UNIVERSITY OF CAMBRIDGE

P&G

# Methods for detailed study of detergent action in cleaning food soils

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# Project Aims

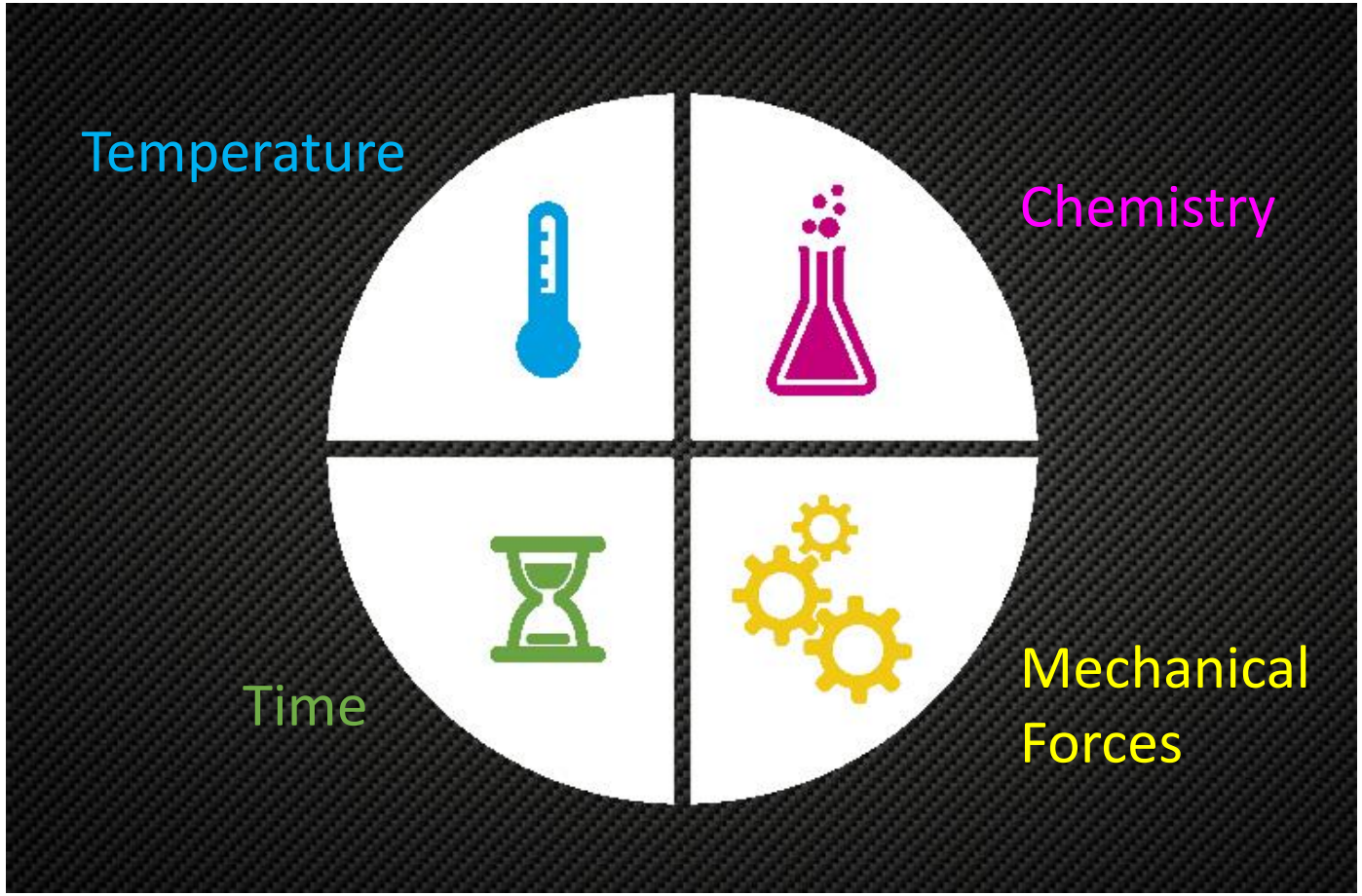


www.currys.co.uk/gbuk/household-appliances/dishwashing/dishwashers/kenwood-kid60s17-full-size-integrated-dishwasher-10164144-pdt.html

stirlaughrepeat.blogspot.co.uk/2015/10/use-baking-soda-to-clean-that-dirty.html

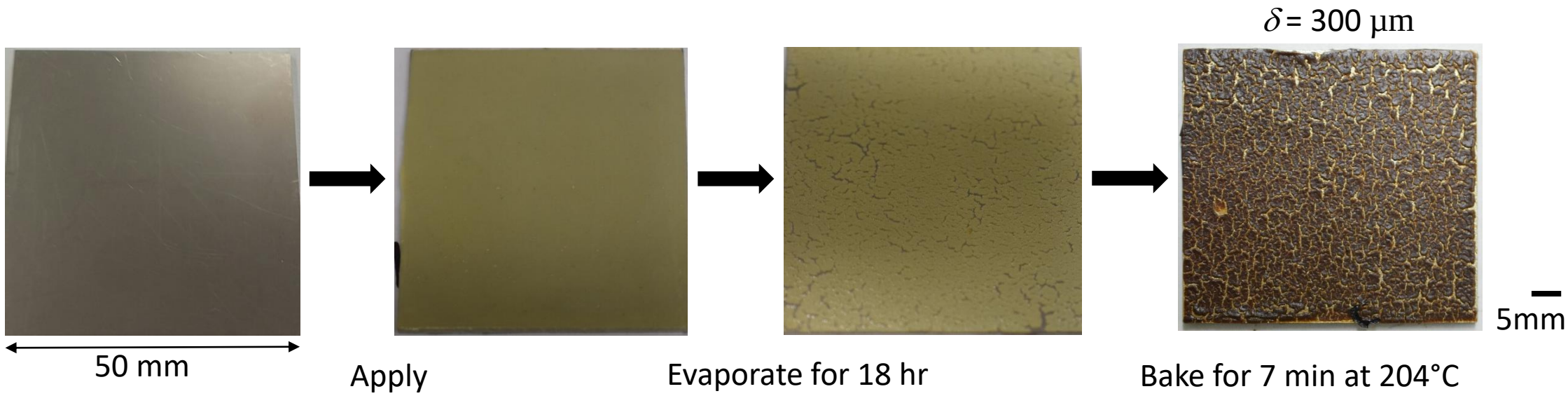
https://pollyparrot.co.uk/product/fairy-original-all-in-one-dishwasher-tablets-lemon-x125/

# Sinner's cleaning circle



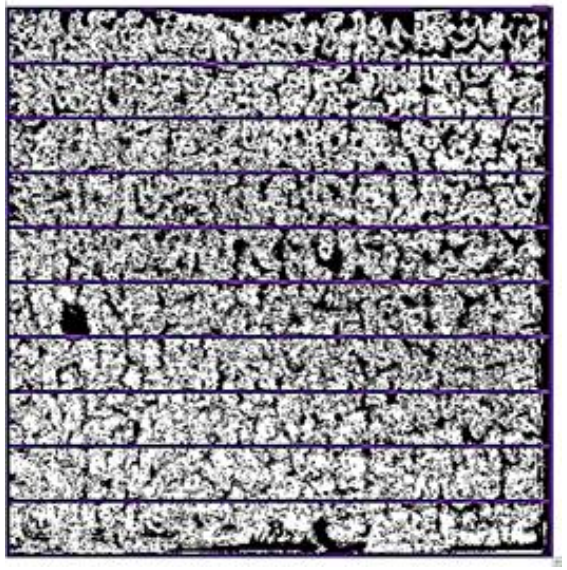
# Complex model soil (CMS)

Fresh soil: **52 wt%** water, **24 wt%** carbohydrate, **18 wt%** fat, **5.7 wt%** protein, **0.3 wt%** salt



# CMS cracking

5mm



Fraction of cracked area per strip 38.8% +/- 5.3%.

