The Super Air Meter: A Test for Plastic Concrete

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Tyler Ley, P.E., Ph. D

Acknowledgements

- Oklahoma DOT
- FHWA
- Kansas DOT
- Nebraska DOT
- Iowa DOT
- Minnesota DOT
- Idaho DOT
- North Dakota DOT
- Colorado DOT
- **Penn DOT**
- **Connecticut DOT**
- **New Jersey DOT**
- Illinois DOT
- Indiana DOT
- Michigan DOT
- Wisconsin DOT
- RMC Foundation

Outline

- Introduction to Air entrained concrete
- Why is the SAM useful?

Why Do We Add Air to Concrete?

- Air-entrained bubbles are a key to the freeze-thaw resistance of concrete

Air volume ≠ freeze-thaw performance

- Smaller bubbles are more effective in providing freeze-thaw resistance and have less of an impact on our concrete than larger bubbles

The Air-Entrainment Blues…

The most challenging aspect of concrete to get right is the air content.

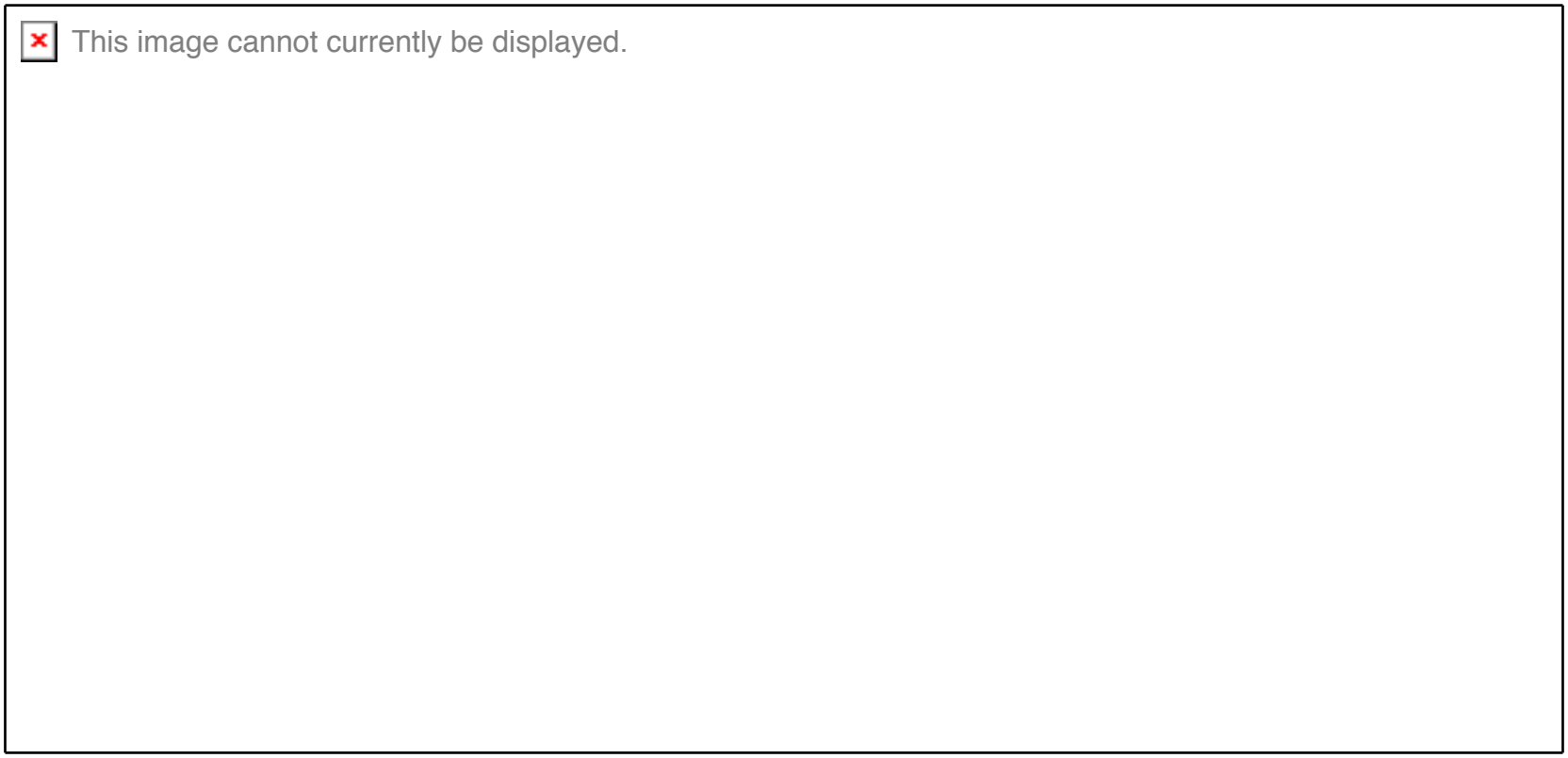
The Air-Entrainment Blues…

The most challenging aspect of concrete to get right is the air content.

Large bubbles are the enemy!

What Do You Want in an Air-Void System?

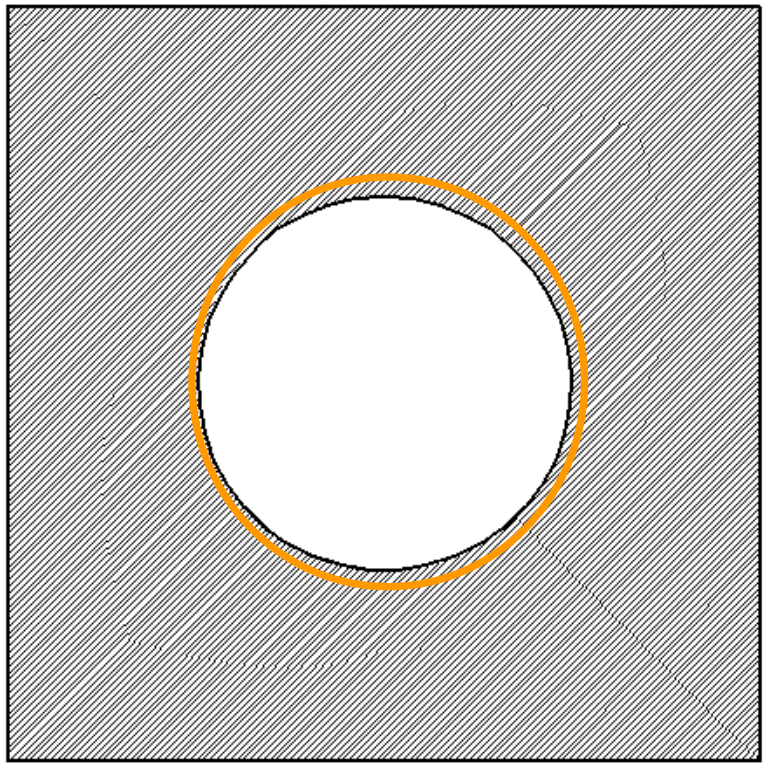
A B



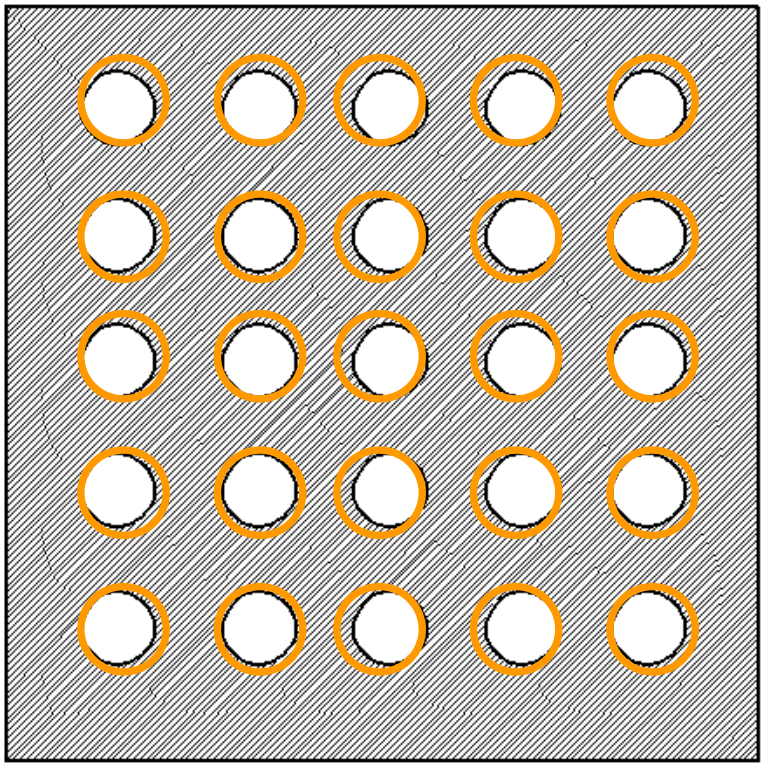
- Volume of air provided is the same for both.
- Case B has a better air void distribution.

What Do You Want in an Air-Void System?

A



B



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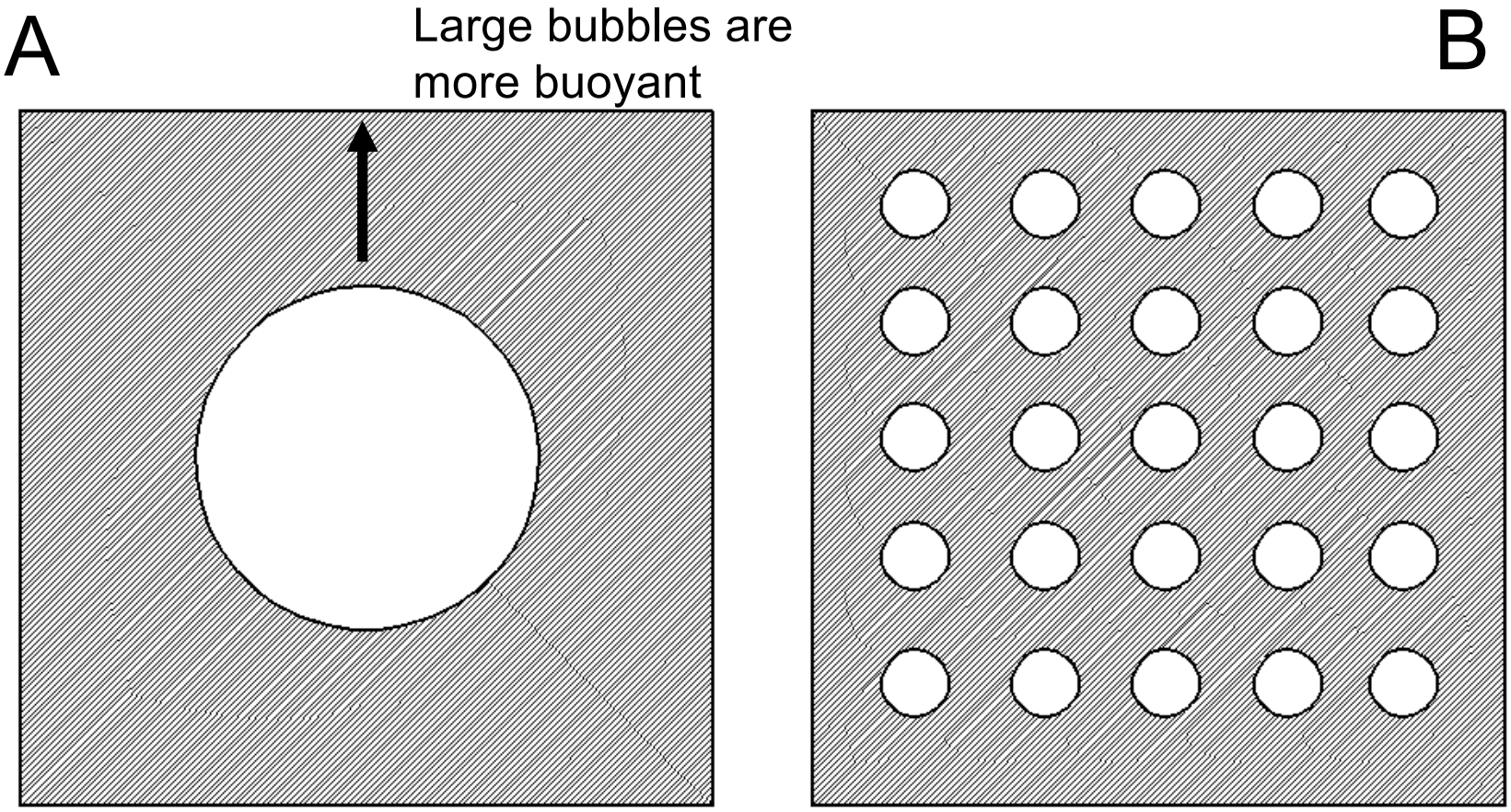
What Do You Want in an Air-Void System?



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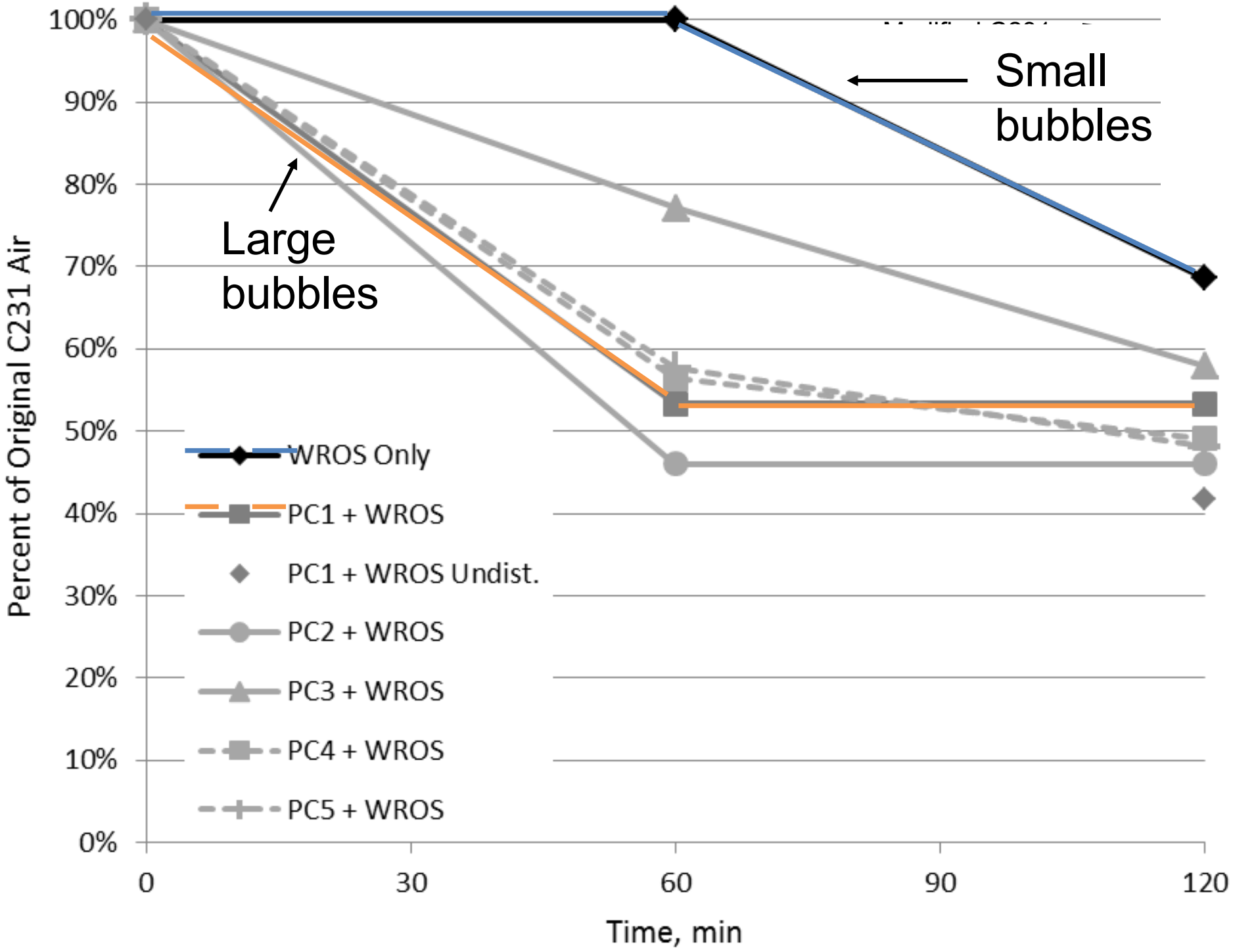

Small bubbles
Large bubbles
Percent of Original C231 Air
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
30
60
90
120
Time, min
WROS Only
PC1 + WROS
PC1 + WROS Undist.
PC2 + WROS
PC3 + WROS
PC4 + WROS
PC5 + WROS

Why are large bubbles bad?

- They leave the concrete and change your air volume
- They don’t help with freeze-thaw durability
- They reduce your strength more than smaller bubbles

What causes large bubbles?

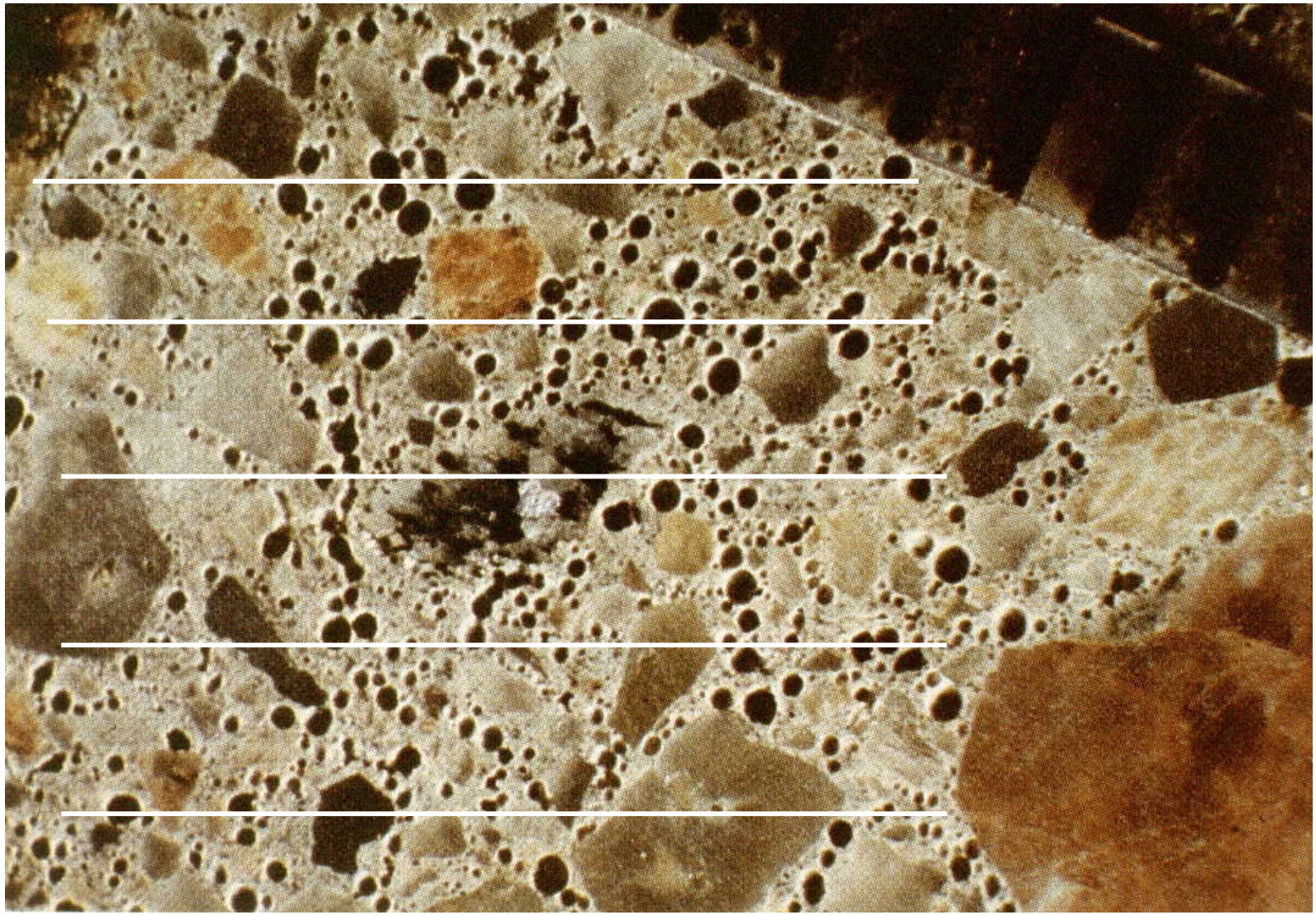
- Admixture incompatibility
- Admixture/cement incompatibility
- Sand gradation
- Inadequate mixing
- Alkali content of binder
- Cement grinding aids
- Changes in temperature
- Pumping

How do you measure them?

