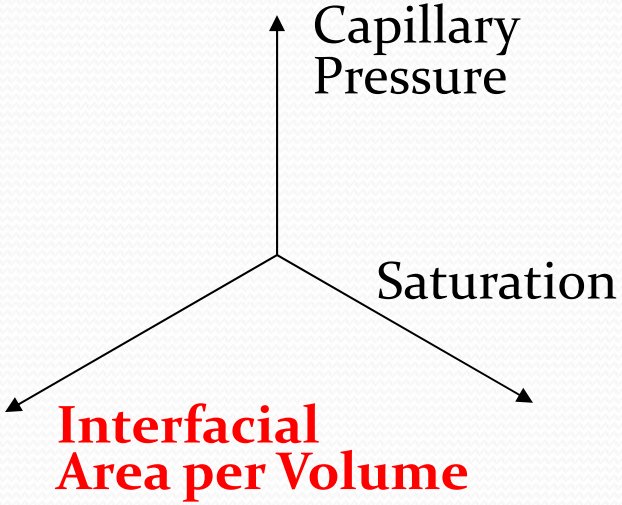


http://www.ec.gc.ca/EnviroZine/english/issues/36/any_questions_e.cfm

Capillary Pressure - Saturation Hysteresis



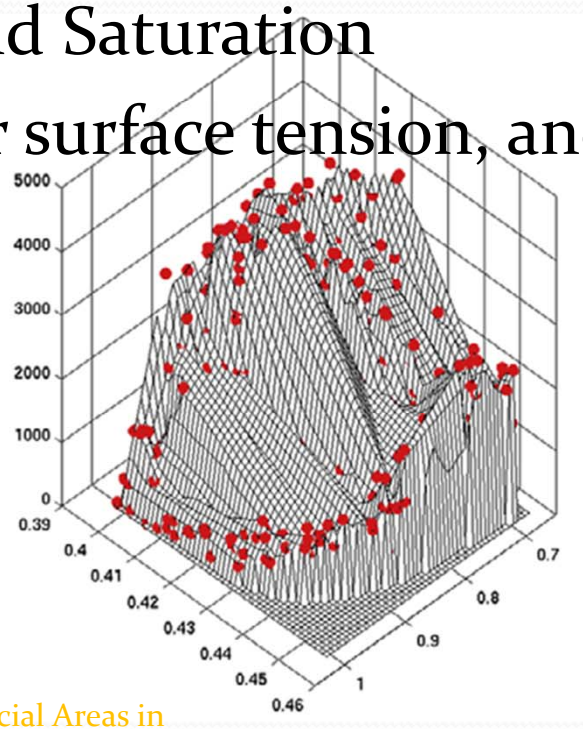




Diagrams from Pyrak-Nolte

Past Experiments

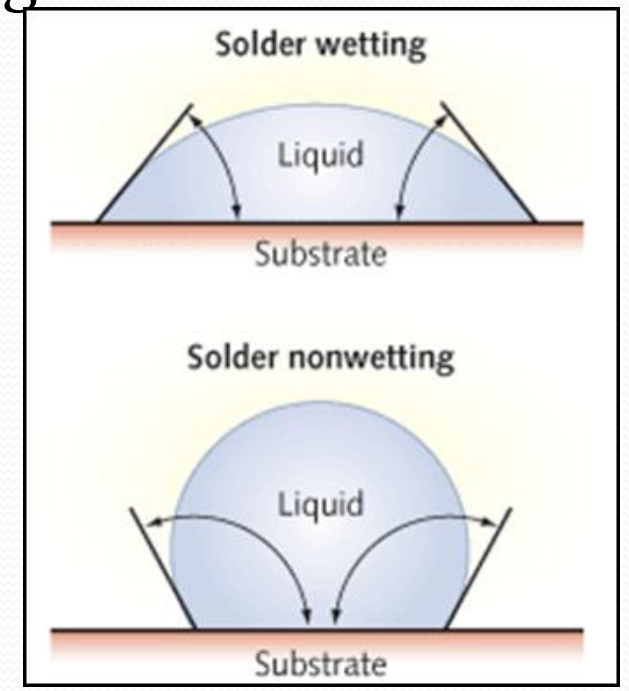
- Cheng, Pyrak-Nolte, et al found that IAV works as a state variable
- IAV is a function of Pressure and Saturation
- Some have questioned whether surface tension, and not IAV could predict the flow



"Linking Pressure and Saturation Through Interfacial Areas in Porous Media", Cheng et al, 2004

Purpose

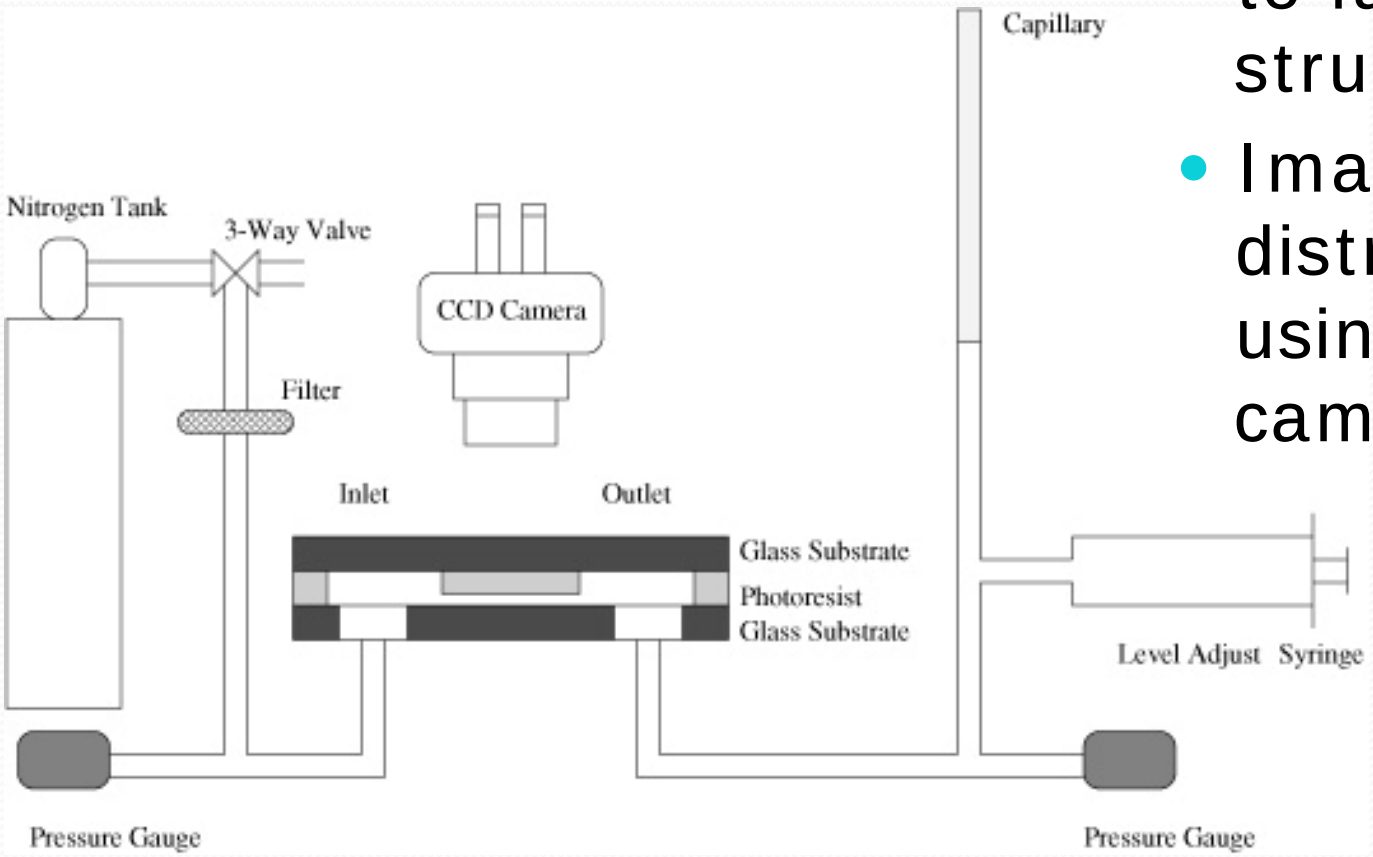
- Compare the effects of surface tension on fluid flow, using different fluids with Nitrogen gas
  - 1. Decane --23.83mN/m
  - 2. Glycerine --64.00mN/m
  - 3. Olive Oil --40mN/m
  - 4. Water --72mN/m
- Wetting and Non-wetting



http://solutions.palomartechnologies.com/Portals/60069/images//Wetting%20vs%20non-wetting%20conditions-resized-600.JPG