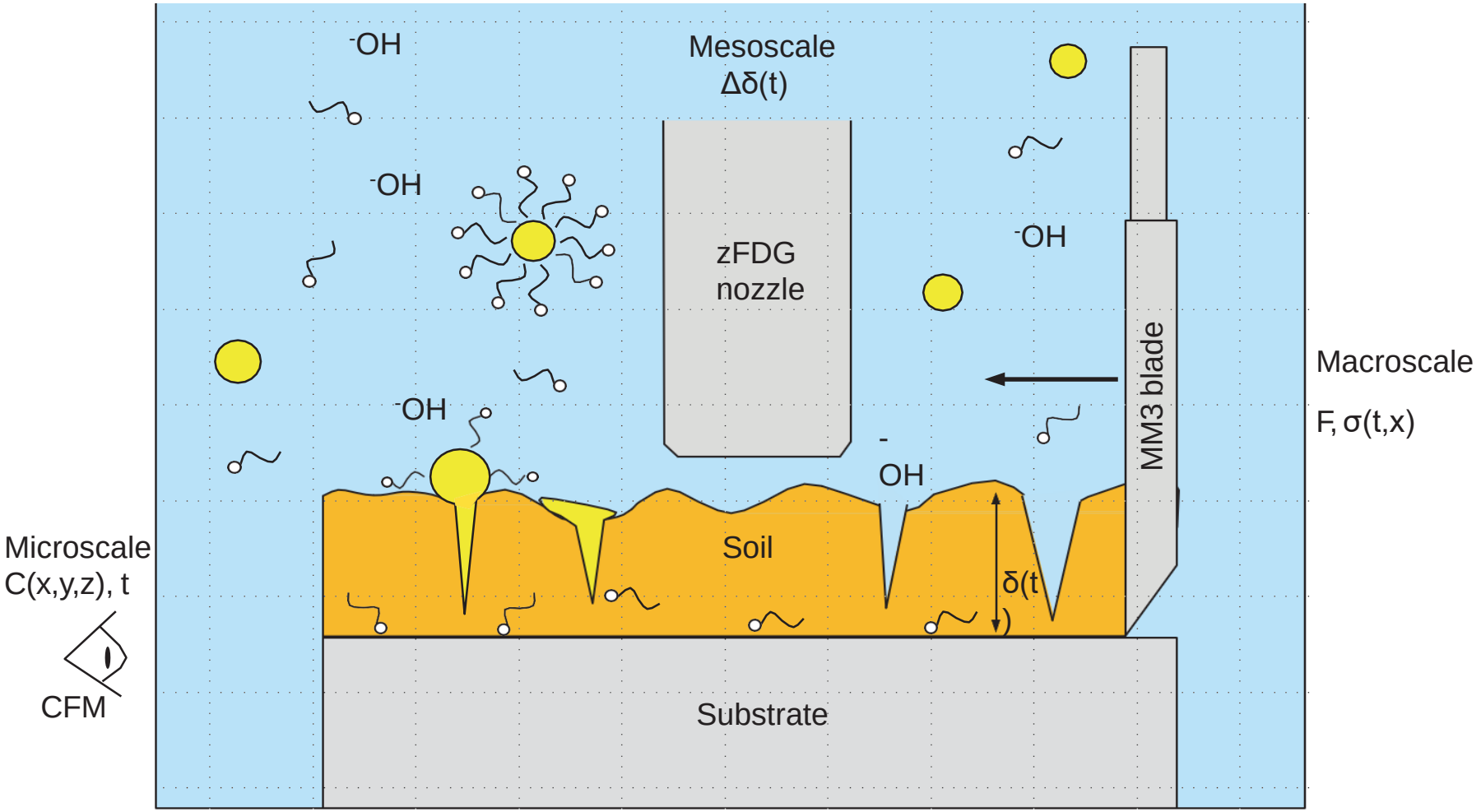
Number of cracks along gridlines

Vertical 19.0 ± 3.0 . Horizontal 21.2 ± 2.6

Or ~ 1 crack per 2.5 mm

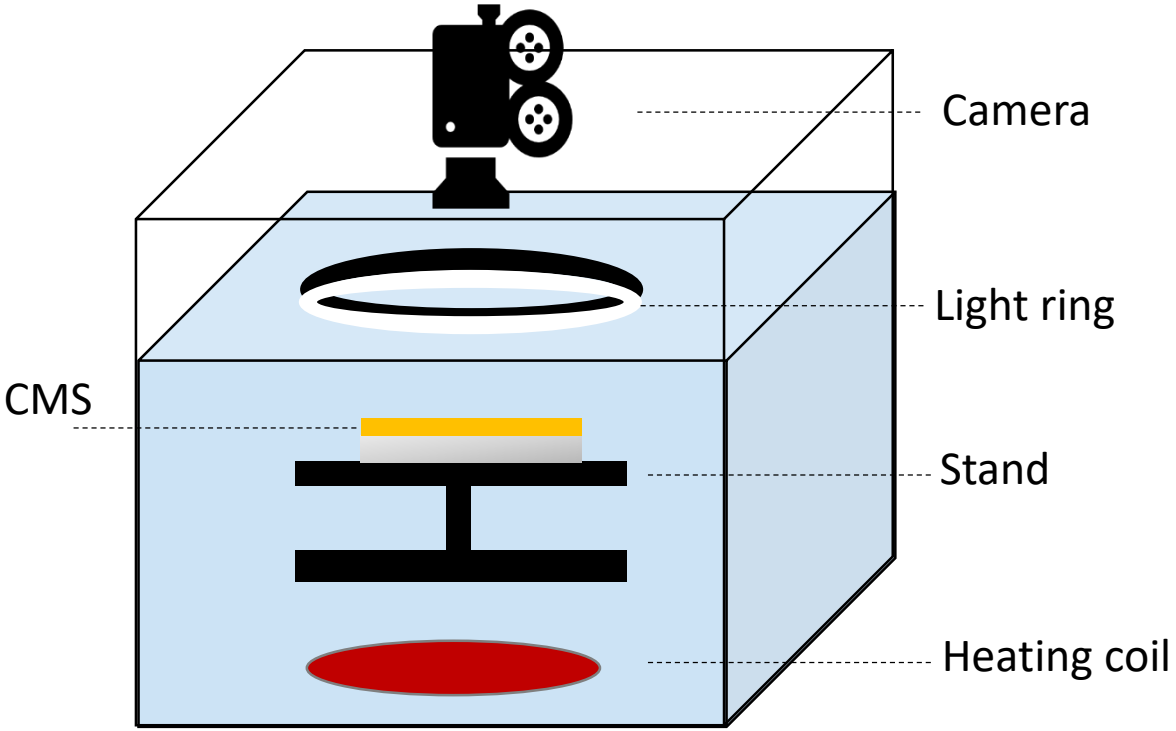
*Note square samples shown as examples. Samples used in this study were circular

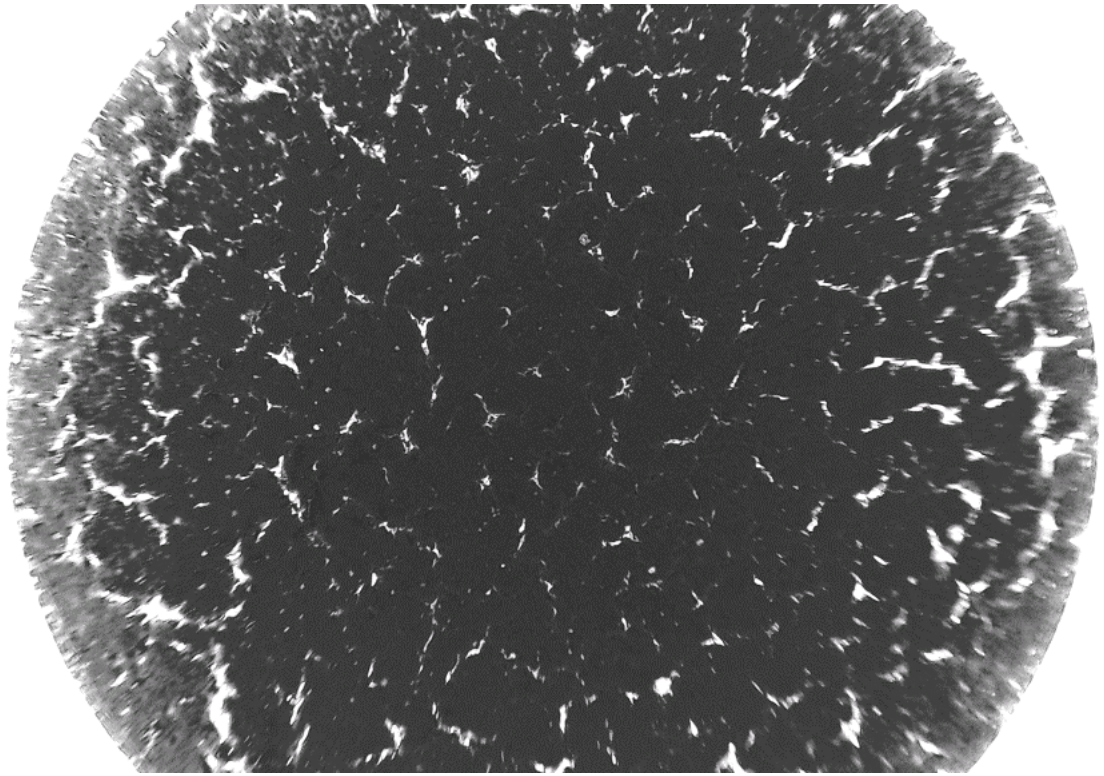
# Data Fusion


-OH
Mesoscale
Δδ(t)
-OH
zFDG
nozzle
-OH
-OH
MM3 blade
Macroscale
F, σ(t,x)
-
OH
Microscale
C(x,y,z), t
Soil
δ(t
)
CFM
Substrate