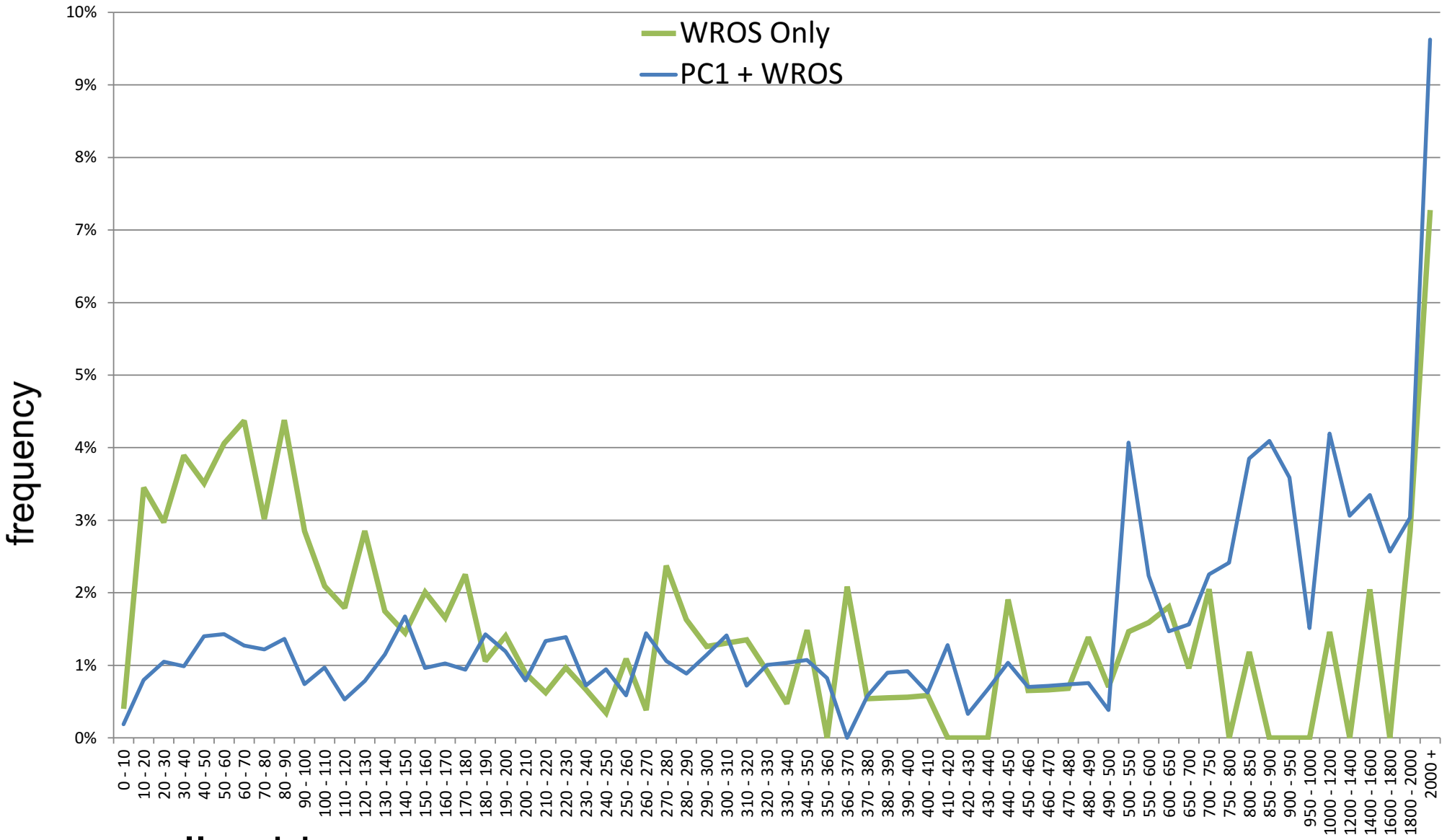
Hardened Air Void Analysis

From Hover

Hardened Air Void Analysis



From Hover

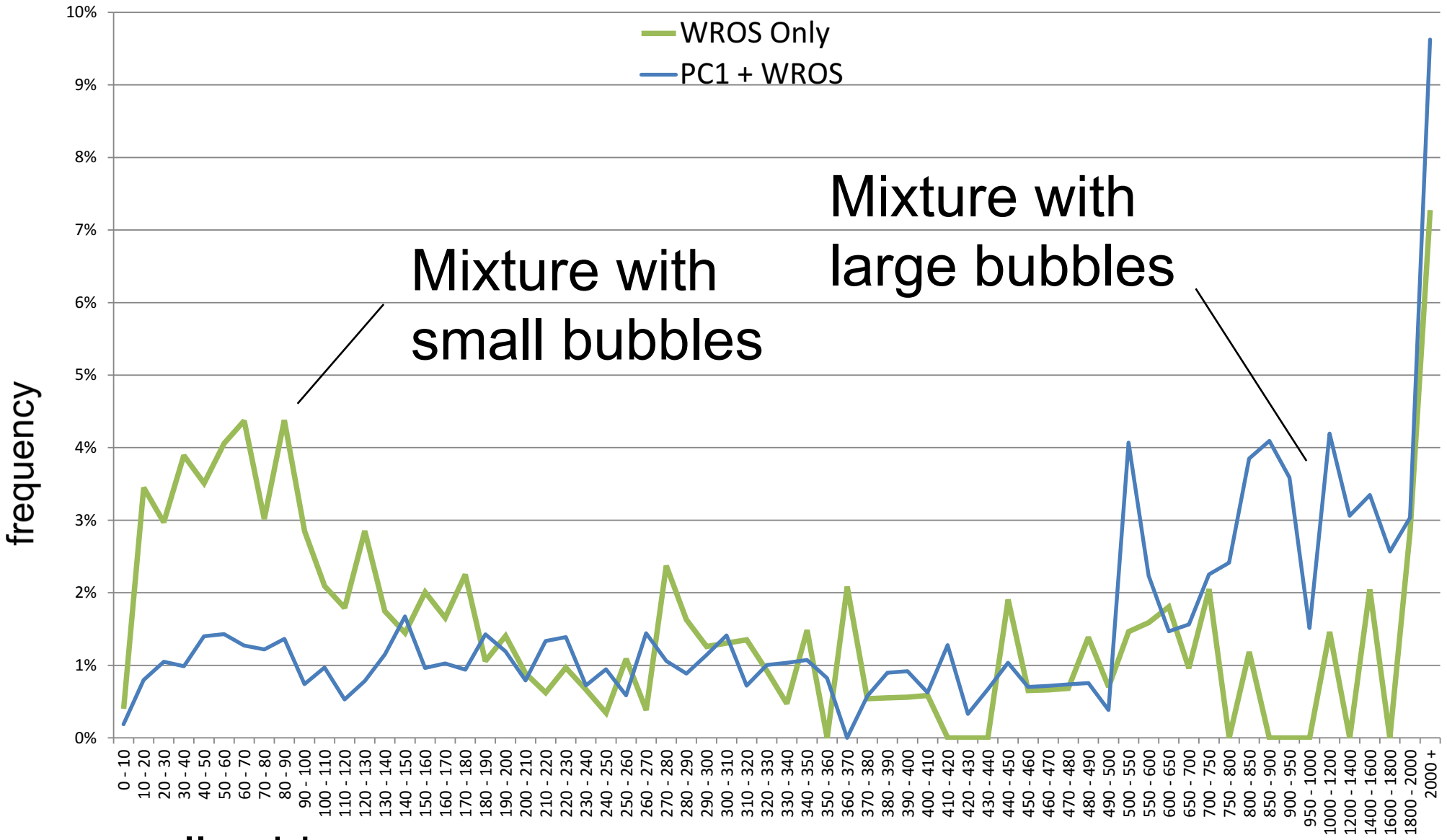


small voids

Chord Size, microns

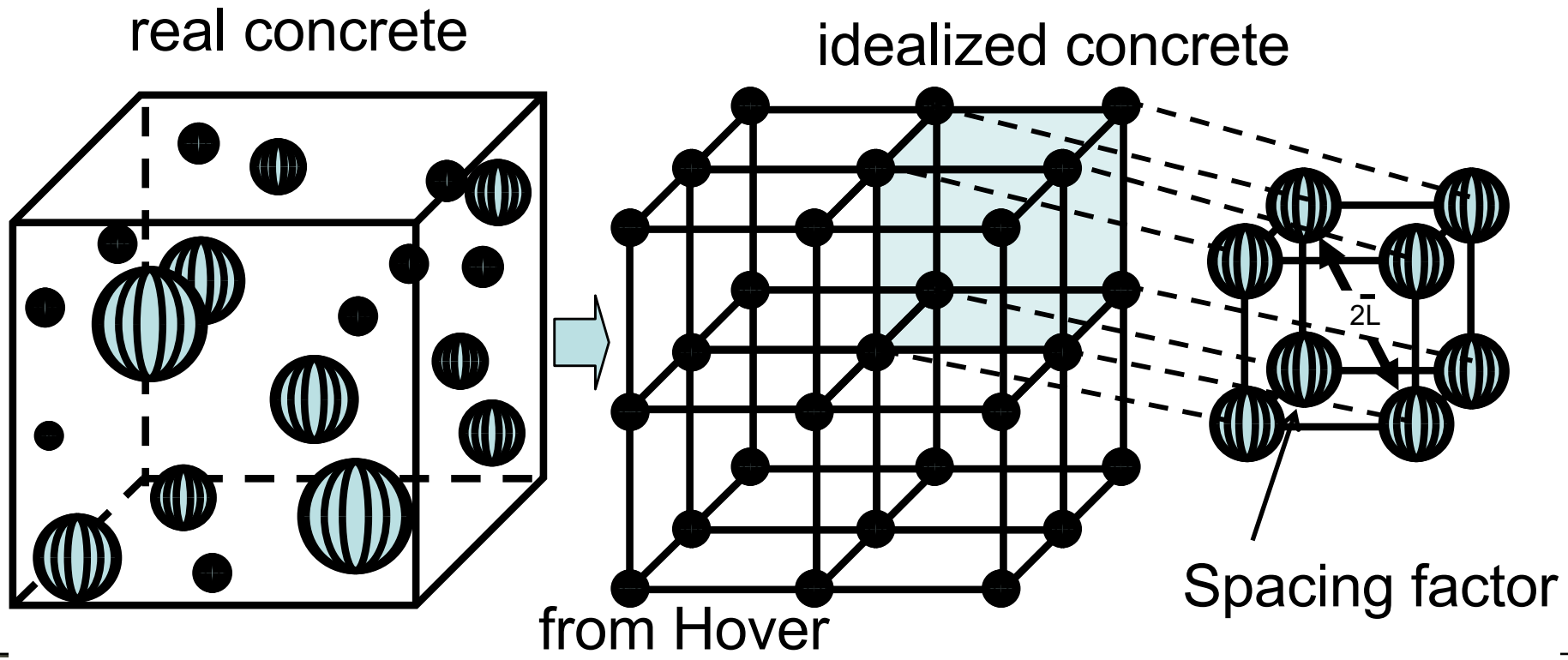
large voids

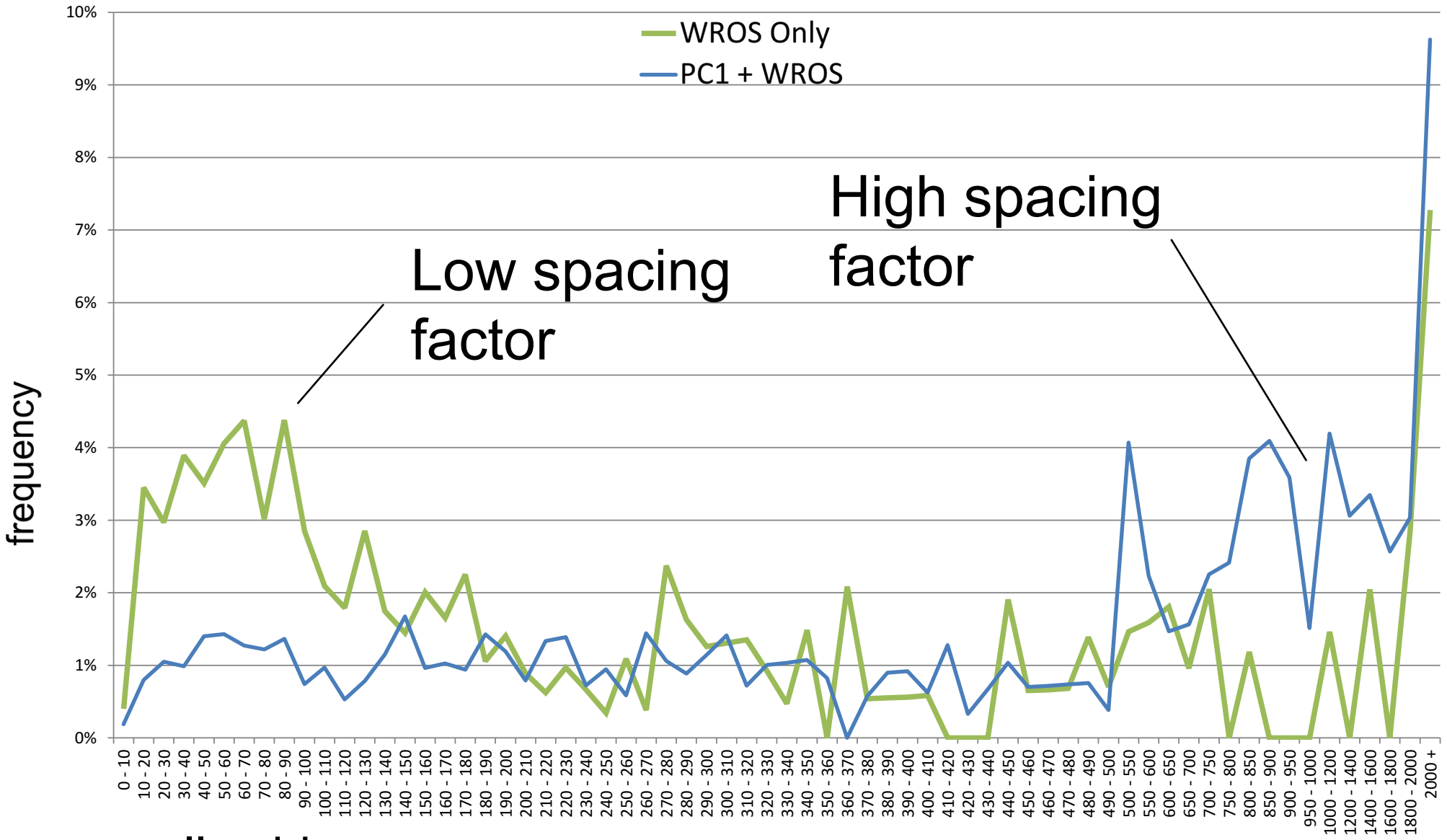
Freeman et al., 2012



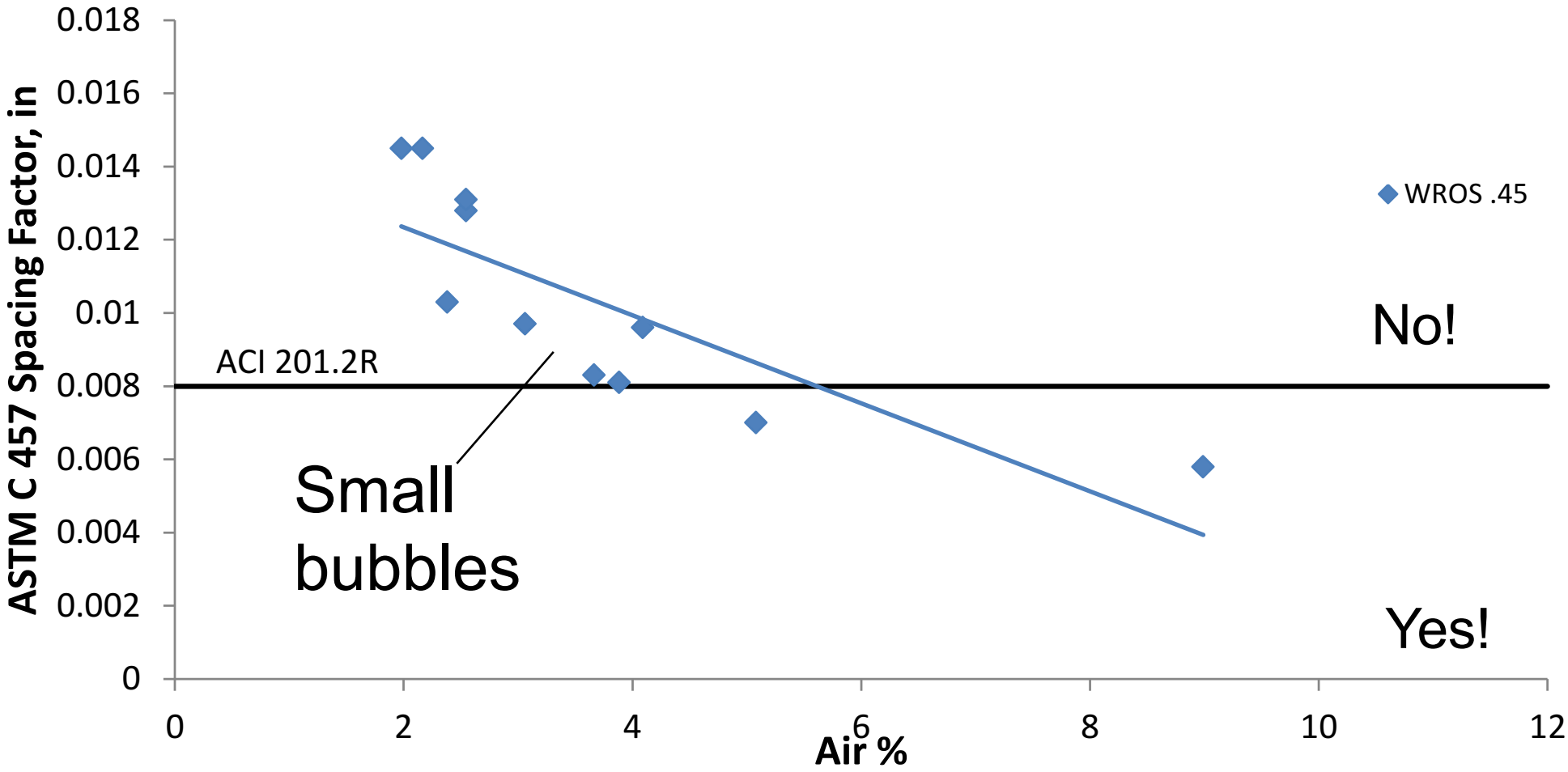
Freeman et al., 2012

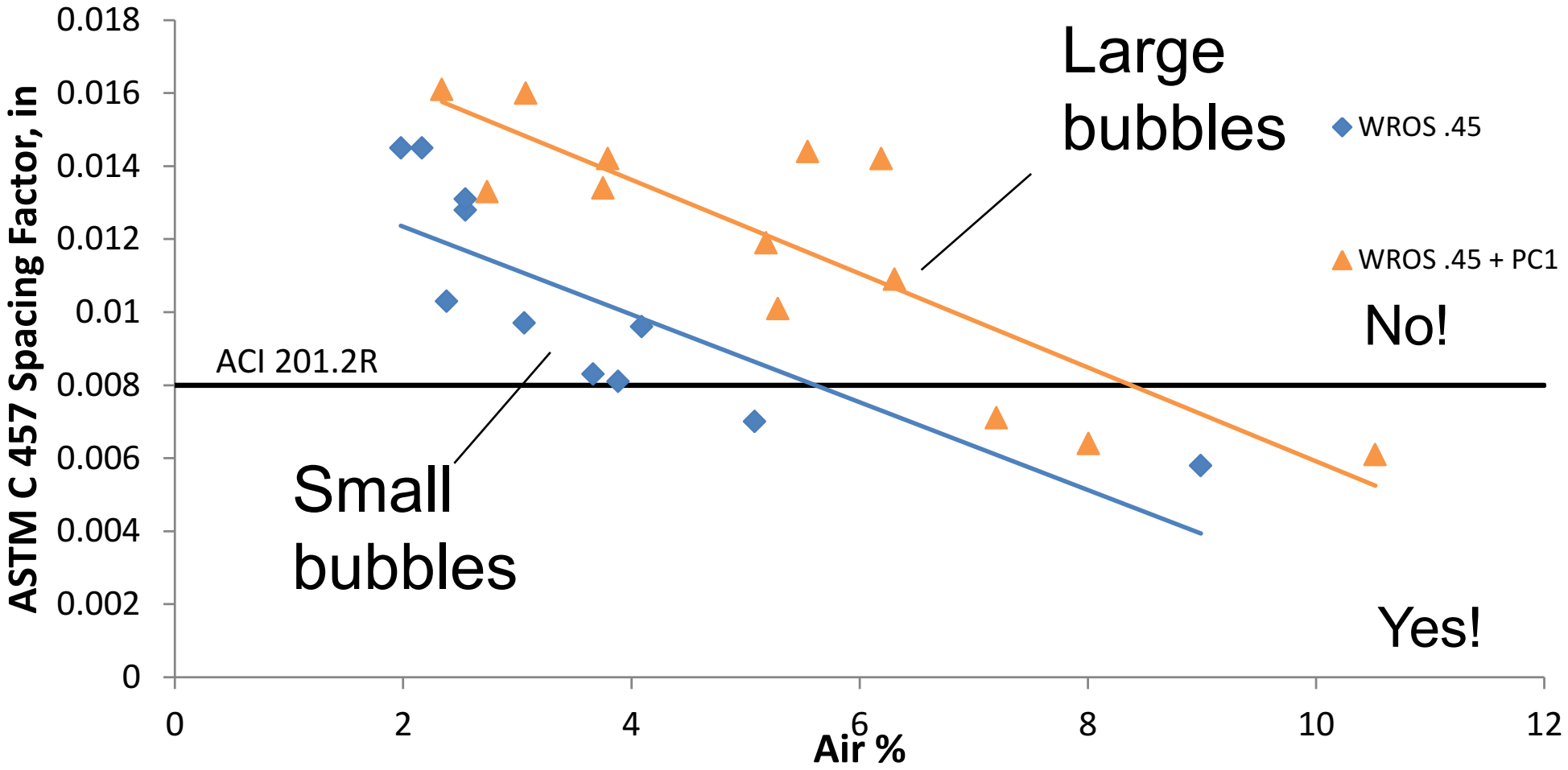
- Spacing Factor – ½ of the average distance of an average sized void uniformly distributed in the paste
- **<u>Desired Value < 0.008 in (ACI 201)</u>**