Micromodels

- Use Photoresist to fabricate pore structures
- Image fluid distributions using CCD camera



http://www.physics.purdue.edu/rockphys/support.php

Making Micromodels

- Clean slides
- Coat with photoresist and bake
- Expose patterns
- Develop
- Seal
- 105 slides fabricated

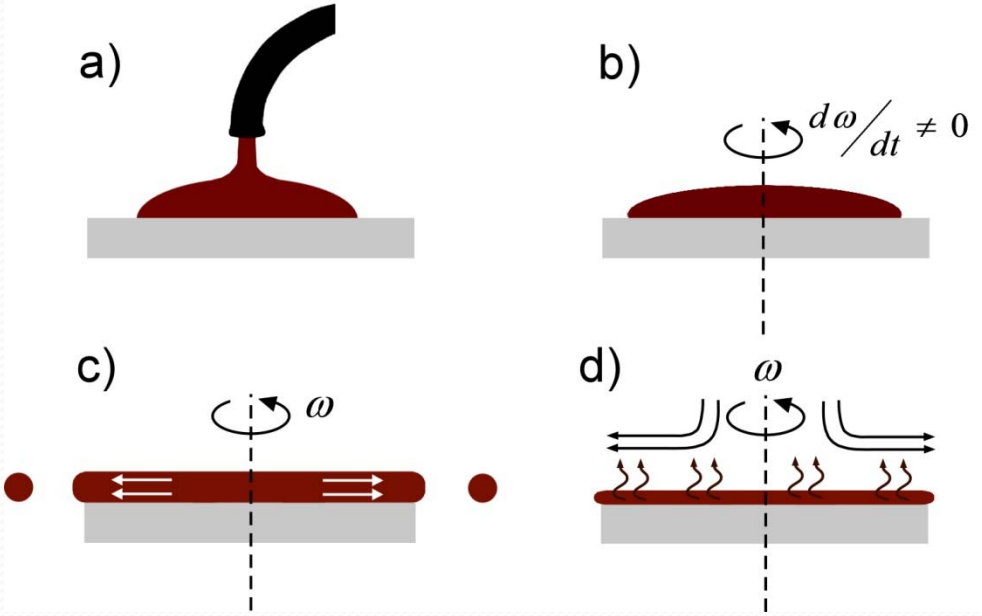
Cleaning Slides

- Dust
- Alcohol
- Acetone
- HCl
- Piranha
- Sonicator
- Filtered Water

Sonicator

Spin Coating

- Need even layer of Photoresist
- 1 micron(10^{-6} m)thick
- 3000 rpm for 30 sec
- Bake 30 min at 90°C



$$h = \frac{h_o}{\sqrt{1 + \frac{4\omega^2 \rho h_o^2 t}{3\eta}}}$$

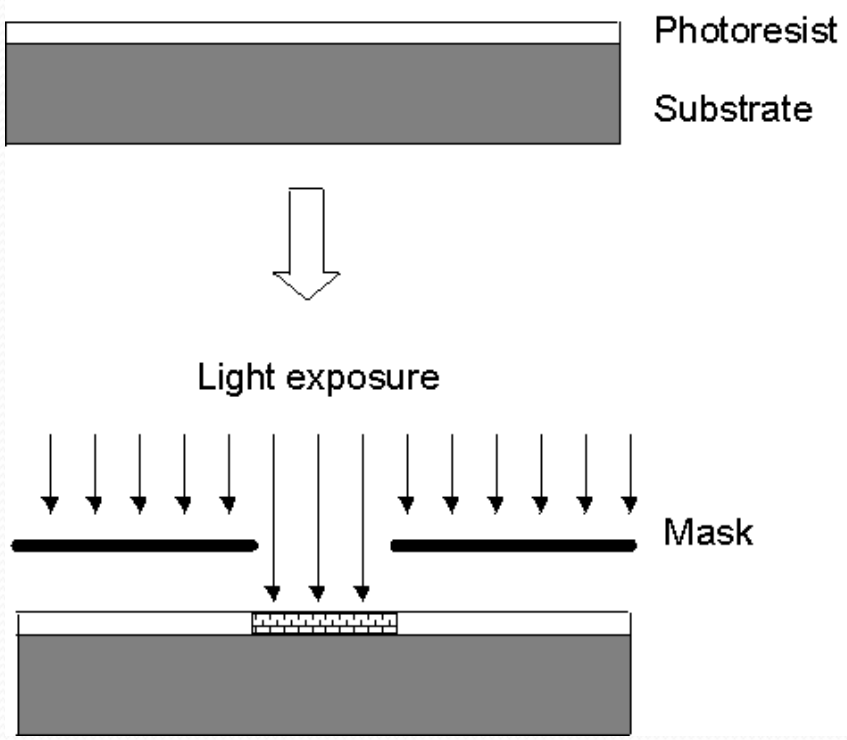
$$r = r_o \sqrt[3/4]{1 + \frac{4\omega^2 \rho h_o^2 t}{3\eta}}$$

http://large.stanford.edu/courses/ph210/hellstrom1/

SpinCoater

Photoresist

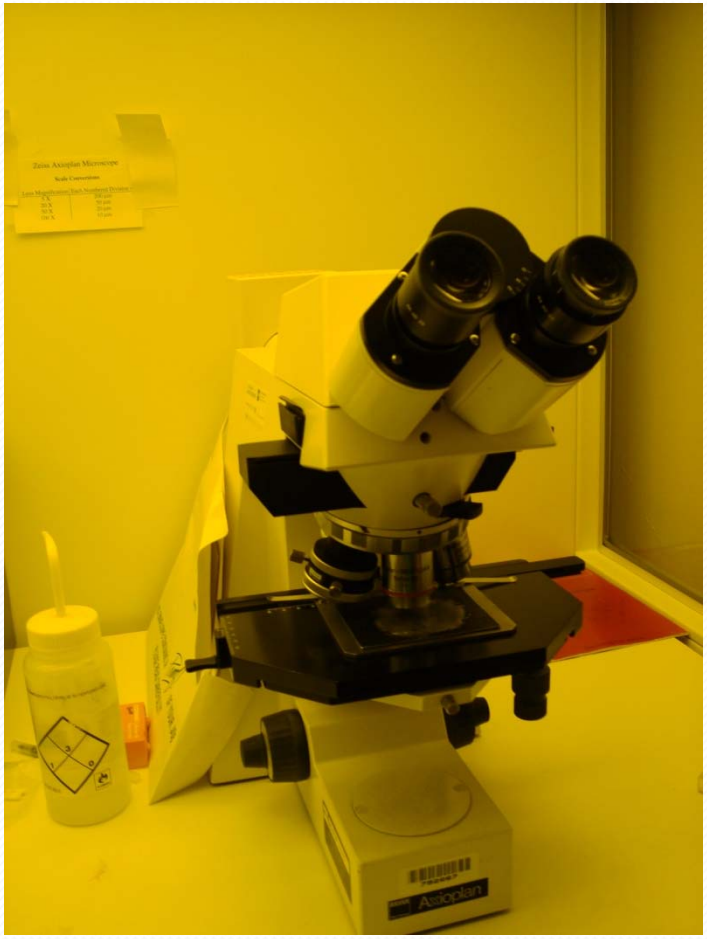
- PMMA: Polymethylmethacrylate
- Positive photoresist reacts with UV light to become soluble in developer
- Yellow Room