# Droplet tracking

5 mm

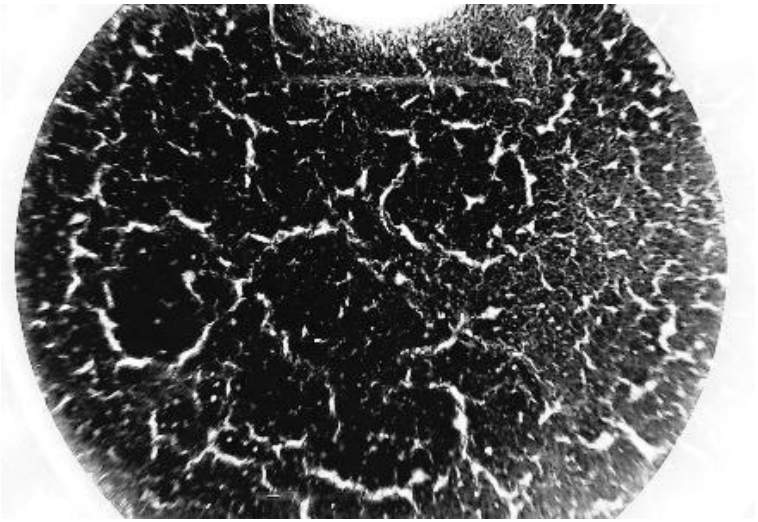


5 mm

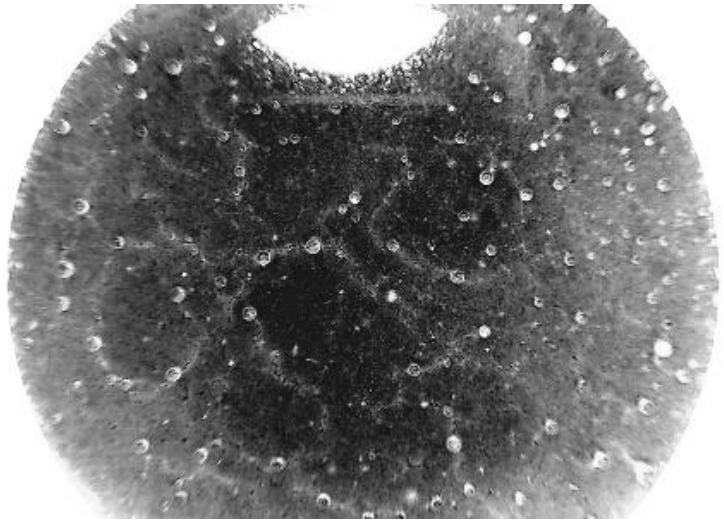
# Droplet tracking

0 min



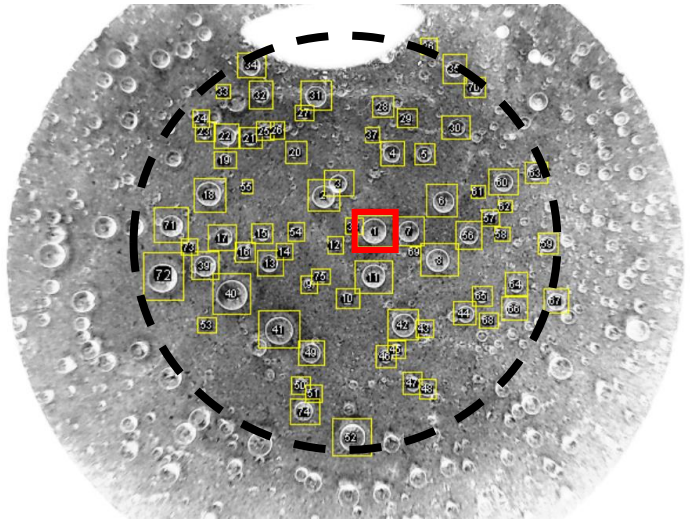
5 mm

14 min



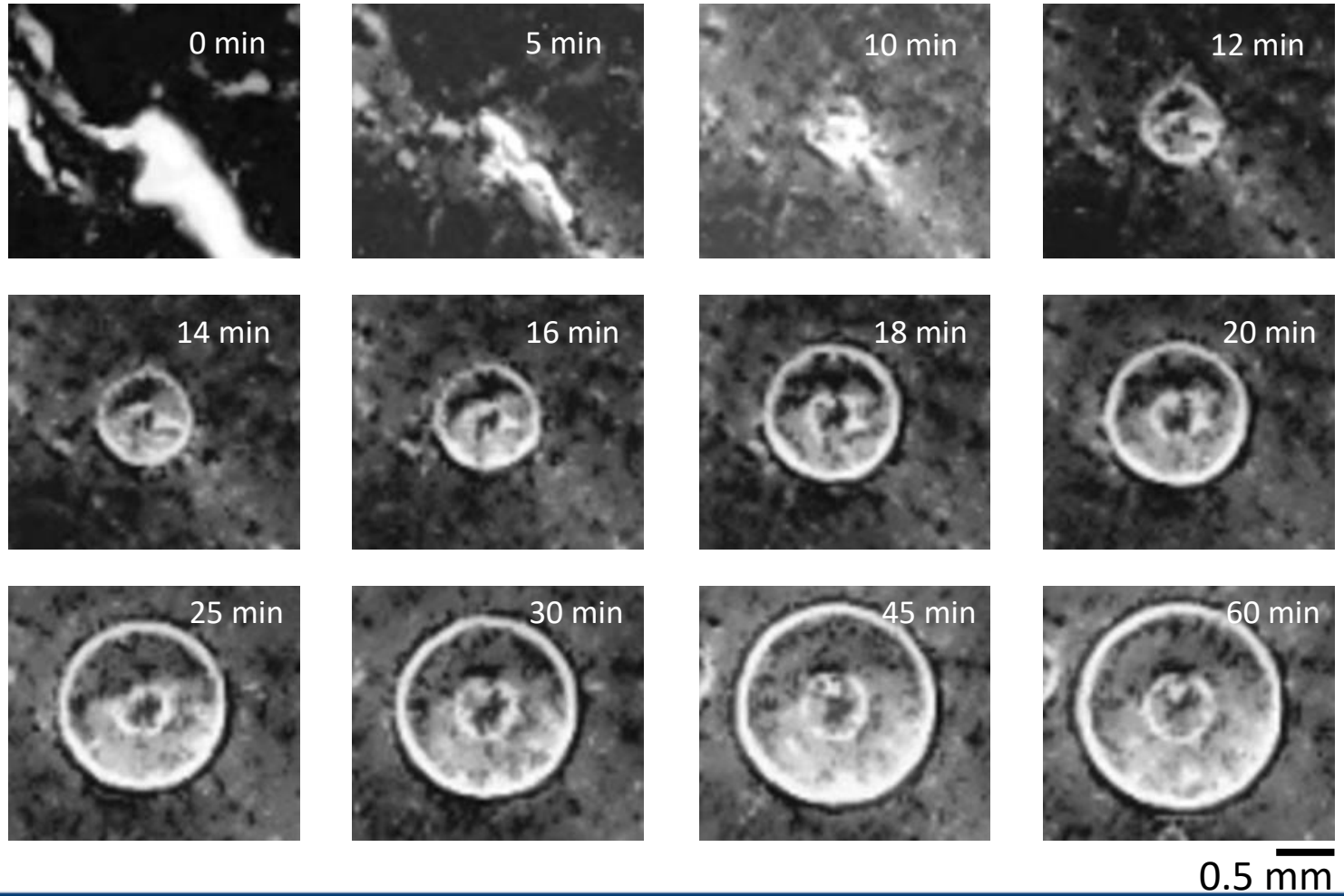
5 mm

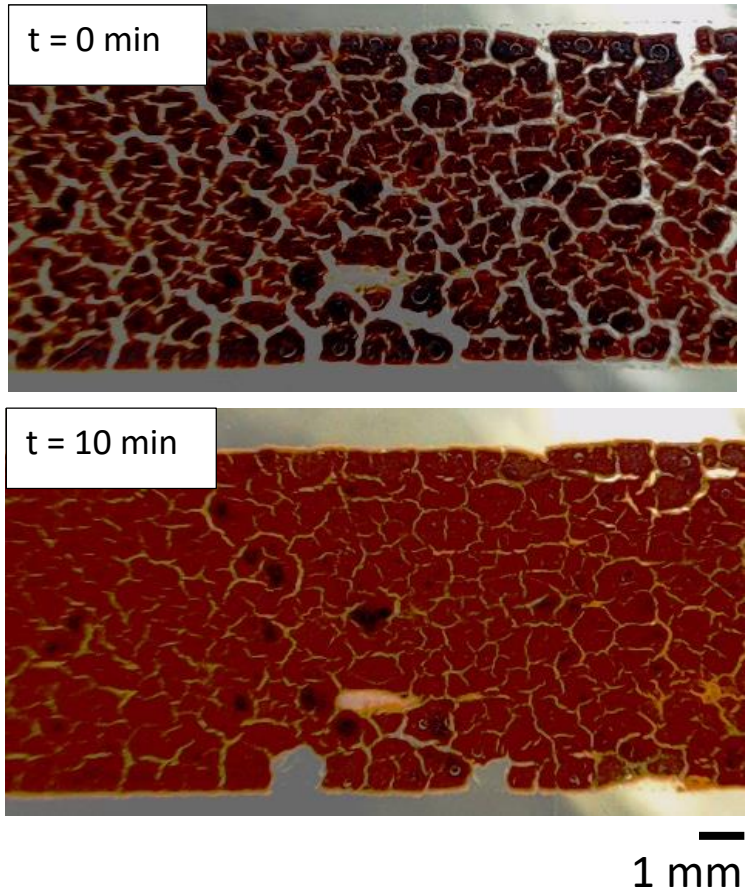
60 min



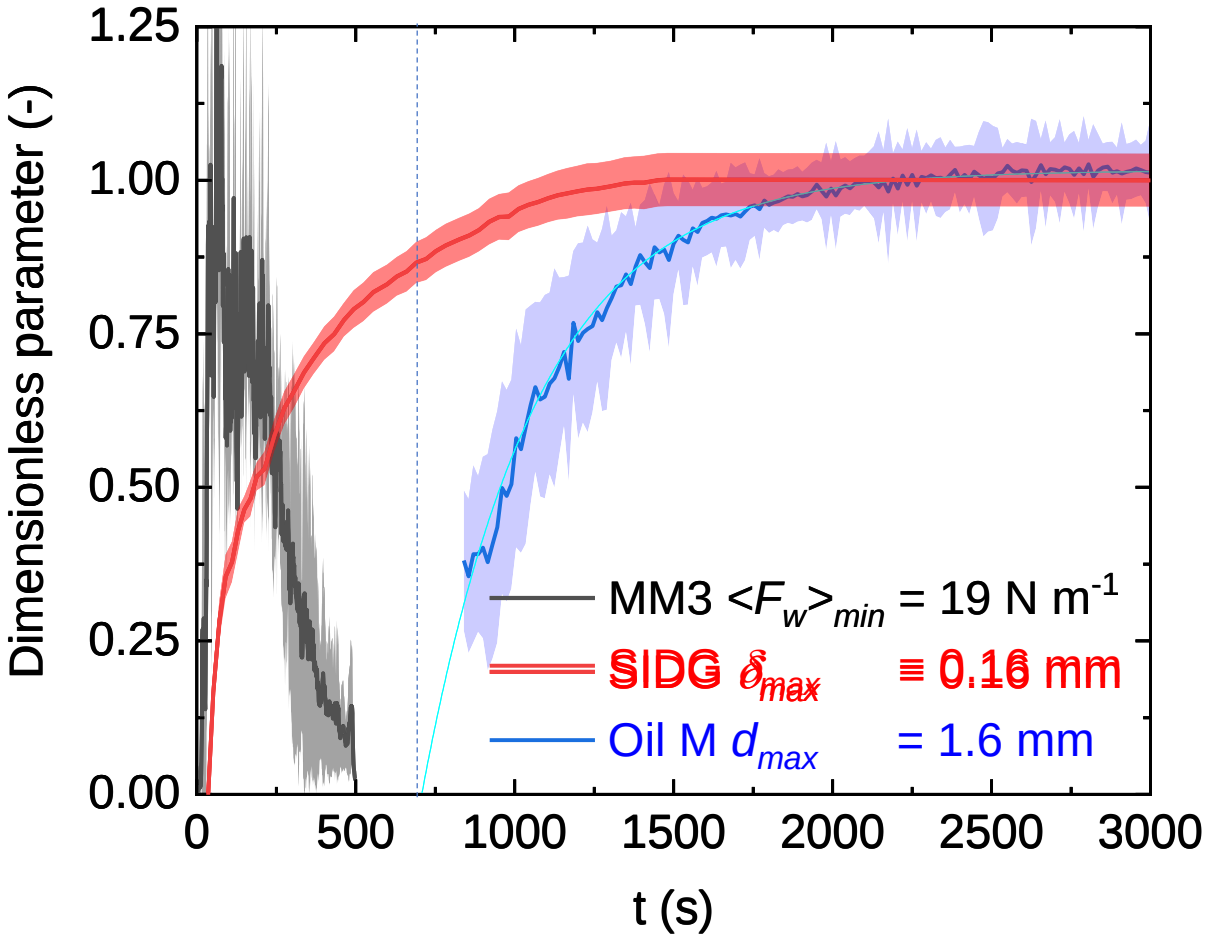
5 mm

# Droplet tracking

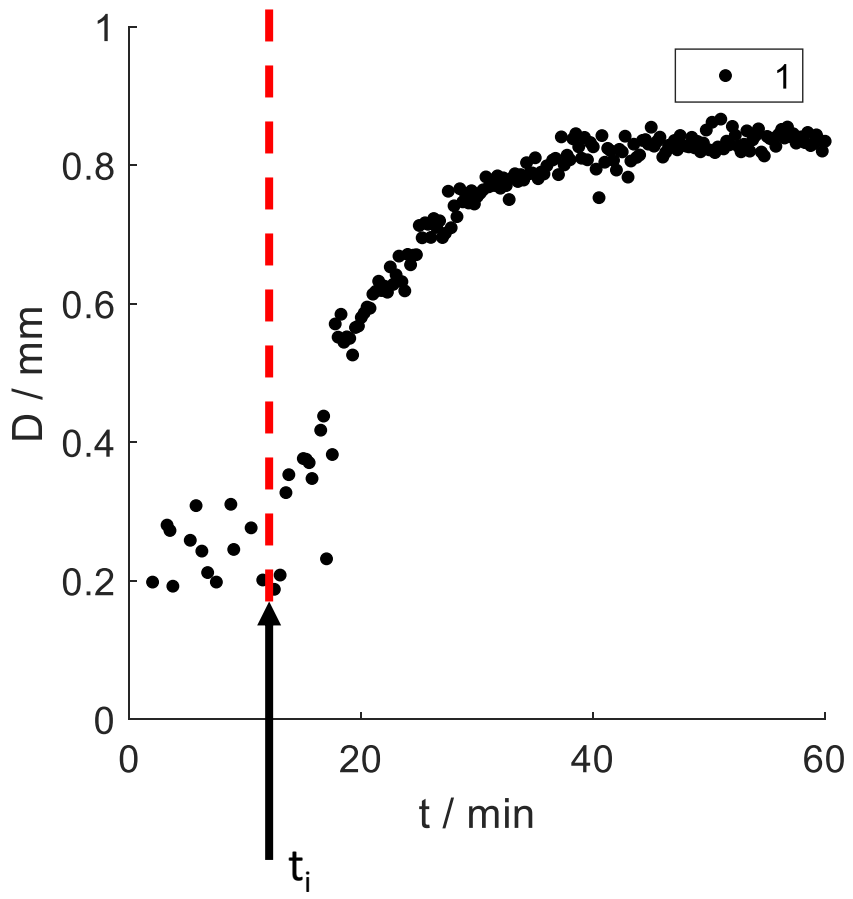


# Data Fusion

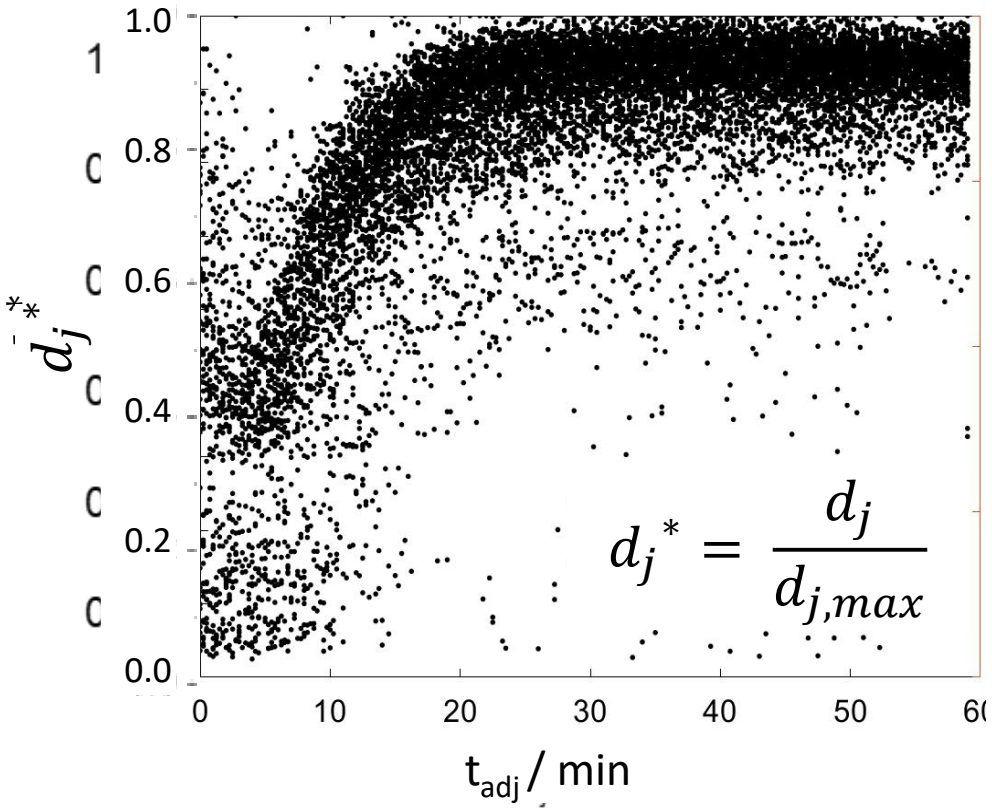

1.25
1.00
0.75
0.50
0.25
