Methods for detailed study of detergent action in cleaning food soils

George Cuckston, Chemical Engineering and Biotechnology
Project Aims

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

Temperature

Chemistry

Time

Mechanical Forces

www.cidlines.com/en-INT/circle-sinner-optimal-results-0
Complex model soil (CMS)

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

1. Apply
2. Evaporate for 18 hr
3. Bake for 7 min at 204°C

\[ \delta = 300 \, \mu m \]
CMS cracking

Number of cracks along gridlines
Vertical $19.0 \pm 3.0$. Horizontal $21.2 \pm 2.6$
Or ~ 1 crack per 2.5 mm

Fraction of cracked area per strip $38.8\% \pm 5.3\%$.

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

[Diagram showing Droplet tracking setup with labels for Camera, Light ring, CMS, Stand, Heating coil, and 5 mm scale marker]
Droplet tracking
Droplet tracking

0 min

5 min

10 min

12 min

14 min

16 min

18 min

20 min

25 min

30 min

45 min

60 min

0.5 mm

1 mm

t = 0 min

t = 10 min
Data Fusion

![Graph showing dimensionless parameter vs. time.](image)

- **MM3**: $\langle F_w \rangle_{min} = 19 \text{ N m}^{-1}$
- **SIDG**: $\delta_{max} = 0.16 \text{ mm}$
- **Oil M**: $d_{max} = 1.6 \text{ mm}$
Droplet tracking

\[ d_j^* = \frac{d_j}{d_{j,\text{max}}} \]

Combine for all droplets

\[ t_{\text{adj}} = t - t_i \]
Modelling droplet growth

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

\[
d^*(t^*) \approx \begin{cases} 
\sqrt[3]{1 - \frac{t^* - 1}{W_{-1} \left( \frac{t^* - 1}{e} \right)}}, & 0 \leq t^* < 1 \\
1, & t^* \geq 1 
\end{cases}
\]

*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
- 0.01% SDBS
- 0.1% SDBS
Impact of temperature

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

35 °C: \( k \approx 4.5 \text{ s}^{-1} \)
40 °C: \( k \approx 6.5 \text{ s}^{-1} \)
45 °C: \( k \approx 8.4 \text{ s}^{-1} \)
50 °C: \( k \approx 9.9 \text{ s}^{-1} \)

Here \( E \) gives an indication of the driving force of water penetration.
Impact of temperature

V_s / µL on 707 mm²
pH 7 35°C
pH 7 50°C

Count / mm²
pH 7, 35°C
Count (/ 707 mm²)

Count / mm²
pH 7, 50°C
Count (/ 707 mm²)
Impact of temperature

35 °C

50 °C
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

- pH 7 water
- 0.1% SDBS
Impact of Surfactant

pH 7, 50 °C

pH 7, 0.01% SDBS
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.
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