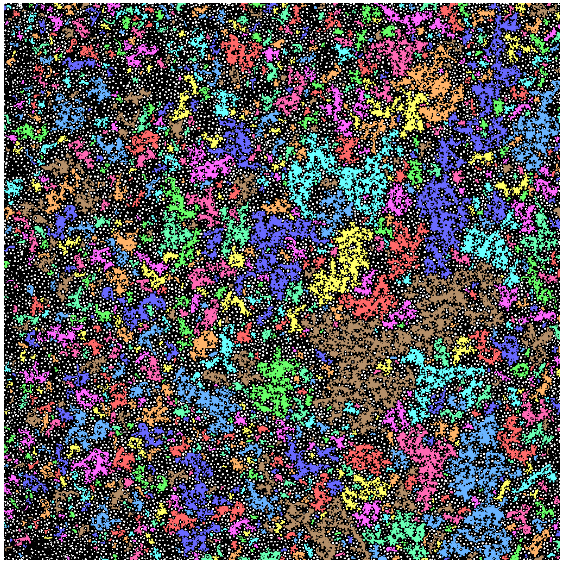
Steady-state, simultaneous two-phase flow in porous media: An experimental study



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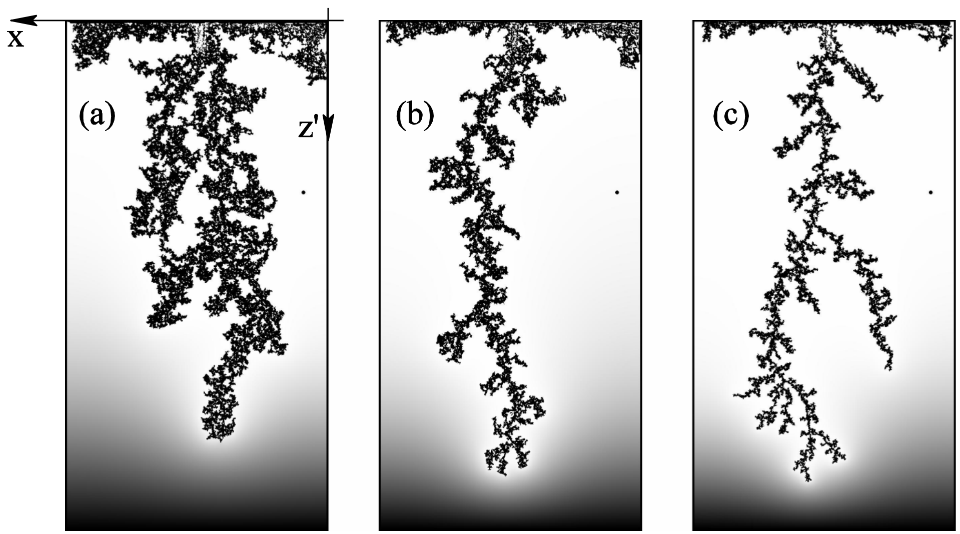
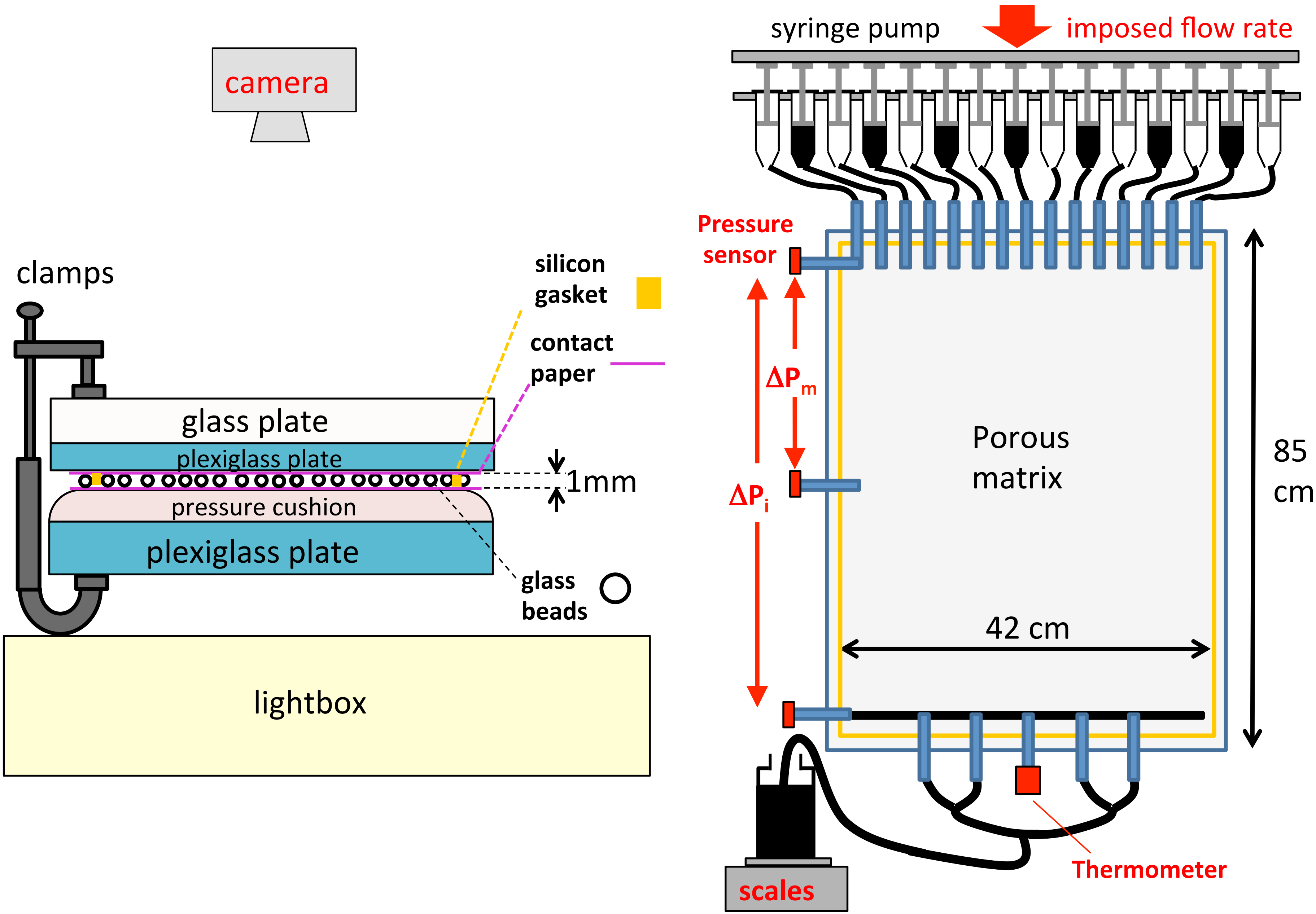


Experimental setup



Simultaneous injection of two fluids.