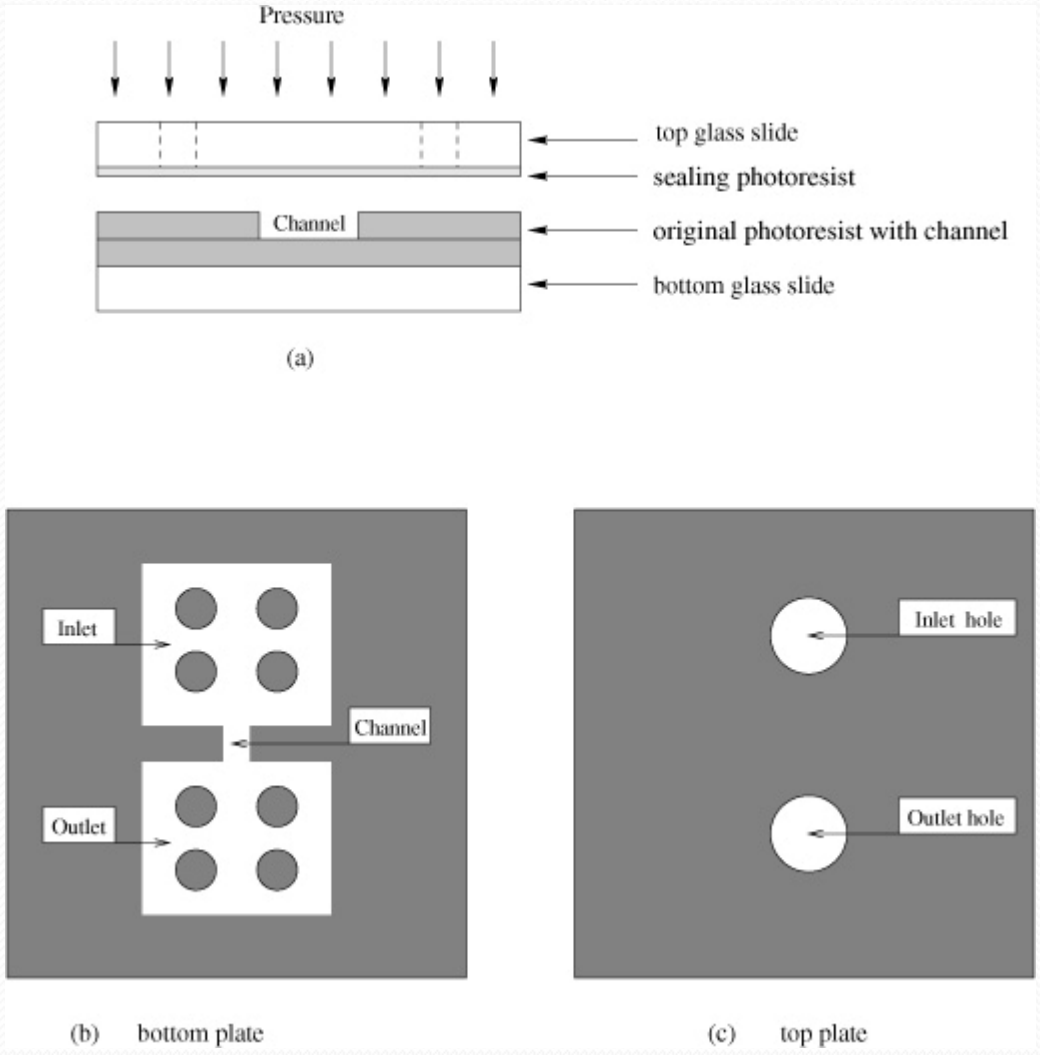
http://chem.chem.rochester.edu/~chem421/polymod2.htm