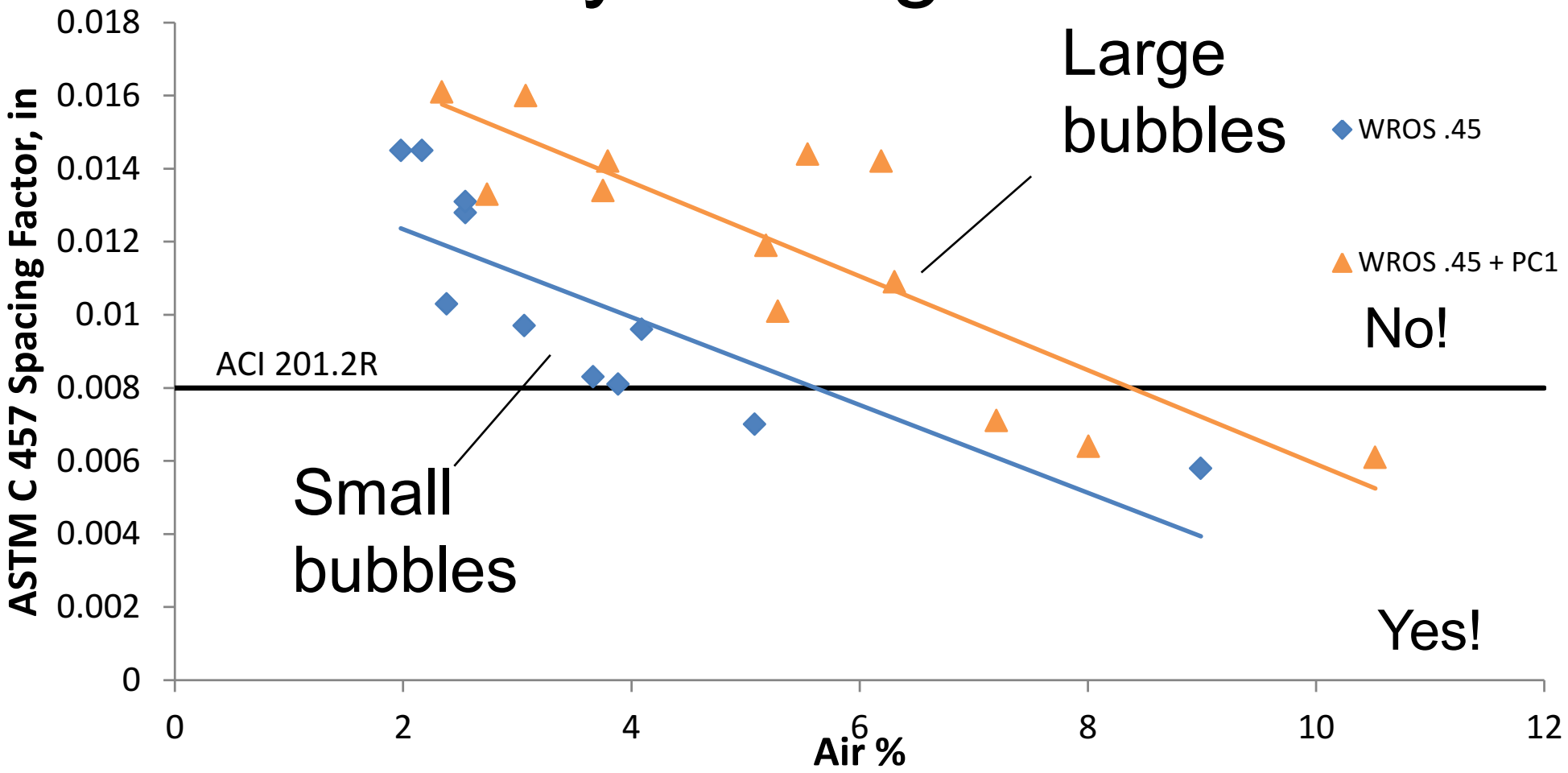


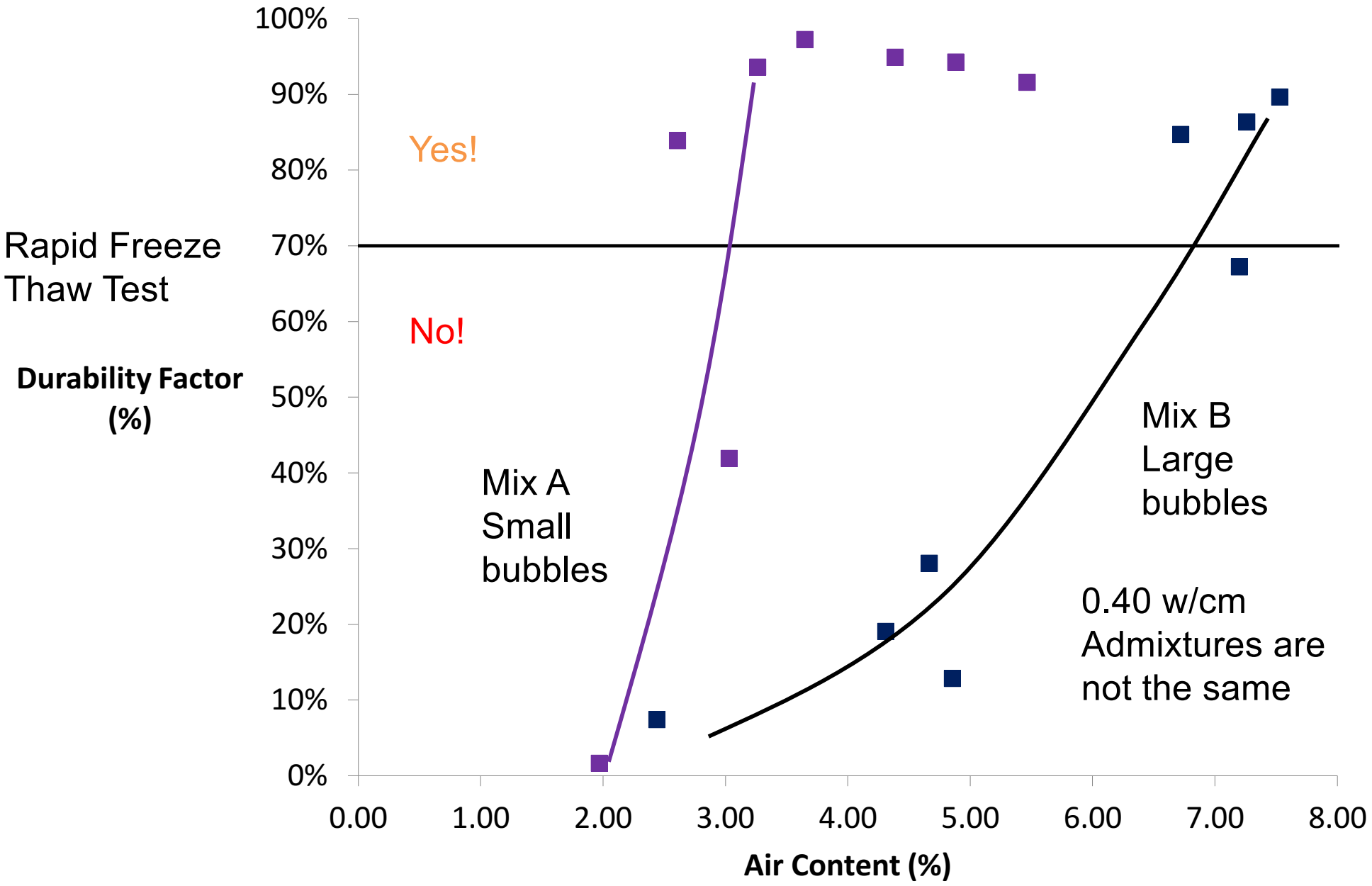
Freeman et al., 2012

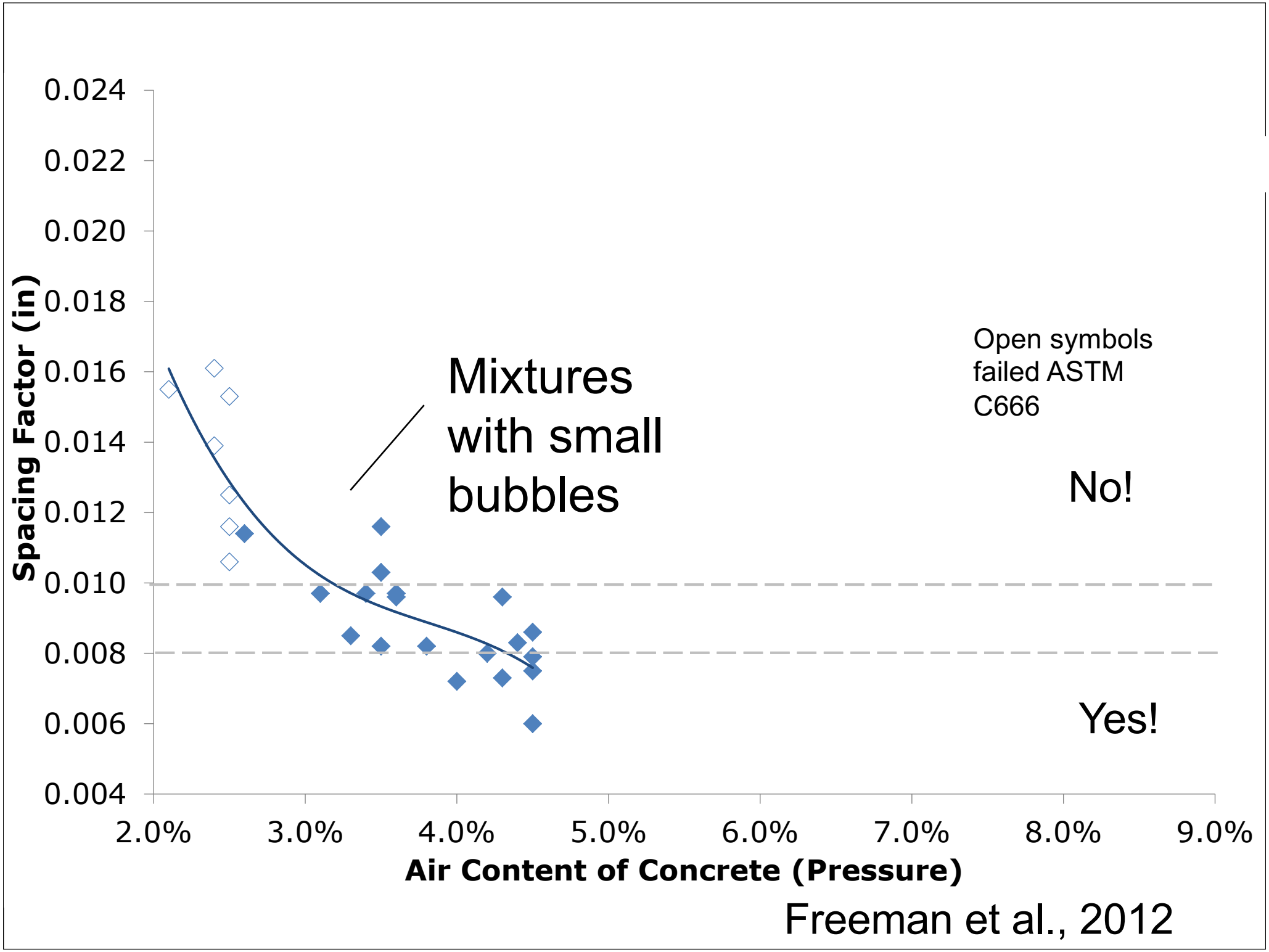

ASTM C 457 Spacing Factor, in
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
Air %
WROS .45
ACI 201.2R
No!
Small bubbles
Yes!

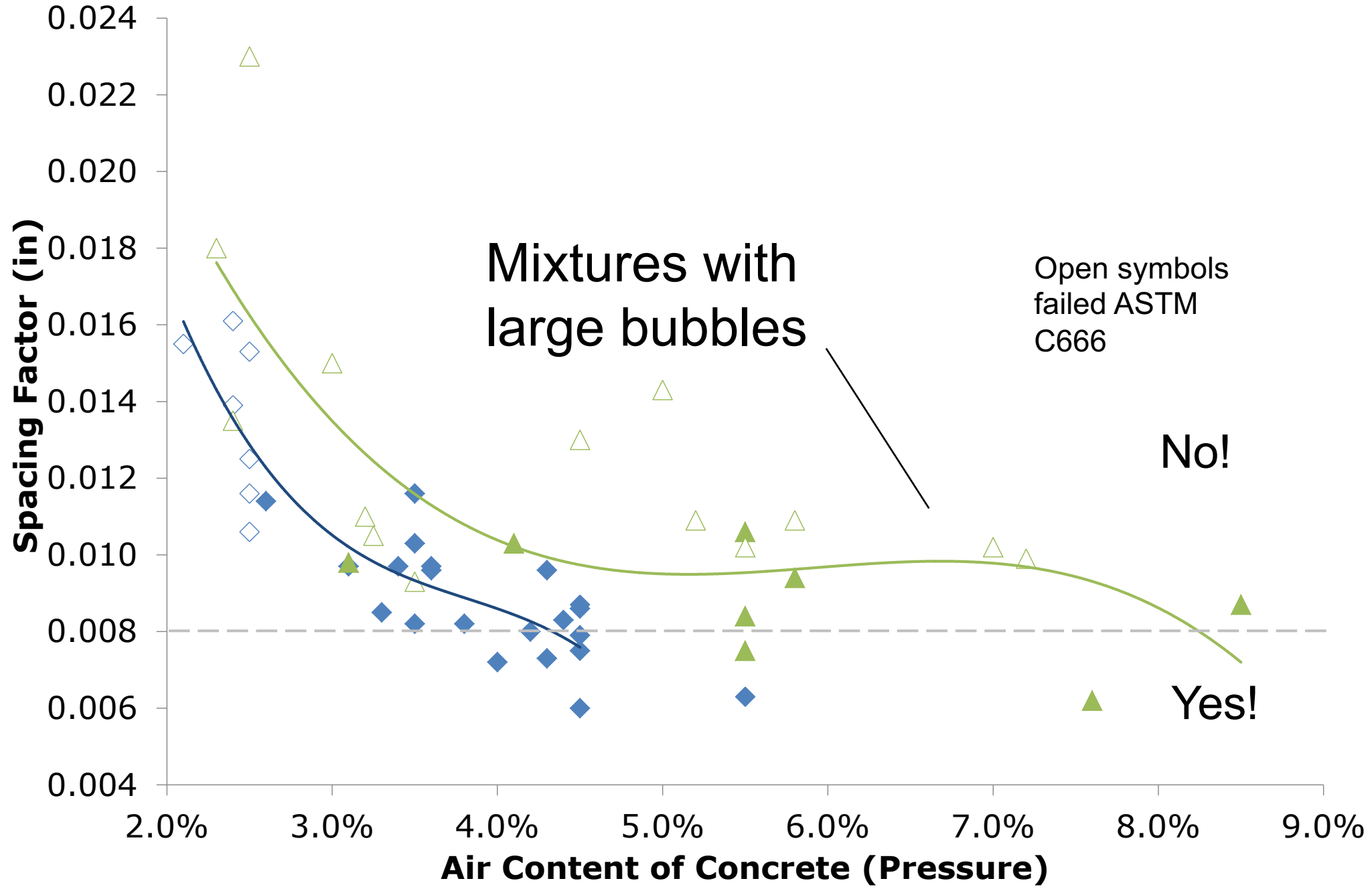

ASTM C 457 Spacing Factor, in
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
2
4
6
8
10
12
Air %
ACI 201.2R
Large bubbles
Small bubbles
WROS .45
WROS .45 + PC1
No!
Yes!

You can't tell the size of the bubbles by looking at the volume!!!




Rapid Freeze Thaw Test
Durability Factor (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Yes!
No!
Mix A Small bubbles
Mix B Large bubbles
0.40 w/cm Admixtures are not the same
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Air Content (%)


0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
Spacing Factor (in)
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
Air Content of Concrete (Pressure)
Mixtures with small bubbles
Open symbols failed ASTM C666
No!
Yes!
Freeman et al., 2012



Freeman et al., 2012

Summary

- **We need to know the size of bubbles within the concrete**
- *The volume of air does not tell you anything about bubble size*
- Although a hardened air void analysis can measure this, it is not practical to run regularly

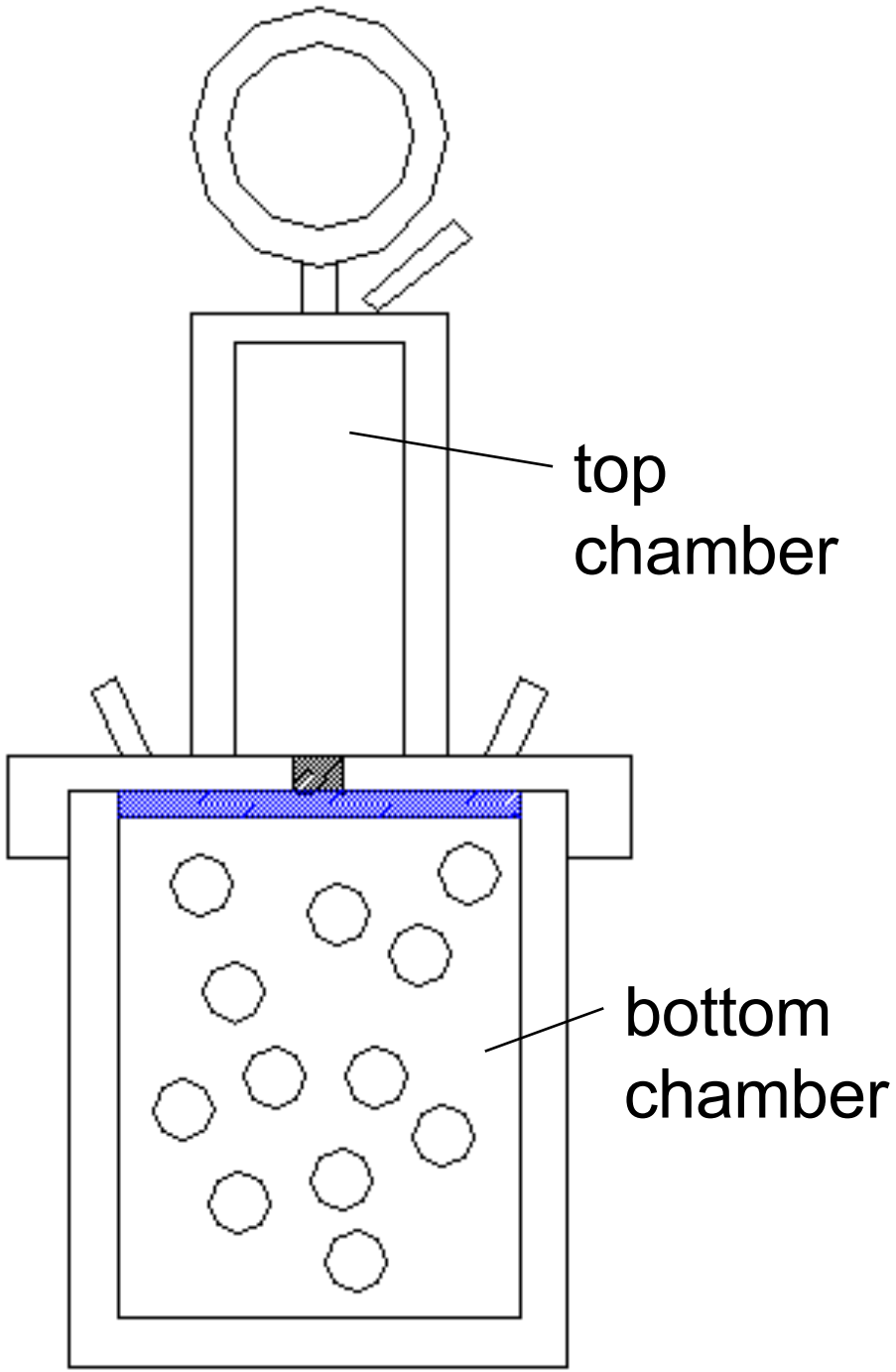
Super Air Meter (SAM)

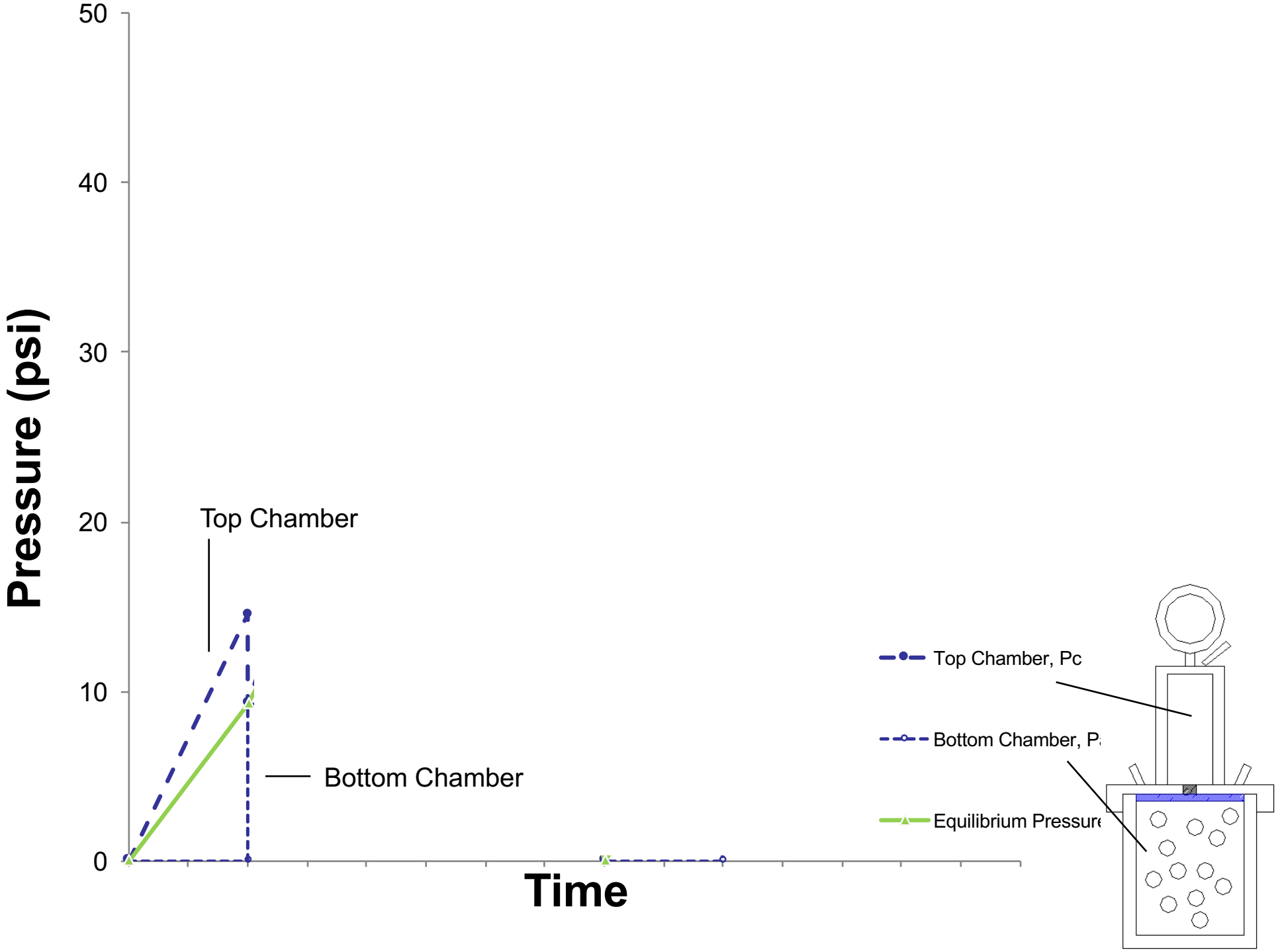
- We have modified a typical ASTM C 231 pressure meter so that it can hold larger pressures
- We have replaced the dial gage with a digital one

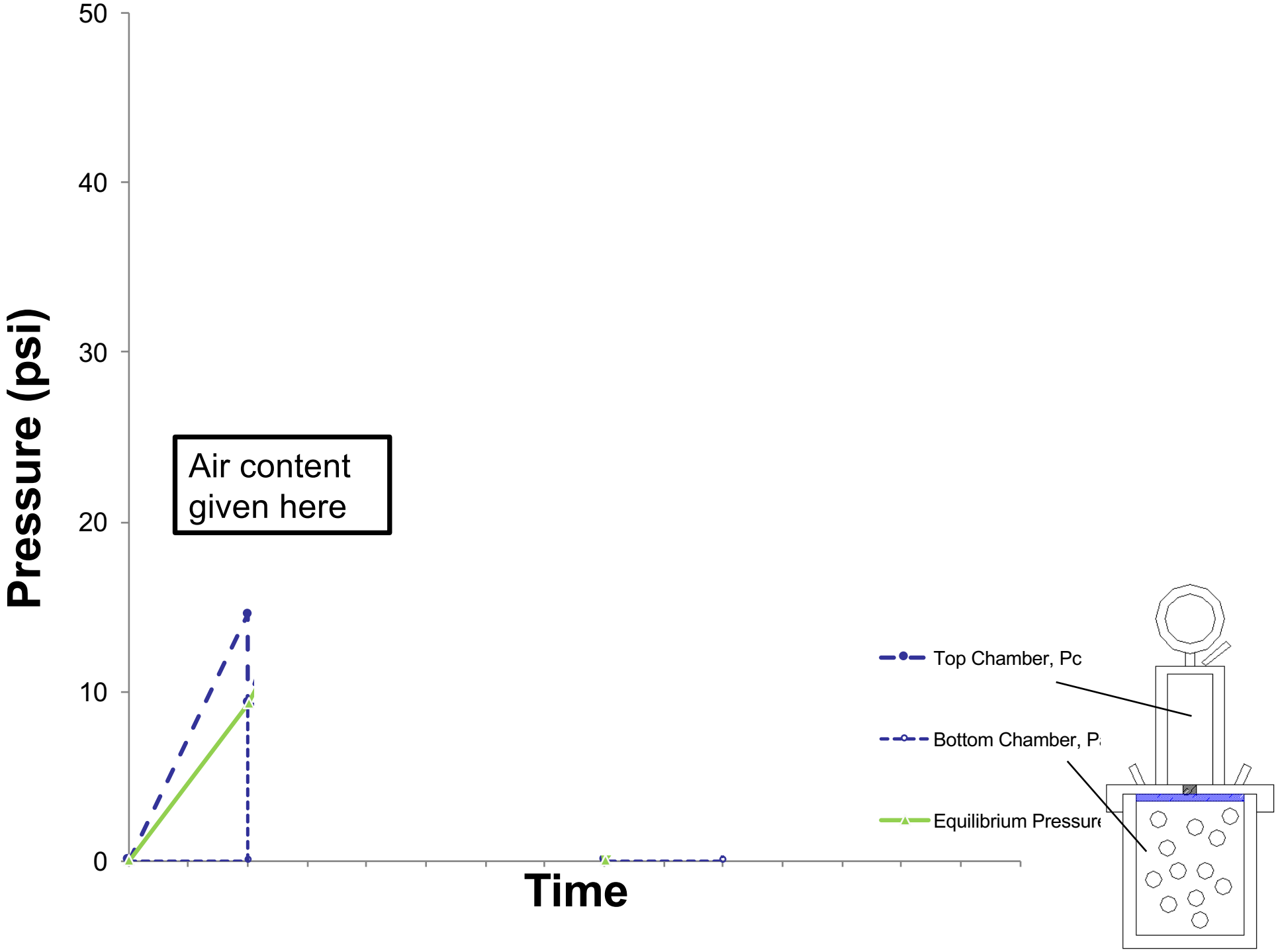

digital
gauge
six
clamps!