Will discuss two cases:

A) Non wetting fluid: Air Wetting fluid: Water-glycerol (15% water b.w.)
Viscosity contrast 10^{-4}, Surface tension 0,064 Nm^{-1}

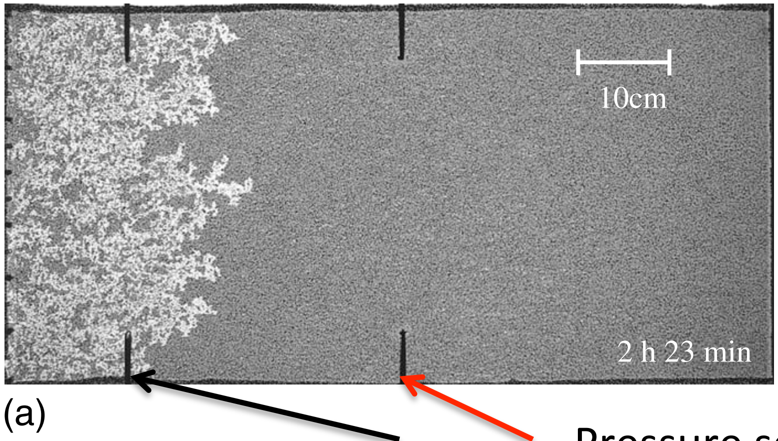
B) Non wetting fluid: Rapeseed Oil Wetting fluid: Water-glycerol (20%water b.w)
Viscosity contrast 1.3, Surface tension 0,019 Nm^{-1}

Case A)

Non wetting fluid: Air

Wetting fluid: Water-glycerol

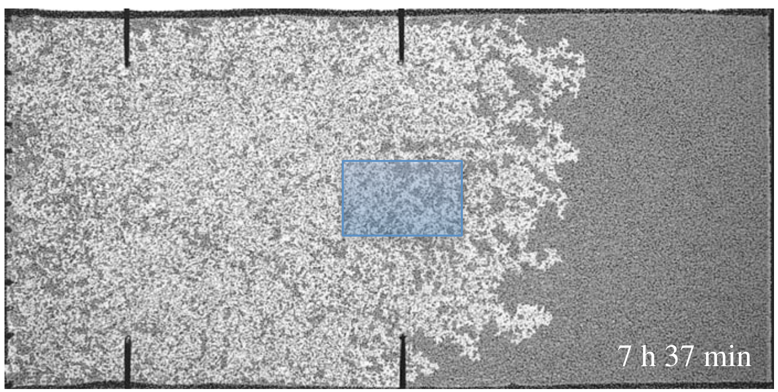
Front propagation



(a)

Pressure sensors

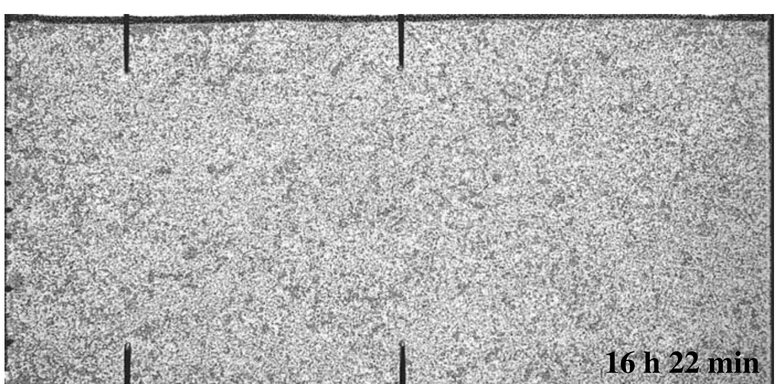
Transient regime



(b)

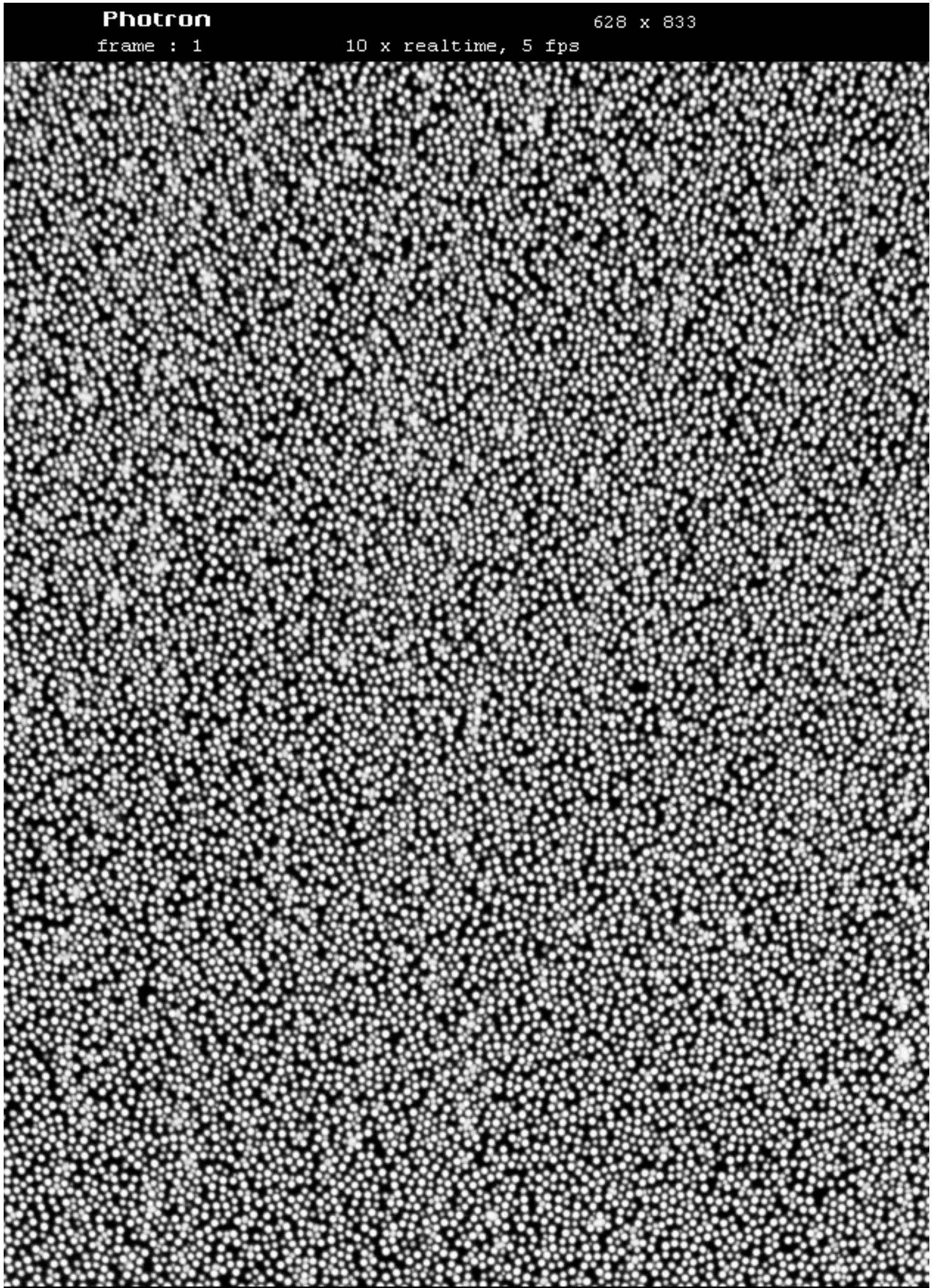
$$\mathrm{Ca} = \frac{\mu_w Q_w a^2}{\gamma \kappa_0 A}$$