0.00
Dimensionless parameter (-)
0
500
1000
1500
2000
2500
3000
t (s)
MM3 <$F_w$>$_{min}$ = 19 N m$^{-1}$
SIDG $\delta_{max}$ = 0.16 mm
Oil M $d_{max}$ = 1.6 mm

# Droplet tracking

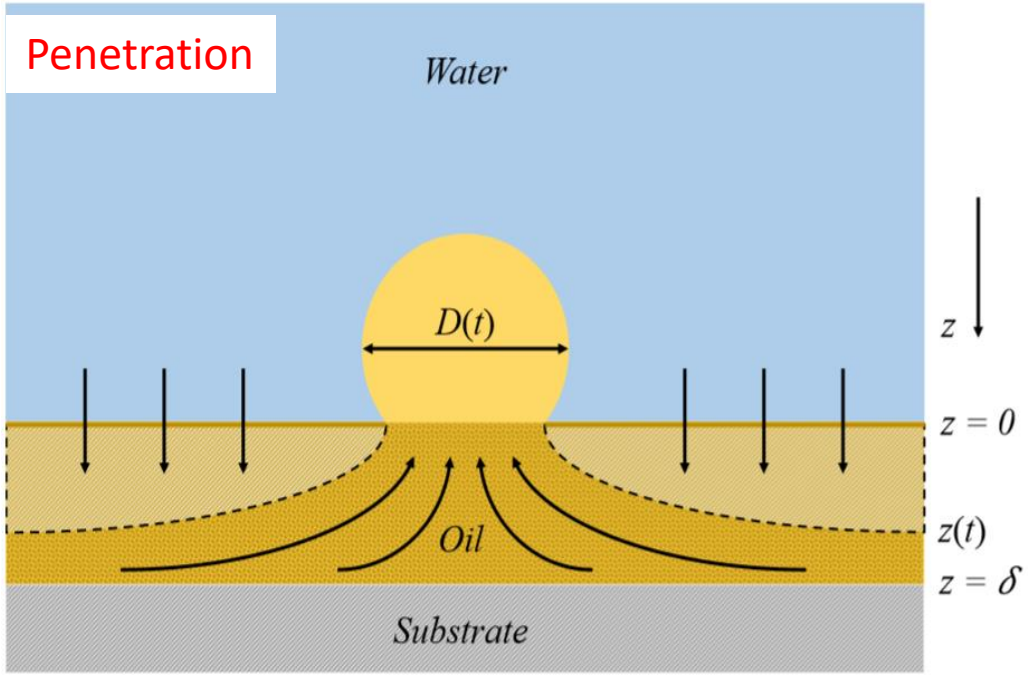


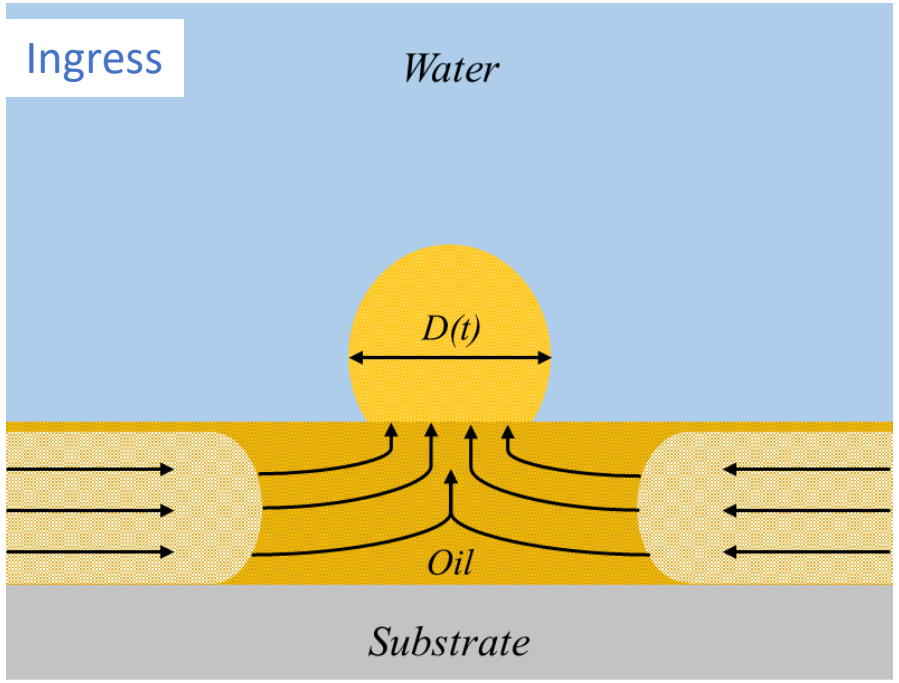

$t_{adj} = t - t_i$

Combine for all droplets



# Modelling droplet growth



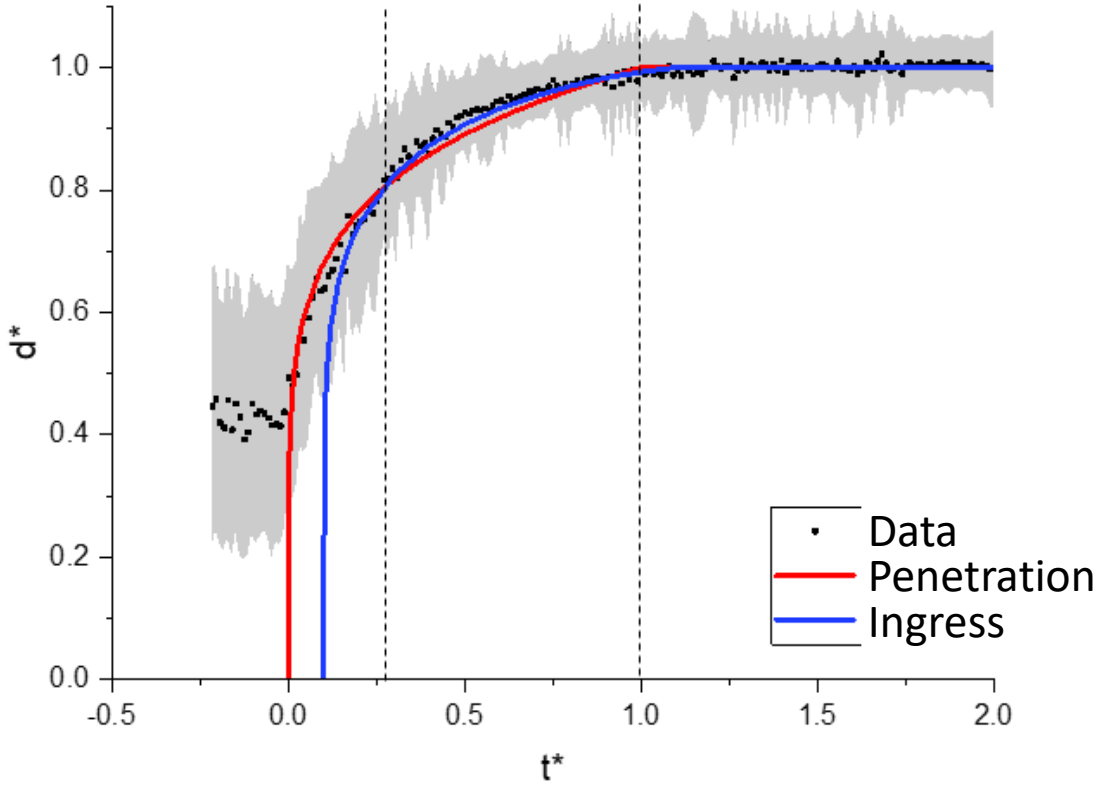




$$d^*(t^*) \approx \begin{cases} \sqrt[6]{t^*}, & 0 \le t^* \le 1 \\ 1, & t^* > 1 \end{cases}$$