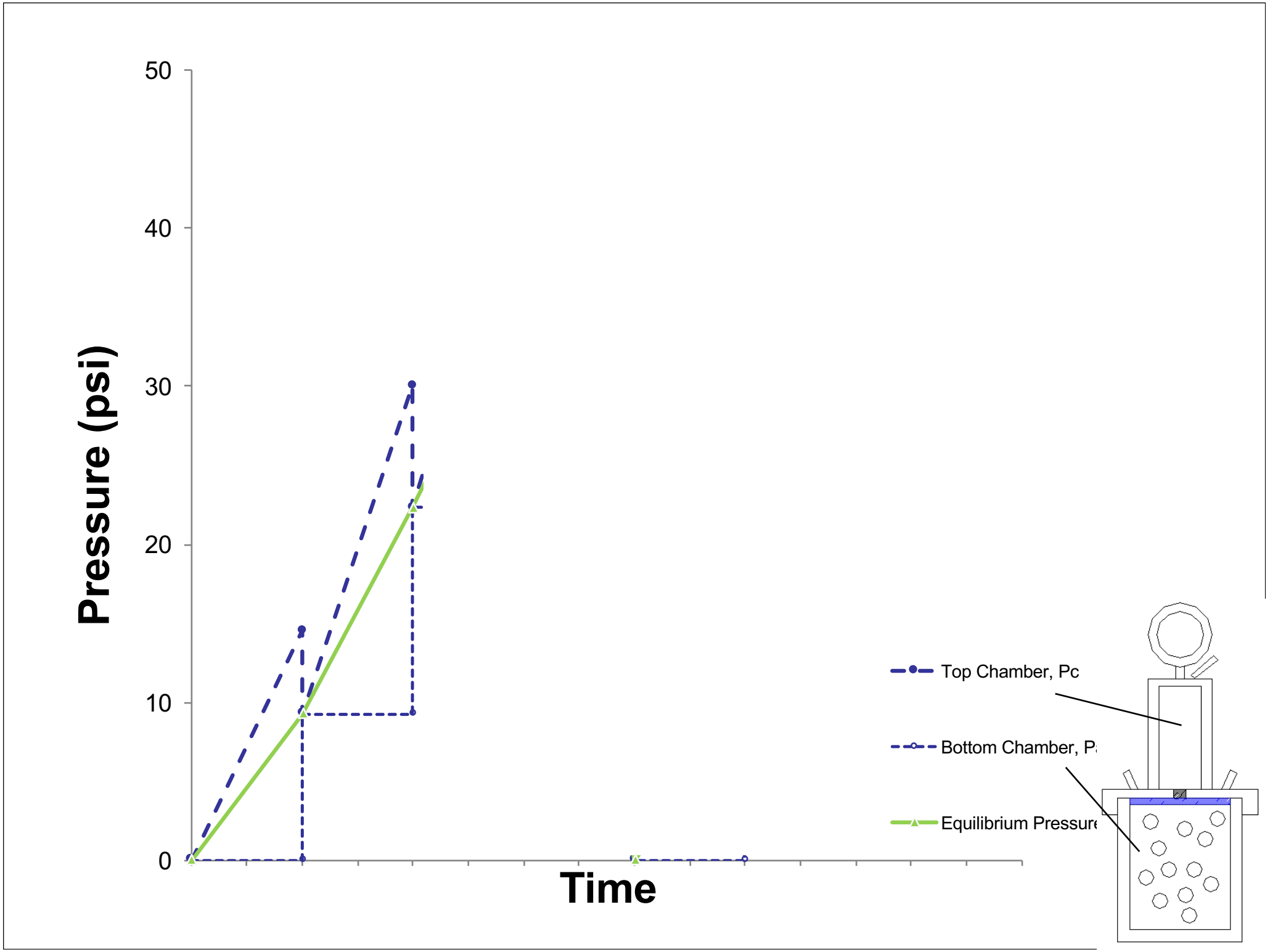
AASHTO TP 118

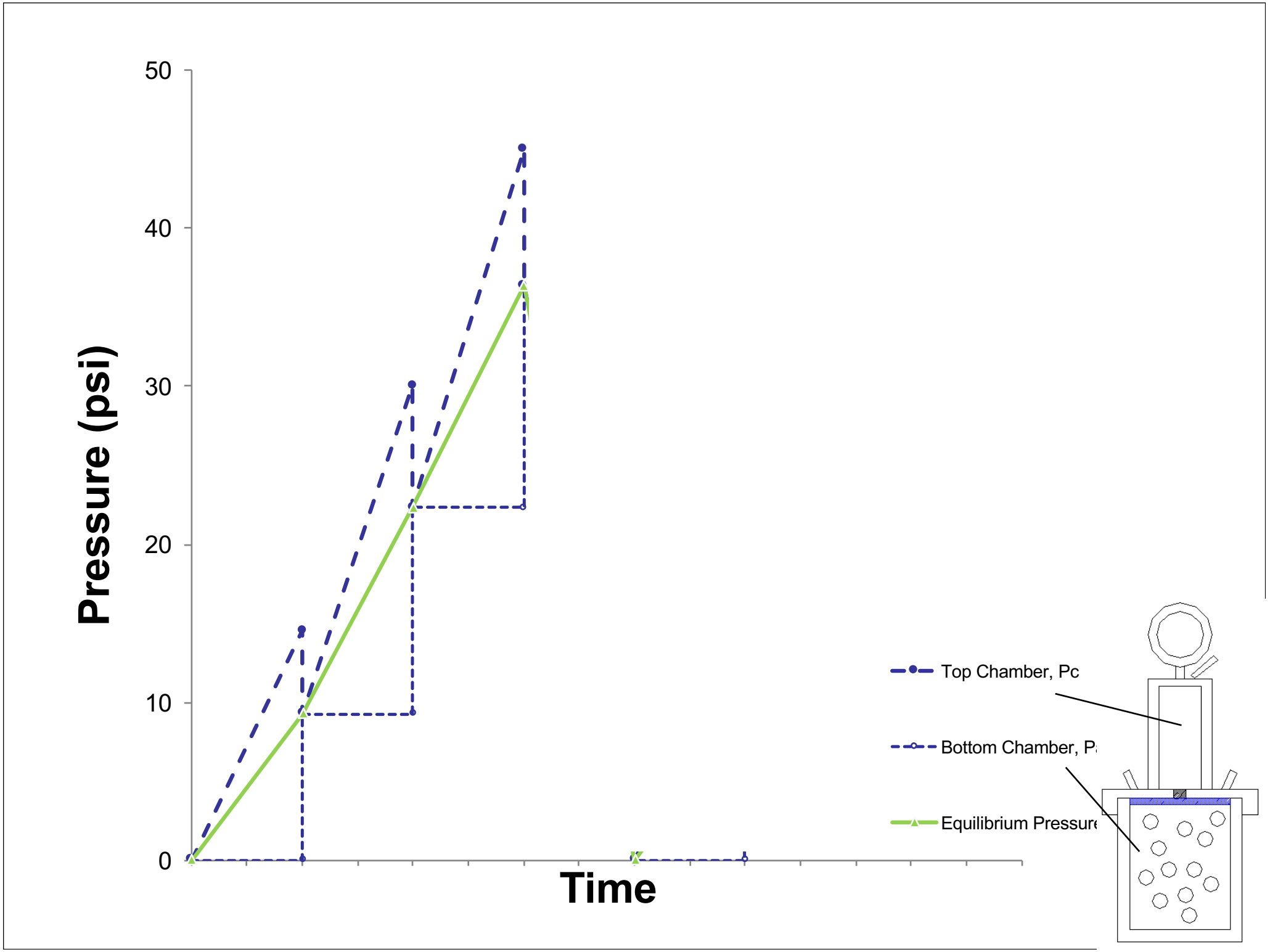
www.superairmeter.com

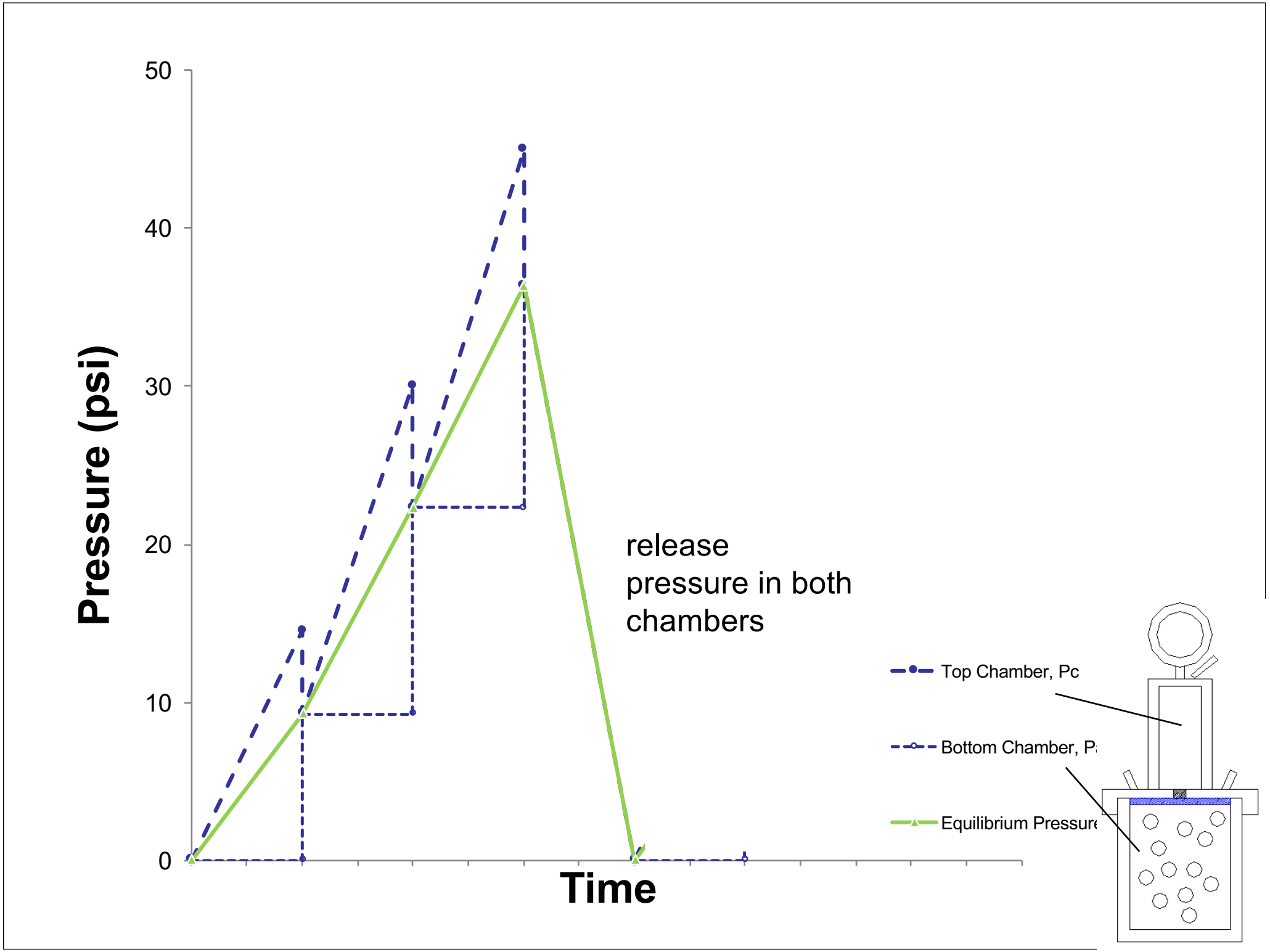

top
chamber
bottom
chamber

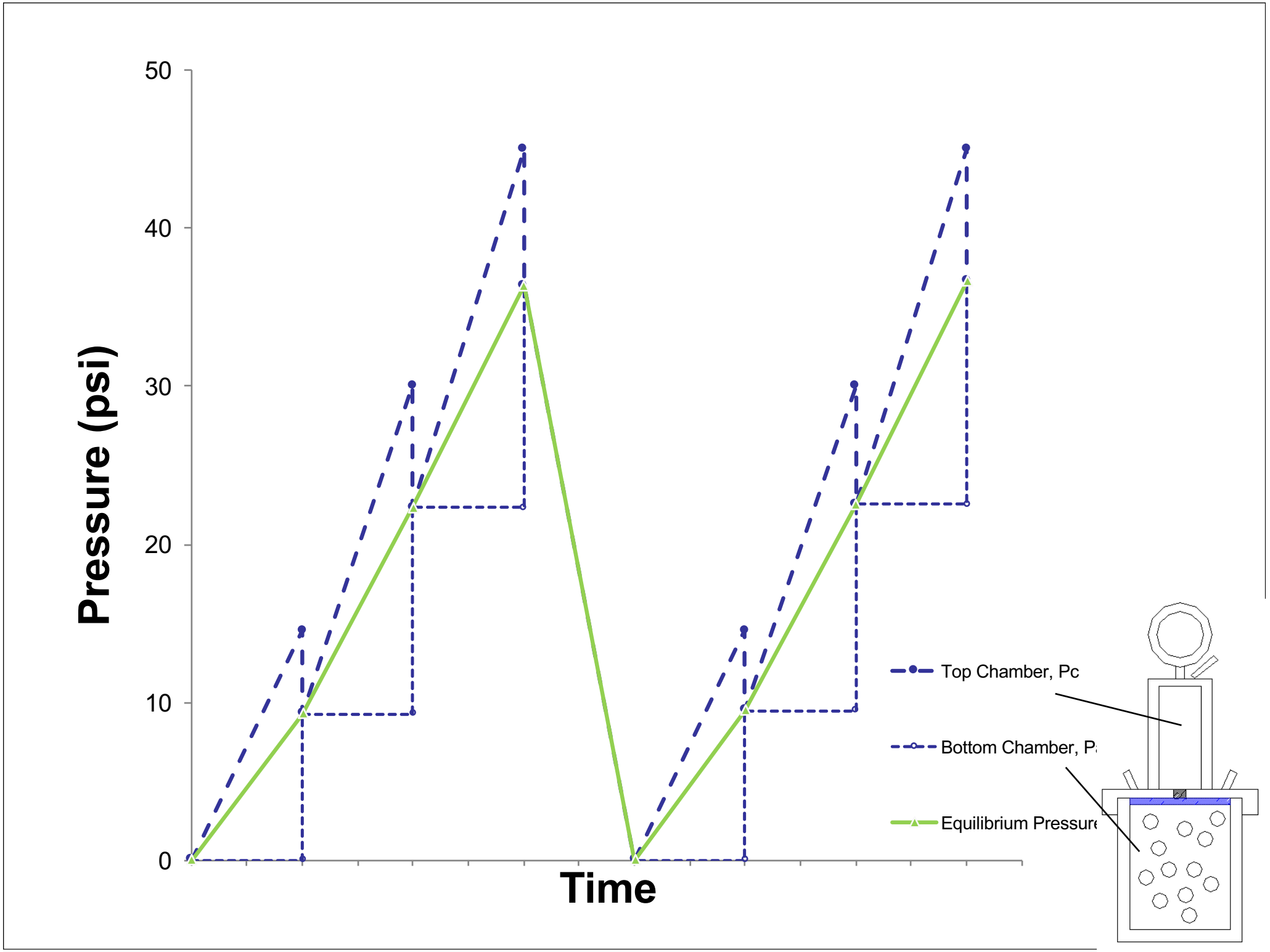

50
40
30
20
10
0
Pressure (psi)
Top Chamber
Bottom Chamber
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure

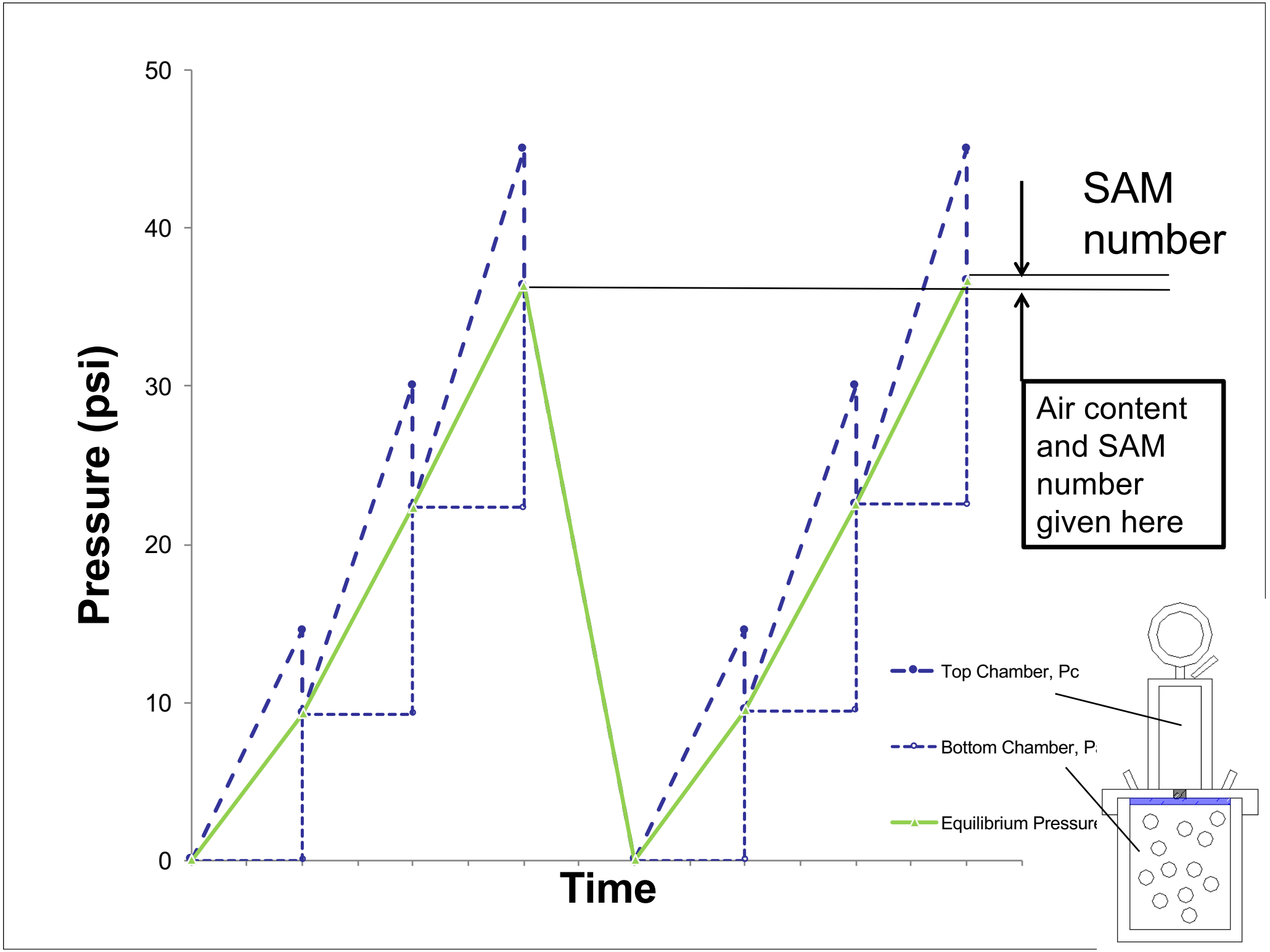

50
40
30
20
10
0
Pressure (psi)
Air content given here
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


50
40
30
20
10
0
Pressure (psi)
Time
release
pressure in both
chambers
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


50
40
30
20
10
0
Pressure (psi)
Time
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure


50
40
30
20
10
0
Pressure (psi)
Time
SAM number
Air content and SAM number given here
Top Chamber, Pc
Bottom Chamber, P
Equilibrium Pressure

How long does that take?

With just the SAM

Inexperienced user – 10 min

Experienced user – 7 min

With the CAPE

Inexperienced user - 7 min

Experienced user – 4.5 min

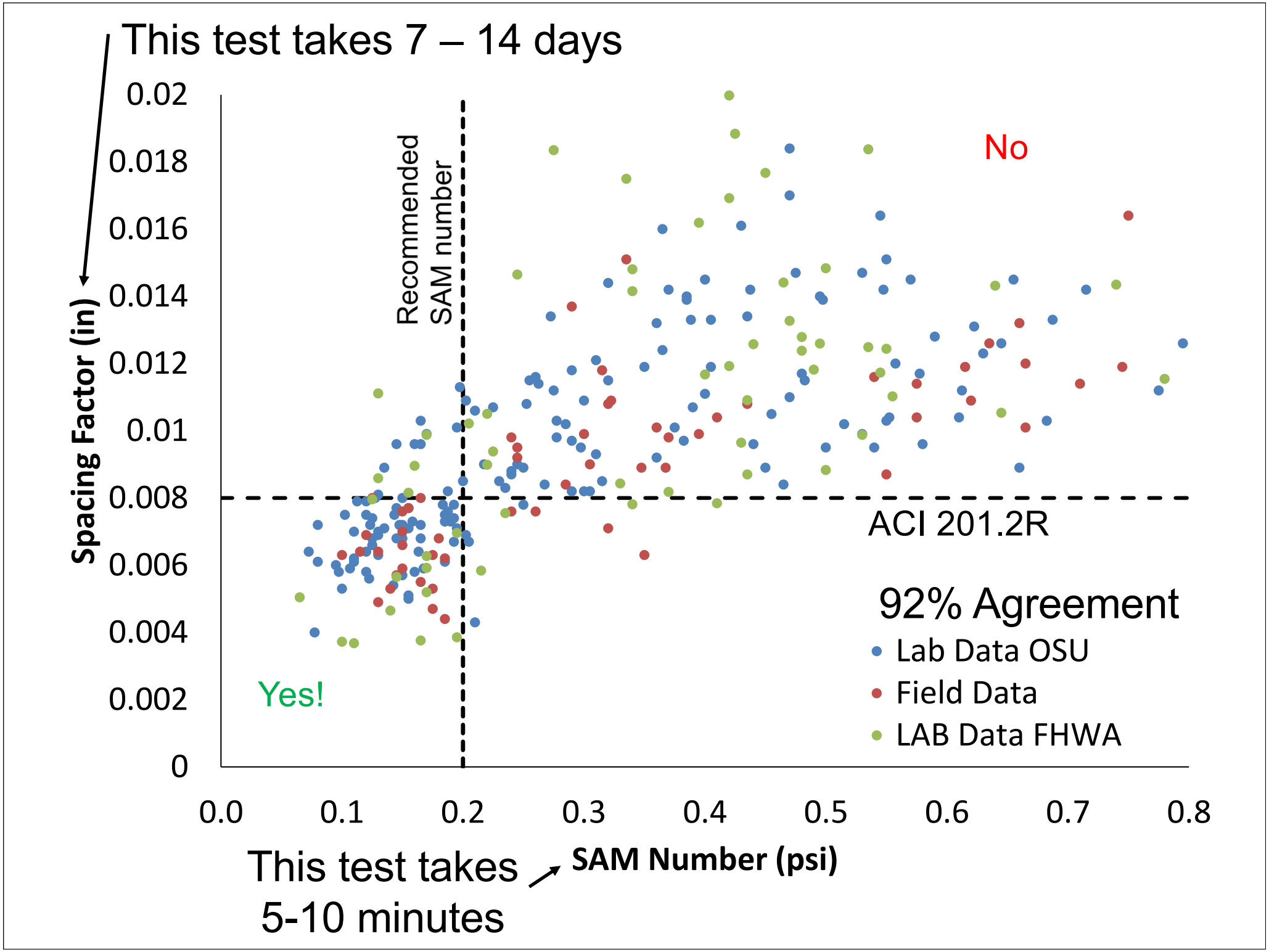
Controlled **A**ir **P**ressure **E**xtender aka **CAPE**

Discussion

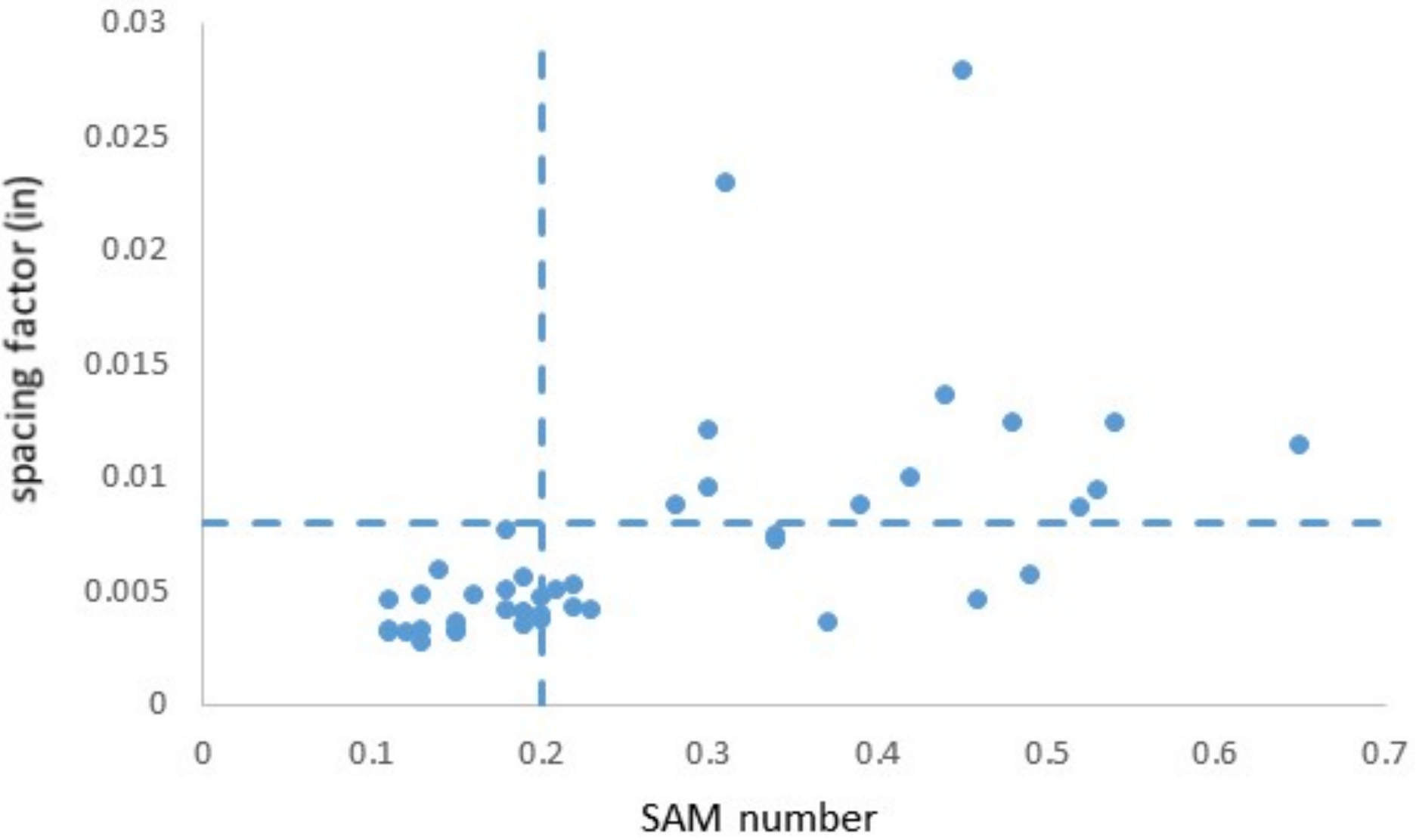
The Super Air Meter gives you the air volume and the SAM number.

The CAPE is a portable air tank and regulators that can help you run the test faster.

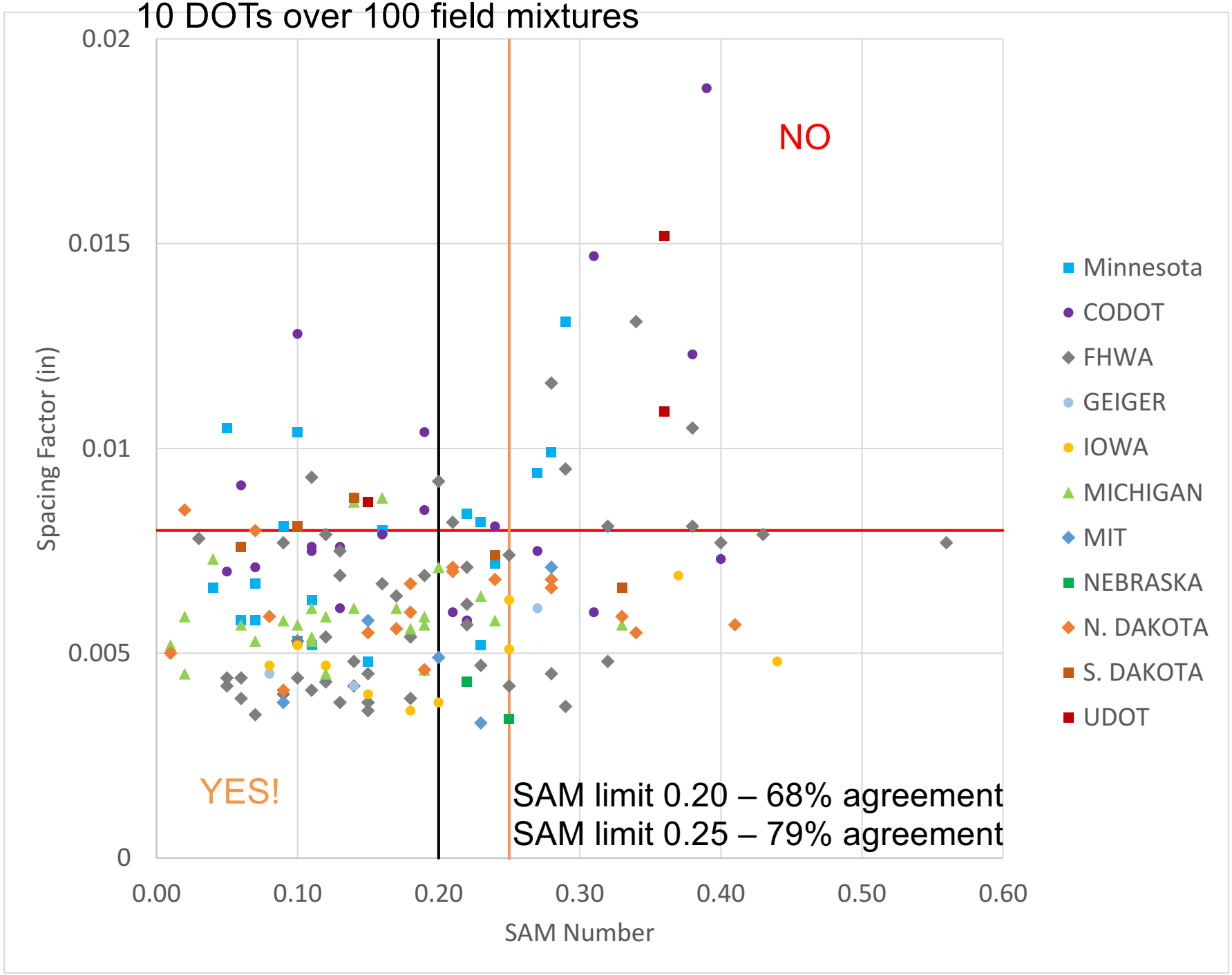
Why is the SAM number useful?