Ca=0.0079



Dynamic cluster configuration

Steady state regime



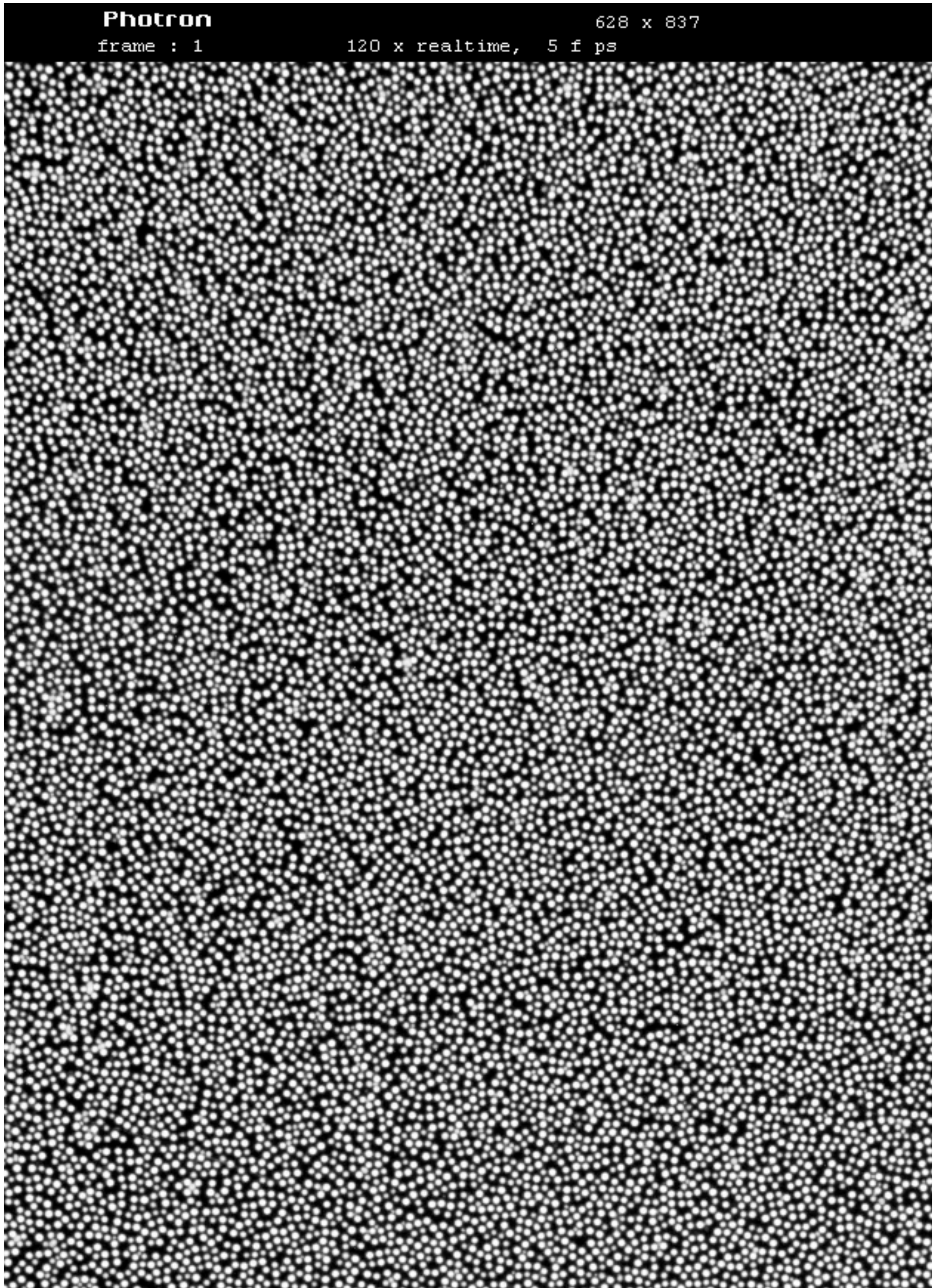
Fast experiment.

10 times real time, Ca=0.090

Fractional flow rate:

$F=Q_{nw}/Q_{tot}=1/2$

10cm x 15 cm section in the middle
Of the model.



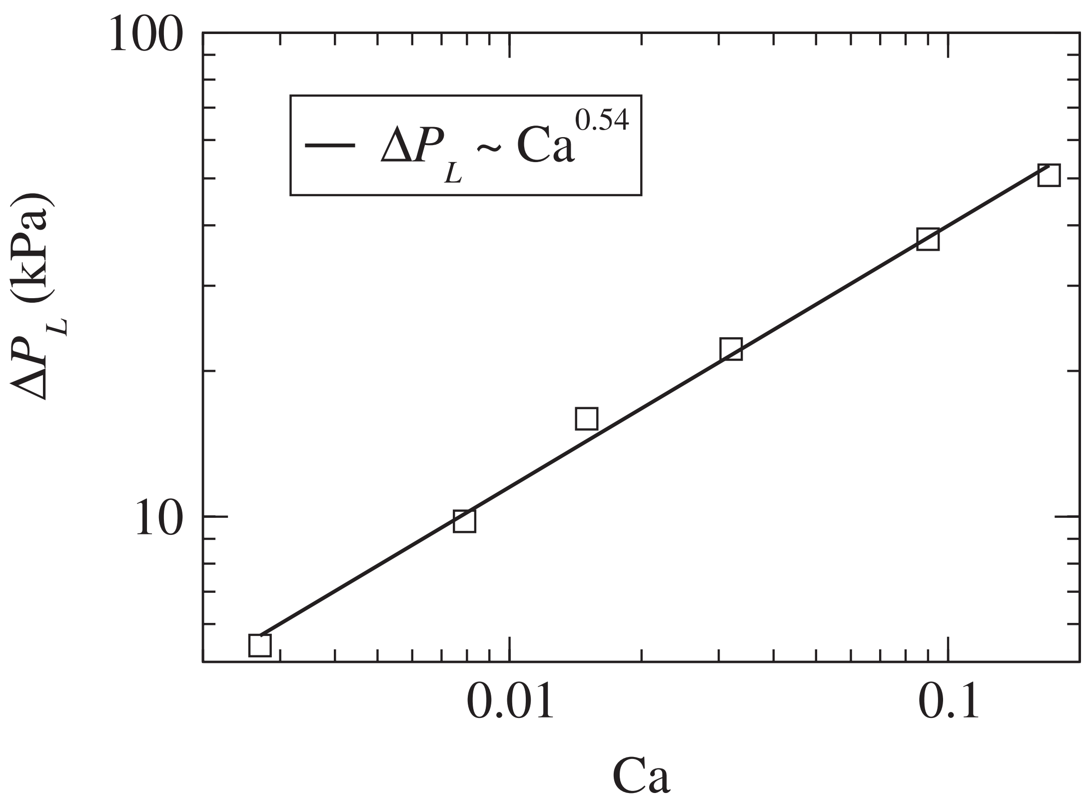
Slow experiment

120 times real time, Ca=0.0079

10cm x 15 cm section in the middle
Of the model.