$$d^*(t^*) \approx \begin{cases} \sqrt[3]{1 - \dfrac{t^* - 1}{W_{-1}\left(\dfrac{t^* - 1}{e}\right)}}, & 0 \le t^* < 1 \\ 1, & t^* \ge 1 \end{cases}$$

*where W is the Lambert W

# Modelling droplet growth

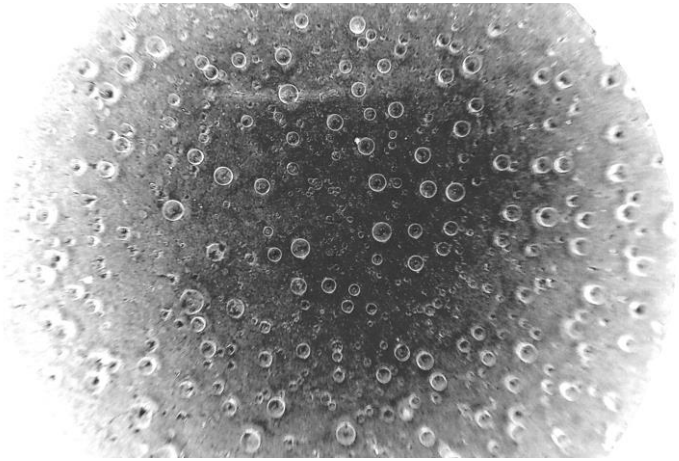



$$d_j^* = \frac{d_{j,k}}{\max_j(d_{j,k})}$$

$$t^* = \frac{t_{adj}}{t_p}$$

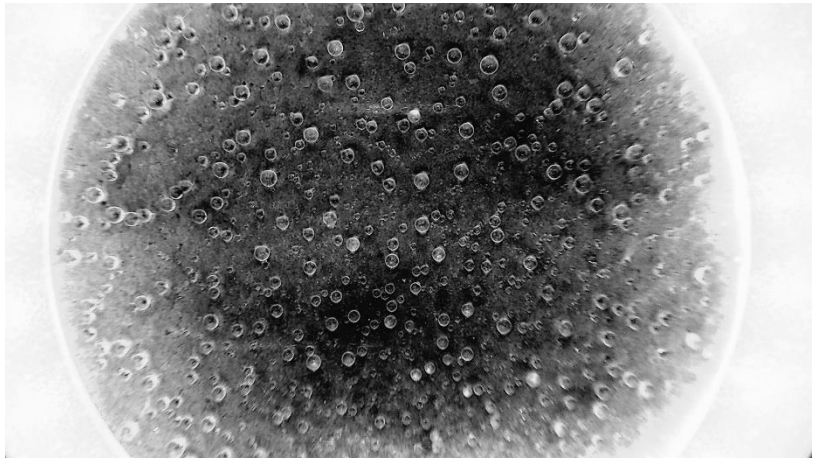
*where $t_p$ is time taken for the solution to penetrate the entire soil layer