Exposures

Direct Exposure

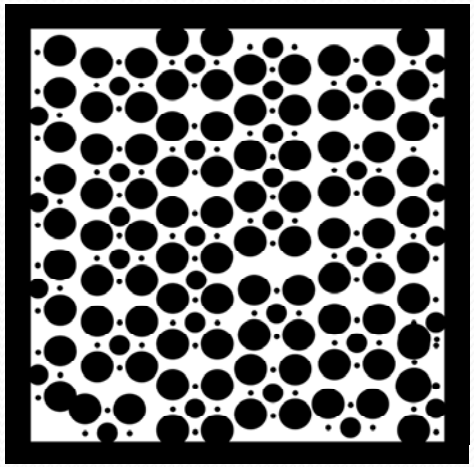


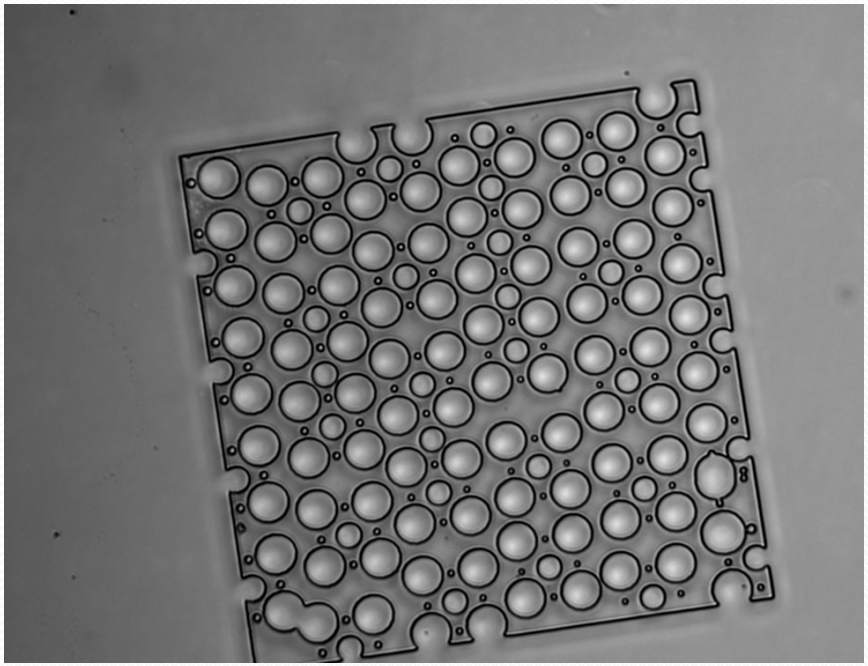
Projection



http://www.physics.purdue.edu/rockphys/support.php

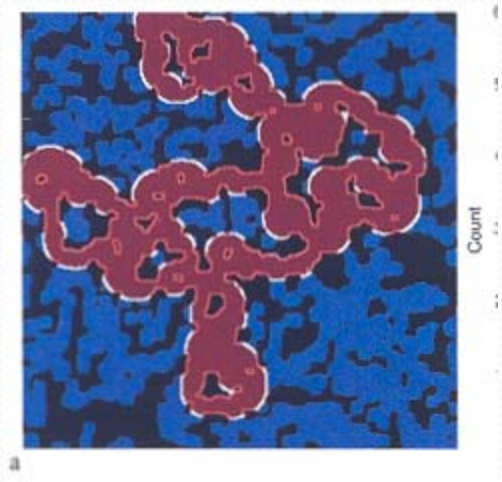
Pore Structure





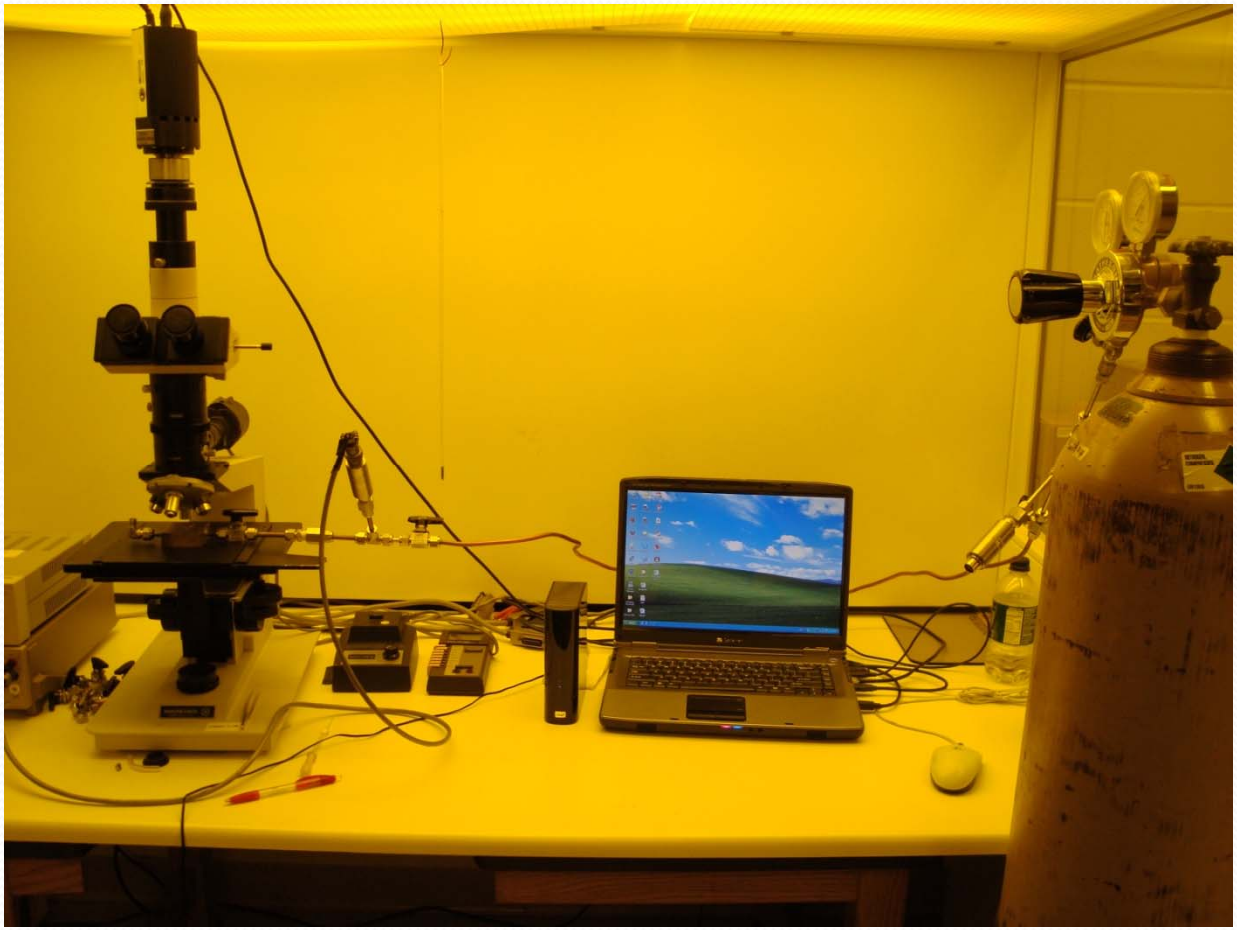
Data Collection

- Fill pores with wetting fluid, then Nitrogen
- Take CCD images during experiment
- Measure pressure
- Use IDL program to count pixels and find IAV and saturation



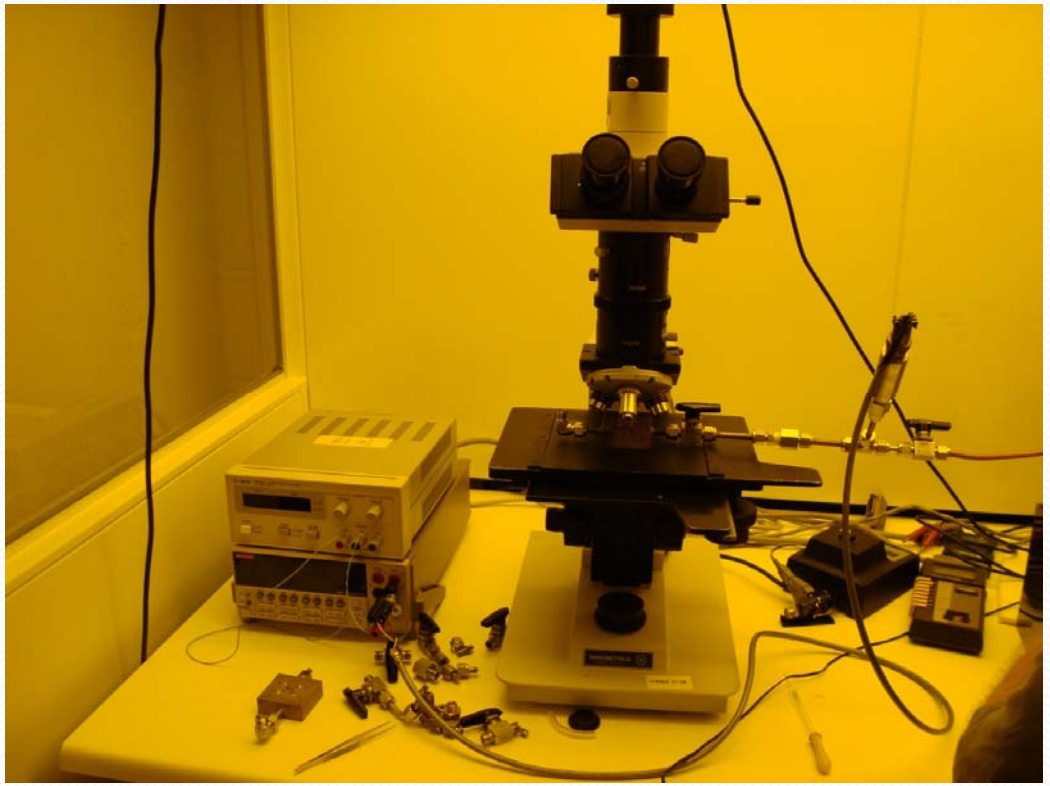
"Linking Pressure and Saturation Through Interfacial Areas in Porous Media", Cheng et al, 2004