This test takes 7 – 14 days
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Spacing Factor (in)
Recommended SAM number
No
ACI 201.2R
92% Agreement
Lab Data OSU
Field Data
LAB Data FHWA
Yes!
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
SAM Number (psi)
This test takes 5-10 minutes

PennDOT 50 field mixtures



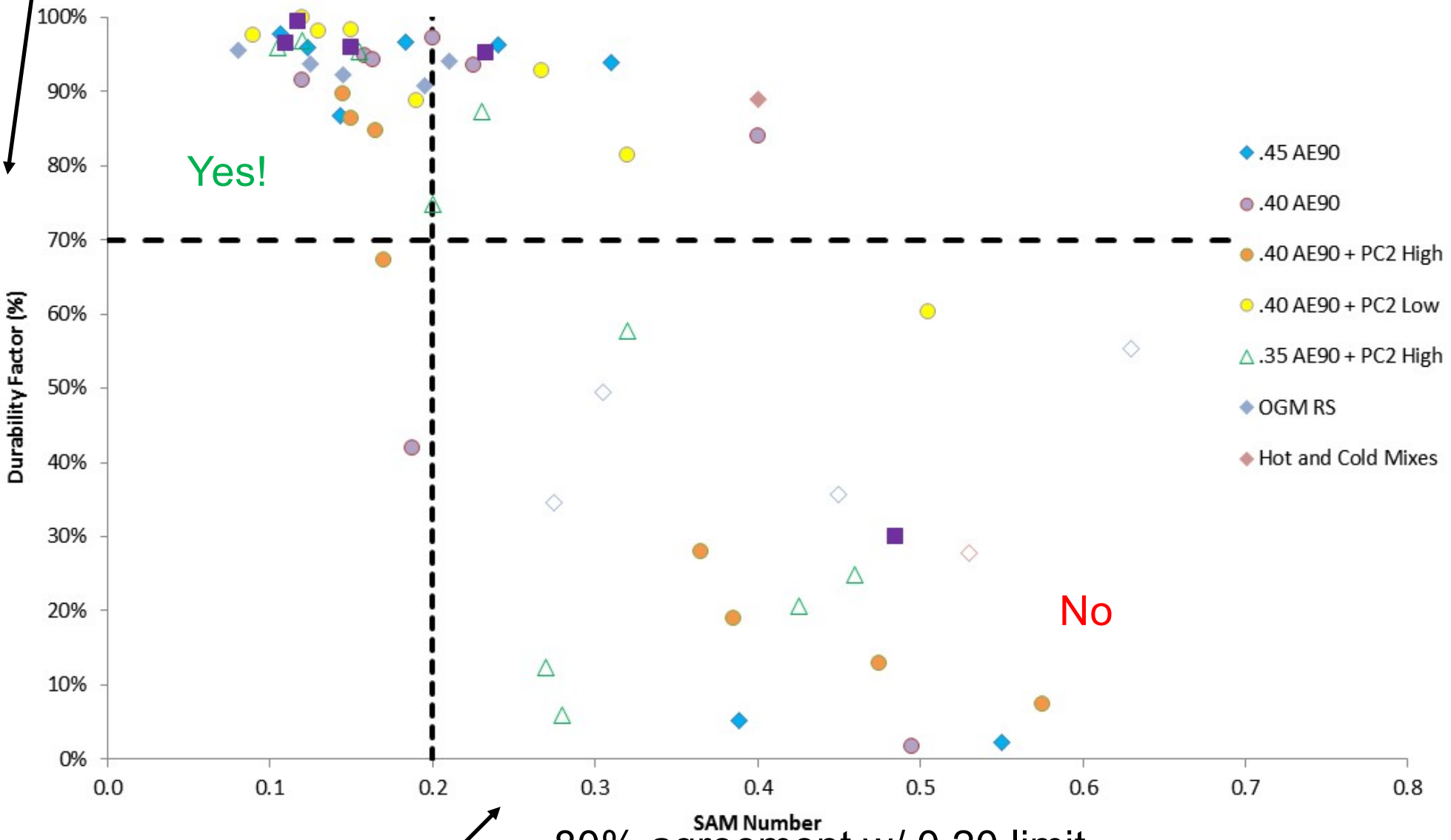
83% agreement


10 DOTs over 100 field mixtures
0.02
0.015
0.01
0.005
0
Spacing Factor (in)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
SAM Number
NO
YES!
SAM limit 0.20 – 68% agreement
SAM limit 0.25 – 79% agreement
Minnesota
CODOT
FHWA
GEIGER
IOWA
MICHIGAN
MIT
NEBRASKA
N. DAKOTA
S. DAKOTA
UDOT

Discussion

The SAM number of 0.20 correlates well with the spacing factor of 0.008” for over 350 lab and field mixtures completed 13 different states.

This test takes 3.5 months

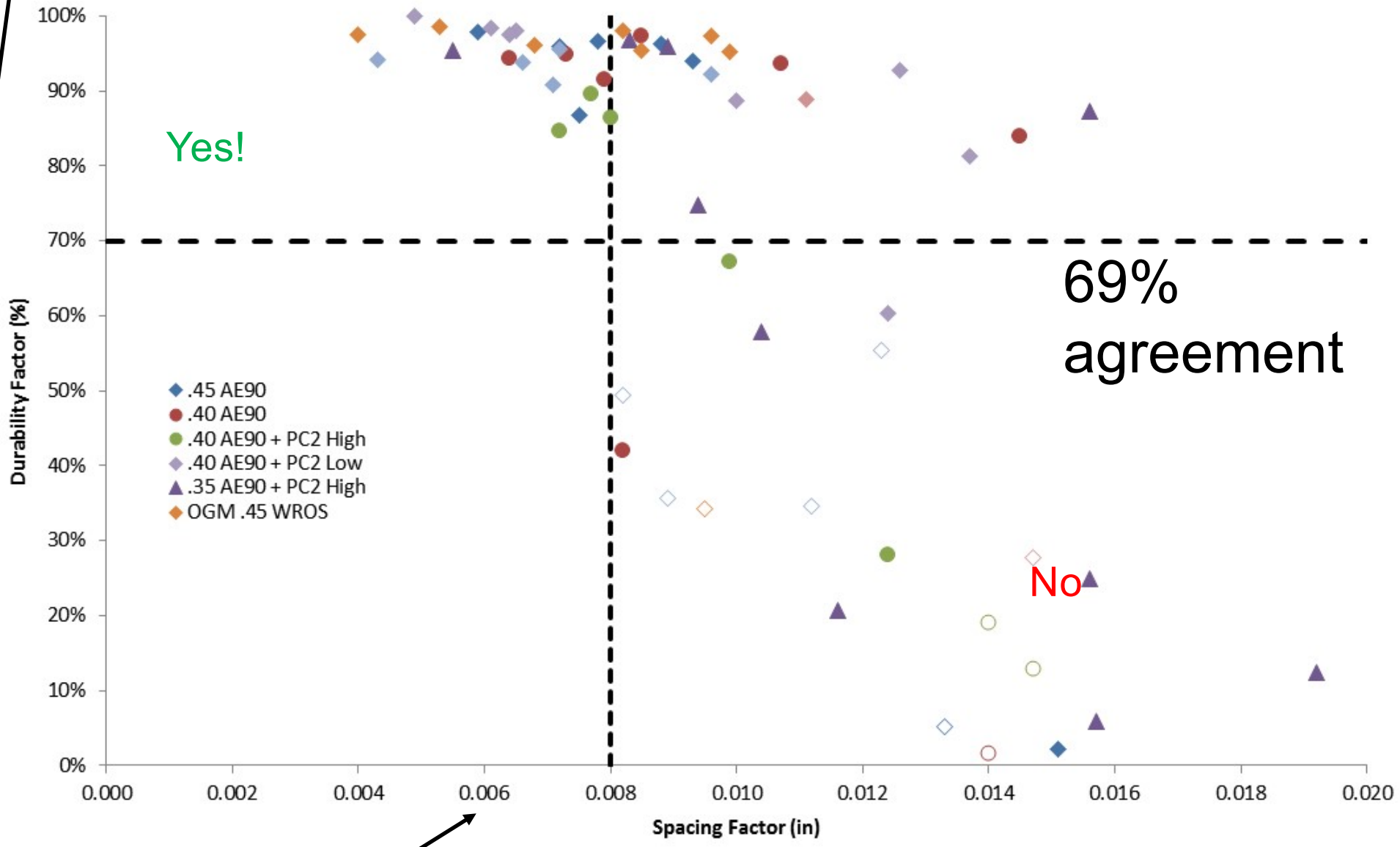


80% agreement w/ 0.20 limit

89% agreement w/ 0.25 limit

This test takes 5 -10 minutes

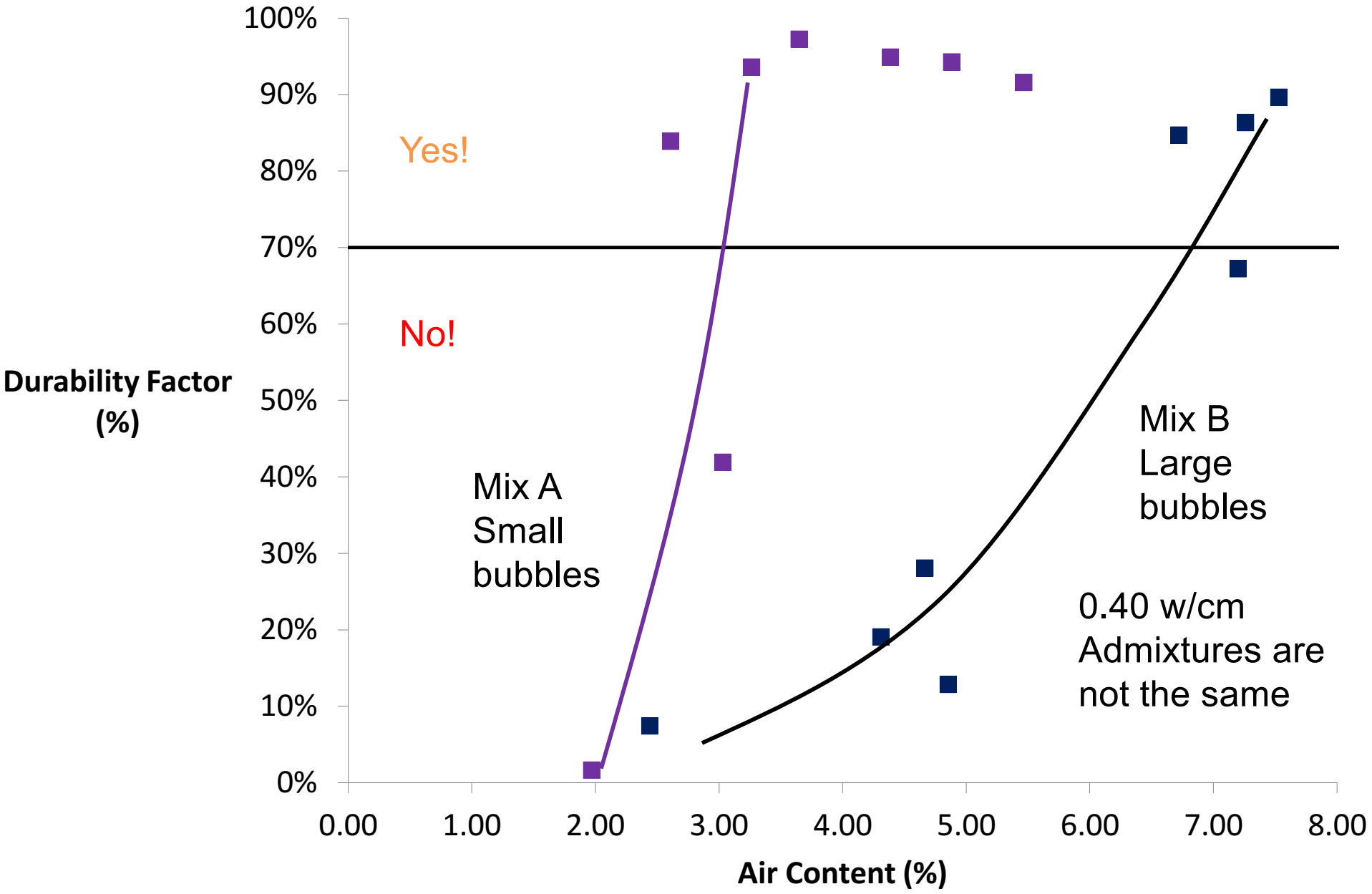
This test takes 3.5 months

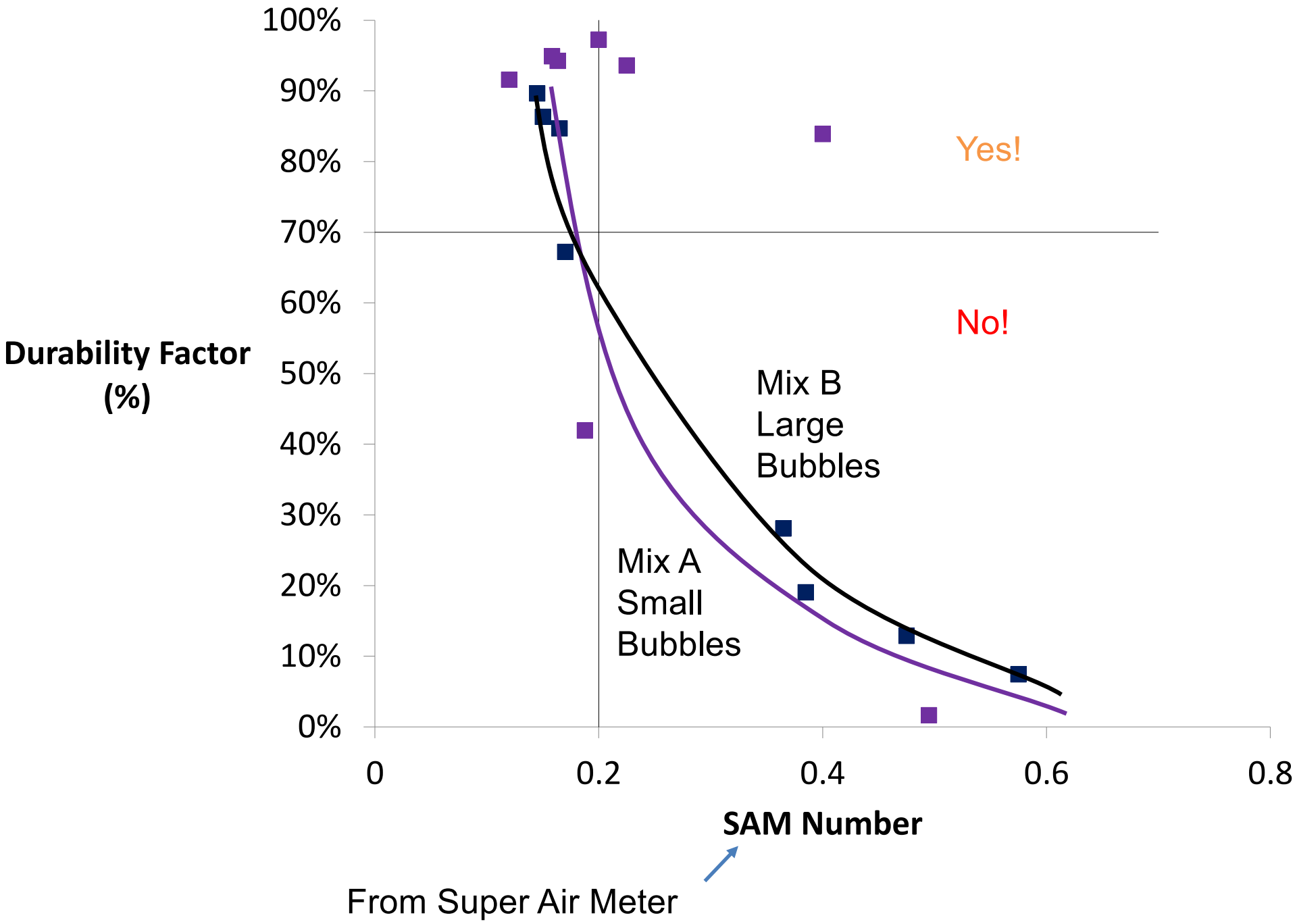


This test takes 7 - 14 days

Discussion

A SAM number of 0.20 correlates better to rapid freeze thaw durability than a spacing factor of 0.008”.


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Durability Factor (%)
Yes!
No!
Mix A
Small
bubbles
Mix B
Large
bubbles
0.40 w/cm
Admixtures are
not the same
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
Air Content (%)


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Durability Factor (%)
0
0.2
0.4
0.6
0.8
SAM Number
Yes!
No!
Mix B Large Bubbles
Mix A Small Bubbles
From Super Air Meter

Why is this useful?

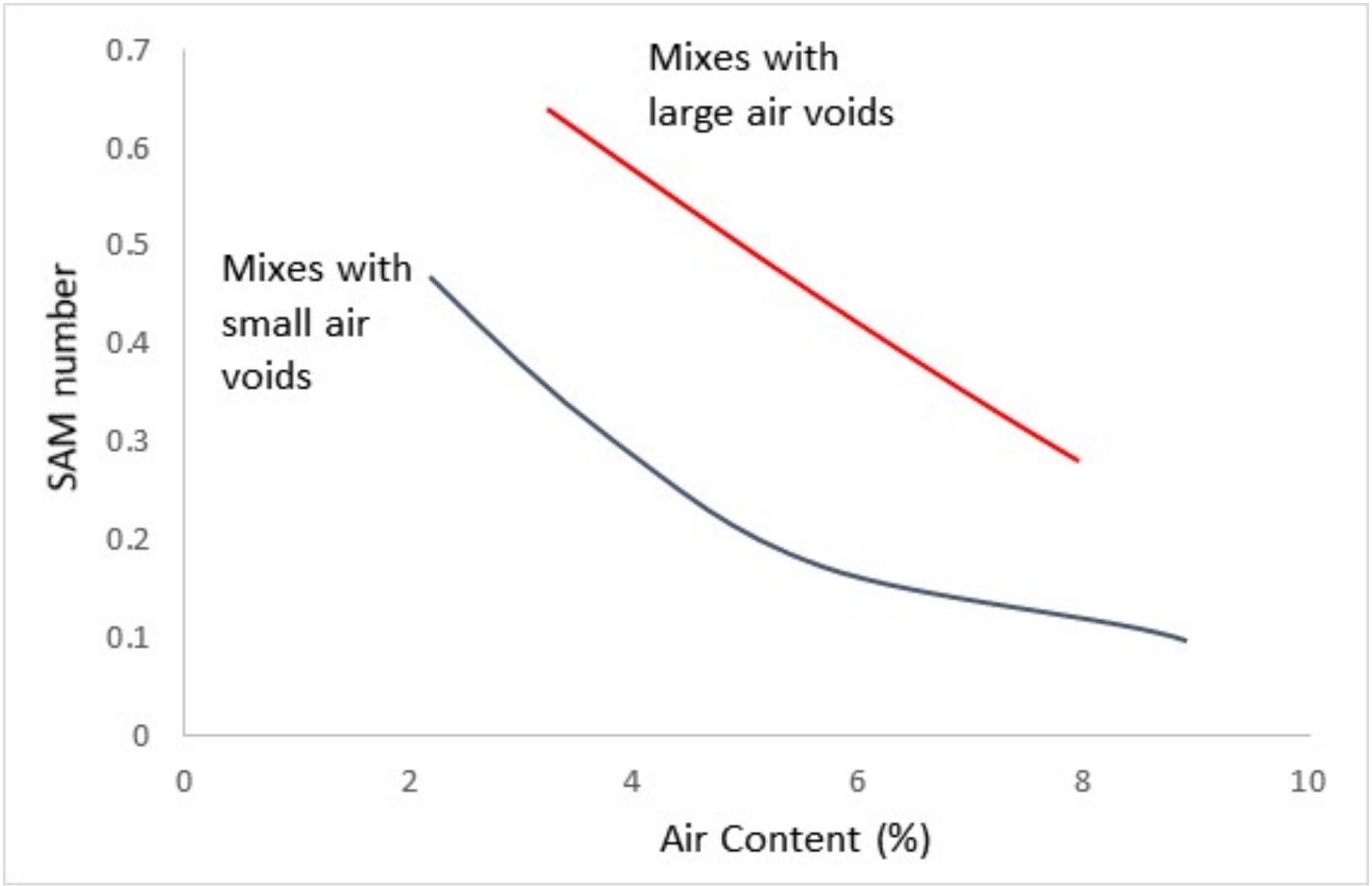
- The SAM can tell us about the quality (size and spacing) of our air void system before the concrete sets
- It can tell us about the freeze thaw durability of our air void system
- It can also tell us if we will have air void stability problems during our mixture design process!!!!

Why is this useful?

- This can give you important testing information that was almost impossible to get in the past

- This is helpful when:
  - mixtures are designed in the lab
  - mixtures are placed in the field
  - trial batching in the field
  - troubleshooting field problems
  - measuring variation in materials

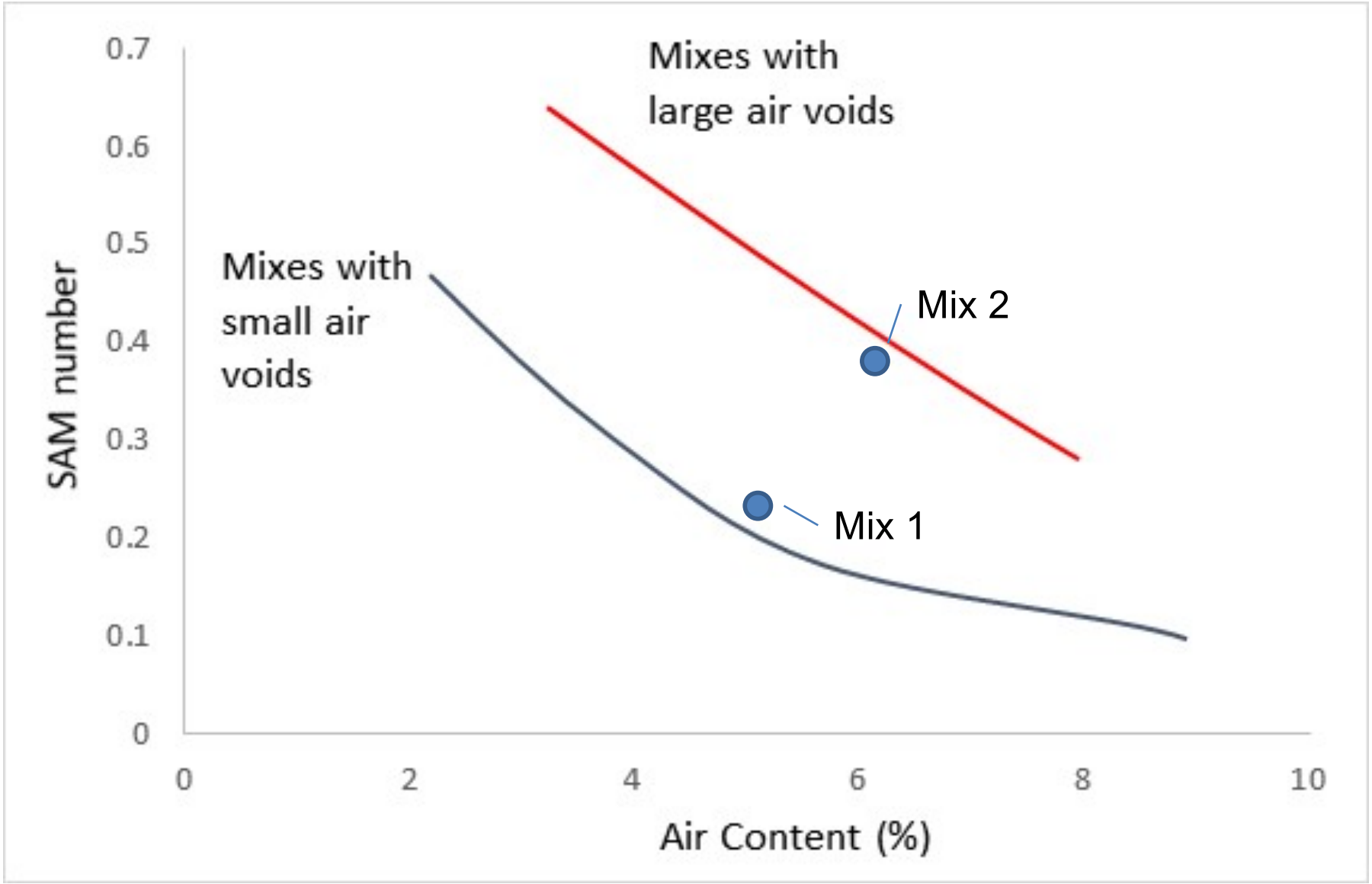
How do I do this?