Non wetting fluid: Air
Wetting fluid: Water-glycerol

Pressure dependence on capillary number Ca .

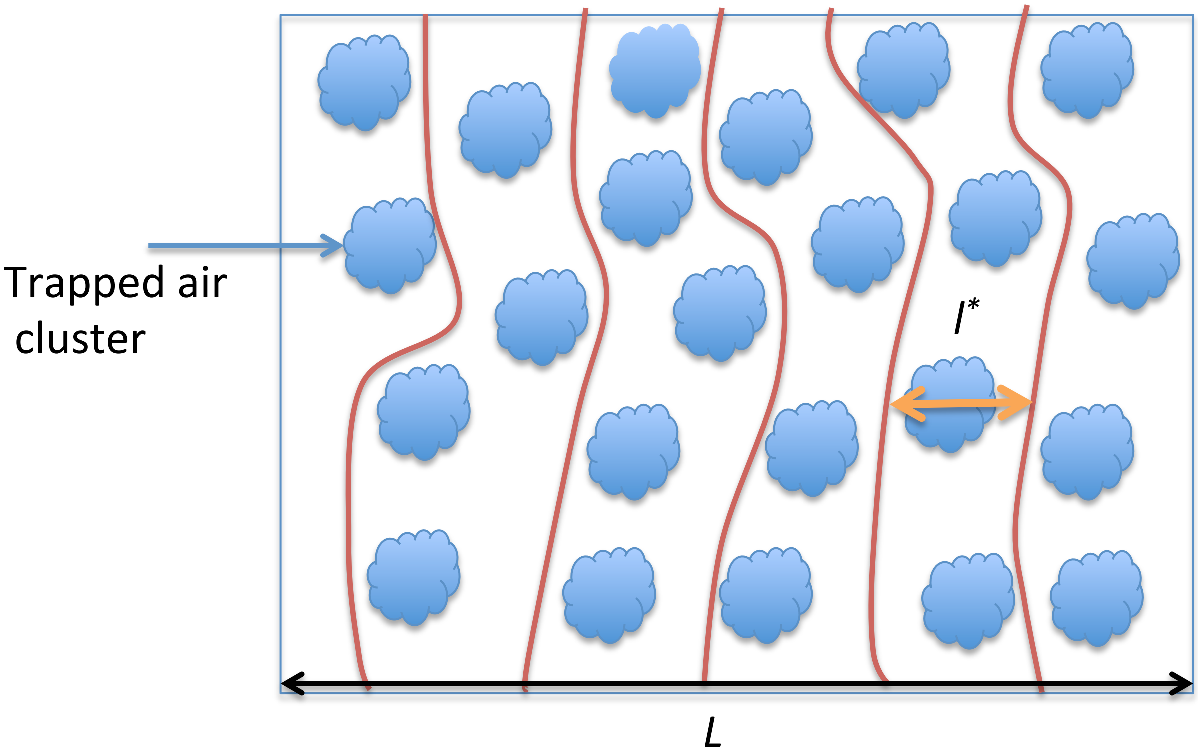


$$\text{Ca} = \frac{\mu_w Q_w a^2}{\gamma \kappa_0 A}$$

$$\Delta P \propto Ca^{0.54}$$

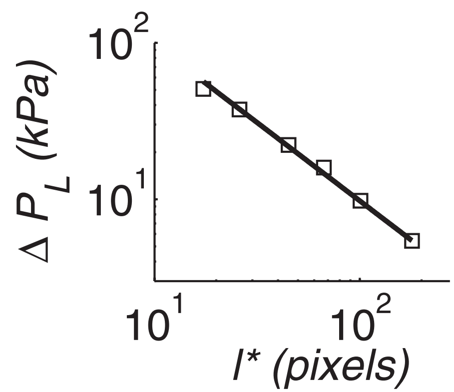
$$\beta = 0.54 \pm 0.08$$

Tallakstad et al PRL **102,** 0742, (2009)



Assumption:
Flow restricted to narrow channels separated a distance corresponding to the characteristic cluster size.

$$N = L/l^*$$



Total flux of wetting fluid:

$$Q = q \cdot N = a^2 \cdot \frac{a^2}{\mu}\frac{\Delta P}{L} \cdot \frac{L}{l^*}$$