# Impact of temperature/surfactant



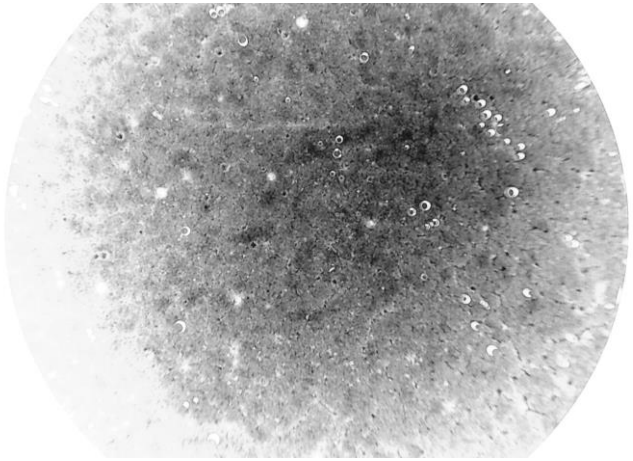
DI

5 mm



0.01% SDBS

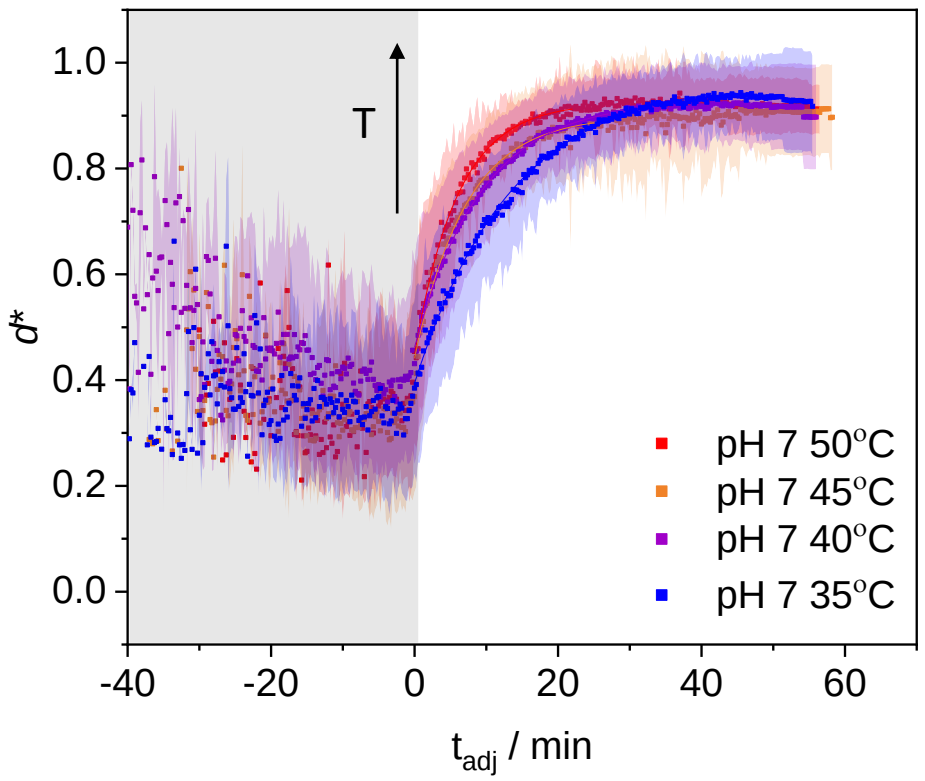
5 mm



0.1% SDBS

5 mm

# Impact of temperature




$$\left(d_j^* - d_0^*\right) = d_{j,max}^*\left(1 - e^{-k(t_{adj})}\right)$$

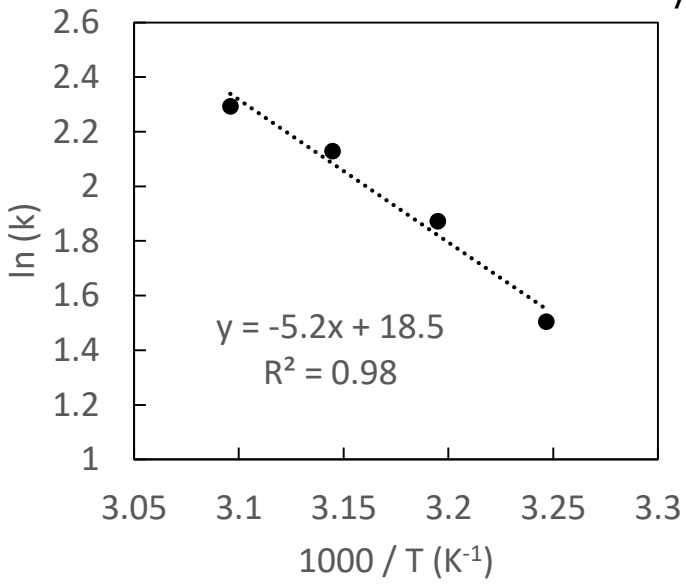
35 °C: $k \approx 4.5\ s^{-1}$

40 °C: $k \approx 6.5\ s^{-1}$

45 °C: $k \approx 8.4\ s^{-1}$

50 °C: $k \approx 9.9\ s^{-1}$

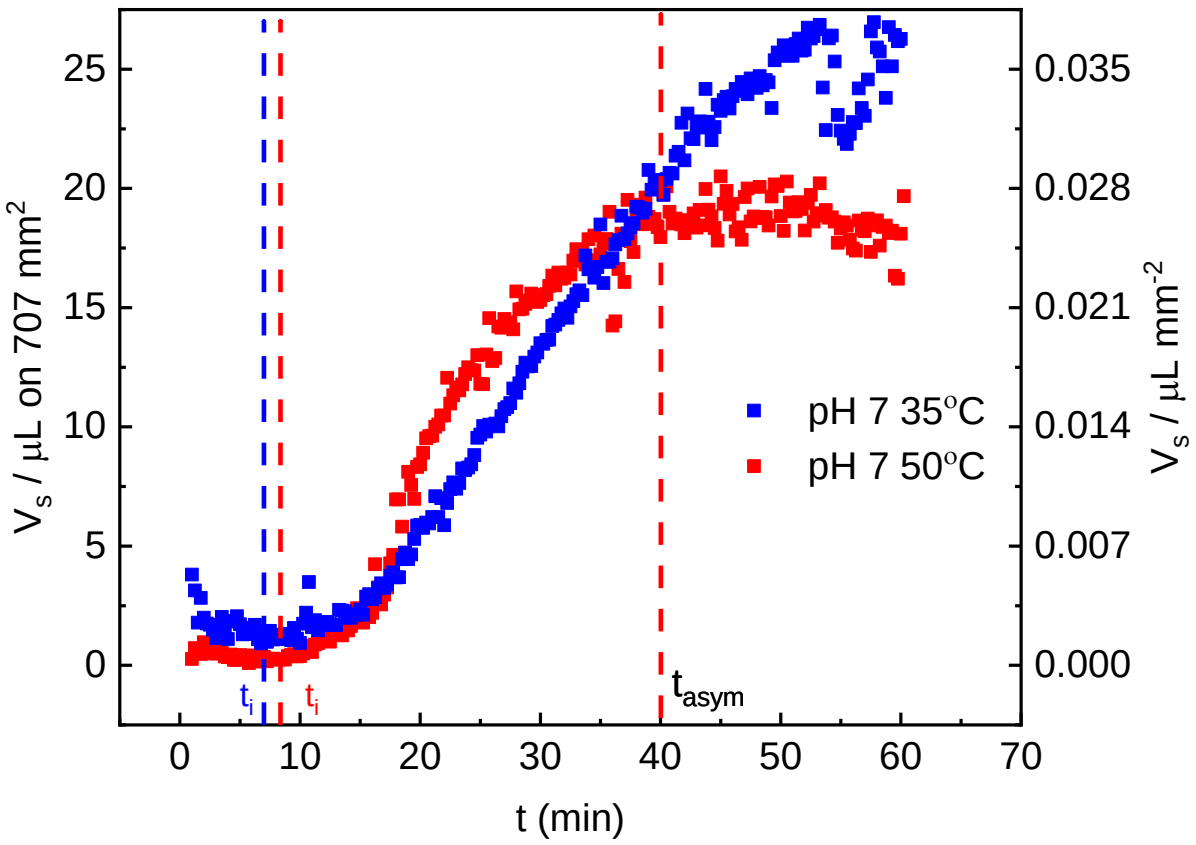
$$\ln(k) = \ln(A) - {}^{E}/_{R_g T}$$

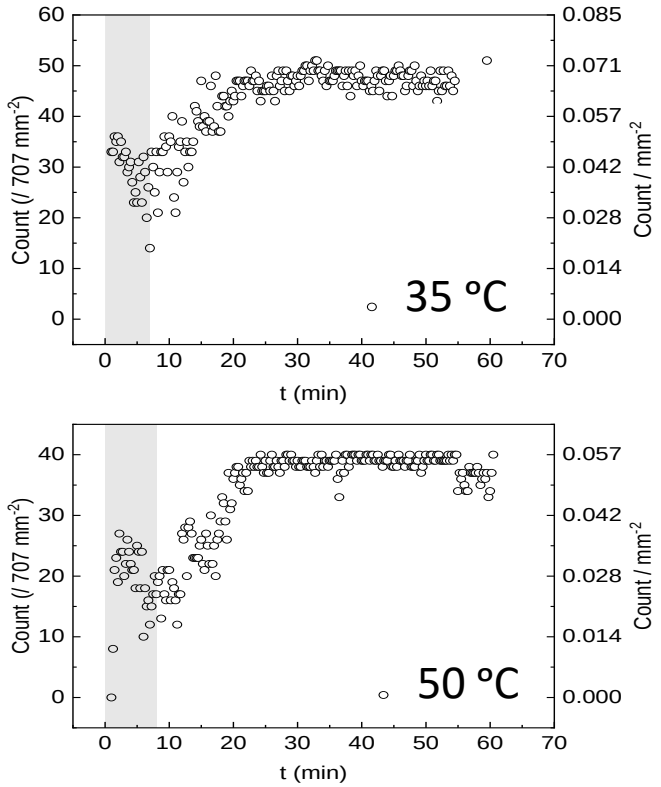



E = 44 kJ mol$^{-1}$

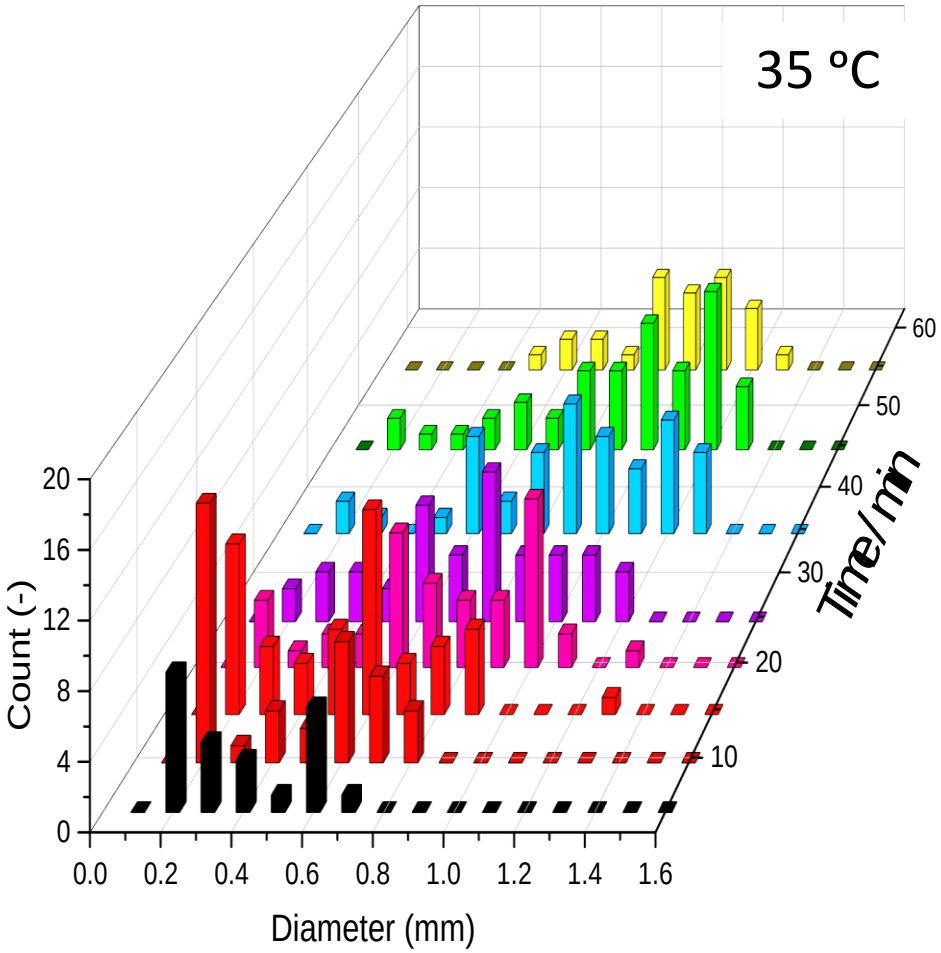
Here E gives an indication of the driving force of water penetration