An example

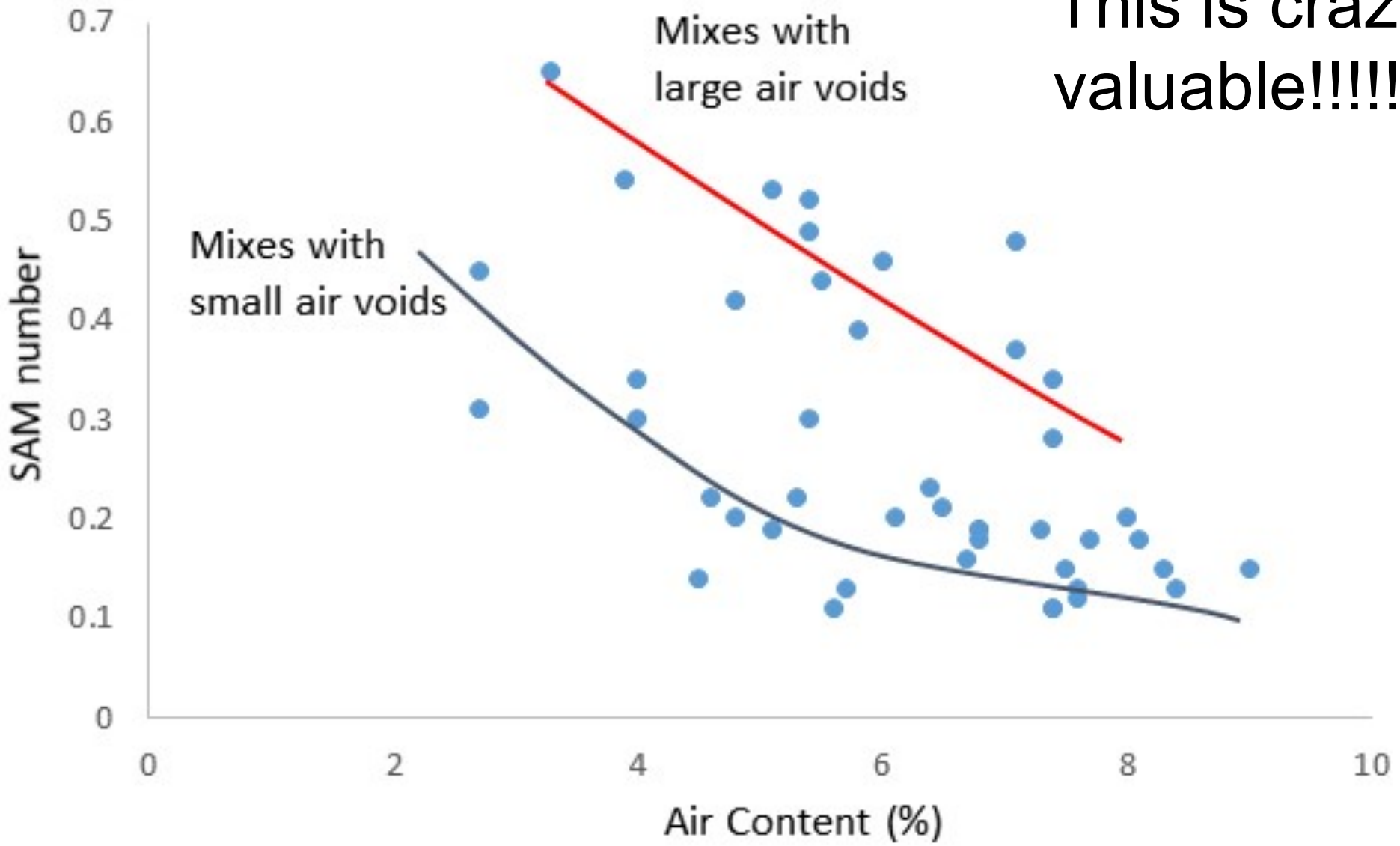
- Mix 1 - SAM number of 0.22 and an air content of 5%

- Mix 2 - SAM number of 0.40 and an air content of 6%


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
SAM number
Mixes with large air voids
Mixes with small air voids
Mix 2
Mix 1
0
2
4
6
8
10
Air Content (%)

PennDOT

This is crazy valuable!!!!!!



Discussion

By plotting your data on the SAM Curve you can immediately tell if your air void system is made of large or small bubbles.

This immediate feedback can be used to troubleshoot field issues and give you feedback on your concrete mixture design.

The following states have a SAM

- Michigan (5)
- Kansas (16)
- Utah
- Colorado (2)
- Iowa (2)
- Illinois (5)
- Indiana (2)
- Wisconsin (4)
- Massachusetts
- Idaho (2)
- Tennessee (2)
- Pennsylvania
- Missouri (2)
- California
- N. Carolina (3)
- N. Dakota
- Oklahoma (10)
- Nebraska (3)
- Ohio (5)
- Minnesota (3)
- Texas (2)
- FHWA (6)
- Georgia
- New Jersey
- New Mexico
- New York (5)
- S. Dakota
- Mississippi
- Iowa (2)
- Oregon
- Manitoba (5)
- Ontario (2)
- England
- Poland (2)

Test methods	Parameter	COV	Agreement with durability factor of 70 in ASTM C 666	Time to complete the test
AASHTO TP 118	SAM number (OSU) SAM number (workshop**)	17.1 18.1	80%	10 min
ASTM C 457	spacing factor	20.1	69%	7 days
ASTM C 666	durability factor*	22.7	-	3.5 months

* assuming a durability factor of 75 and method B

** includes all participants

Discussion

The variability of SAM is similar to the variability in the hardened air void analysis and rapid freeze thaw testing and the test can be run in the field on fresh concrete in less than 10 min.

Discussion

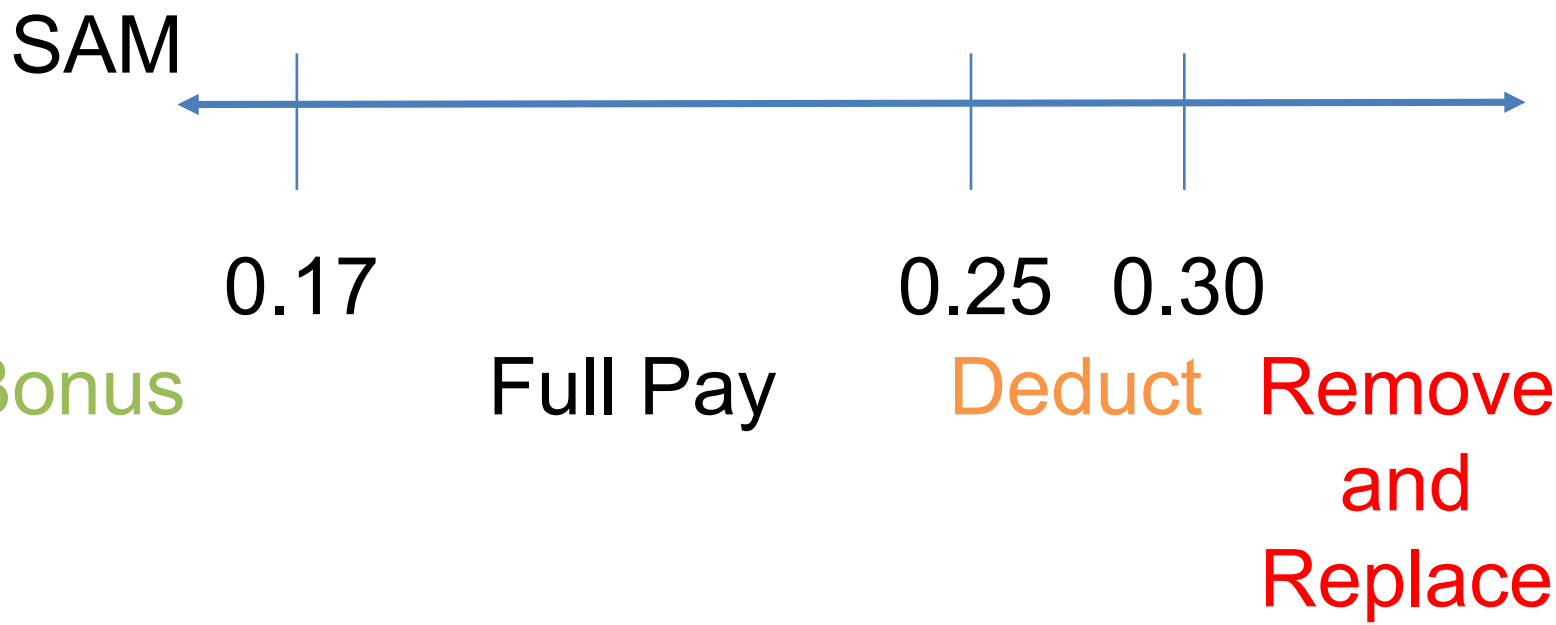
I don’t think it is a coincidence that the variability is so similar between the three different methods.

Each test is designed to investigate the air void distribution. Air void distribution may be more variable than other concrete properties such as compressive strength.

How do you specify the SAM?

1. Replace the air meter with the SAM in the field
2. Use the SAM during the mixture design stage and validate in the field.

SAM replaces air meter



- Air content must be above 4%

SAM used during mixture acceptance

- During mixture design stage run trial batches with air < 5% and SAM number must be < 0.25.
- Test air as per typical practice.
- Validate that SAM < 0.25 and air > 4% once a day or every 1000 yds in the field.

I need your help

- Taking the industry from a horse and buggy to an internal combustion engine is not easy.

- Try the SAM!
- Ask questions!
- Give suggestions

- Share what you learn here with others
- Help others become knowledgeable of the SAM

I need your help

- Help extend my Pooled Fund Study. We need 5 more states. TPF-5(97)
- Myers Assoc. has a SAM in the exhibitor hall.
- Request a SAM from FHWA
- AASHTO Webinar this Thursday (10/20/16)

Conclusion

- Large bubbles are the enemy!
- Air volume does not tell you bubble size.
- The SAM can measure the volume and size distribution of the bubbles in fresh concrete
- This is helpful for making your air more consistent and ensure freeze thaw durability

Conclusion

- A SAM number of 0.20 seems to correspond to a spacing factor of 0.008”
- Over 90% of the lab and field data is correctly separated with this limit
- The SAM number correlates with ASTM C666 testing
- The SAM has been investigated by a number of others and all have found similar correlations

Questions???

Tyler.ley@okstate.edu

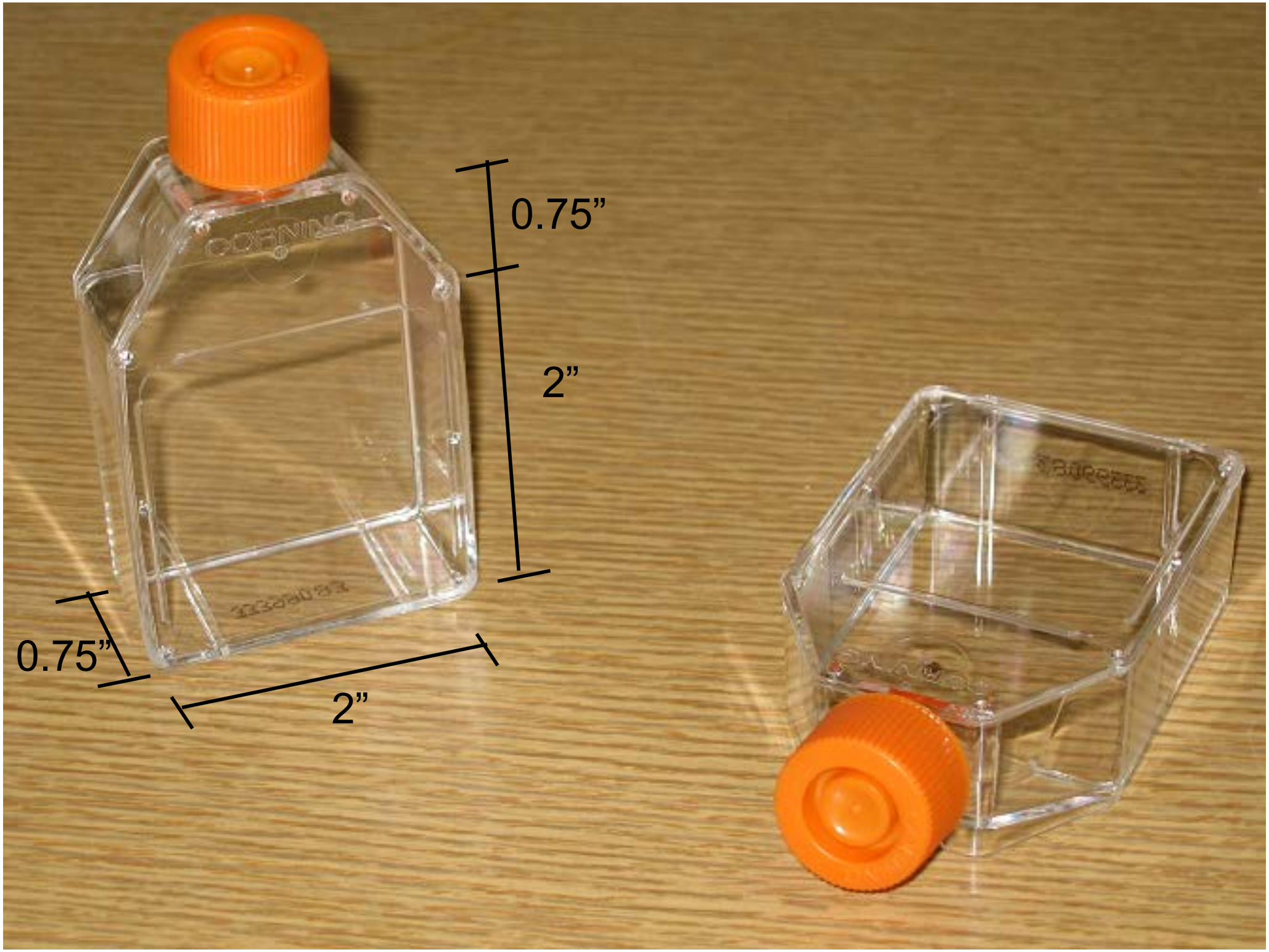
www.tylerley.com

www.superairmeter.com

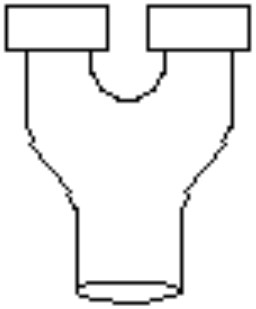
What if my SAM number is too high?

- Add more air
- Change mixture proportions
- Change mixing/batching operations

How does the SAM work?


0.75”
2”
0.75”
2”