Experiment Setup



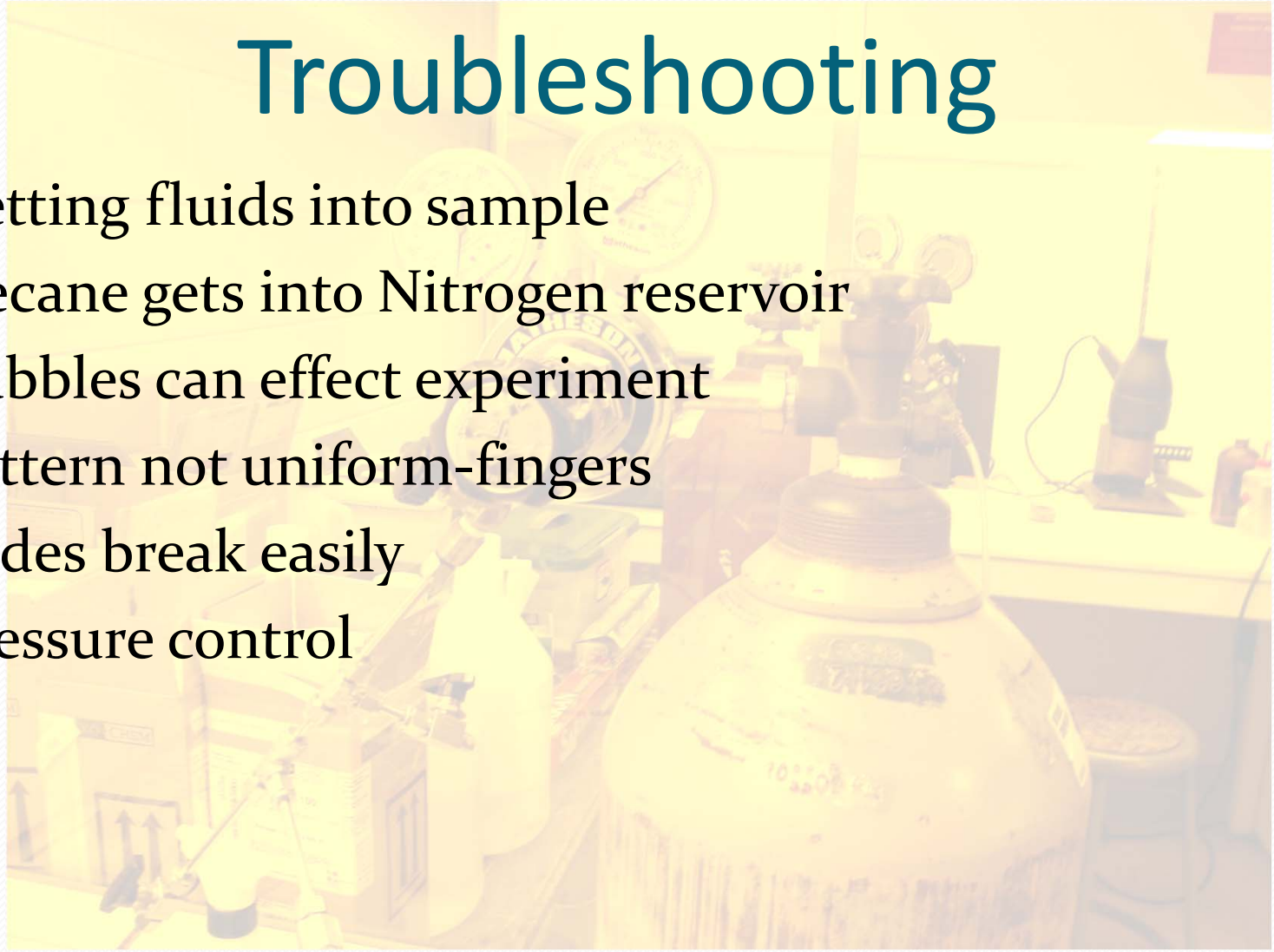
Running the Experiment

- Decane (wetting)
- Breakthrough
- Paths in the pattern
- Equilibrium



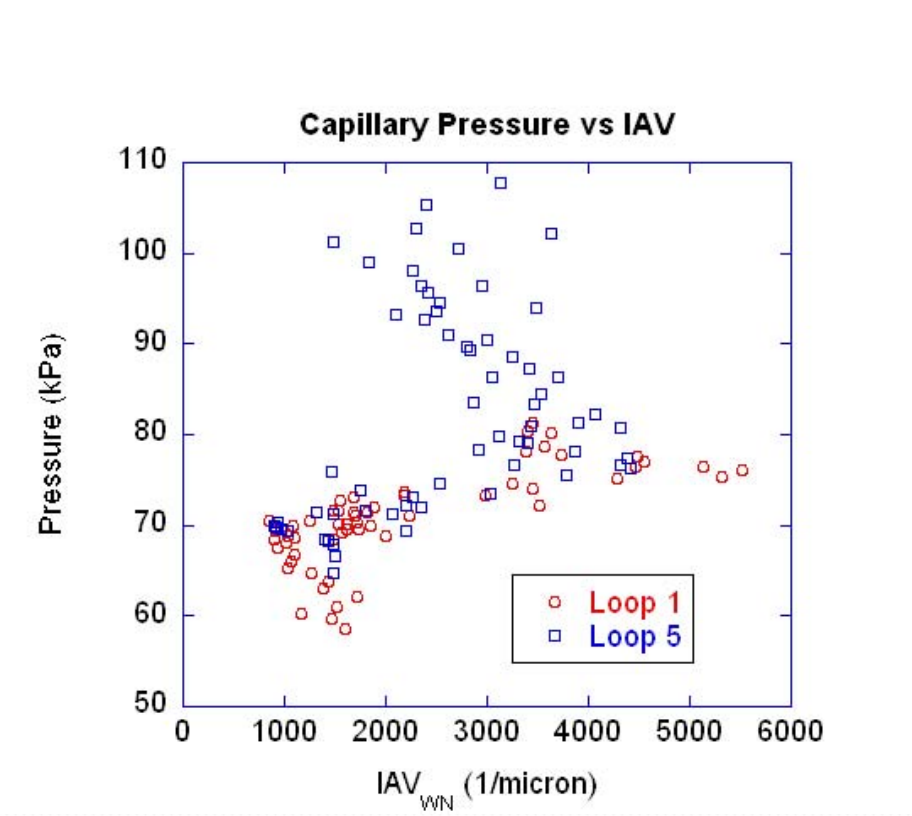
Troubleshooting

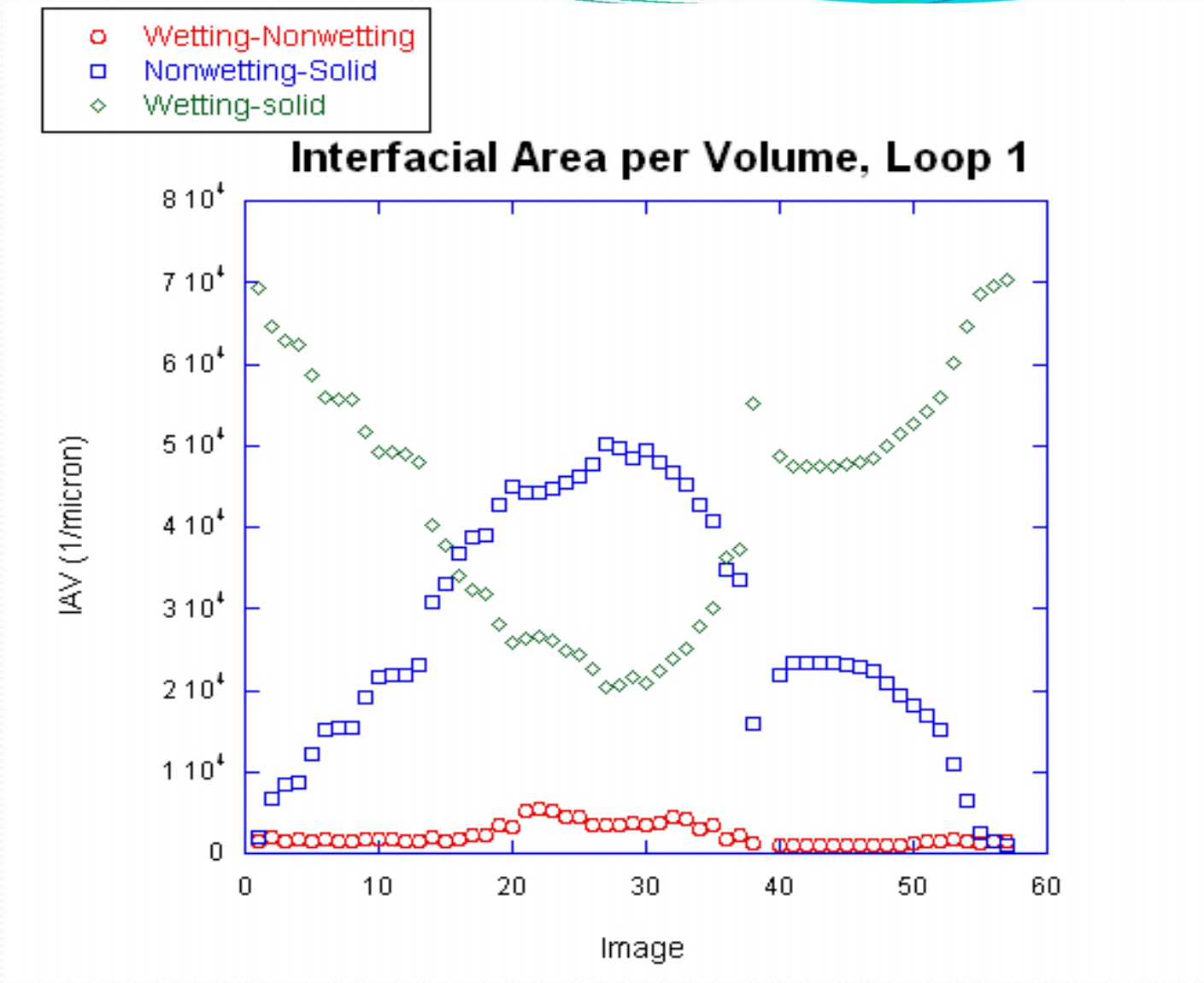
- Getting fluids into sample
- Decane gets into Nitrogen reservoir
- Bubbles can effect experiment
- Pattern not uniform-fingers
- Slides break easily
- Pressure control