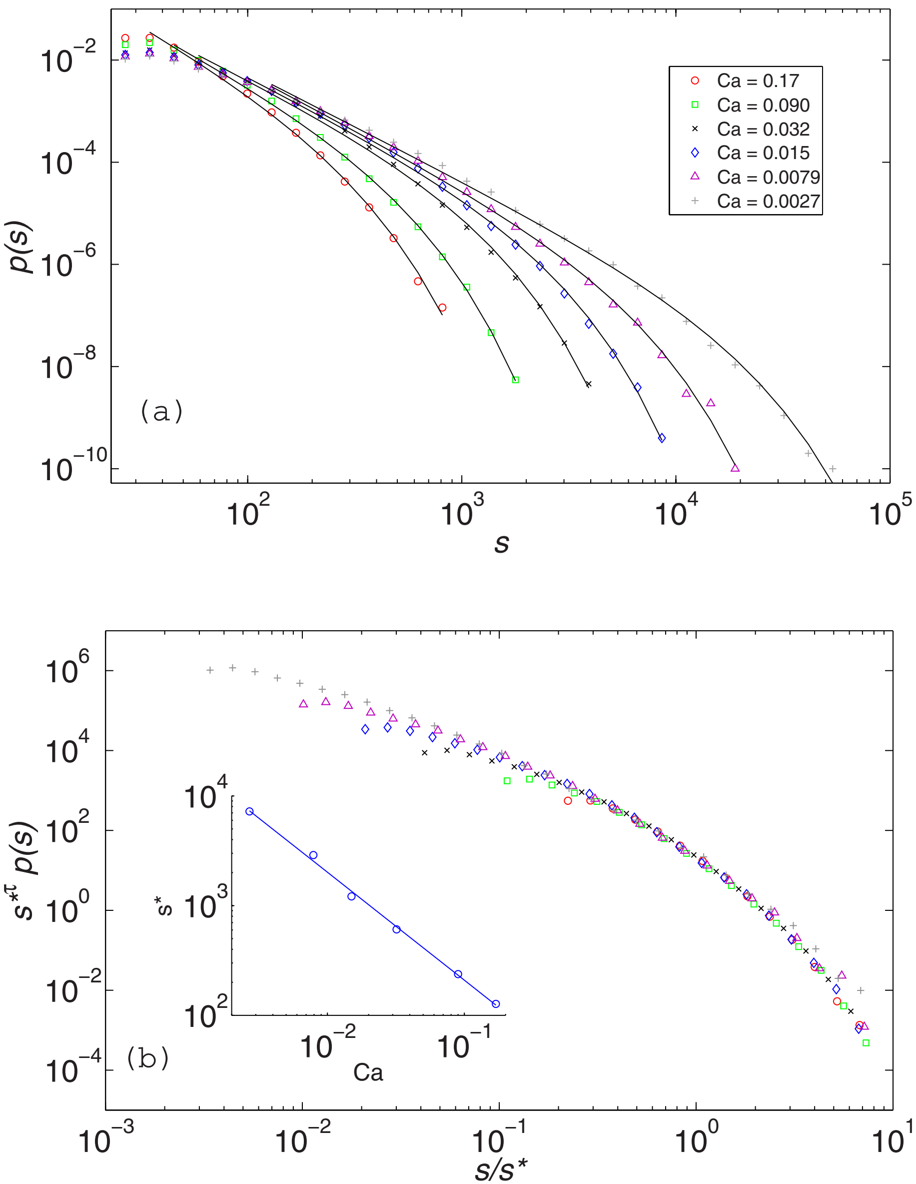
$$\Delta P \propto Q^{1/2} \propto Ca^{1/2}$$

Balance between viscous pressure and capillary threshold.

$$l^* \frac{\Delta P}{L} = \Delta P_c = P_d - P_i$$

Theory by Eirik G. Flekkøy

Cluster size distribution



$$p(s) \propto s^{-\tau} \exp(-s/s^*),$$

$\tau = 2.0 \pm 0.2$

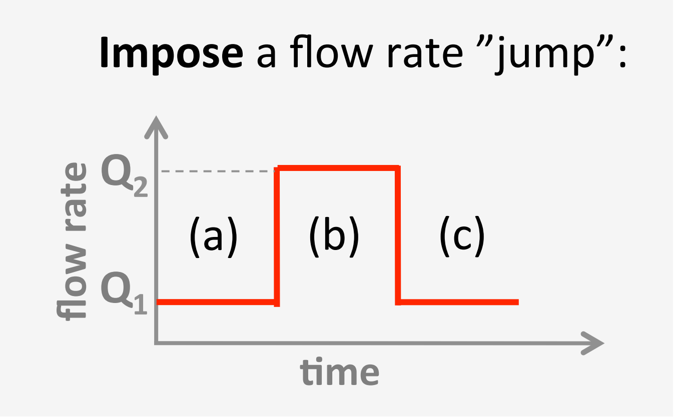
$$s^* \propto \mathrm{Ca}^{-\zeta},$$

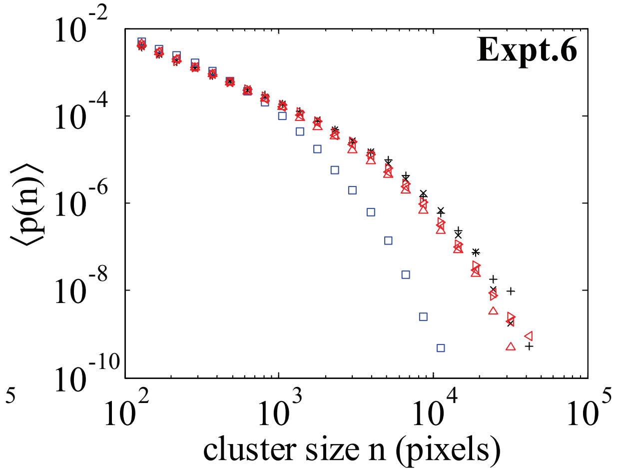
$\zeta = 0.98 \pm 0.07.$

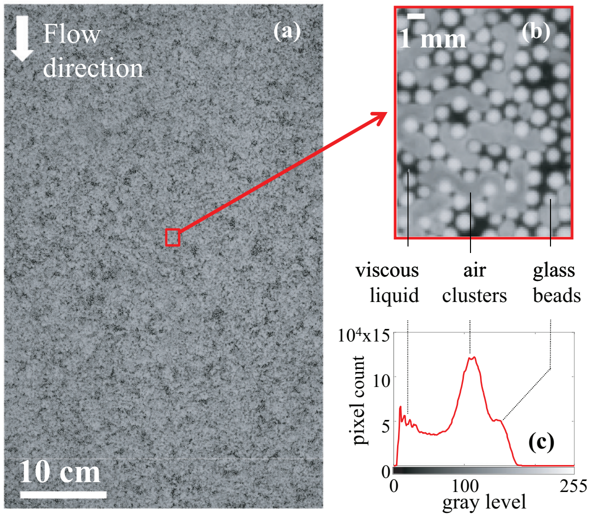
Tallakstad et al. PRE **80**, 036308 (2009)

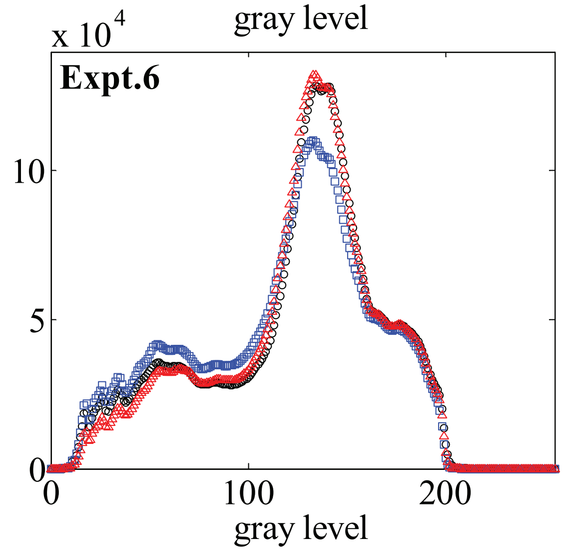
Question: is this "steady state" *really* a state?

i.e., does it depend on the history of the system ?