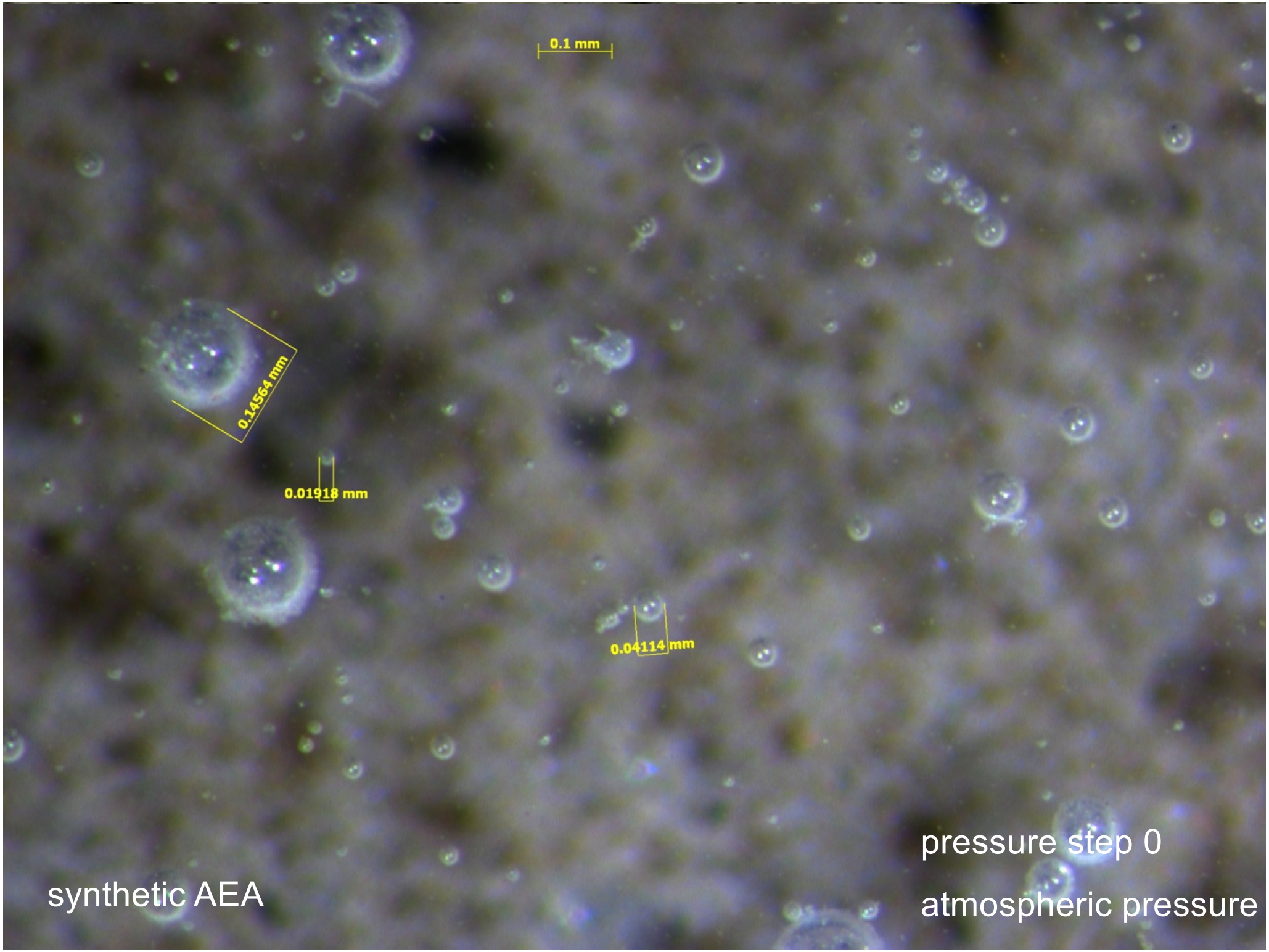
Air pump

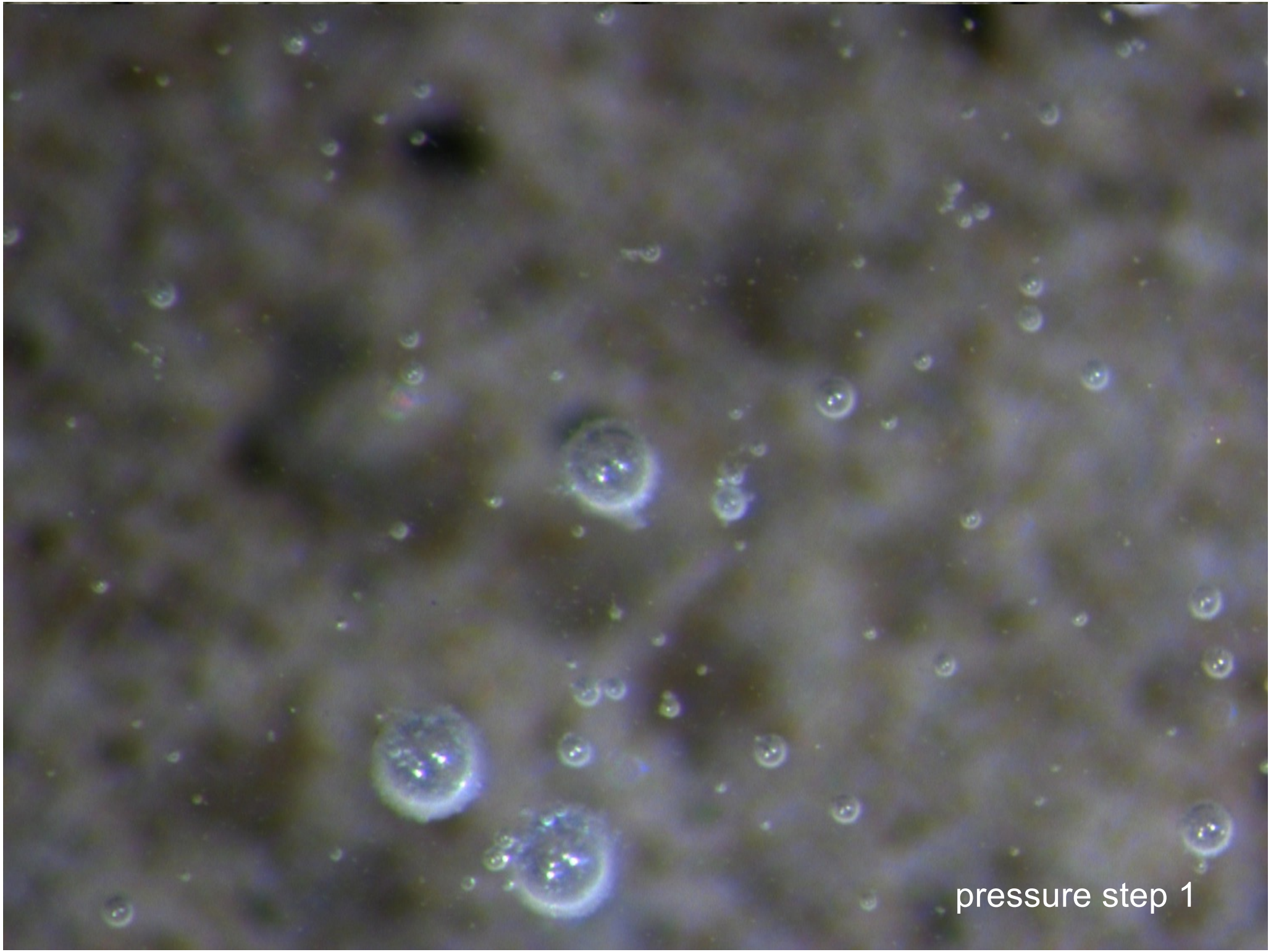


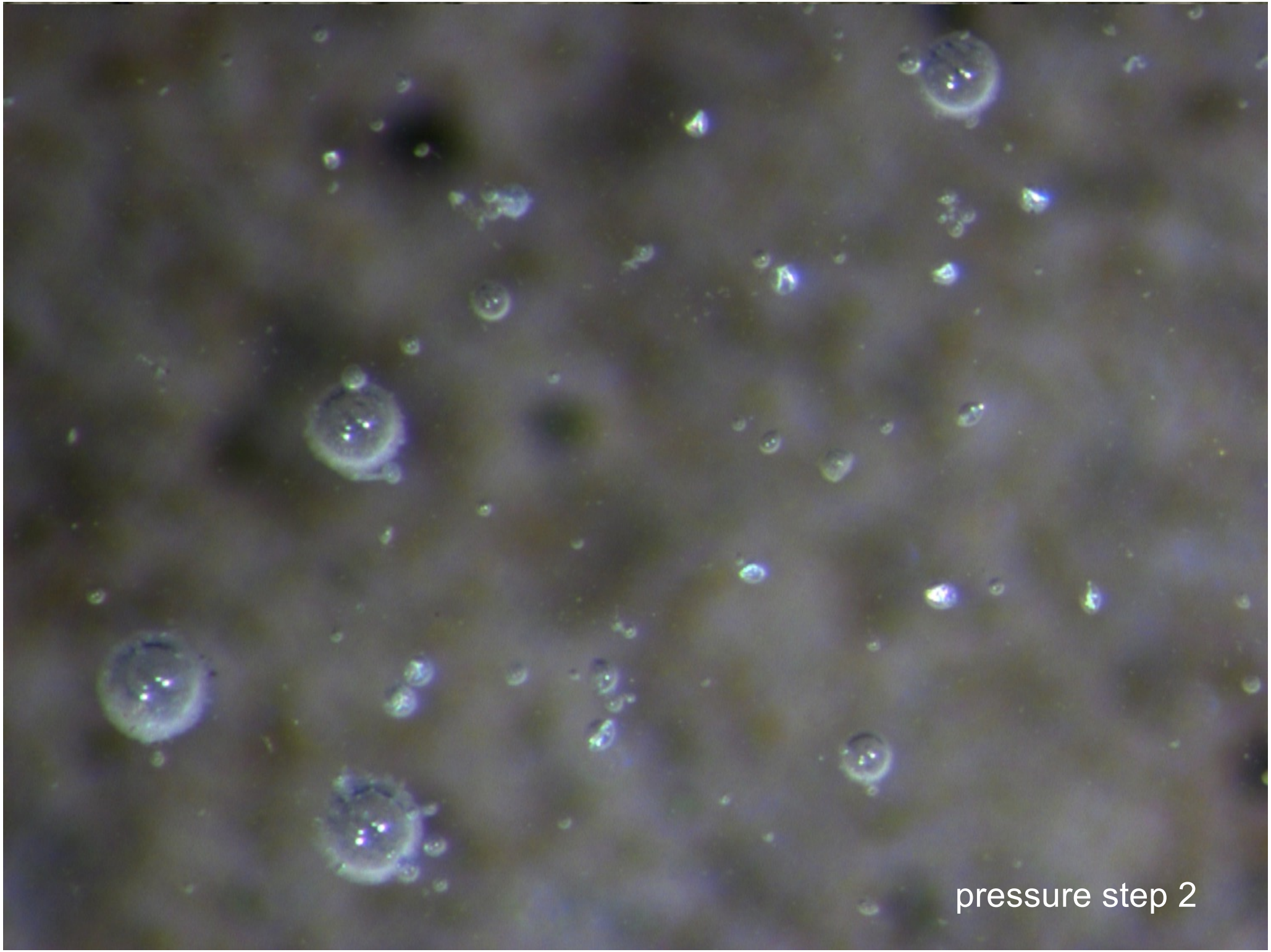
Stereo Microscope

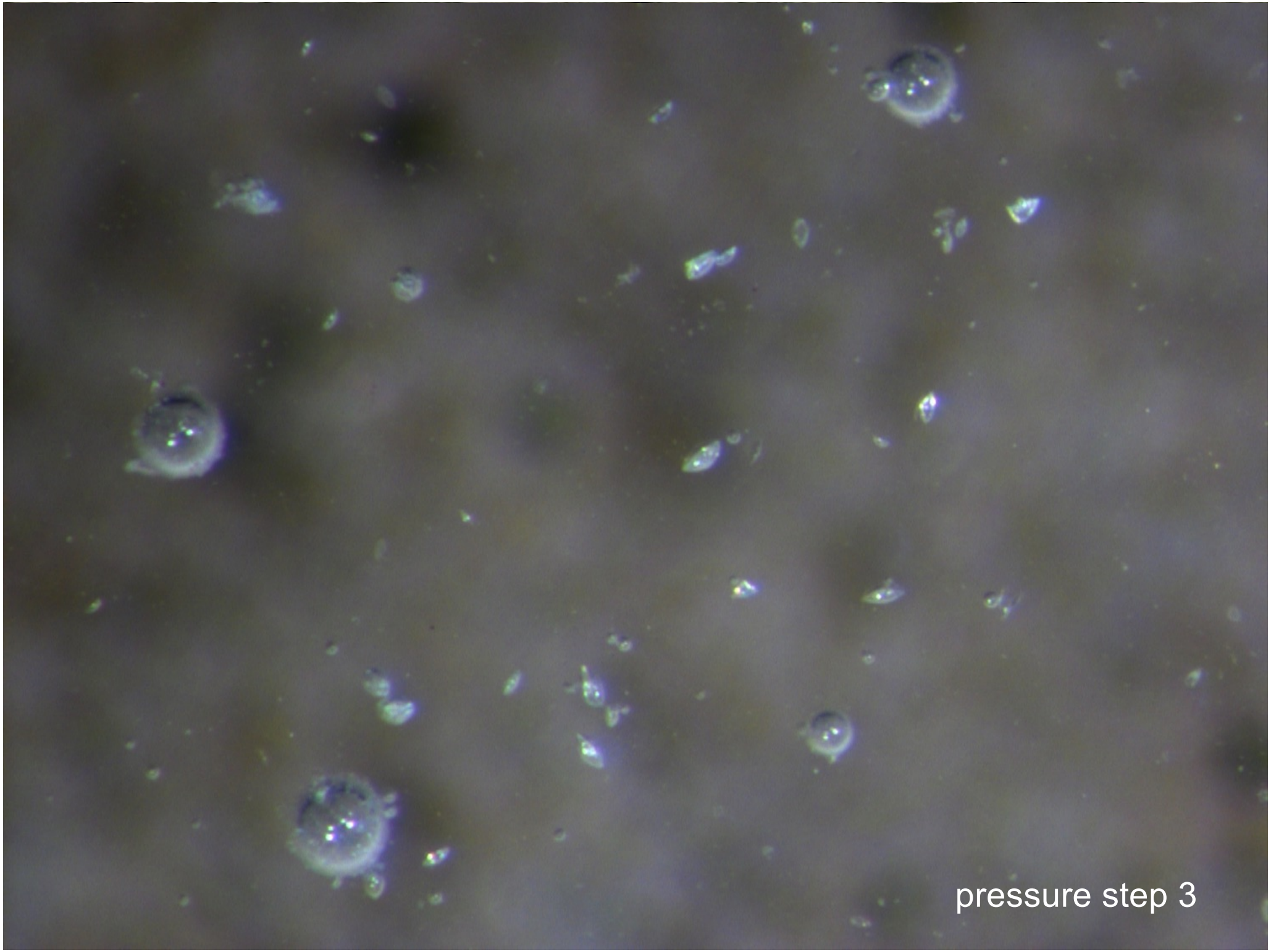
Modified Lid

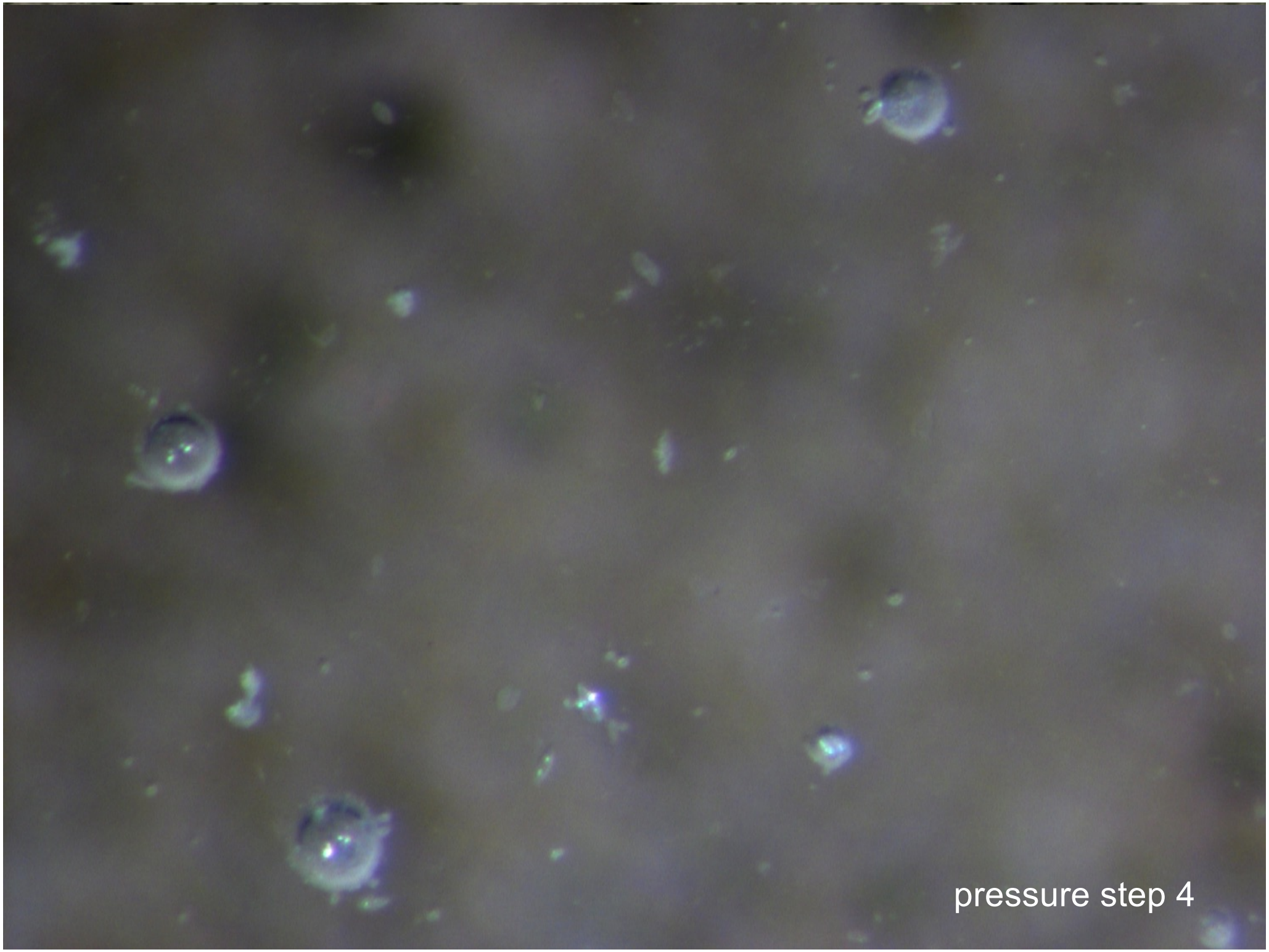
Paste

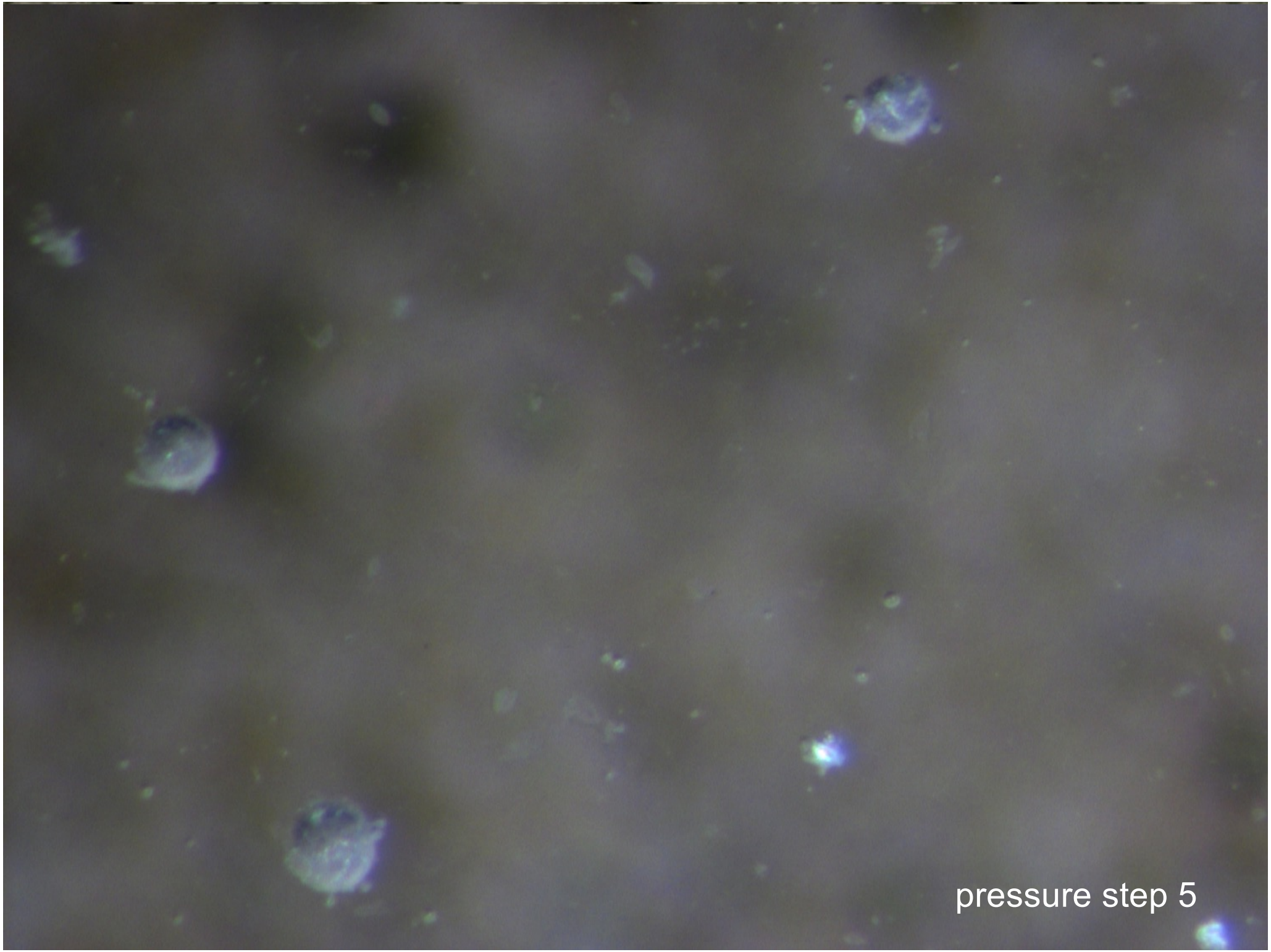

0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
synthetic AEA
pressure step 0
atmospheric pressure

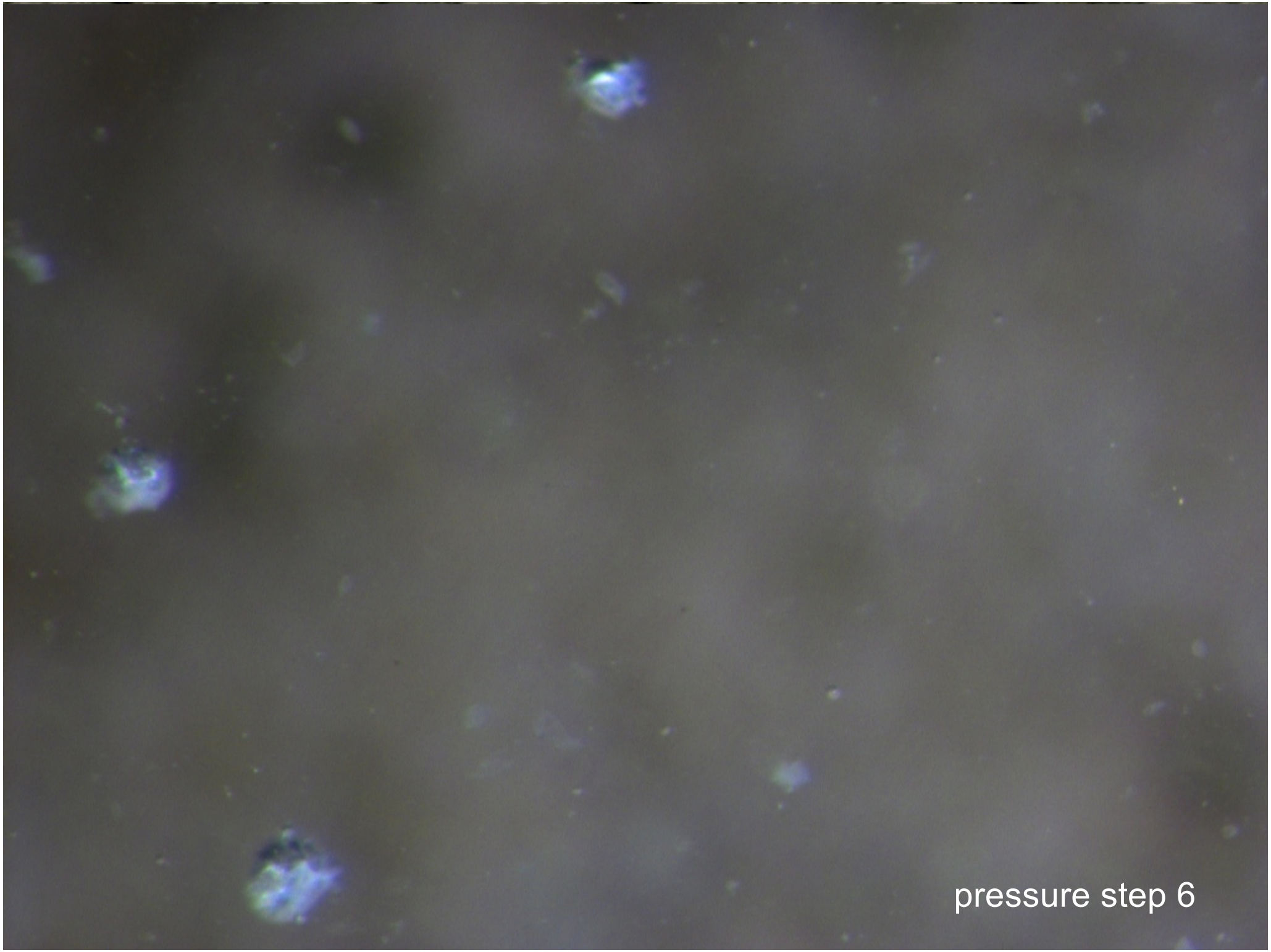

pressure step 1

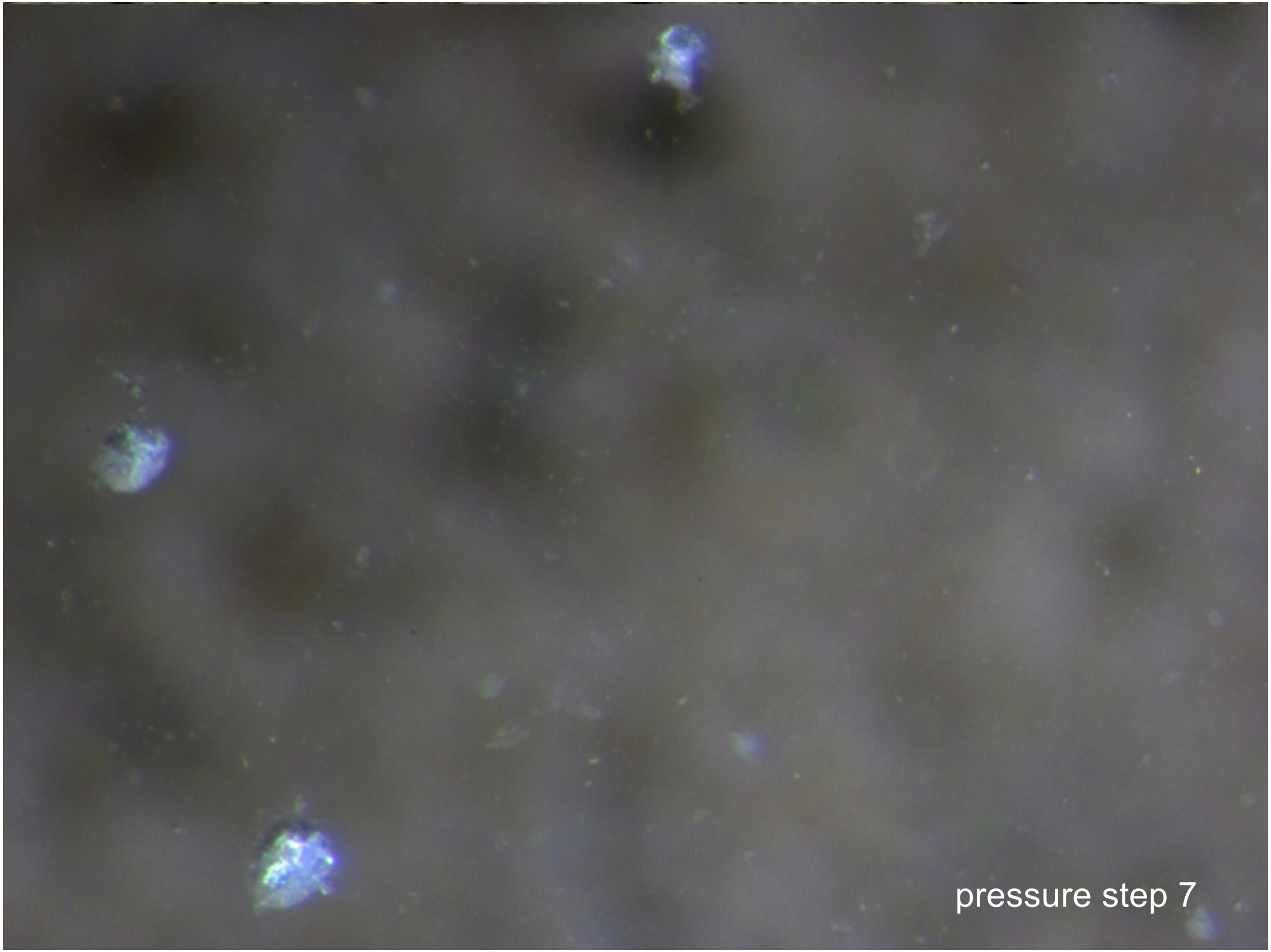

pressure step 2

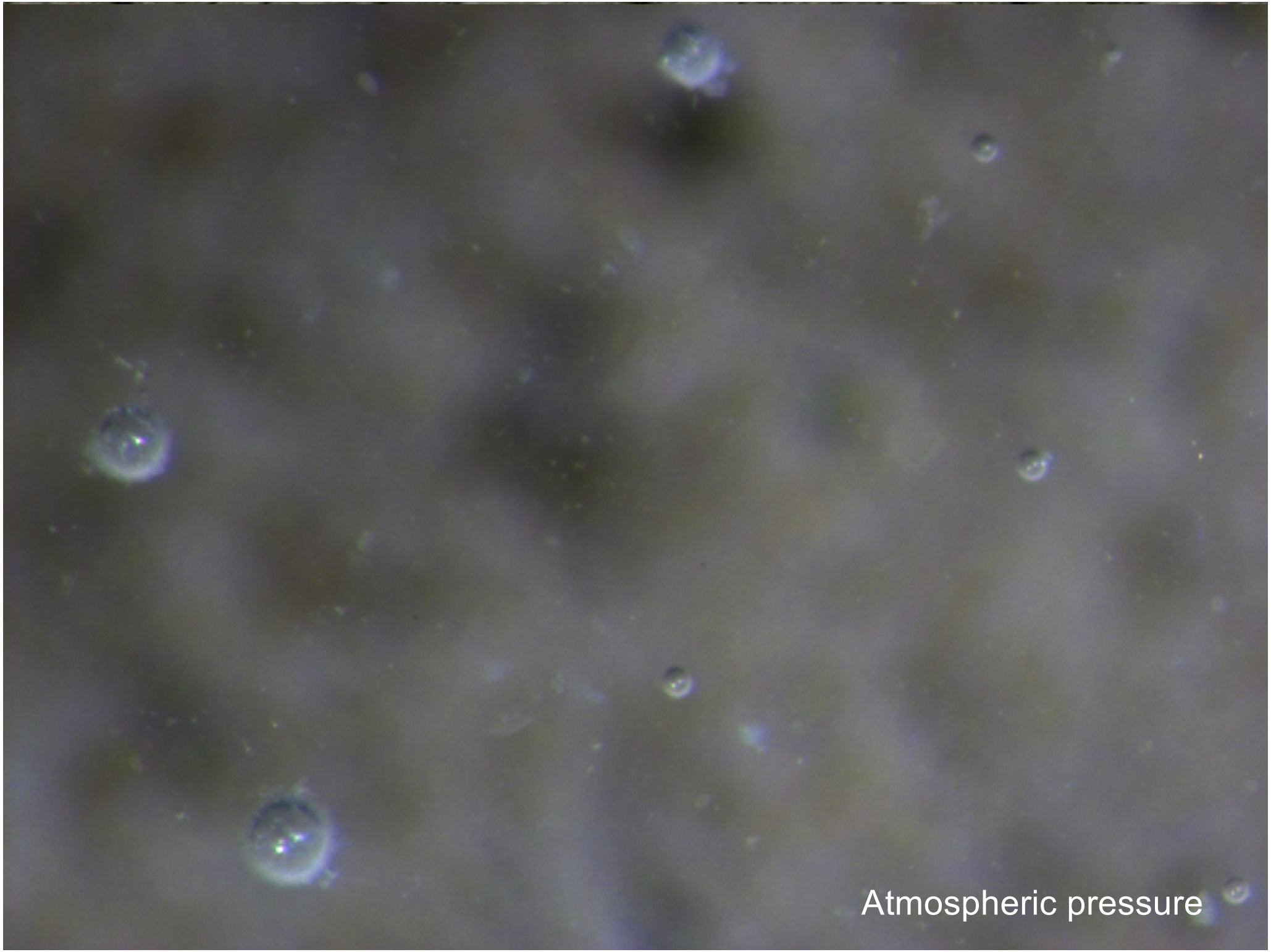

pressure step 3

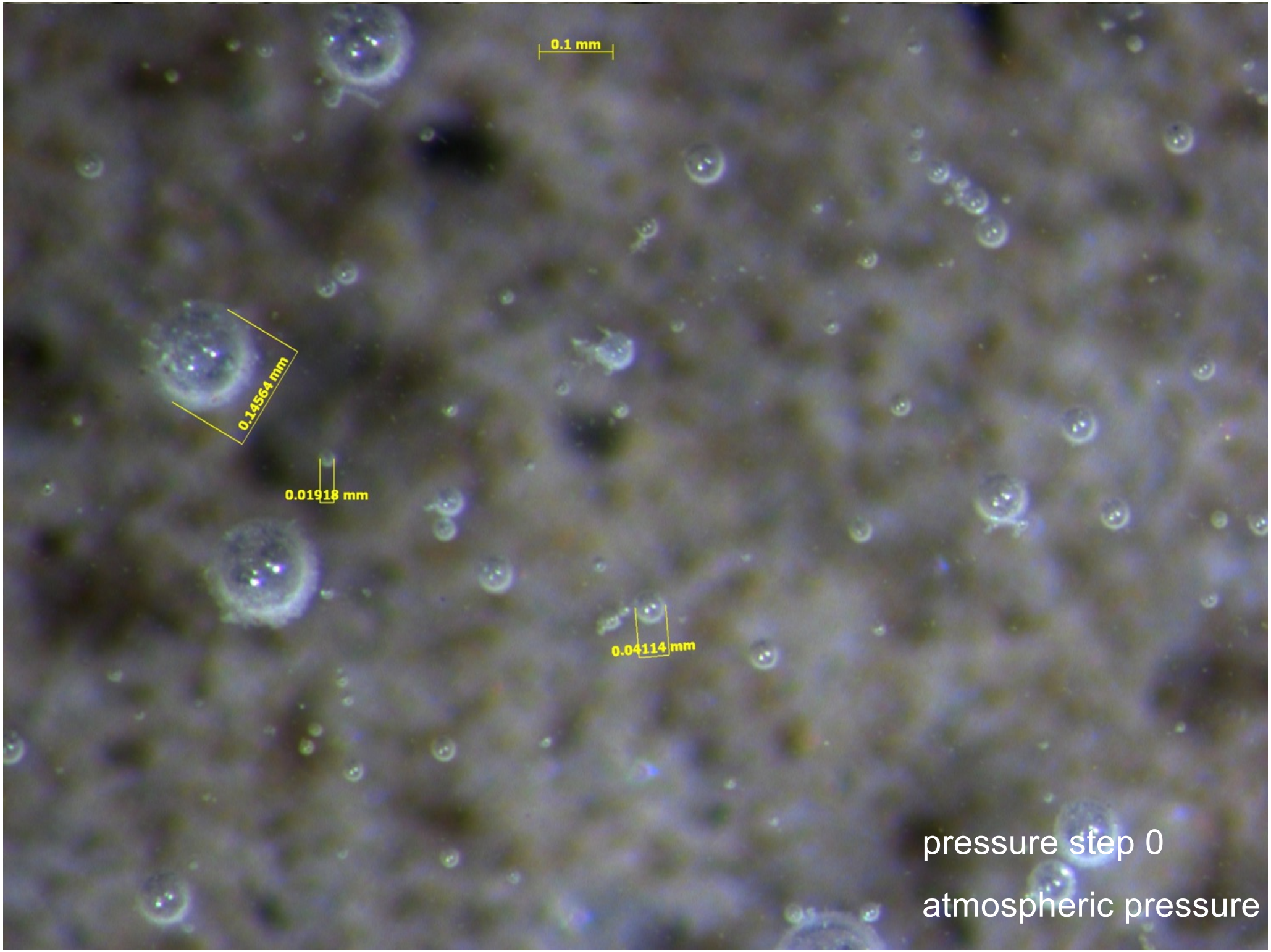

pressure step 4


pressure step 5


pressure step 6


pressure step 7


Atmospheric pressure


0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
pressure step 0
atmospheric pressure

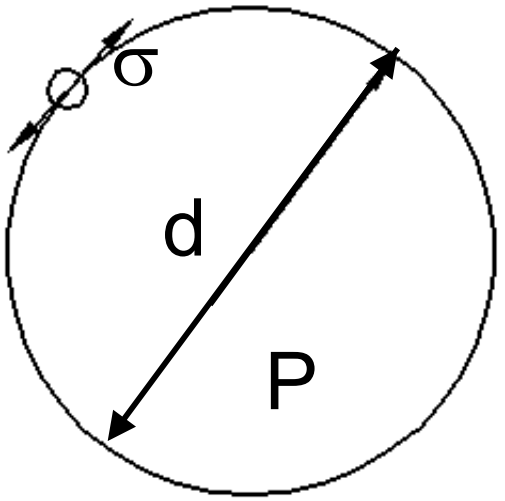
What is happening?