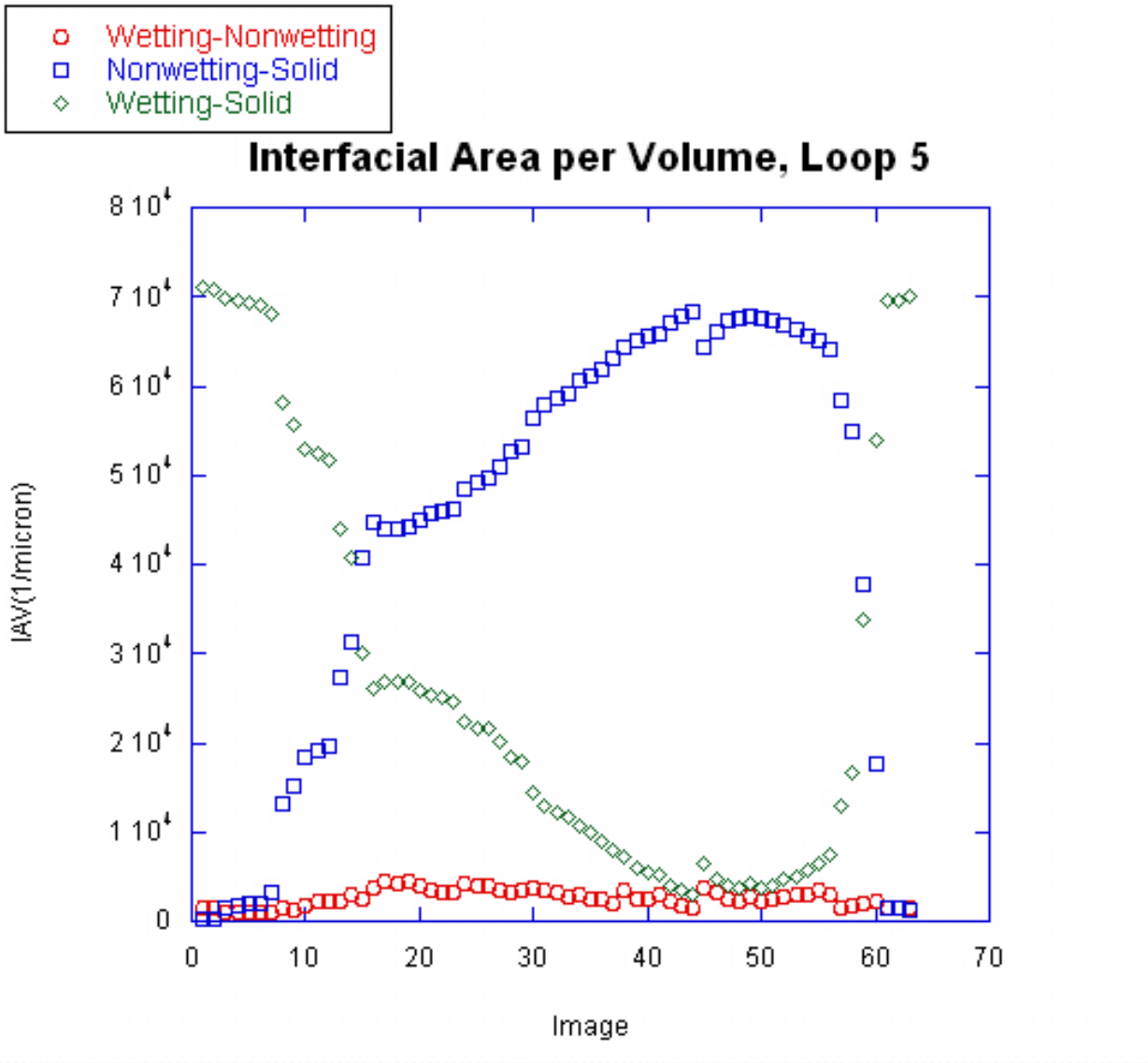


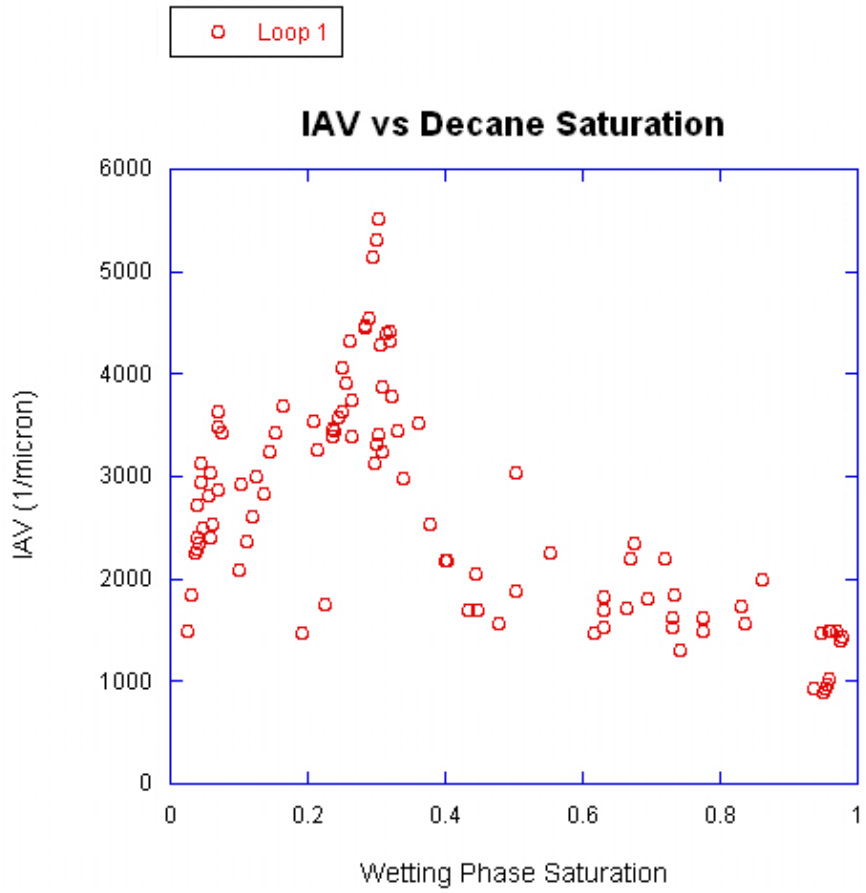
Data Analysis

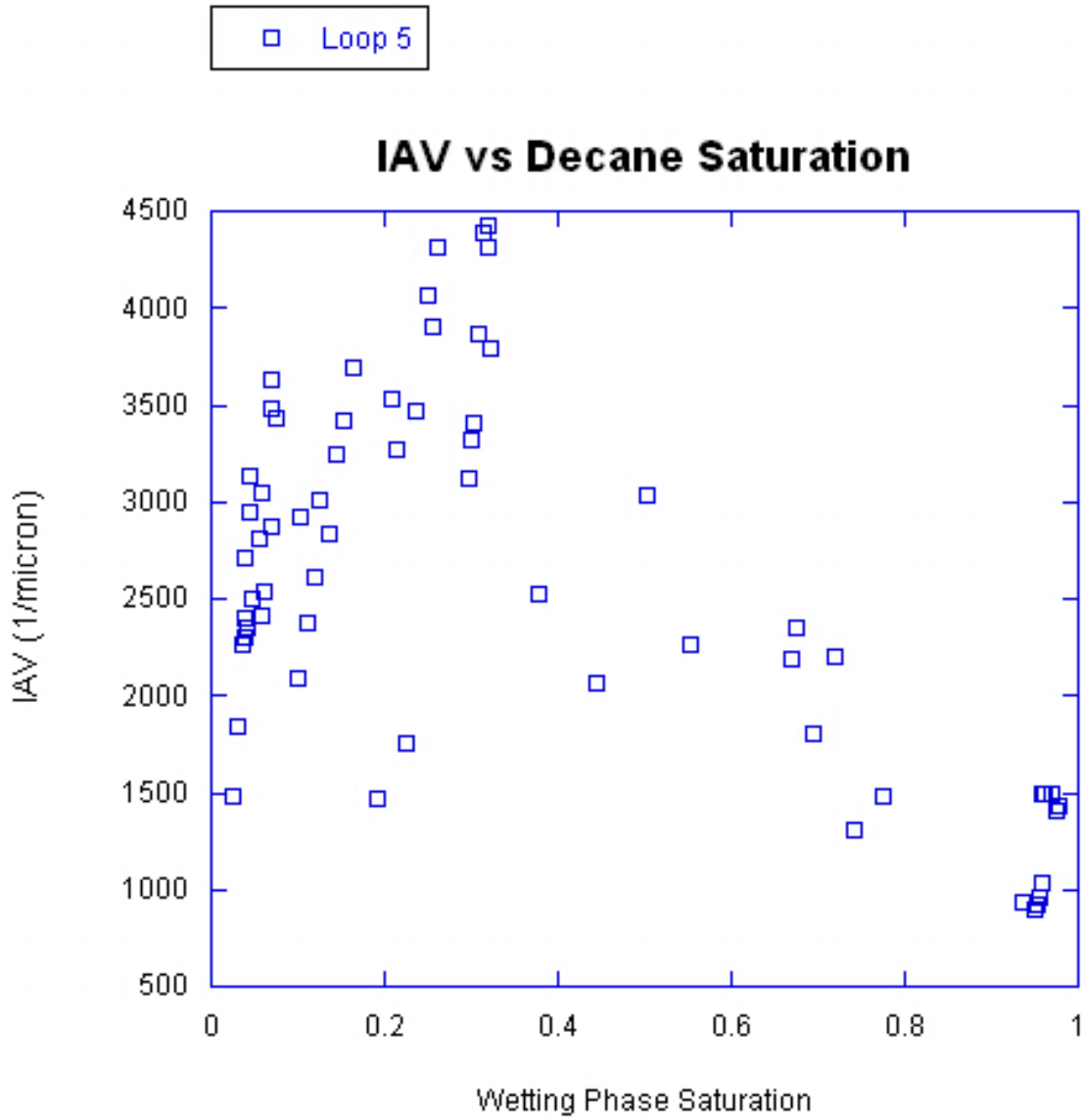
- IDL
- 2 Loops
- Threshholds
- Separate Phases
- Calculate IAV and saturation



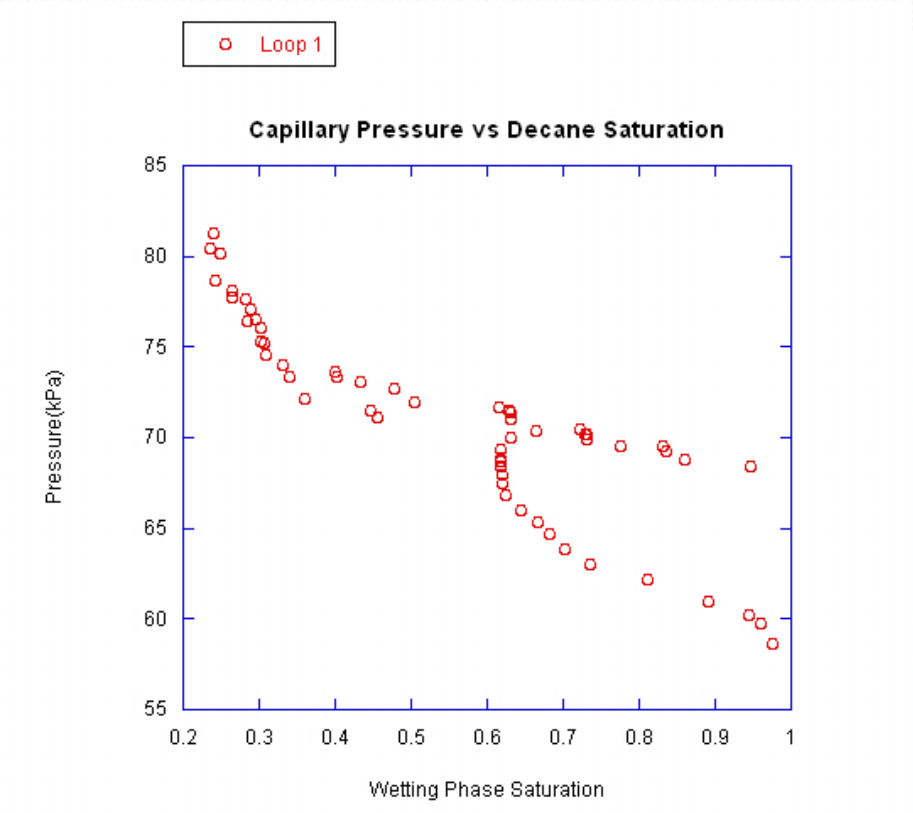

Wetting-Nonwetting
Nonwetting-Solid
Wetting-solid
Interfacial Area per Volume, Loop 1