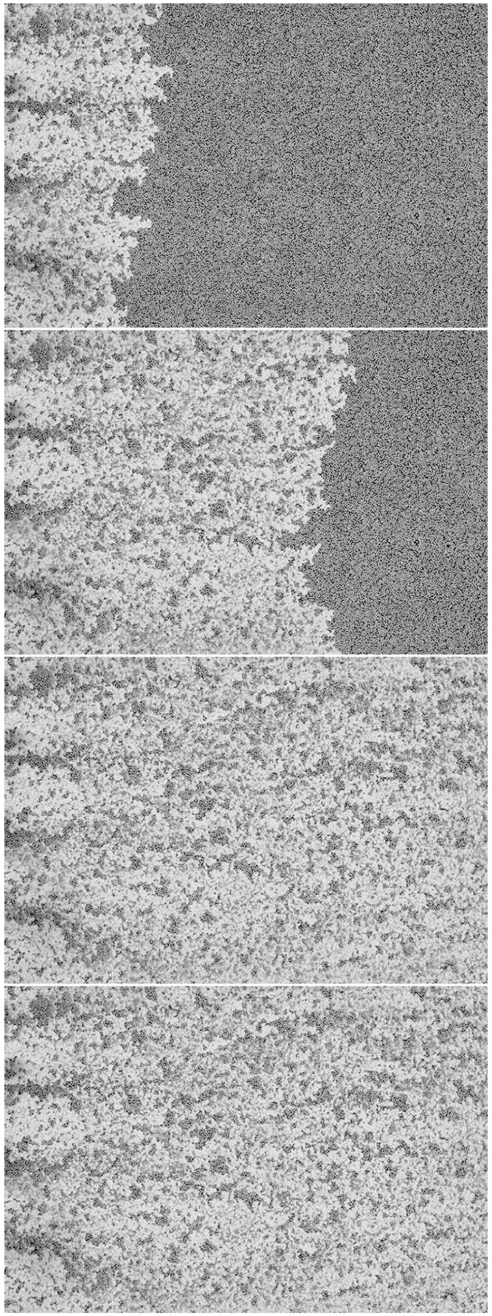




Marion Erpelding et al. PRE, **88** , 053004, (2013) Case B:

Non wetting fluid: Rapeseed Oil

Wetting fluid: Water-glycerol



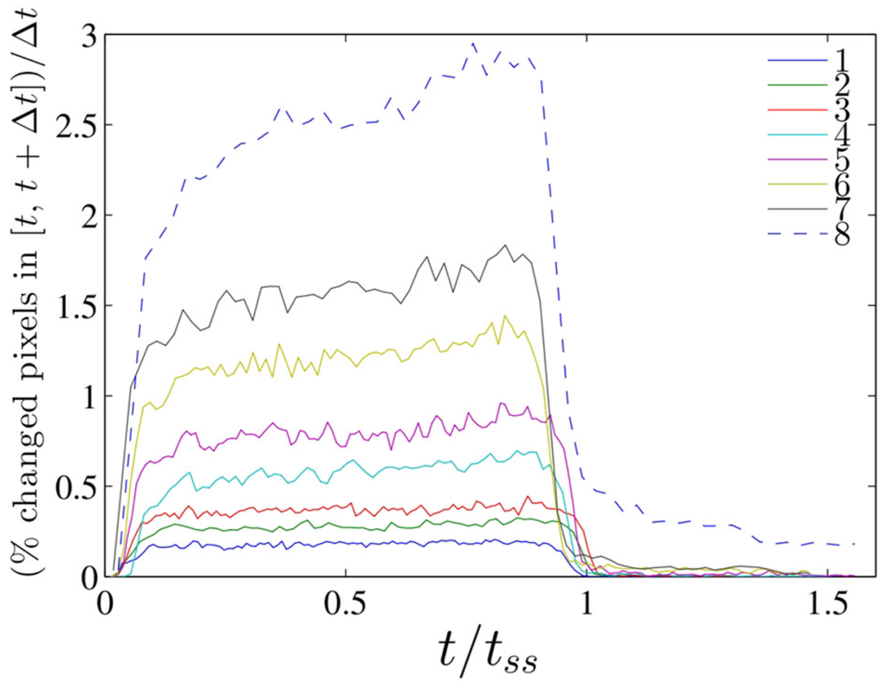


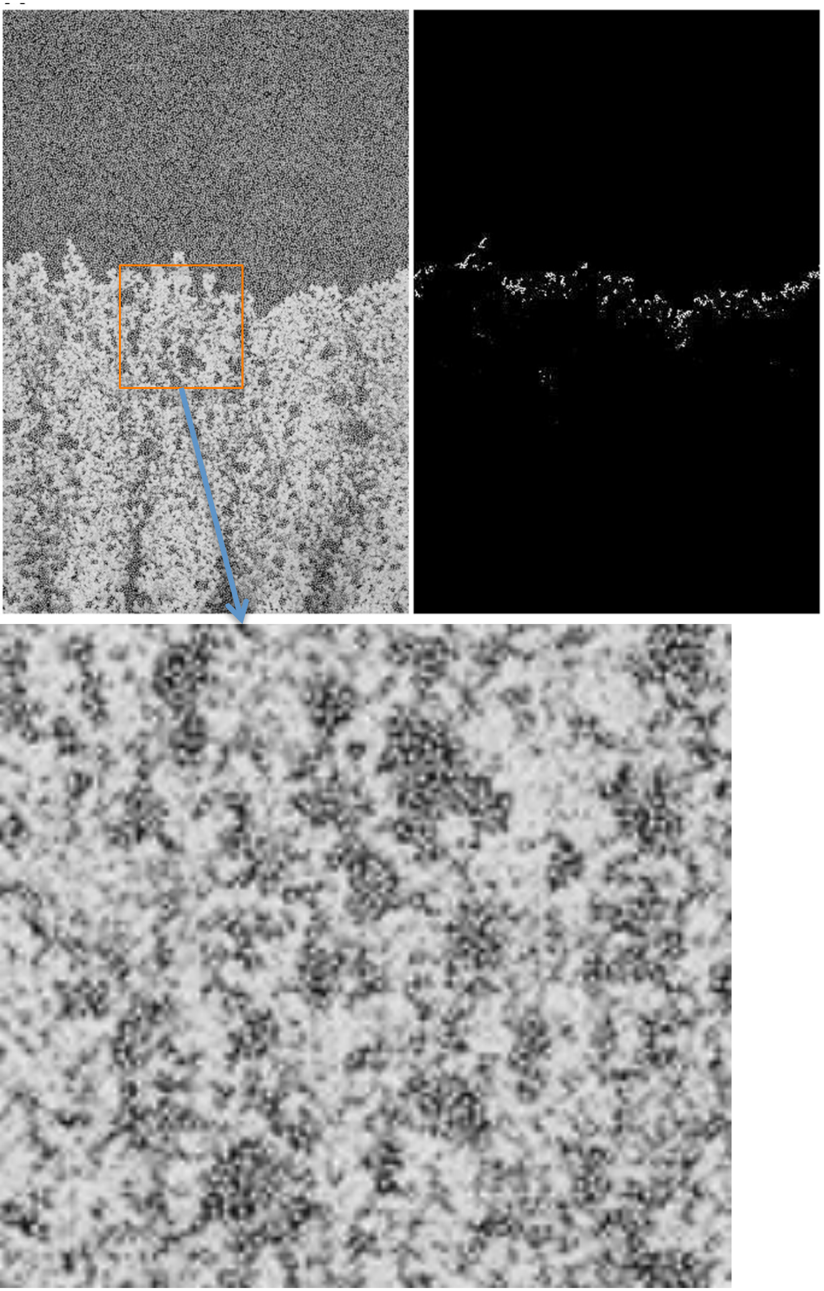
Table 2 | Total flow rates Q_{tot} and capillary numbers Ca corresponding to the legend numbers presented in the forthcoming graphs.