- As you increase the pressure you are dissolving the small bubbles into solution and then they do not immediately come back when you decrease the pressure.
- Notice that these bubbles are not close to one another.

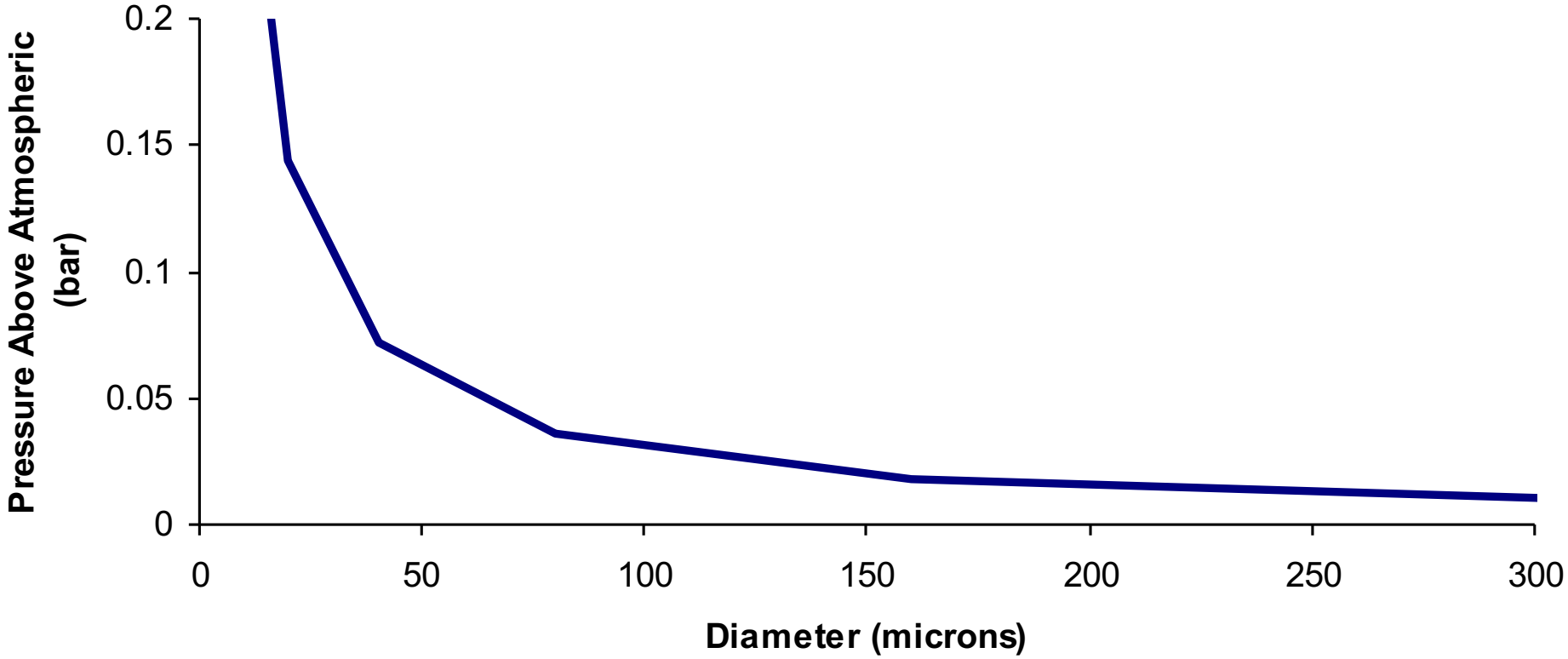
Why is this happening?

- According to the Laplace – Young equation smaller bubbles have higher pressures in them than larger bubbles

$$P = Po + 4\sigma/d$$



- This is caused by the differences in curvature of the bubble wall



Assumes σ = 72 dynes/cm

Atmospheric pressure

Why do the bubbles dissolve?

- Henry's Law states that at a certain pressure that a certain amount of the gas would rather dissolve in the liquid than remain a gas

$$p = k_H c$$

p = pressure

c = concentration

k_H = Henry's Law constant

More pressure experiments

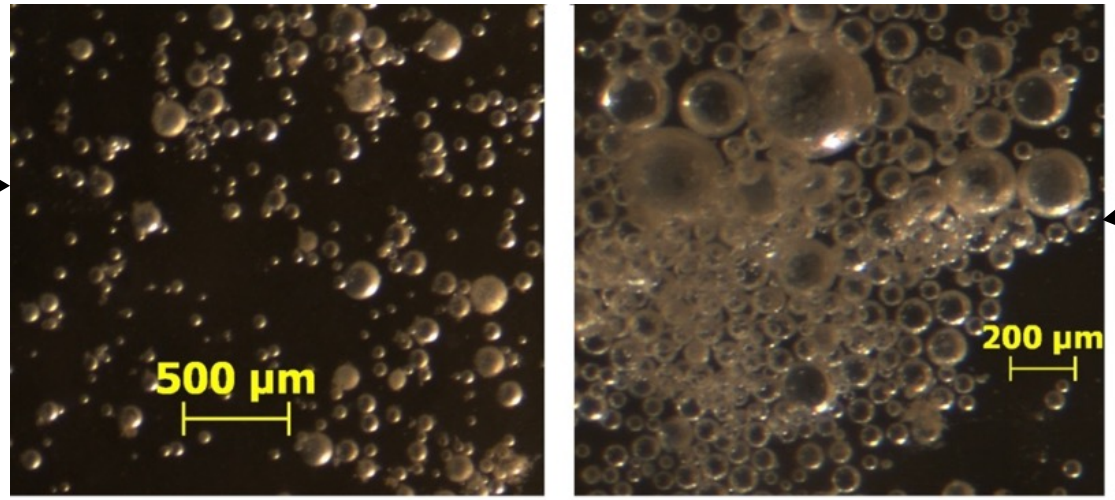
- We ran additional experiments where we tracked individual bubbles every 5 psi from atmospheric until 35 psi.

- We looked at two different situations:
  1. High spacing factor (bubbles far apart)
  2. Low spacing factor (bubbles close together)

High spacing factor

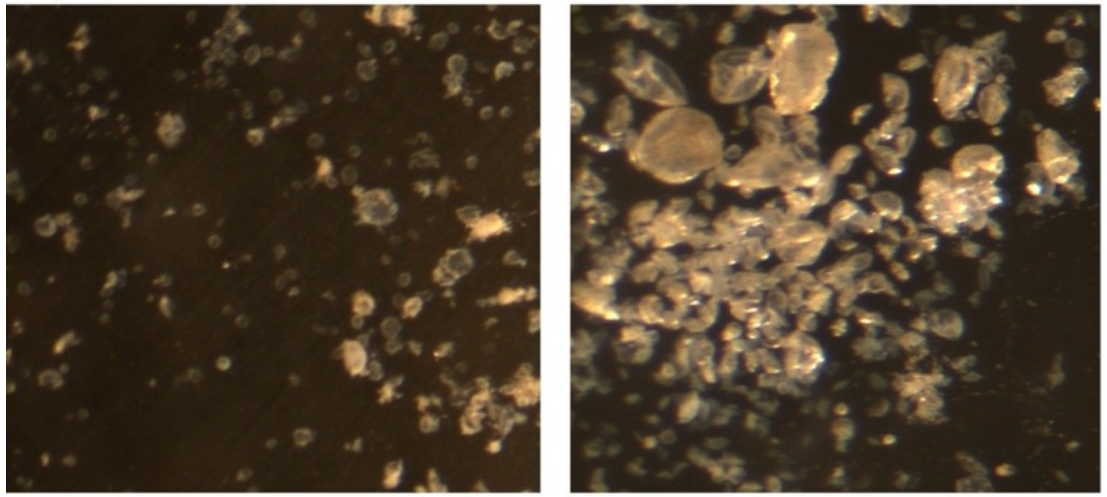
Low spacing factor

Atmospheric Pressure

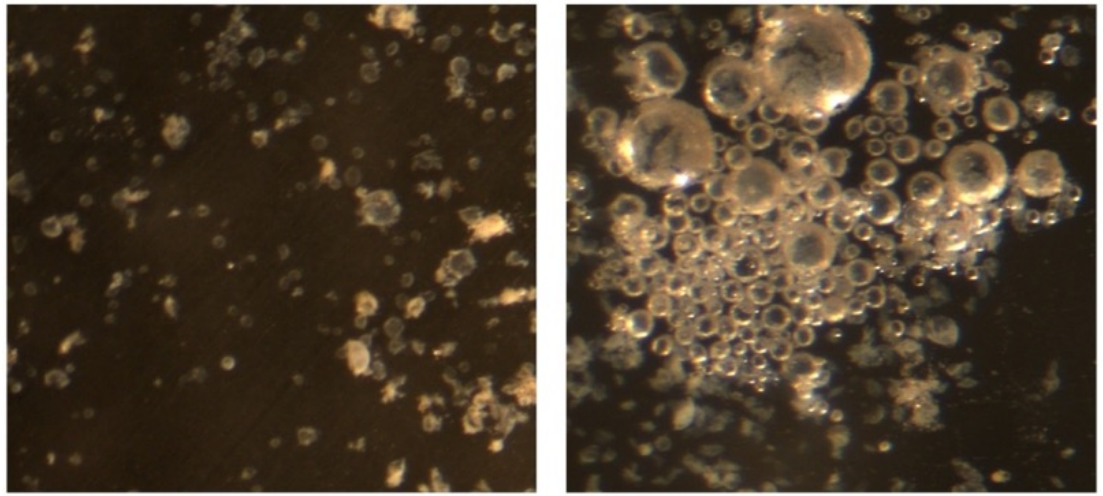


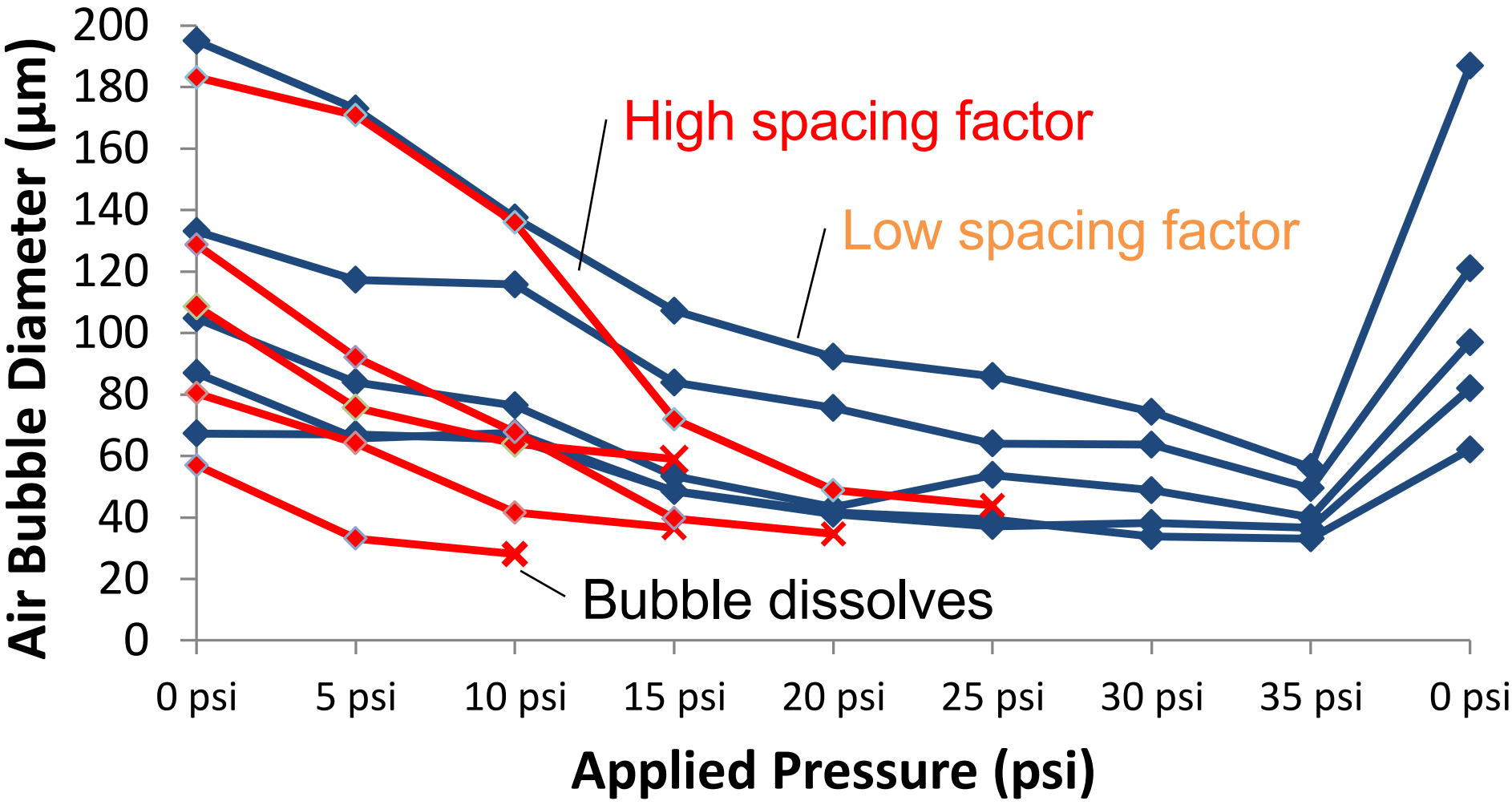
35 psi

other pressures not shown



Returned to Atmospheric Pressure




Air Bubble Diameter (µm)
200
180
160
140
120
100
80
60
40
20
0
High spacing factor
Low spacing factor
Bubble dissolves
0 psi
5 psi
10 psi
15 psi
20 psi
25 psi
30 psi
35 psi
0 psi
Applied Pressure (psi)

Results

- The bubbles in the high spacing factor system (bubbles far apart) almost entirely dissolve and do not come back.
- The bubbles in the low spacing factor system (bubbles close together) do not dissolve very much.

Results

- If you have a high spacing factor (bubbles far apart) then the bubbles dissolve from the first set of pressures and they won't be around to resist the second pressure step.
- This will cause a high SAM number.
- If you have a low spacing factor (bubbles close together) then the bubbles will only dissolve a little and the first and second pressure step is about the same.
- This will cause a low SAM number.

Results

- We did a lot of testing with a lot of different materials to find how this pressure change corresponded to spacing factor.

Case Studies from FHWA Mobile Concrete Lab

These slides are from
Jagan Gudimettla

FHWA Mobile concrete lab

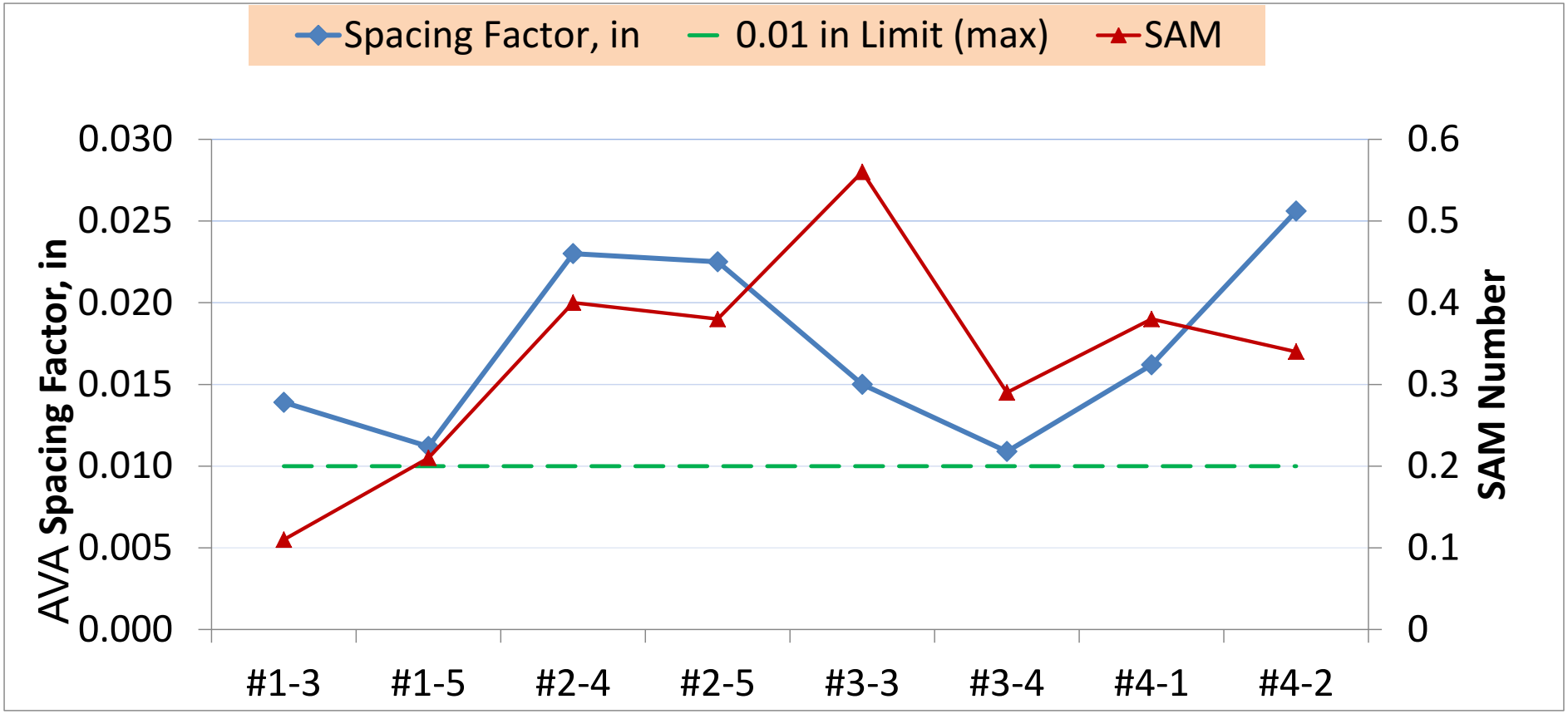
Air Void System - AVA

Air Void Analyzer (AVA)

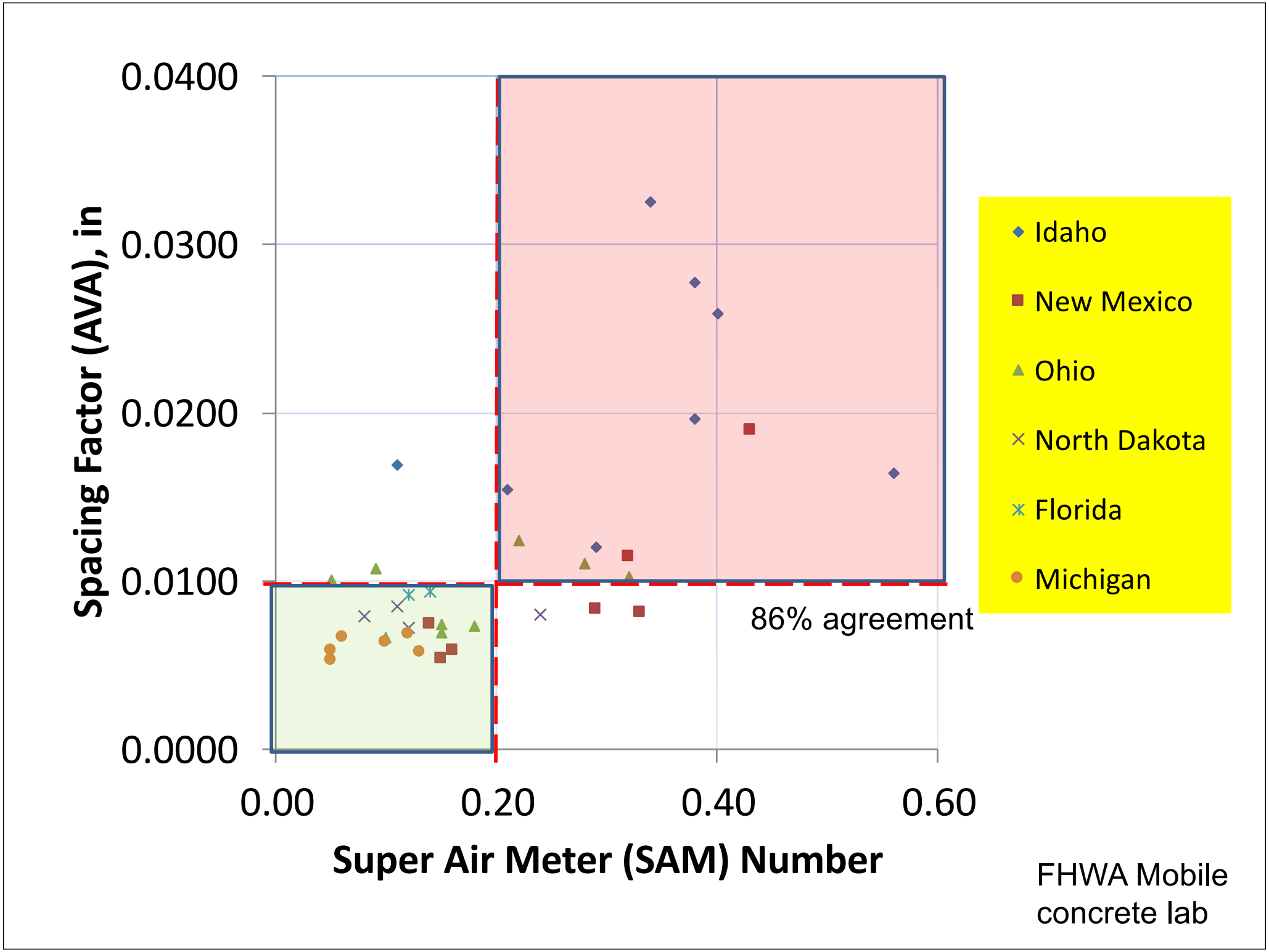
Slide from Jagan Gudimettla

FHWA Mobile concrete lab

Air Void System – SAM vs. AVA



Slide from Jagan Gudimettla


0.0400
0.0300
0.0200
0.0100
0.0000
Spacing Factor (AVA), in
0.00
0.20
0.40
0.60
Super Air Meter (SAM) Number
86% agreement
Idaho
New Mexico
Ohio
North Dakota
Florida
Michigan
FHWA Mobile concrete lab