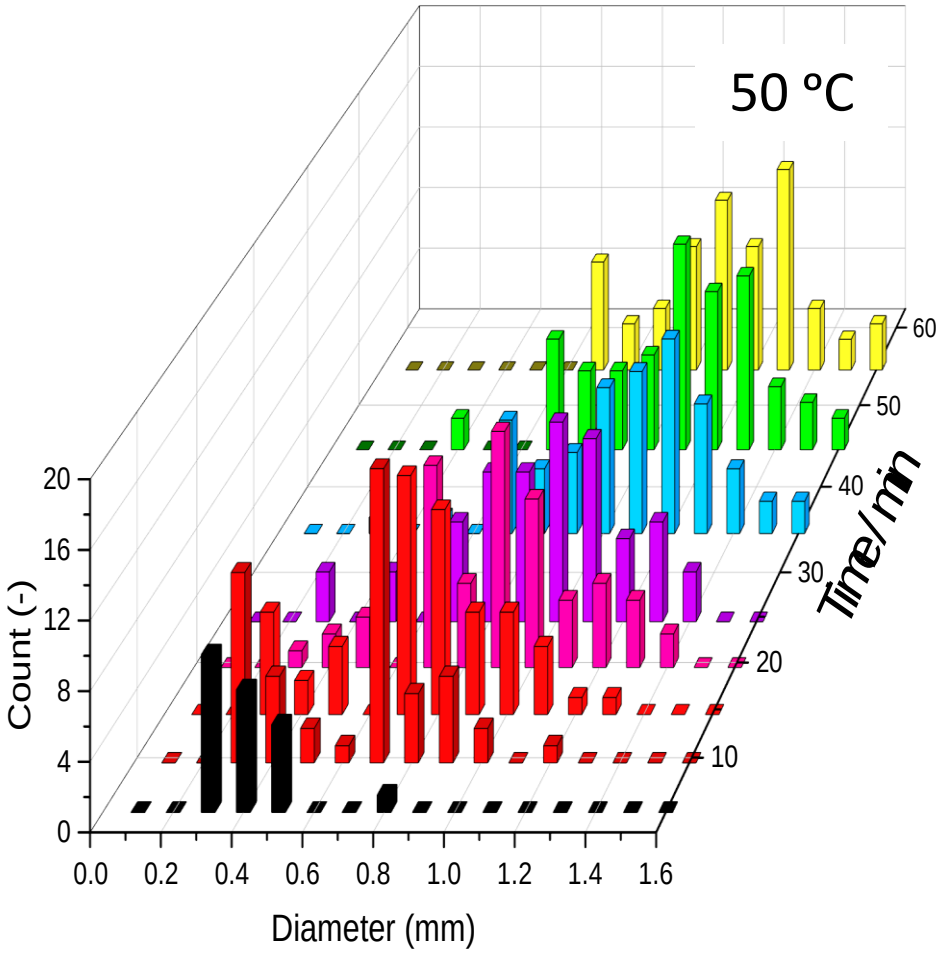
# Impact of temperature



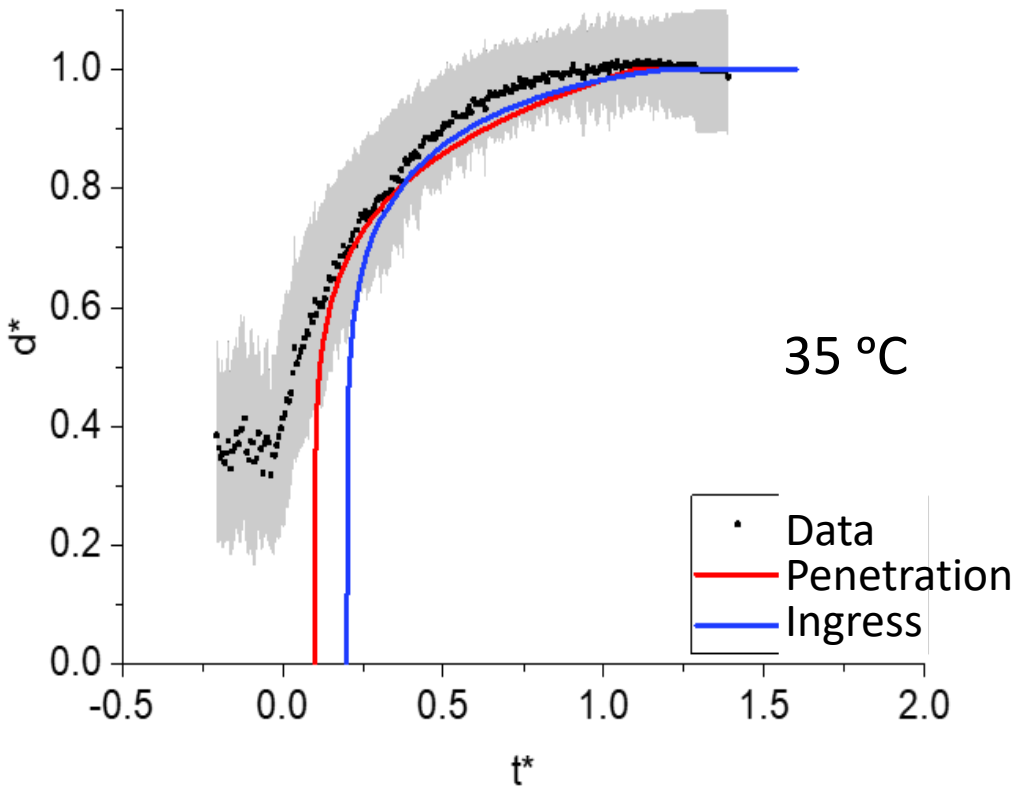



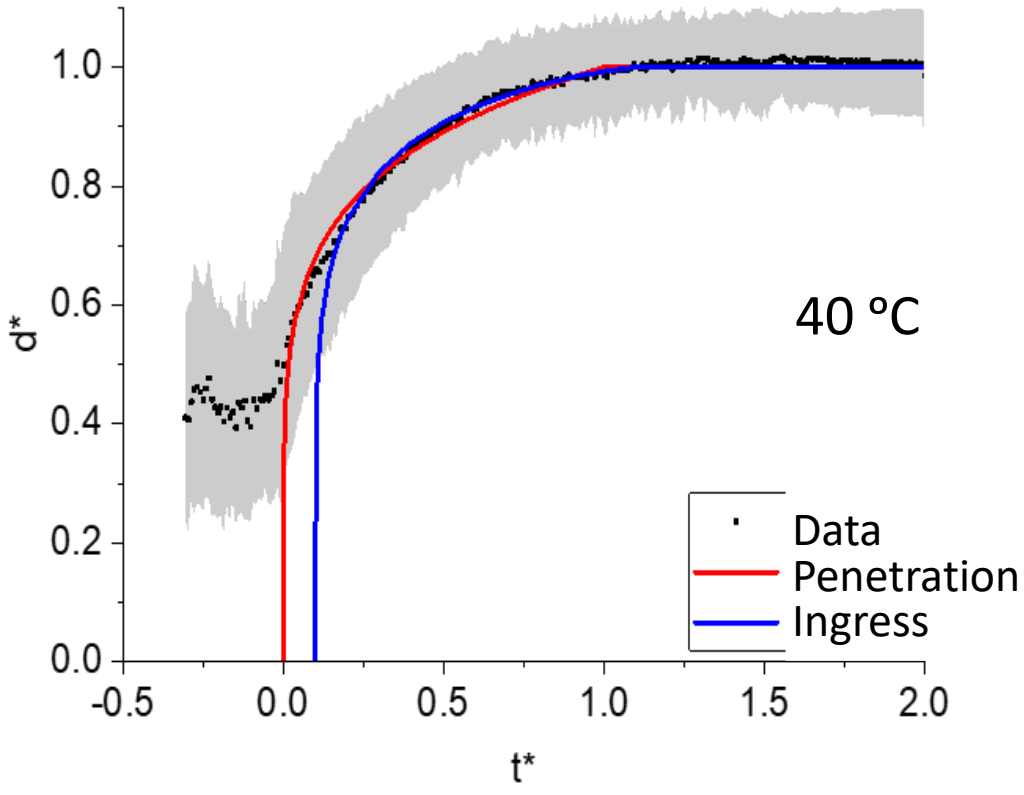
# Impact of temperature



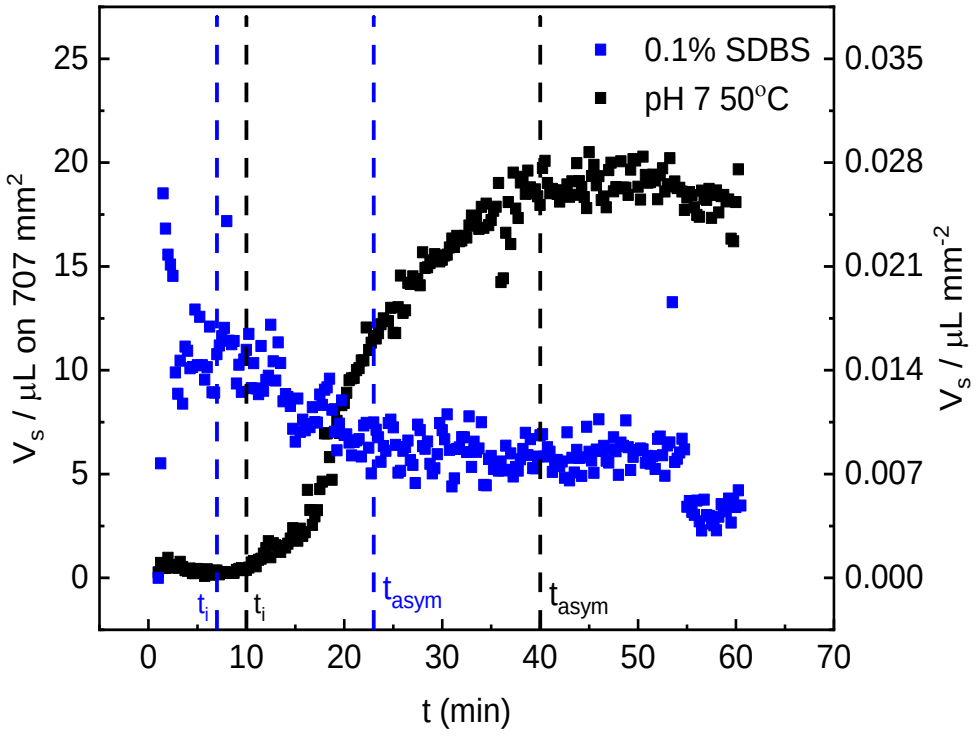
# Impact of temperature



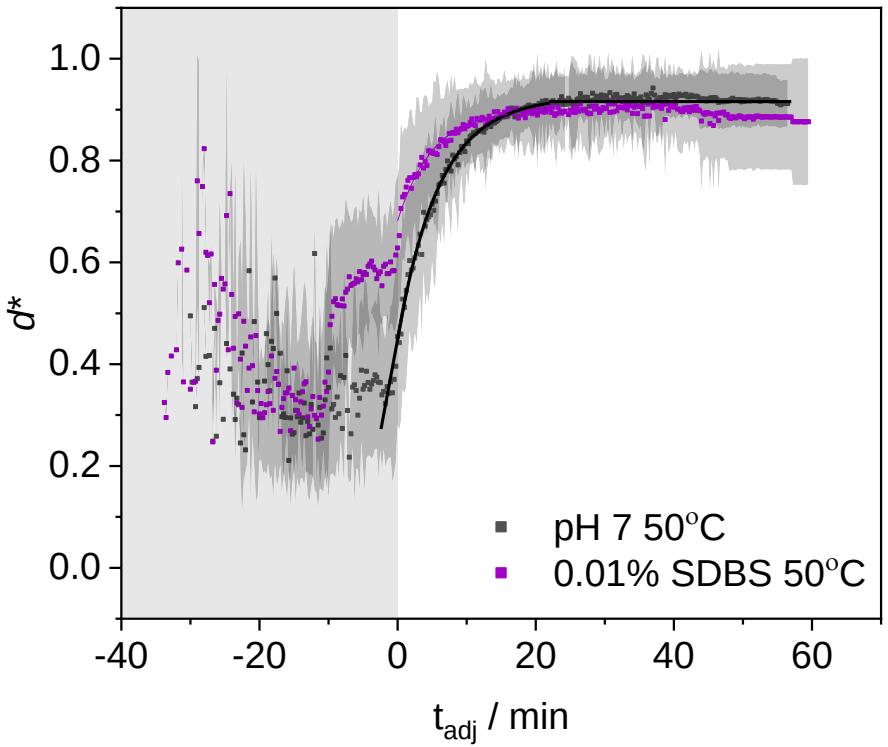




Modelling opportunities are available here: this modelling is very early days so there is scope to model it properly. We have not found evidence of modelling like this having been conducted before.