IAV (1/micron)
8 10^4
7 10^4
6 10^4
5 10^4
4 10^4
3 10^4
2 10^4
1 10^4
0
0
10
20
30
40
50
60
Image

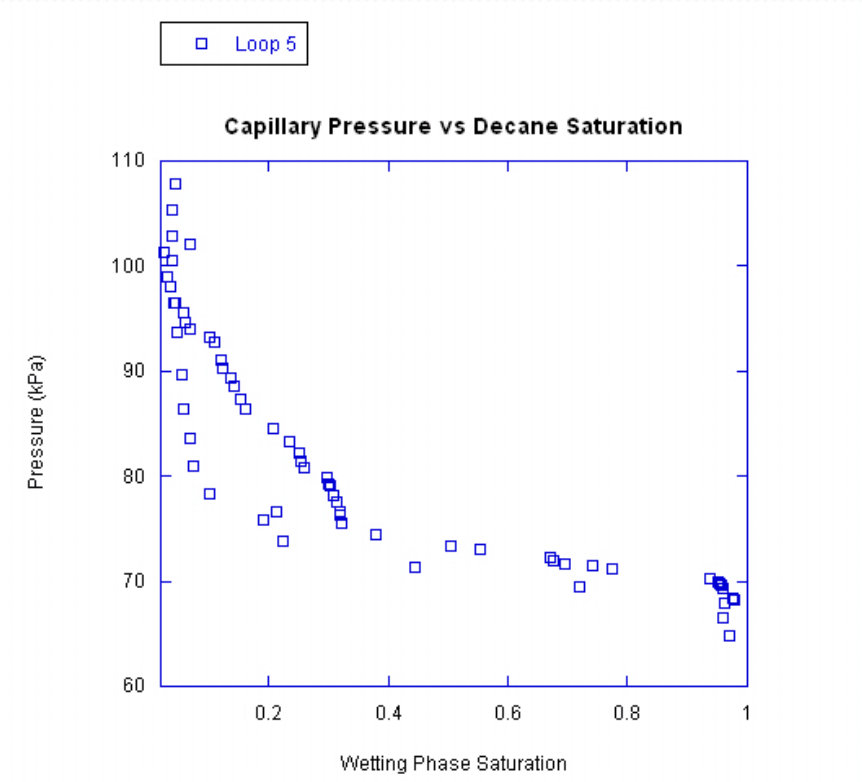

Wetting-Nonwetting
Nonwetting-Solid
Wetting-Solid
Interfacial Area per Volume, Loop 5
IAV(1/micron)
8 10^4
7 10^4
6 10^4
5 10^4
4 10^4
3 10^4
2 10^4
1 10^4
0
0
10
20
30
40
50
60
70
Image