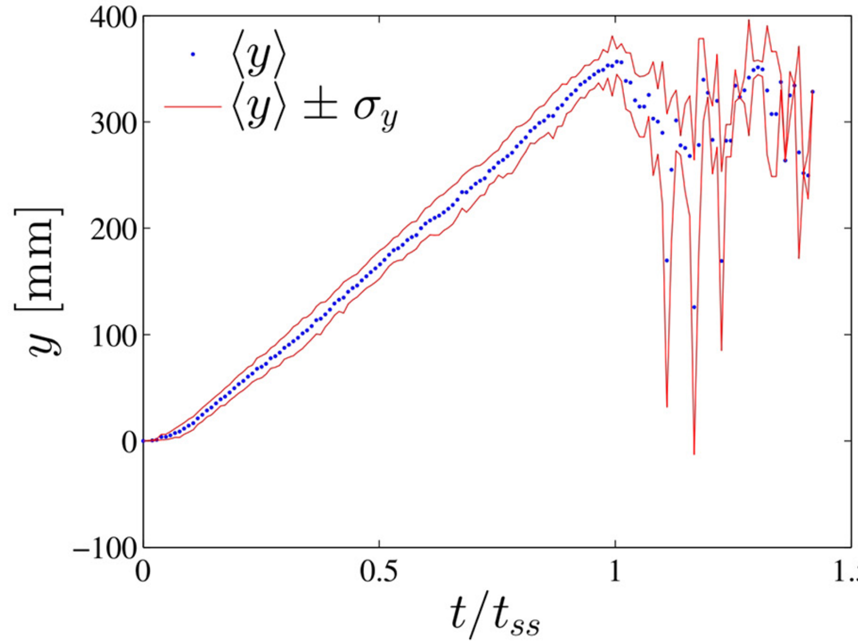
Legend no.	Q_{tot} [ml/min]	Ca
1	0.30	0.0241
2	0.45	0.0362
3	0.60	0.0482
4	0.90	0.0723
5	1.2	0.0964
6	1.8	0.145
7	2.4	0.193
8	3.6	0.289

"Static" cluster configuration

For $Q_{tot} = 0.3\,\text{ml/min}$ and $F_{\text{oil}} = 1/2$,

Average position <y> of changes as function of time.





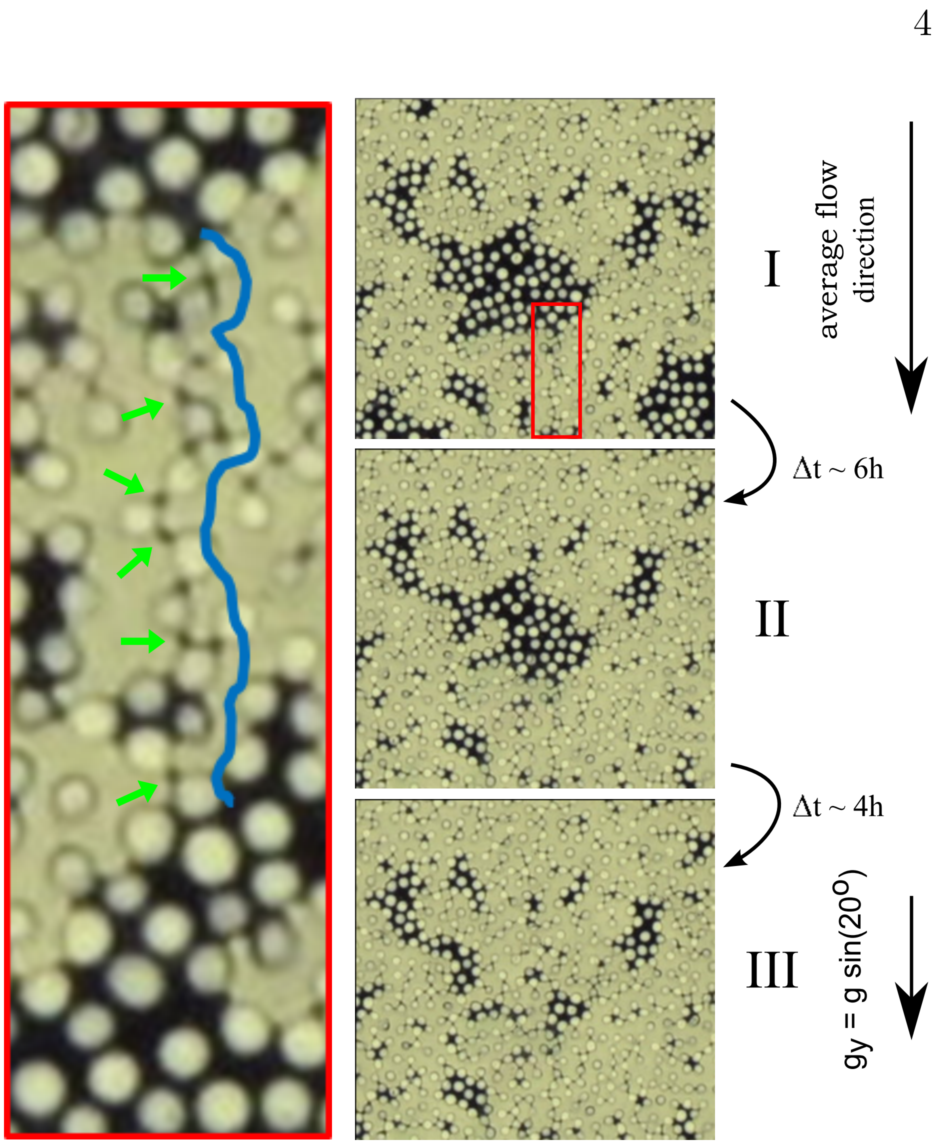
“Static” cluster configuration

Flow by film or flow trough capillary bridges.