# Impact of surfactant

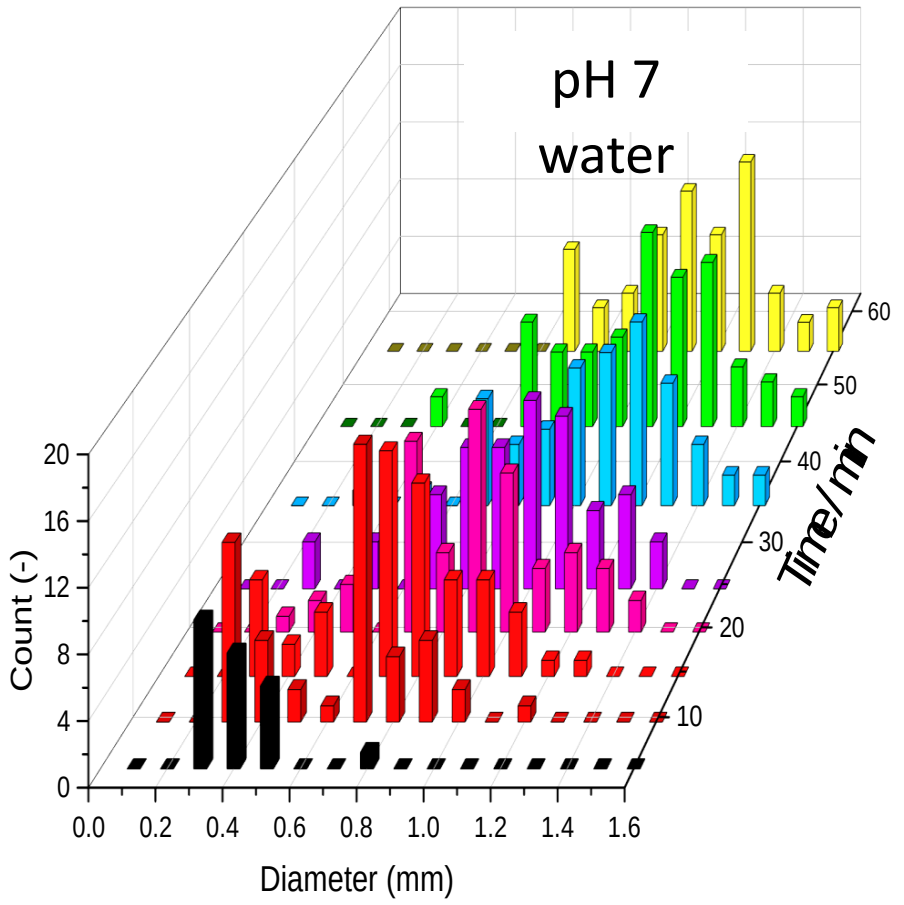


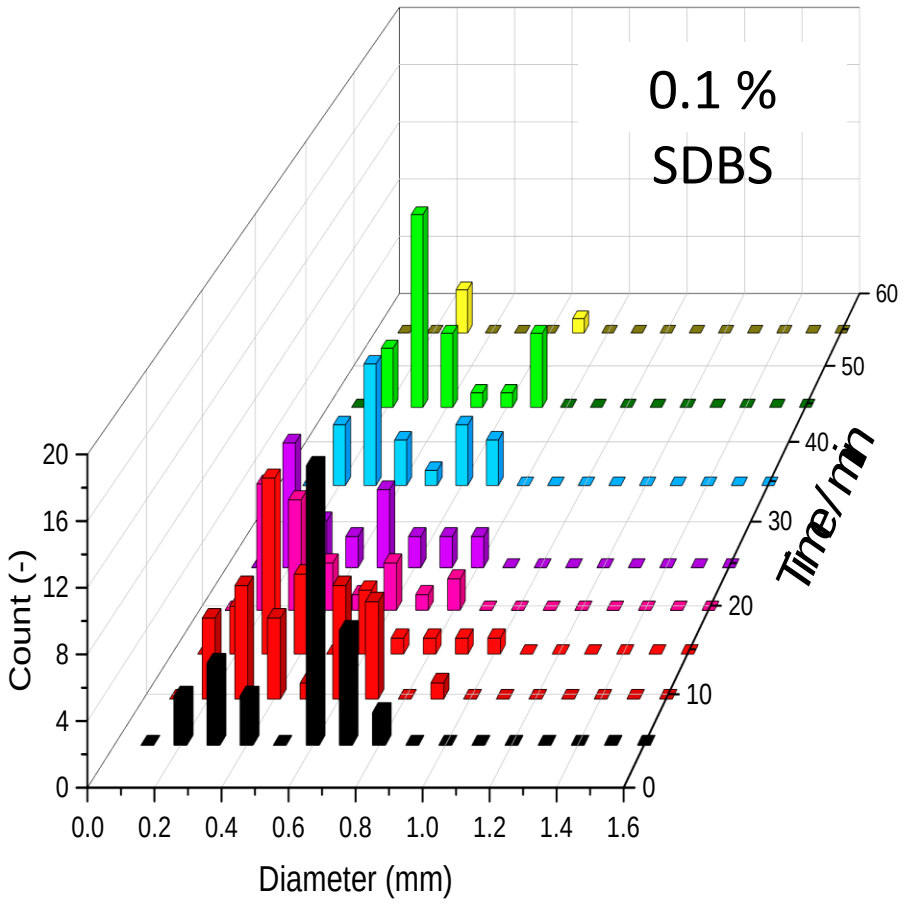

DI: 25.5 mN m$^{-1}$
0.1% 3.1 mN m$^{-1}$



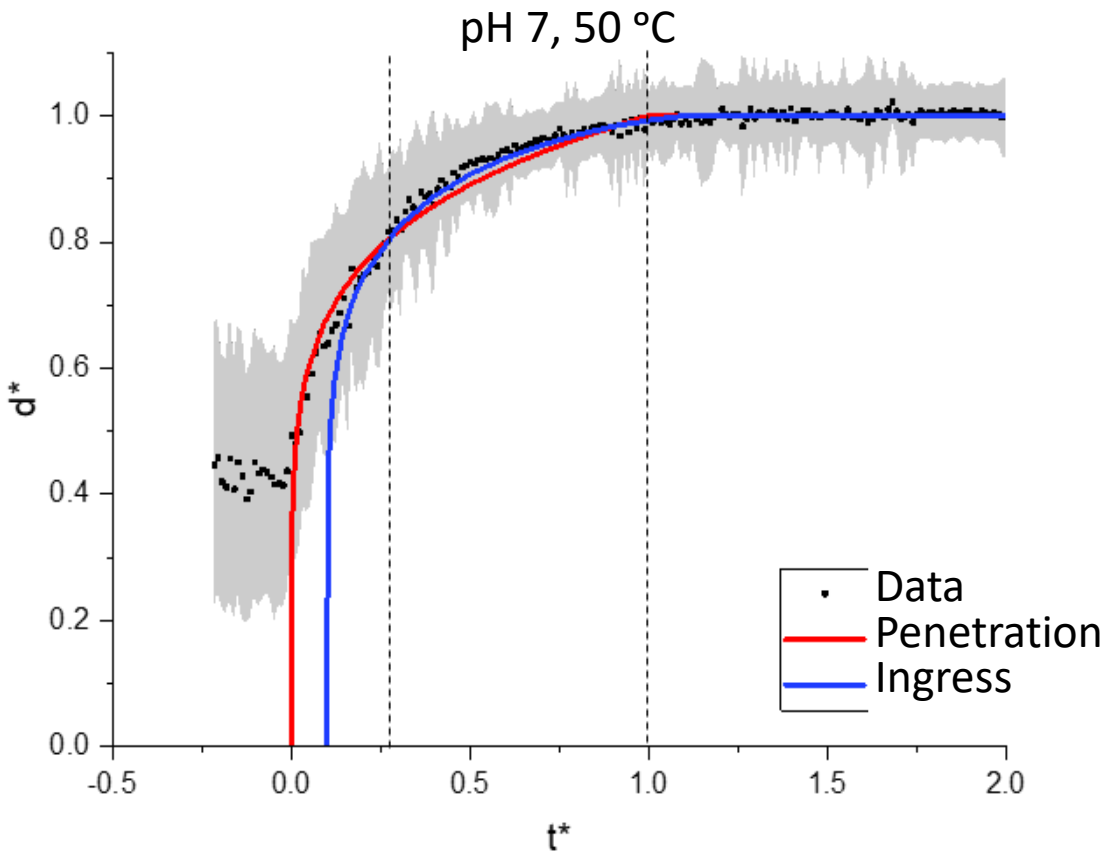

DI: 25.5 mN m$^{-1}$
0.01%: 16.8 mN m$^{-1}$

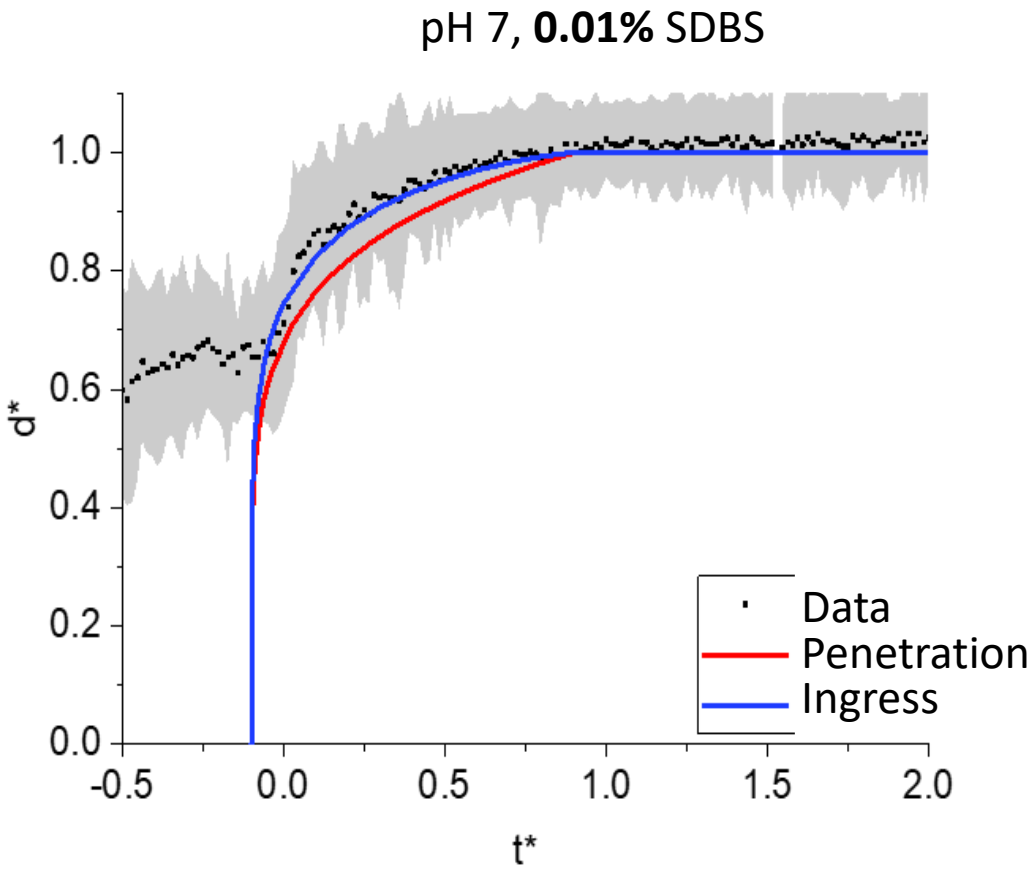
# Impact of Surfactant



# Impact of Surfactant



# Overall learnings

- Droplet appearance and growth follows the swelling of the soil matrix.
- The physics of the system thus differs from the EOR case.
- The two simple models describe the droplet size evolution - inviting further work.
- The droplet size, total volume, and timescale depend on temperature and surfactancy.

# Acknowledgements

Supervisor:
Ian Wilson

Sponsors:

Zayeed Alam
Glenn Ward
Mike Groombridge
James Goodwin
Kevin Blyth

EPSRC iCASE Studentship