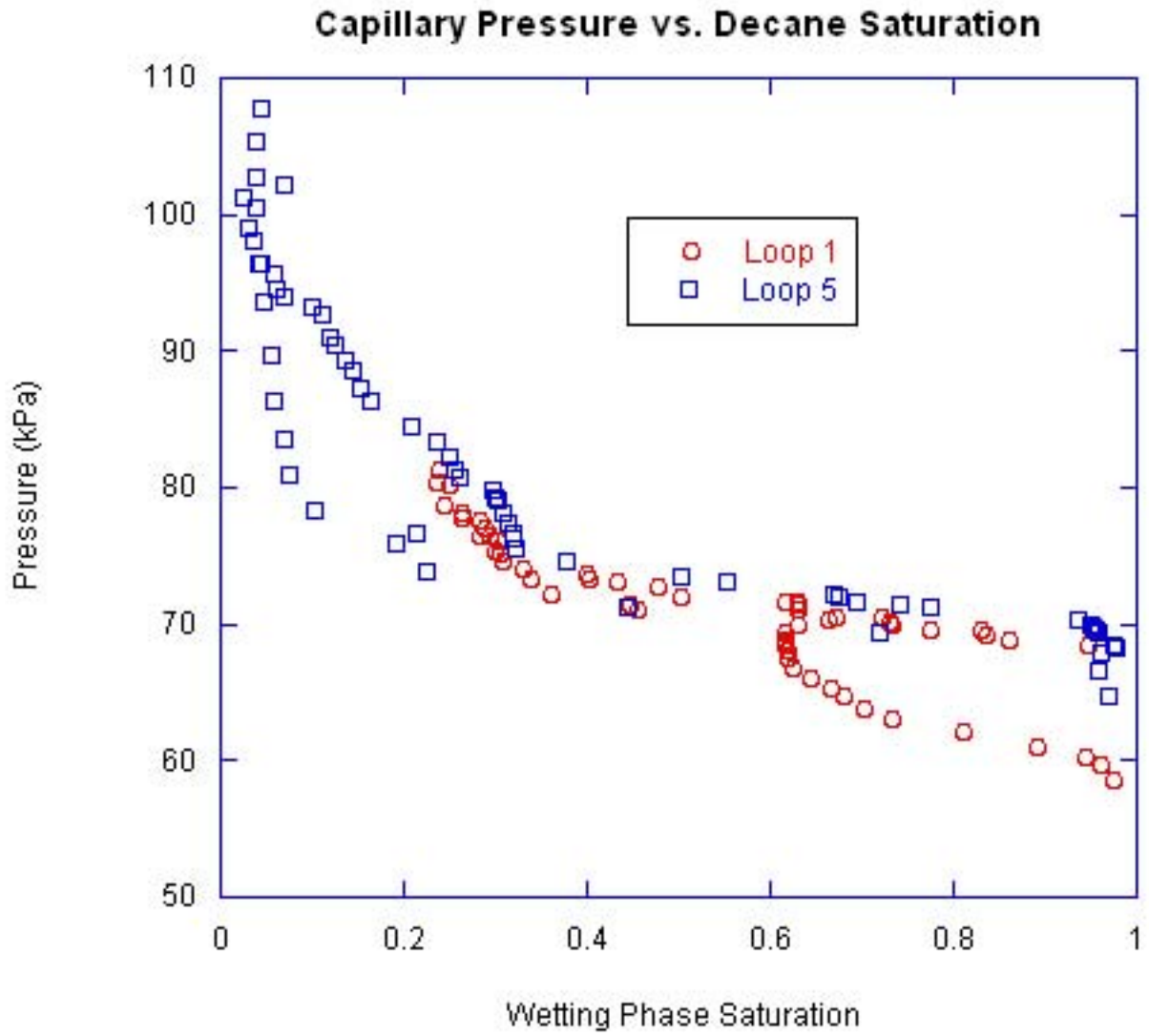

Loop 1
IAV vs Decane Saturation
IAV (1/micron)
Wetting Phase Saturation
0
1000
2000
3000
4000
5000
6000
0
0.2
0.4
0.6
0.8
1

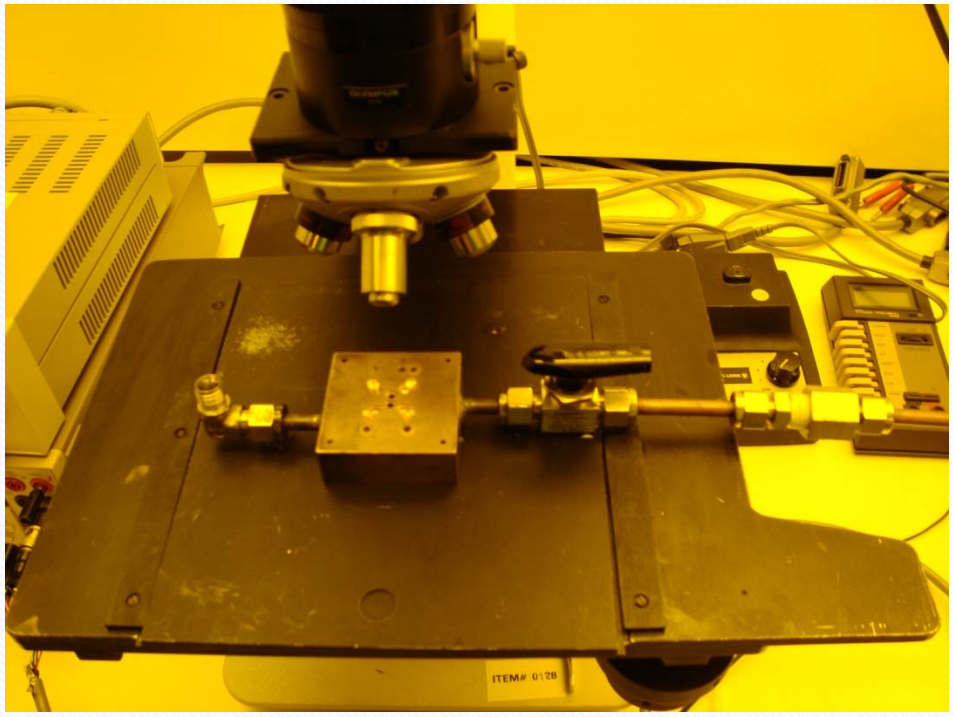

Loop 5
IAV vs Decane Saturation
IAV (1/micron)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.2
0.4
0.6
0.8
1
Wetting Phase Saturation

Hysteresis Loops






Capillary Pressure vs. Decane Saturation
Pressure (kPa)
Wetting Phase Saturation
Loop 1
Loop 5
110
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1

Future Experiments and Recommendations

- Try Olive Oil (surface tension=40mN/m)
- New pattern
- Clean room
- New mask
- Syringe set-up
- Locking microscope stage