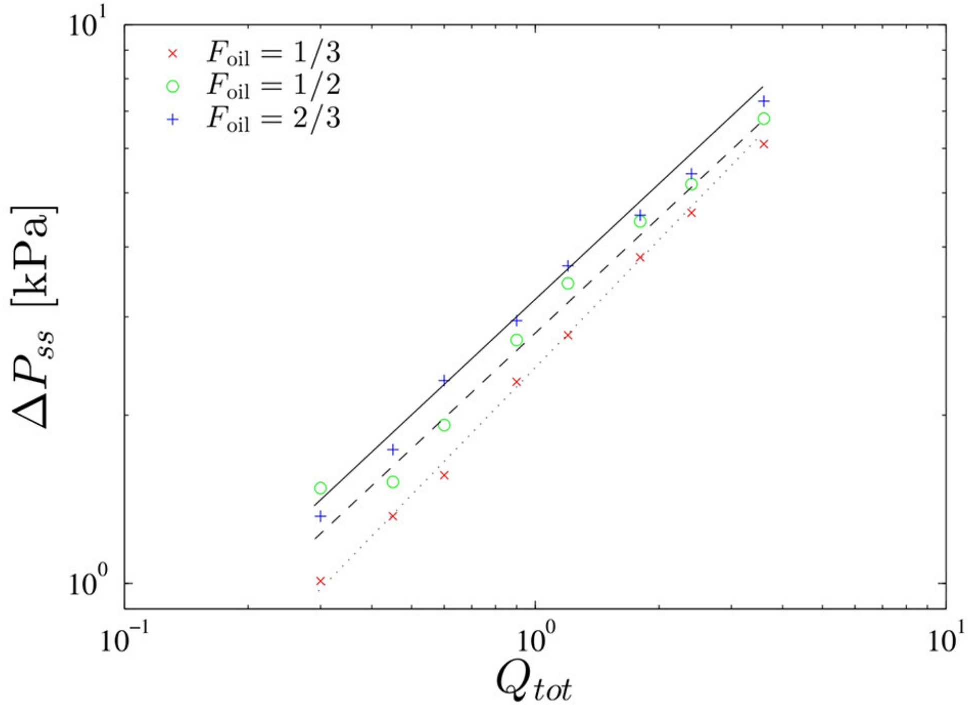
Film flow and capillary bridges

Experiment by
Marcel Moura

Monem Ayaz



Pressure dependence on capillary number Ca .



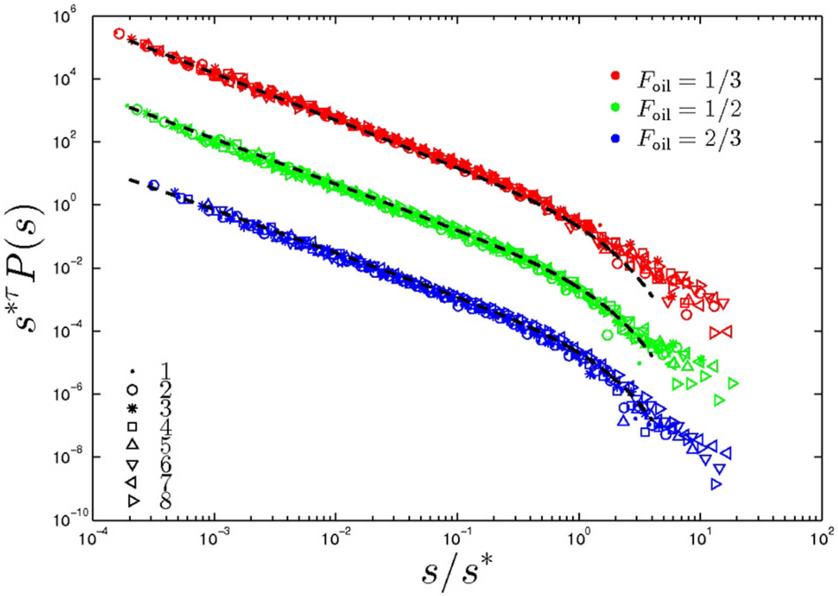
$$\Delta P_{ss} \sim Q_{tot}^{\beta},$$

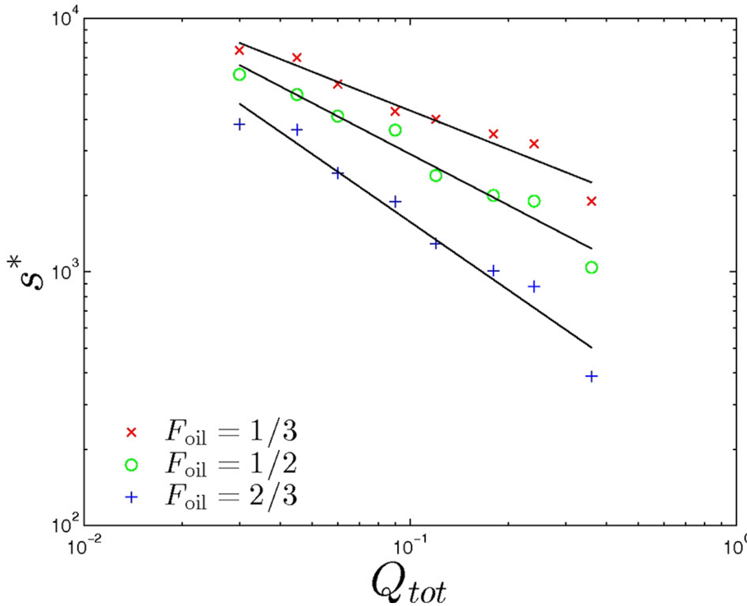
$$\beta_{1/2,\,2/3} = 0.67 \pm 0.05 \text{ for } F_{\text{oil}} = 1/2 \text{ and } 2/3,$$

$$\beta_{1/3} = 0.74 \pm 0.05 \text{ for } F_{\text{oil}} = 1/3.$$

Aursjø et al. Frontiers in Physics (2014)

Cluster size distribution





$$p(s) \propto s^{-\tau} \exp(-s/s^*),$$

$$s^* \propto Q_{tot}^{-\zeta}$$

$$\tau_{2/3} = 1.37 \pm 0.09, \ \tau_{1/2} = 1.43 \pm 0.06,$$

$$\tau_{1/3} = 1.48 \pm 0.04,$$

$$\zeta_{2/3} = 0.89 \pm 0.08, \ \zeta_{1/2} = 0.67 \pm 0.05,$$

$$\zeta_{1/3} = 0.51 \pm 0.05$$

Aursjø et al. Frontiers in Physics (2014)

Summary

Air + water/glycerol	*Oil + Water/glycerol*
Compressible	*Incompressible*
$\Delta P_{ss} \sim Q_{tot}^{\beta}$, $\beta = 0.54 \pm 0.08$	$\beta = 0.67 \pm 0.05$
$p(s) \propto s^{-\tau} \exp(-s/s^{*})$, $\tau = 2.07 \pm 0.18$	$\tau = 1.43 \pm 0.06$
Dynamic air cluster configuration	*Static glycerol/water cluster configuration*
History independence	?